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Nasser Abdel- Kader , Mohssen Elbagory , Mohamed E. Ahmed , Esraa Saber , Alaa El-Dein Omara , Tamer H. Khalifa *

Posted Date: 26 December 2023

doi: 10.20944/preprints202312.1845.v1

Keywords: Biochemical soil characteristics; Common bean; Mulching; Nano Chitosan; Salt affected soil

Article

Interactive Effect of Nano Chitosan and Soil Mulching on Salt Affected Soil Characteristics and *Phaseolus vulgaris* L. productivity

Nasser Abdel- Kader [1], Mohssen Elbagory [2], Mouhamed Ahmed [3], Esraa Saber [1], Alaa El-Dein Omara[4] and Tamer Khalifa [5,*]

[1] Soil and Water Department , Faculty of Agriculture, Tanta University, Tanta 31527, Egypt; nasserkamal@agr.tanta.edu.eg & Esraasaber185@gmail.com
[2] Department of Biology, Faculty of Science and Arts, King Khalid University, Mohail 61321, Assir, Saudi Arabia; mhmohammad@kku.edu.sa
[3] Horticulture Department, Faculty of Agriculture, Tanta University, Tanta 31527, Egypt; dr.memahmed@agr.tanta.edu.eg
[4] Soil Microbiology Research Department, Soil, Water, and Environment Research Institute (SWERI), Agriculture Research Center (ARC), Giza 12112, Egypt; alaa.omara@yahoo.com
[5] Soil Improvement and Conservation Research Department, Soil, Water, and Environment Research Institute (SWERI), Agriculture Research Center (ARC), Giza 12112, Egypt; tamerkhalifa1985@gmail.com
* Correspondence: tamerkhalifa1985@gmail.com; Tel.: +20-1060822017

Abstract: Soil salinity is seen as a major restriction for crop production, and with water scarcity this problem becomes more complicated. Mulching is crucial to salinity dynamics management by decreasing evaporation with improving the soil's characteristics. Using chitosan as an eco-friendly biostimulant can enhance plant defense genes during different abiotic stresses. Recently, agricultural research has recognized nanoparticles as a pioneer material due to their distinctive physicochemical features. Therefore, a lysimeter experiment was conducted to investigate the interactive effects of mulching (UNM: un-mulched, WPM: white plastic, RSM: rice straw and SDM: sawdust) and chitosan foliar application (Ch_0: control, Ch_1: 250 mg chitosan L^{-1}, Ch_2: 125 mg nano chitosan L^{-1}, and Ch_3: 62.5 mg nano chitosan L^{-1}) on the biochemical soil characteristics and common beans productivity under salt affected soil conditions. Organic mulching (RSM and SDM) treatments significantly improved the soil's organic carbon, available nutrient content, and total count of bacteria. WPM treatment lowered soil EC to 6.63 dS m^{-1} and increased soil water content to 34.13%. The application of Ch_3 caused considerable increases in the plant height, shoot dry weight, root dry weight, grain yield, and nutrient content in the seed. The total fungi count in the soil and Na% in the seed was significantly decreased due to chitosan foliar applications. Moreover, the interactive effect of different mulch materials plus foliar by chitosan applications gave a statistically similar seed yield in both seasons. Overall, this study revealed the potential of the mulching treatments and foliar application of nano chitosan in improved biochemical soil characteristics and common bean productivity under saline soil conditions.

Keywords: biochemical soil characteristics; common bean; mulching; nano chitosan; salt affected soil

1. Introduction

Salt stress has a deleterious effect on global crop production [1]. In semi-arid and arid climates, soil salinization can be the result of natural and climate change impacts, and anthropic activities [2-3]. Globally, salt-affected soil covers approximately 1.1* 10^9 hectares [4]. At local level, in Kafr El-Sheikh Governorate (current study area, North Nile Delta of Egypt), salt affected soil covers approximately 151.05 hectares (56%) of the total cultivated area [5]. Consequently, a variety of factors, such as freshwater shortage, drought, soil texture, seawater intrusion, leaning on wastewater and inefficient drainage networks can lead to the salt accumulation and soil health degradation [6-8]. Fertility disruption, decreased microbial activity, and compromised soil structure are the negative

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effects of soil salinization [9]. Under salt-affected soil conditions, the osmotic potential is higher in soil solution than in plant root cells [10]. Therefore, it is crucial to fairly manage the salinity dynamics by decreasing soil water evaporation, reducing salt accumulation, and improving the soil's characteristics in order to increase crop productivity in salt-affected soils.

By mulching with various materials, soil water evaporation can be decreased, the amount of soil water available for plants can be increased, and salt buildup can be reduced in the soil [11]. Currently available various mulching materials such as plastic, non-woven, biodegradable plastic, paper films, and organic mulches, such as straw or wood chips, and gravels [12-13]. Plastic mulching had a positive effect on soil physicochemical properties [14-15]. According to Fan et al., [16], straw mulch can beneficially reduce soil water evaporation which encumbers salt accumulation. Also, sawdust mulching decreased soil EC, increased the soil organic matter content, and reserved the soil available nutrients [17]. Different sources of mulches afflicted soil organic carbon content, total nitrogen, soil pH, exchangeable cations, available phosphorous and EC, and base saturation in soil [18]. At the same time, mulching applications encourage soil biological activities [19-20]. Different mulching materials showed an exhibited the highest growth parameters and yield of common beans (*Phaseolus vulgaris* L.) under saline stress [21-23].

Chitosan (CS; poly _-(1,4)-N-acetyl-D-glucosamine) is non-toxic, non-allergenic, cost-effective, biodegradable, and eco-friendly, and it is used in agriculture as a biostimulant [24]. This natural substance is effective in promoting plant growth and resisting abiotic stress [25-26]. Cataldo et al., [27] found that the chitosan improved several defensive genes in plants, including pathogenic-related genes (glucanase and chitinase). It also reduces the impact of salinity stress on plants and enhances plant growth by regulating cellular osmotic pressure and increasing the availability and uptake of water and essential nutrients [28].

Currently, nanotechnology has recently been extensively utilized in several areas of plant improvement, with nanoparticles (NPs) being replaced by bulk materials [29]. Chitosan nanoparticles (CSNPs) are advantageous due to their interface and surface effects, as well as their small size, which makes them more effective than normal chitosan [30]. The effectiveness of chitosan nanoparticles (CNPs) is enhanced by their small size (less than 100 nm), high aspect ratio, and surface area [31]. Which, their enhancement of plant metabolic activity leads to more efficient transport of active chemicals across cell membranes [32].

Despite using chitosan nanoparticles has been proven to have beneficial impacts on plant productivity, there are limited studies about using chitosan or chitosan nanoparticles to enhance growth and productivity in common bean (*Phaseolus vulgaris* L.) plants under salinity stress. Also, the interactive effect of nano chitosan and soil mulching on the biochemical characteristics of salt-affected soil and common bean productivity is still unclear. Therefore, this research tried to study the effect of Nano chitosan as a foliar application and organic and inorganic mulching on the biochemical soil characteristics and common bean productivity under salt-affected soil conditions.

2. Materials and Methods

2.1. Experimental Site

A lysimeter experiment was conducted in consecutive two growing seasons during first week of March 2022 and 2023 at the Sakha Agricultural Research Station (30° 56' 53" E, 31° 05' 38" N, with elevation from sea level is about 6 m.) Kafer El-Sheikh Governorate, Egypt. The climate of experimental area is arid climate. Detailed information about the daily rainfall and temperature of two growing seasons 2022 and 2023 (Figure 1) was collected from Weather Station installed at experimental site with an average annual precipitation was 62.21–37.84 mm and temperature were 23.2 and 24.3 °C during cultivation period of 2022 and 2023. The soil characteristics (average values of 48 lysimeter) before sowing indicated that the soil was saline heavy clay (clay 57.97%, silt 25.37%, sand 18.66%, pH 8.16, EC 7.78 dS m^{-1}, ESP 14.76, bulk density 1.42 Mg m^{-3}, soil water content was 27.48%), with a low content of organic carbon 0.620 g g^{-1}, available-N 23.09 mg kg^{-1}, available-K 204.46

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mg kg^{-1}, available-P (Olsen method) 11.77 mg kg^{-1}. Also, total count of bacteria was 5.45 x 10^3 CFU g^{-1} and total count of fungi was 4.07 x 10^2 CFU g^{-1}.

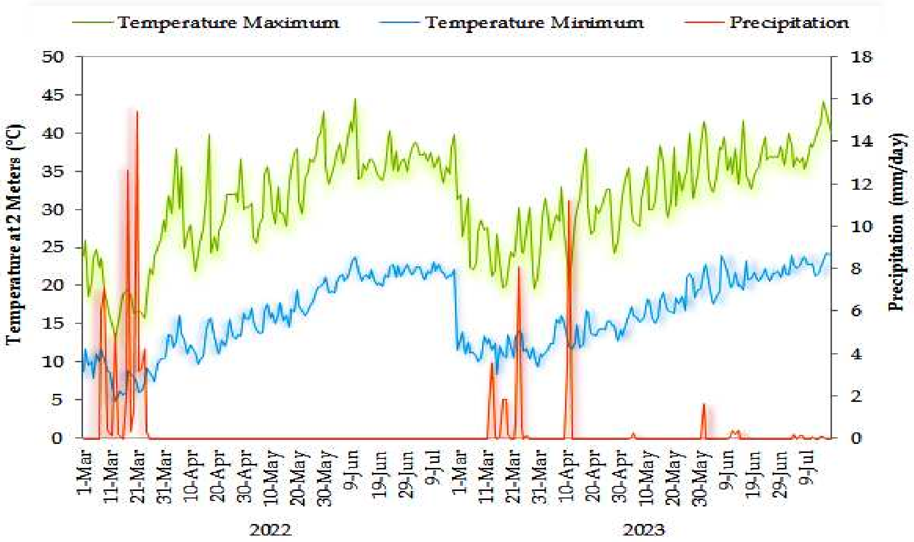

Figure 1. Daily rainfall and temperature during the experimental period of common bean crop (2022 and 2023).

2.2. Material

2.2.1. Corp variety

Common bean (*Phaseolus vulgaris* L.) cv. Giza 6 seeds were obtained from Horticulture Research Dep., Sakha Agri. Res. Station in Kafr El-Sheikh Gov.

2.2.2. Mulching materials

White plastic (30 µm) was obtained from the Arasya Plastic Company, Heliopolis, Cairo Gov. Rice straw, and sawdust were obtained from a farmer and wood machinery in Kafr El-Sheikh Gov.

2.2.3. Chitosan

It was purchased from Chitosan Egypt Company. Chitosan $(C_6 H_{11} NO_4)n$, from shrimp shell, with a deacetylation degree (DD) of about 90-95% and molecular weight: <100 cP.

2.2.3.1. Synthesis and characterizing of nano chitosan

In the present work, the nano-chitosan particles were prepared using the ball milling method for a 60-minute to synthesize nano-sized, after milling, the samples were dried for 10 minutes [33]. Characterizing nano-sized chitosan at Alexandria University was done by scanning electron microscope (SEM), and particle size distribution analysis. A Fourier Transform Infra-Red (FTIR) spectrum is being measured at the Central Laboratory of Tanta University Egypt.

2.2.3.2. Chitosan solution preparation

Different doses of the chitosan or its nanoparticles (250 or 125 and 62.5 mg L^{-1}) solubilized in 800 ml of distilled water with 1% acetic acid. Then, constant stirring until completely dissolved, and then completes a volume to one litter. Finally, the solution was alkalized to pH 6 with 1 M NaOH solution [34].

2.3. Treatment and design

The treatments were arranged as a factorial experiment in a completely randomized design with three replications. There were 2 factors as follows (1) mulching materials, UNM: un-mulched, WPM: white plastic mulching (30 µm), RSM: rice straw mulching (5 cm), and SDM: sawdust mulching (5 cm), (2) the chitosan foliar application, Ch_0, Ch_1, Ch_2 and Ch_3: distilled water, 250 mg chitosan L^{-1}, 125 mg nano chitosan L^{-1}, and 62.5 mg nano chitosan L^{-1} respectively. Each treatment was randomly arranged with 48 lysimeters of 0.64 m^2 (80 cm × 80 cm).

2.4. Experiment setup

Two rows were setup in every lysimeter with 60 cm length, 25 cm width and 20 cm height, as the plant spacing was 20 cm. Seeds were sown on 1 March 2022 and 2023. The mulch treatment was applied after 1 week from sowing and foliar application treatments were applied at 15, 30, and 45 days after sowing, the plants received three separate foliar applications. The irrigation water used has a pH of 7.08 and an EC of 2.51 dS m^{-1} and irrigation was adapted to 60 cm depth through reaching the FC + 5% as a leaching requirement. The fertilization and agricultural practices were done according to common bean cultivation in the North Nile Delta region of Egypt. After full maturity, the plants were harvested on 18 July.

2.3. Sampling and Measurement

2.3.1. Soil Characteristics

Soil samples with a surface area of 30 cm were collected before sowing and after harvesting common beans to be analyzed using the methods cited by [35-36]. Soil microbial communities were determined as outlined by [37].

2.3.2. Yield and quality of seeds:

After 60 days, the plant height (cm) was measured. The shoot dry weight (g), root dry weight (g), and seed yield (kg ha^{-1}) were determined after the full maturity of common beans. For determination of N, P, K and Na percentages in common bean seed. The seed samples were dried, ground, and wet-digested as described by [38]. The N, P, K and Na% were determined according to stander methods [39].

2.4. Data analysis and processing

All data were subjected to analysis of variance (ANOVA) using Minitab v 21. Tukey's test was performed to make multiple comparisons between different treatments at $p \leq 0.05$. Data was processed in R (ver. 4.1.3), for Principal Component Analysis (PCA) uses Factoextra packages [40] and Visualize Correlation Matrix using corrplot packages [41].

3. Results

3.1. Characterization of Nano chitosan

Characterizing nano chitosan as shown in Figure (2 a,b,c). Figure (2a) displays the particle size distribution of chitosan nanoparticles that represent an average diameter of 86.4 nm. Figure (2b) displays an SEM image of nano chitosan. The result of SEM was consistent with the DLS measurement in terms of nanoparticle size. The surface structure of nano chitosan powder is smooth, compact, and uniform.

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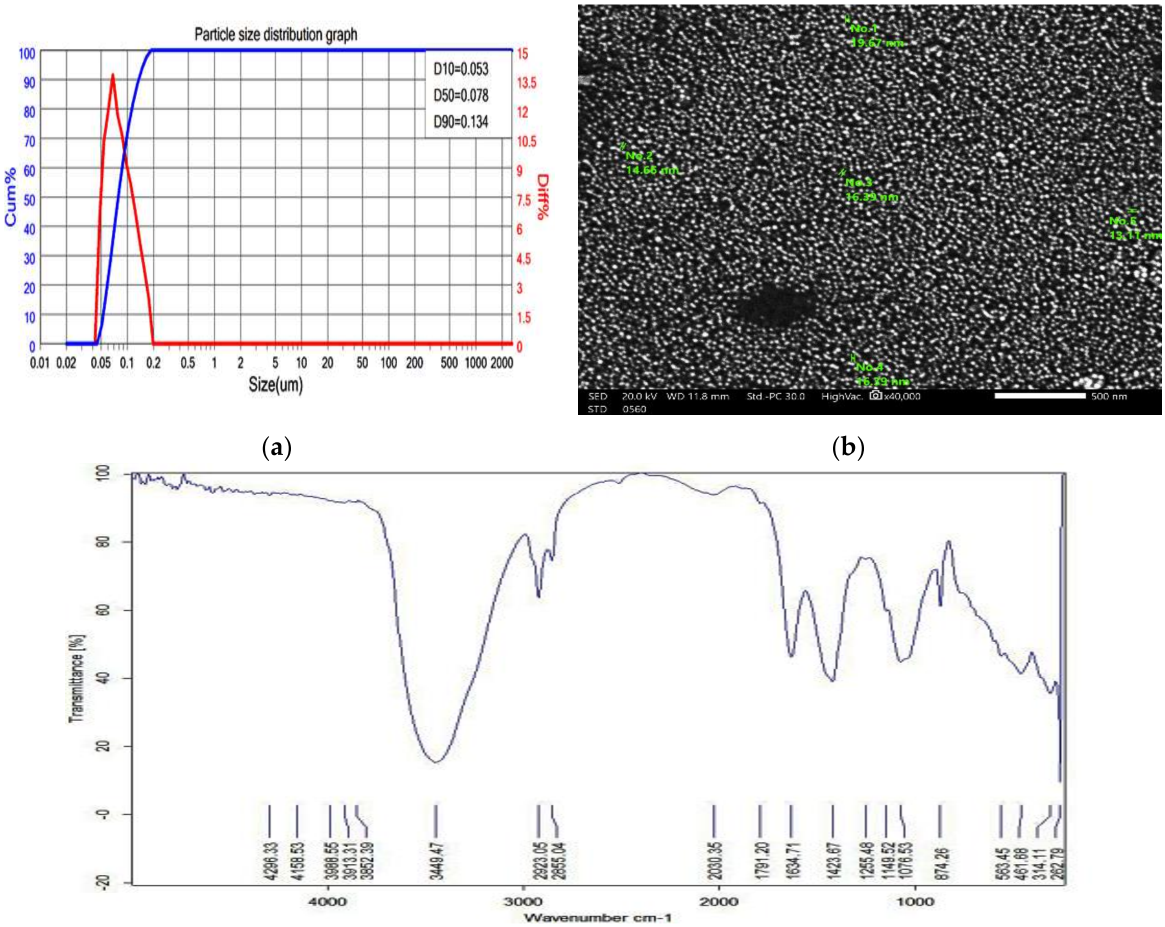

(**a**) (**b**)

(**C**)

Figure 2. Characterization of nano chitosan (**a**) Particle size distribution image (**b**) Scanning electron (**c**) microscope (SEM) and FTIR spectrum.

The functional groups of nano chitosan were characterized using Fourier Transform Infrared (FTIR) spectra analysis as shown in Figure (2c).The results indicated that the absorption at wavenumber 3852.39-3449.47 cm^{-1} showed the presence of O-H. Absorption at wavenumber 2923.05-2855.04 and 2877 cm^{-1} showed the presence of the methylene and methyl group. Absorption at wavenumber 1634.71 and 1076.53 cm^{-1}, respectively, were related to the C=O stretching and C-O bending vibrations. Absorption at wavenumber 1423.67 cm^{-1} indicated the C–N stretching which showed the acetyl group. Absorption at wavenumber 1149.52 cm^{-1} indicated that the vibration absorption CN (NH_2) stretching as evidence of amine groups was formed. Absorption at wavenumber 1076.53 cm^{-1} indicated the CN (H_2) stretching because the amine groups were formed. Absorption indicates that intramolecular hydrogen bonds in the structure were very strong.

3.2. Soil parameters

The results of study soil parameters of each treatment were shown in Table 1. In general, the obtained results from the analysis of mulching treatment application, all mulching materials used caused a significant change in all studied soil parameters. Also, chitosan foliar applications, compared with control application (Ch_0), using nano chitosan foliar applications caused a slight significantly changes on soil EC, SOM and microbial communities. The interactive effects of different mulching materials and chitosan foliar applications were found significant (at $p \leq 0.05$) on all study soil parameters.

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3.2.1. Soil Electrical Conductivity

From the analysis of mulching treatments, different mulching materials had different effects on soil EC (Table 1). The white plastic mulch treatment (WPM) was better, which could decrease the soil EC by 7.91 and 12.83% compared to UNM in both seasons, respectively. Ch_0 application had the highest soil EC values, averaging 7.42 dS m^{-1} in 2 seasons (Table 1). Both doses of nano chitosan foliar application (Ch_2 and Ch_3) showed a slight reduction in soil EC in 2 seasons. Different mulching materials combined with chitosan foliar application reduced EC in soil compared with control (UNM+Ch_0). The lowest values of EC (7.04 and 6.51dS m^{-1}) were observed under WPM + Ch_3 with insignificant differences with Ch_1 and Ch_2 in both seasons, respectively (Table 1).

3.2.2. Soil Water Content

The soil water content (SWC) under the mulching treatment increased sequentially compared to UNM (Table 1). AS, WPM and SDM contain relatively a higher soil water content. Using WPM or SDM to cover the soil increased the soil water content by an average by 22.99% or 20.84% compared to UNM in 2 seasons, respectively. Among all the chitosan foliar applications, the soil water content values did not show any significant difference after 2 seasons due to the application of the various chitosan foliar applications (Table 1). There is no significant distinction between the combined soil mulching materials with the chitosan foliar applications in obtained values of SWC (Table 1).

3.2.3. Soil organic carbon

The soil organic carbon was found in the mulching soils significantly larger than un-mulched bare soil (UNM). The SOC content increased by 0.159 and 0.184 g g^{-1} under SDM treatment, followed by RSM treatment with an increasing 0.097 and 0.130 g g^{-1} comparing with UNM in 2 seasons, respectively (Table 1). Compared with control application, the nano chitosan foliar application at a rate of 63 mg L^{-1} (Ch_3) had the highest values of soil organic carbon content (0.690 and 0.716 g g^{-1}) in 2 seasons, respectively. Under the organic mulching treatments, SOC content increased with all chitosan foliar applications (Table 1), and the maximum content sawdust mulching with nano chitosan foliar application at a rate of 63 mg L^{-1} treatment (SDM+Ch_3).

 doi:10.20944/preprints202312.1845.v1

Table 1. Soil chemical characteristics under different treatments affect.

Soil parameters	EC		S.O.C		AV. N		AV. P		AV. K		SWC		TBC		TFC	
Seasons	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mulching materials																
UNM	7.77^{a}	7.60^{a}	0.598^{d}	0.602^{d}	27.26^{c}	27.56^{c}	12.57^{b}	12.38^{c}	201.19^{d}	201.34^{d}	27.14^{c}	27.89^{b}	5.92^{d}	5.96^{c}	3.61^{a}	3.31^{a}
WPM	7.15^{c}	6.63^{d}	0.643^{c}	0.660^{c}	33.61^{b}	34.60^{b}	13.68^{b}	14.19^{b}	256.36^{c}	257.31^{c}	33.54^{a}	34.13^{a}	6.96^{c}	7.23^{b}	3.06^{ab}	2.47^{b}
RSM	7.51^{b}	7.16^{b}	0.695^{b}	0.732^{b}	36.33^{a}	36.90^{a}	16.89^{a}	16.82^{a}	266.13^{b}	268.91^{b}	29.63^{b}	29.16^{b}	7.45^{b}	7.49^{ab}	3.15^{ab}	2.31^{b}
SDM	7.40^{b}	7.01^{c}	0.757^{a}	0.786^{a}	35.50^{ab}	36.17^{ab}	16.10^{a}	15.82^{a}	283.55^{a}	284.63^{a}	32.94^{a}	33.55^{a}	7.98^{a}	8.33^{a}	2.40^{b}	1.33^{c}
F-Value	30.07	116.89	81.08	66.08	58.67	56.51	47.11	50.21	862.68	1156.48	64.99	27.49	43.15	18.26	4.86	13.76
P-Value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.007	<.0001
Chitosan foliar application																
Ch$_0$	7.61^{a}	7.23^{a}	0.659^{b}	0.668^{b}	32.32	32.77^{b}	15.30	15.42	251.03	252.05	31.15	31.58	6.64^{c}	6.66^{c}	3.43	2.86^{a}
Ch$_1$	7.47^{ab}	7.12^{ab}	0.669^{ab}	0.691^{ab}	33.35	34.03^{a}	14.74	14.74	251.86	253.11	30.87	31.22	7.10^{b}	7.28^{b}	3.03	2.33^{b}
Ch$_2$	7.41^{b}	7.05^{b}	0.676^{ab}	0.705^{ab}	33.44	34.14^{a}	14.66	14.61	252.09	253.31	30.72	31.08	7.26^{a}	7.45^{ab}	2.92	2.15^{b}
Ch$_3$	7.35^{b}	7.00^{b}	0.690^{a}	0.716^{a}	33.59	34.29^{a}	14.55	14.43	252.26	253.71	30.51	30.86	7.31^{a}	7.62^{a}	2.85	2.08^{b}
F-Value	5.75	7.08	2.88	4.42	1.17	2.11	1.29	2.51	0.20	0.45	0.53	0.26	55.46	57.15	1.31	19.91
P-Value	0.003	0.001	0.051	0.01	0.338	0.043	0.294	0.076	0.894	0.722	0.667	0.856	<.0001	<.0001	0.288	0.002
Interaction																
UNM Ch$_0$	7.89^{a}	7.78^{a}	0.588^{f}	0.555^{g}	26.44^{c}	24.39^{d}	12.93^{de}	12.52^{cd}	200.64^{c}	199.79^{f}	27.37^{e}	28.19^{bcd}	5.21^{h}	4.75^{b}	4.07	3.92^{a}
UNM Ch$_1$	7.77^{ab}	7.61^{ab}	0.599^{f}	0.601^{fg}	27.43^{bc}	28.52^{cd}	12.50^{e}	12.41^{cd}	201.28^{c}	201.65^{f}	27.13^{e}	27.87^{cd}	6.09^{g}	6.19^{ab}	3.53	3.28^{ab}
UNM Ch$_2$	7.72^{abc}	7.53^{abc}	0.607^{f}	0.638^{efg}	27.55^{bc}	28.58^{cd}	12.48^{e}	12.32^{d}	201.30^{c}	201.87^{f}	27.06^{e}	27.87^{cd}	6.17^{g}	6.32^{ab}	3.49	3.07^{ab}
UNM Ch$_3$	7.69^{abc}	7.49^{abcd}	0.596^{ef}	0.613^{fg}	27.61^{bc}	28.77^{bcd}	12.38^{e}	12.29^{d}	201.53^{c}	202.03^{f}	26.98^{e}	27.64^{d}	6.21^{g}	6.57^{ab}	3.35	2.98^{ab}
WPM Ch$_0$	7.36^{bcde}	6.75^{fghi}	0.625^{def}	0.632^{efg}	32.87^{ab}	34.20^{abc}	14.17^{bcde}	14.93^{abcd}	255.70^{b}	255.85^{e}	33.90^{a}	34.54^{a}	6.66^{f}	6.80^{ab}	3.38	3.00^{ab}
WPM Ch$_1$	7.16^{de}	6.67^{ghi}	0.638^{def}	0.659^{def}	33.77^{a}	34.64^{ab}	13.63^{cde}	14.10^{bcd}	256.31^{b}	257.48^{de}	33.59^{ab}	34.22^{ab}	6.90^{ef}	7.15^{ab}	3.05	2.42^{ab}
WPM Ch$_2$	7.06^{de}	6.58^{hi}	0.646^{def}	0.665^{cdef}	33.85^{a}	34.73^{a}	13.50^{de}	13.99^{bcd}	256.55^{b}	257.70^{cde}	33.50^{ab}	33.85^{abcd}	7.10^{de}	7.42^{a}	2.92	2.26^{ab}
WPM Ch$_3$	7.04^{e}	6.51^{i}	0.665^{cdef}	0.68^{bcdef}	33.94^{a}	34.85^{a}	13.42^{de}	13.72^{bcd}	256.87^{b}	258.21^{bcde}	33.16^{abc}	33.92^{abc}	7.18^{de}	7.53^{a}	2.89	2.19^{ab}
RSM Ch$_0$	7.66^{abc}	7.31^{bcde}	0.685^{bcde}	0.719^{abcde}	35.39^{a}	36.53^{a}	17.33^{a}	17.73^{a}	264.45^{b}	268.62^{bcd}	30.13^{abcde}	29.64^{abcd}	7.03^{def}	7.09^{ab}	3.48	2.92^{ab}
RSM Ch$_1$	7.53^{abcd}	7.19^{cd}e	0.694^{bcd}	0.723^{abcde}	36.47^{a}	36.93^{a}	16.89^{ab}	16.56^{ab}	266.35^{b}	268.76^{bc}	29.81^{bcde}	29.10^{abcd}	7.37^{cd}	7.45^{a}	3.11	2.18^{ab}
RSM Ch$_2$	7.48^{abcde}	7.10^{def}	0.696^{bcd}	0.733^{abcde}	36.62^{a}	37.01^{a}	16.71^{abc}	16.52^{ab}	266.86^{b}	268.92^{b}	29.43^{cde}	29.06^{abcd}	7.65^{bc}	7.64^{a}	3.04	2.09^{ab}
RSM Ch$_3$	7.38^{bcde}	7.05^{efg}	0.704^{bcd}	0.752^{abcd}	36.86^{a}	37.15^{a}	16.63^{abc}	16.44^{ab}	266.86^{b}	269.35^{b}	29.16^{de}	28.85^{abcd}	7.74^{abc}	7.79^{a}	2.97	2.05^{ab}
SDM Ch$_0$	7.52^{abcde}	7.09^{ef}	0.739^{abc}	0.76^{abc}	34.58^{a}	35.97^{a}	16.76^{ab}	16.51^{ab}	283.32^{a}	283.92^{a}	33.19^{abc}	33.94^{abcd}	7.65^{bc}	8.01^{a}	2.78	1.61^{b}

SDM Ch_1	7.42[abcde]	7.03[efg]	0.743[abc]	0.778[ab]	35.72[a]	36.06[a]	15.95[abcd]	15.91[ab]	283.49[a]	284.56[a]	32.96[abcd]	33.70[abcd]	8.02[ab]	8.33[a]	2.41	1.43[b]
SDM Ch_2	7.36[bcde]	6.98[efg]	0.754[ab]	0.785[a]	35.75[a]	36.23[a]	15.93[abcd]	15.61[ab]	283.63[a]	284.77[a]	32.87[abcd]	33.53[abcd]	8.11[a]	8.41[a]	2.23	1.18[b]
SDM Ch_3	7.28[cde]	6.95[efgh]	0.793[a]	0.818[a]	35.94[a]	36.41[a]	15.76[abcd]	15.26[abc]	283.78[a]	285.25[a]	32.74[abcd]	33.02[abcd]	8.13[a]	8.57[a]	2.18	1.11[b]
F-Value	0.12	0.19	0.51	0.51	0.01	0.7	0.02	0.21	0.03	0.04	0.03	0.01	2.90	0.37	0.01	0.06
P-Value	0.999	0.994	0.855	0.857	1.000	0.704	1.000	0.992	1.000	1.000	1.000	1.000	0.013	0.941	1.000	1.000

* **EC**: soil salinity (ds m^{-1}, paste extract), **S.O.C** (g g^{-1}): soil organic carbon content, **Ava. N, P, and K** (mg g^{-1}): available N, P and K content, **SWC** (%): soil water content, **TBC** (log CFU g^{-1}): total bacteria count and **TFC** (log CFU g^{-1}): total fungi count. **UNM**: un-mulched, **WPM**: white plastic mulching, **RSM**: rice straw mulching, **SDM**: sawdust mulching. **Ch_0**: distilled water (control), **Ch_1**: 250 mg chitosan L^{-1}, **Ch_2**: 125 mg nano-chitosan L^{-1} and **Ch_3**: 62.5 mg nano-chitosan L^{-1}.

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3.2.4. Soil Nutrients

The soil's available nitrogen and phosphorus under RSM treatment were significantly higher than other mulch and no-mulch treatments (Table 1). While the highest available potassium contents were obtained under SDM treatment. No significant difference in the soil's available nitrogen and phosphorus content between the RSM and SDM treatments. There was also no significant difference in the soil available nitrogen content between SDM and WPM treatments.

The application of all chitosan foliar applications had insignificant affect soil available phosphorus and potassium content values in both seasons (Table 1). While the result of soil nitrogen content shows a slight significant change in the 2023 season and don't changes was found in the 2022 season with the chitosan foliar applications.

Mulching × chitosan foliar applications interaction was not significant soil nitrogen content in both seasons (Table 1). Also, the results showed that the highest soil phosphorus content was associated with organic mulching (RSM and SDM) of the soil with various foliar chitosan sprays (Ch_0, Ch_1, Ch_2, and Ch_3). RSM + Ch_3 treatment gave the highest values of soil potassium content in both seasons (Table 1), with insignificant differences with other chitosan foliar applications (Ch_0, Ch_1, and Ch_2).

3.2.5. Soil microbial communities

The obtained results in Table 1 showed a significant difference in bacterial and fungal communities in soils under different mulching treatments. Therein, the relative abundance of total bacteria count under SDM treatment (7.98 and 8.33 log CFU g^{-1}) was significantly higher than that under UNM treatment (5.92 and 5.96 log CFU g^{-1}). Also, SDM treatment caused a significantly reduction on the total fungi count than that other mulching treatment.

The chitosan foliar applications presented significant differences in bacterial and fungal communities (Table 1). Foliar application by nano chitosan caused the relative abundances of TBC than that in Ch_0 and Ch_1, while TFC was significantly decreased in second season due to 3 foliar chitosan applications than that Ch_0.

The interactive effect of different mulching materials and chitosan foliar applications was found significant on soil microbial communities (Table 1). The lowest TFC (2.18 and1.11 log CFU g^{-1}) were obtained with SDM + Ch_3 treatment. In addition, combine SDM with Ch_3 gave the highest TBC in soil.

3.2.6. Principal Component Analysis (PCA)

The PCA biplot illustrated in Figure 2 shows all studied soil parameters on the first two principal components (Dim1= 62.3% and Dim2 =15.3%). It is clear that all studied soil parameters positively correlated with Dim1, except soil EC and total fungi count which showed a negative correlation. Meanwhile, Dim2 exhibited positive correlation with soil water content, soil organic carbon, available N, P, K and total bacteria count and negative correlation with soil EC and total fungi count. Dim1 and Dim2 successfully separated the interactive effect of different mulch materials and foliar applications by chitosan, as seemed to group together. Meanwhile the effect of the control treatments (UNM) varied strongly.

3.3. Common bean yield and its components

3.3.1. Plant Height

Data in Table 2 indicate that the plant height was significantly increased with different mulching materials in comparison with the control. Relative to the control (UNM), the plant height was decreased by 13.44, 16.46 and 13.60% in plants mulched by WPM, RSM, and SDM, respectively. Meanwhile, foliar chitosan application markedly improved plant height and alleviated the adverse salinity effects. In control plants, the plant height reduction was 18.99, 20.07 and 20.98%, compared with the Ch_1, Ch_2, and Ch_3, respectively.

The interactive effects of different mulching materials and foliar applications by chitosan were found significant (at $p \leq 0.05$) on the plant height of common beans (Table 2).

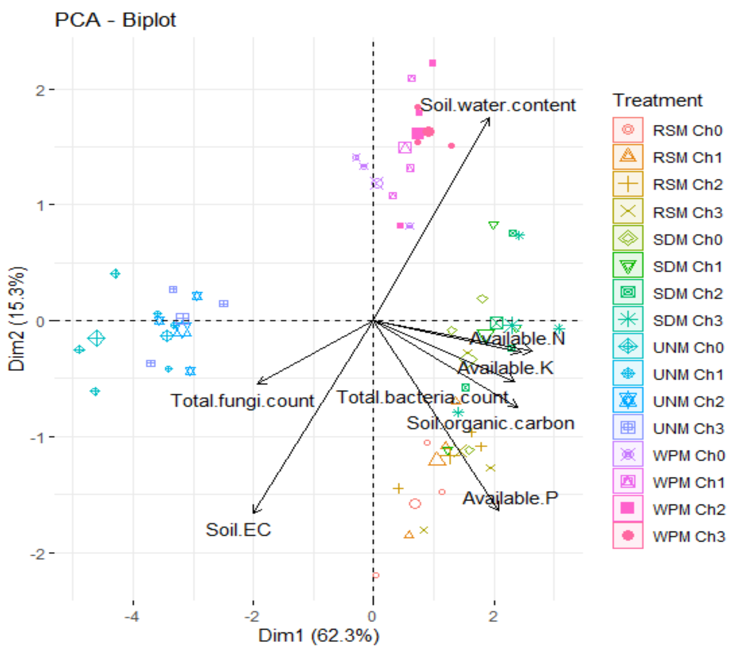

Figure 2. PCA biplot for all studied soil parameters had response to interactive effect of different mulch materials and chitosan foliar applications.

3.3.2. Dry Weights of Shoots and Roots

All mulching treatments gradually increased the dry weights of both shoot and roots (Table 2), and the minimum values in this respect were recorded with un-mulched treatment (UNM).

In addition, plants sprayed with chitosan had significantly higher dry weights of shoots and roots than control plants. Compared with the control plants, the dry weight of shoot was increased by 16.46 and 14.24% with 62.5 mg nano-chitosan L^{-1} treated plants (Ch_3).

Dry weight of shoot was increased by 31.96 and 26.54% under rice straw mulch treatment plus 62.5 mg nano-chitosan L^{-1} treated plants (Table 2).

The same direction was noticed in roots, as dry weight was increased by 23.07 and 22.25%, while they were 39.26 and 39.24% in rice straw mulch treatment plus 63 mg nano-chitosan L^{-1} treated plants, respectively (Table 2).

3.3.3. Seed yield

The different mulch treatments had a statistically similar seed yield in both seasons (Table 2). The highest seed yield (2030.93 and 2075.77 kg ha^{-1}) was obtained with a foliar application of 62.5 mg nano-chitosan L^{-1} (Ch_3). The results evidenced that the interactive effect of different mulch materials plus by chitosan foliar applications gave a statistically similar seed yield in both seasons (Table 2).

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Table 2. Plant height, dry weight of shoots and roots, seed yield and nutrients concentration of common bean seed affect under different treatments affect.

Plant parameters	Ph (cm)		SDW (g)		RDW (g)		SY (kg ha^{-1})		N (%)		P (%)		K (%)		Na (%)	
Seasons	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Mulching materials																
UNM	24.81^{b}	24.91^{c}	2.04^{b}	2.10^{b}	0.206^{b}	0.213^{b}	1450.44^{b}	1481.24^{b}	1.20^{d}	1.24^{c}	0.222^{d}	0.236^{c}	0.659^{c}	0.668^{d}	0.131^{a}	0.119^{a}
WPM	28.14^{a}	28.42^{ab}	2.21^{a}	2.26^{a}	0.232^{a}	0.238^{a}	1981.35^{a}	2014.03^{a}	1.38^{c}	1.45^{b}	0.240^{c}	0.251^{b}	0.985^{b}	1.00^{c}	0.096^{c}	0.077^{c}
RSM	28.89^{a}	29.37^{a}	2.23^{a}	2.29^{a}	0.242^{a}	0.248^{a}	2003.96^{a}	2040.54^{a}	1.47^{a}	1.50^{a}	0.264^{a}	0.272^{a}	1.04^{a}	1.06^{b}	0.102^{b}	0.082^{bc}
SDM	28.18^{a}	28.70^{b}	2.21^{a}	2.28^{a}	0.236^{a}	0.243^{a}	1991.04^{a}	2025.55^{a}	1.43^{b}	1.48^{ab}	0.253^{b}	0.258^{b}	1.06^{a}	1.10^{a}	0.104^{b}	0.085^{b}
F-Value	59.56	80.23	19.73	12.83	36.53	28.07	153.35	154.76	123.47	105.93	61.93	55.47	309.09	389.84	7.92	12.91
P-Value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Chitosan foliar application																
Ch$_0$	23.92^{d}	24.22^{d}	1.97^{c}	2.07^{c}	0.199^{c}	0.206^{b}	1543.36^{c}	1565.80^{c}	1.22^{d}	1.29^{c}	0.185^{d}	0.193^{d}	0.770^{d}	0.783^{d}	0.153^{a}	0.137^{a}
Ch$_1$	28.46^{c}	28.75^{c}	2.17^{b}	2.23^{b}	0.233^{b}	0.240^{a}	1918.59^{b}	1942.63^{b}	1.39^{c}	1.43^{b}	0.243^{c}	0.257^{c}	0.913^{c}	0.940^{c}	0.105^{b}	0.090^{b}
Ch$_2$	28.72^{b}	29.09^{b}	2.24^{ab}	2.28^{ab}	0.239^{ab}	0.245^{a}	1933.92^{b}	1977.14^{b}	1.42^{b}	1.46^{ab}	0.269^{b}	0.275^{b}	1.00^{b}	1.03^{b}	0.092^{b}	0.071^{b}
Ch$_3$	28.93^{a}	29.33^{a}	2.30^{a}	2.36^{a}	0.245^{a}	0.251^{a}	2030.93^{a}	2075.77^{a}	1.45^{a}	1.49^{a}	0.280^{a}	0.292^{a}	1.06^{a}	1.08^{a}	0.083^{b}	0.065^{b}
F-Value	102.38	118.73	48.00	25.79	61.86	46.63	96.29	103.85	91.83	61.14	351.76	472.01	140.76	169.01	31.38	37.88
P-Value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction																
UNM Ch$_0$	21.70^{c}	21.87^{d}	1.60^{h}	1.78^{c}	0.159^{f}	0.164^{g}	1135.43^{c}	1167.80^{c}	0.952^{i}	0.964^{i}	0.166^{h}	0.168^{h}	0.443^{k}	0.444^{n}	0.204^{a}	0.195^{a}
UNM Ch$_1$	25.33^{b}	25.40^{bc}	2.12^{fg}	2.17^{ab}	0.216^{de}	0.224^{def}	1513.68^{b}	1518.44^{b}	1.20^{h}	1.29^{h}	0.231^{f}	0.250^{f}	0.680^{j}	0.703^{m}	0.115^{d}	0.107^{c}
UNM Ch$_2$	25.86^{b}	25.93^{bc}	2.17^{ef}	2.19^{ab}	0.222^{cde}	0.229^{cdef}	1534.62^{b}	1559.07^{b}	1.30^{g}	1.33^{gh}	0.243^{de}	0.258^{def}	0.742^{i}	0.752^{l}	0.109^{de}	0.093^{d}
UNM Ch$_3$	26.33^{b}	26.43^{b}	2.25^{bcd}	2.27^{ab}	0.227^{cde}	0.232^{bcdef}	1618.09^{b}	1679.64^{b}	1.34^{fg}	1.39^{efg}	0.249^{de}	0.269^{d}	0.772^{hi}	0.775^{l}	0.096^{gh}	0.082^{e}
WPM Ch$_0$	24.43^{b}	24.47^{c}	2.07^{g}	2.14^{b}	0.210^{e}	0.216^{f}	1674.26^{b}	1692.35^{b}	1.23^{h}	1.37^{fg}	0.176^{h}	0.194^{g}	0.806^{h}	0.824^{k}	0.125^{c}	0.108^{c}
WPM Ch$_1$	29.23^{a}	29.63^{a}	2.17^{ef}	2.23^{ab}	0.234^{bcd}	0.241^{abcd}	2040.14^{a}	2069.96^{a}	1.41^{de}	1.45^{cde}	0.240^{ef}	0.252^{f}	0.955^{ef}	0.979^{hi}	0.098^{fg}	0.082^{e}
WPM Ch$_2$	29.40^{a}	29.67^{a}	2.25^{bcd}	2.28^{ab}	0.241^{abc}	0.245^{abcd}	2056.63^{a}	2108.37^{a}	1.43^{cde}	1.47^{bcd}	0.267^{c}	0.270^{d}	1.06^{cd}	1.08^{ef}	0.084^{ij}	0.061^{f}
WPM Ch$_3$	29.50^{a}	29.90^{a}	2.31^{ab}	2.38^{ab}	0.244^{abc}	0.250^{abc}	2154.38^{a}	2185.48^{a}	1.46^{bcd}	1.52^{abc}	0.277^{b}	0.287^{bc}	1.11^{b}	1.13^{cd}	0.076^{j}	0.057^{f}
RSM Ch$_0$	25.07^{b}	25.60^{bc}	2.13^{fg}	2.19^{ab}	0.216^{de}	0.222^{def}	1685.68^{b}	1694.87^{b}	1.37^{ef}	1.43^{def}	0.203^{g}	0.207^{g}	0.911^{g}	0.917^{j}	0.140^{b}	0.120^{b}
RSM Ch$_1$	30.00^{a}	30.27^{a}	2.21^{cde}	2.25^{ab}	0.243^{abc}	0.251^{abc}	2070.60^{a}	2101.06^{a}	1.47^{bc}	1.50^{abc}	0.257^{cd}	0.268^{de}	0.980^{e}	1.02^{gh}	0.100^{efg}	0.086^{de}
RSM Ch$_2$	30.17^{a}	30.70^{a}	2.26^{abc}	2.32^{ab}	0.251^{ab}	0.256^{ab}	2072.20^{a}	2131.53^{a}	1.50^{ab}	1.54^{ab}	0.289^{b}	0.297^{b}	1.10^{bc}	1.11^{de}	0.087^{hi}	0.063^{f}
RSM Ch$_3$	30.33^{a}	30.90^{a}	2.33^{a}	2.40^{a}	0.257^{a}	0.265^{a}	2187.39^{a}	2234.65^{a}	1.53^{a}	1.55^{a}	0.306^{a}	0.316^{a}	1.16^{a}	1.18^{ab}	0.080^{ij}	0.059^{f}
SDM Ch$_0$	24.47^{b}	24.93^{bc}	2.10^{g}	2.16^{ab}	0.212^{de}	0.220^{ef}	1678.07^{b}	1708.20^{b}	1.32^{fg}	1.39^{efg}	0.196^{g}	0.202^{g}	0.918^{fg}	0.945^{ij}	0.142^{b}	0.124^{b}

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SDM Ch_1	29.27[a]	29.70[a]	2.19[def]	2.26[ab]	0.239[abc]	0.244[abcd]	2049.97[a]	2081.07[a]	1.46[bcd]	1.49[abcd]	0.246[e]	0.257[ef]	1.04[d]	1.06[fg]	0.106[def]	0.088[de]
SDM Ch_2	29.43[a]	30.07[a]	2.25[bcd]	2.31[ab]	0.243[abc]	0.250[abc]	2072.20[a]	2109.63[a]	1.46[bc]	1.50[abc]	0.278[b]	0.274[cd]	1.11[b]	1.17[bc]	0.088[hi]	0.066[f]
SDM Ch_3	29.57[a]	30.10[a]	2.31[ab]	2.39[a]	0.251[ab]	0.259[a]	2163.90[a]	2203.24[a]	1.49[ab]	1.52[ab]	0.291[b]	0.298[b]	1.20[a]	1.23[a]	0.082[ij]	0.061[f]
F-Value	0.3	0.47	6.79	2.01	2.24	1.96	0.02	0.09	5.23	8.37	1.95	2.76	2.23	2.35	1.41	1.61
P-Value	0.969	0.883	<.0001	0.071	0.046	0.078	1.00	1.00	<.0001	<.0001	0.08	0.017	0.046	0.037	0.221	0.155

* **Ph**: plant height, **SDW**: shoots dry weight, **RDW**: roots dry weight, **SY**: seed yield. **UNM**: un-mulched, **WPM**: white plastic mulching, **RSM**: rice straw mulching, **SDM**: sawdust mulching. **Ch_0**: distilled water (control), **Ch_1**: 250 mg chitosan L^{-1}, **Ch_2**: 125 mg nano-chitosan L^{-1} and **Ch_3**: 62.5 mg nano-chitosan L^{-1}.

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3.3.4. Macro-nutrients concentration of common bean seed

The mulch materials had significant ($P \leq 0.05$) content of N, p, k, and Na in seeds (Table 2). Rice straw mulch (RSM) increased N and P% in seed, while sawdust mulch (SDM) increased significantly K% and white plastic mulch (WPM) reduced significantly Na% in seed, compared to un-mulched (UNM).

Compared with the control plants, chitosan foliar applications reduced significant Na% in seed and gave the highest NPK concentration in parallel with foliar nano-chitosan at a rate of 62.5 mg L^{-1} (Ch_3). Under the interactive effect of mulch and chitosan foliar applications, the soil covered by both organic mulching materials plus 62.5 mg nano-chitosan L^{-1} increased N, P, and K, in seed, whereas seed Na decreased significantly with all treatments compared to control plants (Table 2).

3.3.5. Principal Component Analysis (PCA)

Figure 3, loading PCA biplot of all studied plant parameters showed that, the first and two principal components described (Dim1= 90% and Dim2 =3.9 %) of the total variability which noted that Na% in seed had a negative correlation with other studied plant parameters especially shoot and root dry weight. Dim1 and Dim2 successfully separated the interactive effect of different mulch materials and foliar by chitosan applications. This again indicates that chitosan foliar applications s have the largest impact on studied common beans plant parameters, than different mulches treatments. Interestingly the correlation analyses did show a high relationship between all the soil nutrient content values.

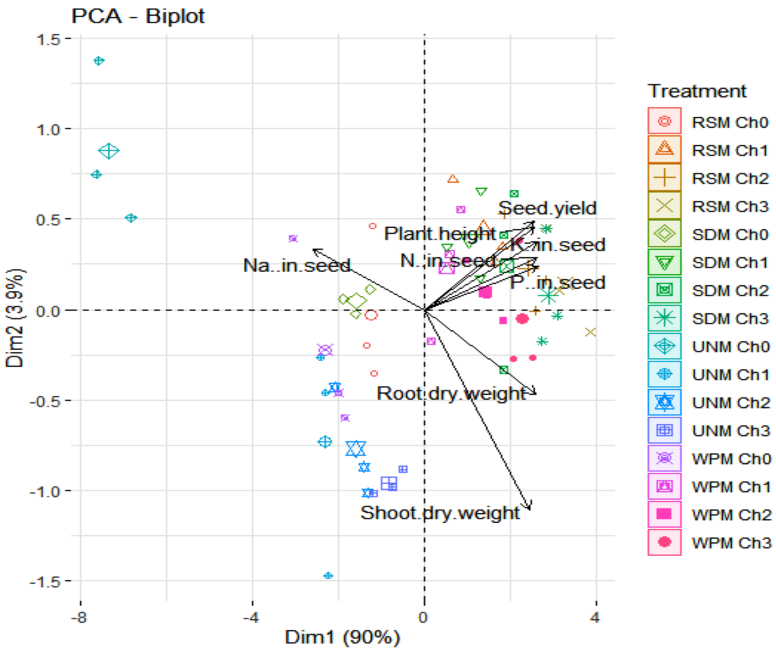

Figure 3. PCA biplot for all studied plant parameters had response to interactive effect of different mulch materials and foliar by chitosan applications.

3.4. Correlation matrix

To explore the impact of soil salinity factors on all studied soil and plant parameters, we analyzed the relationships between all studied parameters using a correlation matrix in R (Figure 4). The soil EC was positively related to the abundance of total fungi count and also increased Na content in common bean seeds. The other soil parameters was positively correlated and also with plant parameters. The results showed that the improvement soil characteristics had great influences on common beans productivity.

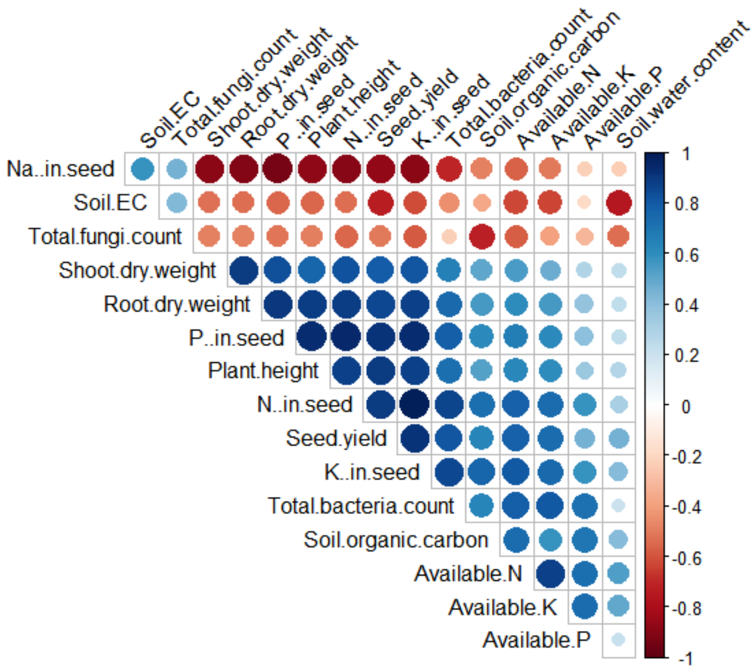

Figure 4. Correlation matrix among all studied parameters affected mulch materials and foliar chitosan application.

4. Discussion

4.1. Soil parameters

Salinization causes significant restrictions and decreases crop production due to limitations on various crops [42]. In the current study, mulching and foliar chitosan spraying application a suitable method was used to reduce the effect of salinity on common bean productivity, as well as comparing different materials of mulching on some chemical and biological soil characteristics. The results showed that the use of white plastic mulch (WPM) led to a decrease in soil salinity and in addition to an increase in the water content in the soil. From this result, the decrease in soil salinity could be linked to an increase in moisture content. These results are consistent with [18, 43-45], they confirmed that the mulching procedures not only boosted soil water content, but also contributed to the leaching of soil salt and reducing the soil salt content; this is attributed to the decrease in soil evaporation.

The increase in the organic carbon content of the soil under organic mulching could be attributed to the increase in organic matter content in the soil due a higher decomposition rate, thereby increasing the organic carbon content [46]. The present finding conformed to Hossen et al., [47]; they indicated that the sawdust mulching treatment increased soil organic carbon more than other mulching treatments studied.

The increase in available nutrients in soils is a result of increased microbial activity and soil moisture content beneath the mulching materials which led to an improvement in soil fertility. Xiaomin [48] indicated that the positive changes in the available nutrients due to organic mulching can be attributed to the increased biological activities, thus, giving rise to the mineralization of organic matter.

The results showed that, the application of different materials of mulching had a contradictory effect on the bacterial communities in the soil, as the numbers of bacteria increased due to the presence of organic carbon, and in contrast, the numbers of fungi in the soil decreased as a result of mulching treatments. These results are consistent with previous studies for both [20,49].

The results revealed that the foliar application of chitosan had a positive effect on soil salinity and carbon content. This can be attributed to helping in the spread of roots through the soil layers, as it led to loosening of the soil, which helped to get rid of salts. Also, root residues in the soil led to an increase in organic matter, which was reflected in an increase the soil organic carbon, and consequently the bacterial populations. However, the total fungi count in the soil was significantly decreased due to chitosan foliar applications. The present finding was conformity with [50-51]. Chitosan or its nanoparticles foliar application have been reported to harm fungi growth by induced defense responses in plants against defense system against the pathogen [52-53]. In addition, these negative effects could be due to the

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repeated amino groups of the chitosan structure [54], the external electrostatic interaction between the positive amino glucosamine groups $-NH_3^+$ of chitosan and phospholipids in the fungal cell membrane, leads to changes in cell permeability and leakage of intracellular electrolytes and proteinaceous constituents and cell death [55].

4.2. Common bean yield and its components

The salt stress had a noxious effect on the growth, physiological, and productivity of common bean [56]. According to Assimakopoulou et al., [57], the common bean (*Phaseolus vulgaris* L.) is considered a salt-sensitive plant, and the 0 - 75 mM NaCl concentration caused biomass and yield reduction. The use of mulching in these conditions led to improved growth and this was reflected in the crop as a result of improved soil characteristics, including a decrease in Salinity, soil fertility, and moisture availability. The results obtained are consistent with [21-23].

The improvement in growth parameters and common yield can be attributed to the use of chitosan which is more active against salt stress by reducing oxygen free radicals or blocking ROS activity, promoting cell division, increasing ionic transport, polyamine content, and membrane stabilization under stress conditions [58]. The stimulating effect of chitosan on plant growth may be attributed to an increase in the availability and uptake of water and essential nutrients via cell osmotic pressure adjustment, as well as a reduction in the accumulation of harmful free radicals (ORS) via increased antioxidants and enzyme activities [59]. Zayed et al., [61] study the effect of nano-chitosan application on *Phaseolus vulgaris* under salinity stress, and found that the plant height and dry weights of the shoots increased significantly with nano chitosan application as a result in increasing of antioxidant enzymes. Also, the application of CSNPs improves chlorophyll content and plant metabolism in salt-stressed mung beans (*Phaseolus vulgaris* L.), as evidenced by a reduction in malondialdehyde and H_2O_2 contents [60].

5. Conclusion

It can conclude that, the beneficial effects of mulching materials have effective for inhibiting salt accumulation and increasing soil water and nutrient content. The foliar spray applications of 62.5 mg nano chitosan L^{-1} at 15, 30, and 45 DAS alleviated the salt stress and improved the growth of common bean plants. For sustainable eco-system, combining mulching with foliar chitosan spray application can be an effective practice for the inhibition of salt accumulation and improved growth and productivity of common bean grown in salt-affected soil.

Author Contributions: Conceptualization, N.A., M.A., T.K., and E.S.; methodology, N.A., M.A., T.K., and E.S.; software, T.K.; validation, N.A., M.A., T.K., and E.S.; formal analysis, T.K., E.S. and A.E-D.O.; investigation, N.A., M.A., T.K., and E.S.; resources, , N.A., M.A., T.K., E.S., M.E., and A.E-D.O.; data curation, N.A., M.A., T.K., and E.S.; writing—original draft preparation, , T.K., and E.S.; writing—review and editing, N.A., M.A., and A.E-D.O.; visualization, N.A., M.A., and E.S.; supervision, T.K.; funding acquisition, M.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sets analyzed during the present study are accessible from the current author on reasonable request.

Acknowledgments: The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through the Larg Groups Project under grant RGP2/164/44. All the authors extend their esteem, Soil, Water, and Environment Res. Inst., Agriculture Research Center, Giza, Egypt, Soil and Water Department, and Horticulture Department Faculty of Agriculture, Tanta University, Tanta, Egypt. Also, thankful for the support provided by Labs of soil improvement and conservation Res. Dep., and soil microbiology Res. Dep., Sakha Agri. Res. station, Kafr El-Sheikh, Egypt.

Conflicts of Interest: The authors declare no conflict of interest.

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 doi:10.20944/preprints202312.1845.v1