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Inoculation of *Chlorella* and Food Waste Improves the Physio-Morphological Features of Red Pepper by Regulating Activating Antioxidant Defense System

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ABSTRACT

Food waste is recognized as a valuable source for potential agricultural applications to supply organic matter and nutrients to arable soil. However, the information on the combined application of food waste and the plant growth-promoting bacterial strain, *Chlorella*, related to plant metabolic features and sodium chloride content in arable soil is limited. The present study was conducted to investigate the exogenous application of food waste along with *Chlorella*, which improved the physio-morphological features of red pepper. Our results revealed that this combination enhanced the organic matter in the soil, ultimately improving the fertility rate of the soil, and the physio-morphological features, such as chlorophyll *a* content (24.5 ± 0.7), root (7.8 ± 0.7) cm and shoot length (12.1 ± 0.7) cm, fresh weight (2.1 ± 0.05) g, dry weight (0.19 ± 0.05) g, mineral contents, and hormonal concentration (ABA by up to 2 folds). The combined treatment also minimized free radicals via the activation of the intrinsic antioxidant series cascade and electrolyte leakage. Our findings showed that adding *Chlorella* and food wastes improved growth characteristics and can be used as a green bio-fertilizer for sustainable agriculture.

KEYWORDS

Food waste; *Chlorella*; hormone; antioxidant

1 Introduction

Food waste is defined as the unconsumed or leftover portion of food [1,2]. Globally, one-third of food is wasted at various stages of production and marketing [3]. Gustavsson et al. [4] reported that over 1 billion tons of food waste are produced annually. Households produce 42% of food waste, manufacturing industries

make up 39%, food service sectors are responsible for 14%, and the distribution process is responsible for 5% of food west [5]. Global food waste is expected to rise to 416 million tons by 2025, owing to rapid population growth in Asian countries [6]. According to reports, Japan generates almost 19 million tons, Taiwan produces 16.5 million tons, and Korea produces over 22% (4.3 million tons) annually of food waste [7–9]. Food waste has been identified as a valuable source of organic matter and nutrients for agricultural applications in arable soils. Composting is a modest, inexpensive, and regular degradation biological process that can transform food waste into nutrient-rich food for plants to improve and stabilize soil properties. Food waste contains nutrients that agriculture can reuse to enhance soil properties, growth, and productivity. Furthermore, the constituents of food waste include biological organic and inorganic compounds that oblige food for microbes; therefore, combining bio-fertilizer with organic fertilizers can be beneficial, and plants grow faster owing to plant root–microbe interactions [10,11]. Additionally, using food waste with *Chlorella* amendments as organic fertilizers can help improve soil chemical properties by bio-remediating pesticide and hydrocarbon-contaminated soils and alleviating salinity problems [12,13].

Many bio-stimulants, including purified seaweed extract, have been used in agriculture in recent years. However, microalgae have received insufficient attention as potential sources of plant bio-stimulants. *Chlorella* has also been investigated as a bio-fertilizer because it is high in carbohydrates, proteins, and growth hormones and is a bio-stimulant in conventional agriculture [14]. Plants have exhibited numerous reactions to microalgae inoculation, including increased growth and yield, improved nutrient acquisition, and tolerance to abiotic stresses, including salinity stress [15,16]. Microalgal treatment reduces the salinity levels in tomatoes by increasing the enzymatic activity of antioxidant enzymes [15]. Synthetic chemical fertilizers are a vital source of nourishment for crops; however, their scarcity, low plant uptake, and overuse have resulted in severe ecological imbalances. The magnitude of their effect on environmental stress has surpassed its limit [17]. Various agrochemicals are reported as carcinogenic and lethal for the environment and human health as well [18–20]. Our research team previously used commercial food waste with rhizobacteria to enhance the salinity tolerance in Chinese cabbage [5,21]. In light of these findings, we designed an experimental study to investigate the potential of food waste powder and plant growth-promoting microorganism (PGPM) *Chlorella* as a biologically safe fertilizer technique for improving crop growth and development. In the current study, we treated red pepper seedlings with *Chlorella* and food waste dry powder separately and together and examined their morphological and physiological parameters. Its impact on endogenous hormonal regulation and mineral contents was also investigated.

2 Materials and Methods

Red peppers were purchased from Syngenta Inc. (Switzerland) (commercial cultivar 'Dokyacheongcheong') and were then sown in a germination tray containing horticultural soil for 21 days. For the current study, the organic fertilizer was mixed with food waste in dry powder form, using two different concentrations (2g/pot FW2) (4g/pot FW4) and was then incorporated into the upper 10 cm of the soil and supplemented with various amounts of food waste according to the experimental design. *Chlorella* was distributed from the Agricultural Technology Center. The pots were appropriately labeled and divided into six groups; after three weeks, growth parameters such as seedling length and biomass were investigated.

2.1 Physiochemical Properties of Soil

To determine the physiochemical properties of soil, the detailed method of [22] was followed. In brief, 15–20 g of soil samples were collected for the field, and impurities were removed. The obtained soil sample was subject to air-dried and sieved through a 4-mm mesh to obtain clean and fine soil for further investigation. 5 g of the obtained soil sample was diluted with 25 ml of deionized water, followed by vortex for 5 min, and incubated at room temperature at continuous shaking for 1 h. After that, the pH and electrical conductivity were measured using pH and EC meters, respectively.

2.2 Endogenous Abscisic Acid Quantification

The endogenous ABA was extracted and quantified through gas chromatography-mass spectrophotometry (GC-MS) following the detailed methodology as previously described by [23] with slight modifications. Briefly, 0.5 g of sample was diluted with 10 mL of extraction buffer and was then subjected to shaking (130–140 rpm) at room temperature for 2 h. After shaking, the sample was then subjected to vacuum filtration and was diluted four times with a 5 mL extraction buffer. The obtained supernatant was treated with 50 ng of ABA standard before being evaporated in a rotary evaporator to a minimum of 2 mL. A 2 mL of 1 N (sodium hydroxide) NaOH was added to RBF and sonicated before being transferred to the long test tube. The pH was adjusted to 12.5, and 4 mL of dichloromethane was added to an empty RBF and sonicated before being transferred to respective test tubes, followed by vertex, and allowing to form layers.

The obtained upper layers were acidified by lowering the pH to 2.5–3.5, followed by adding 4 mL acetyl acetate three times for solvent-solvent partition through vertexing. The upper layer was then subjected to vacuum dry, and a 1 g of PVPP was added to the new flask while the RBF was washed three times with 4 mL of phosphate buffer pH 8.0, sonicated, and then transferred to the respective flask, followed by shaking for 1,30 Hr and they were the cleaned twice with 5 mL of P buffer. The filtrate pH was adjusted to a range of 2.5 to 3.5, and added ethyl acetate was three times, and vortexed again three times; the top layer was removed and added DW pH with 2.5 to the ethyl acetate vortex, and thrower away the bottom part. The solution was dried to 1 mL before transferring it to RBF. One ml was transferred to small vials and dried under an N-dryer. After that, 1 mL of 100% ethyl acetate was added twice and sonicated. Sixty uL of diazomethane was added, vortexed, and subjected to incubation in the dark at room temperature for 30 min. After incubation for 30 min, the vials were dried using N-dry gas; this incubation with diazomethane was repeated two times. Finally, the vials were diluted with 20 µL of dichloromethane and injected into GC-MS (6890N network gas chromatograph, Agilent Technologies), software to monitor signal ions (m/z 1162 and 190 for Me-ABA and m/z 166 and 194 for Me-[^{2}H$_6$]-ABA).

2.3 Measurement of Different Antioxidants

The antioxidant activity was estimated using the method described by Adhikari et al. 2020 [24]. Briefly, to quantify SOD, a 0.2 g of the plant samples were added to 5 mL of extraction buffer (5 mM Tris HCl (60 mL) + 40 mL EDTA (10 mL) and were then centrifuged at 10,000 xg for 10 min. A 50 uL of the obtained supernatant was diluted by the addition of 150 µL of extraction buffer + 50 µL of pyrogallol to record A values, and 50 uL of supernatant was added 200 µL of extraction buffer to record B values, while a 50 uL of supernatant was added 150 uL of extraction buffer + 100 µL of pyrogallol to record C values at an absorbance wavelength of 420 nm.

$$SOD\ activity\ =\ [1 - (A - B/C)]$$

To measure flavonoid content, 0.2 g of plant samples were extracted with NaNO$_2$, followed by centrifuge for 10 mint at 10000 rpm. The obtained supernatant was then diluted with 60 µL of 10% AlCl$_3$, and 1 M sodium hydroxide was added. The absorbance was measured at 510 nm, as described by Adhikari et al. [25].

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity was determined as described by Blois [26] with modifications. Briefly, 0.2 g of sample was extracted using 90% ethanol followed by centrifuge for 10 mint at 10000 rpm. The obtained supernatant was then diluted with 0.5 mM DPPH and 100 mM acetate buffer pH 5.5. The absorption was measured using a spectrophotometer at 517 nm and deliberated using the following equation:

$$Scavenging\ effect\ (\%)\ =\ 1\ -\ (Abssample - Abscontrol)\ *\ 100$$

To measure LPO lipid peroxidation levels, a 0.2 g of freeze-dried samples were diluted with 10 mM phosphate buffer pH 7.8% and 5% TCA and followed by centrifuge at 15,000 rpm for 12 min at 4°C. After centrifugation, 1 ml of supernatant and 2 ml of 0.5% TBA was added and incubated at room temperature for one hour, and then absorbance was measured at 532 nm.

For MDA quantification, a 0.2 g of grounded fresh leaves were combined with 5 mL of 5% TCA solution, followed by centrifuging at 10,000 xg for 10 min; the obtained 100 uL of supernatant was added to 1 mL TBA reagent and heated in a water bath at 45°C or 10 mins, and cooled immediately in a refrigerator, later centrifuged again at 10,000 xg for 10 mins and 250 uL of supernatant was taken, the absorbance was read as follows.

R_1 at 530 nm, R_2 at 600 nm, and the final value were obtained using MDA equation R_3 (R_1–R_2) as the absolute value.

For Chlorophyll a, 0.2 g of freeze-dried grounded shoot sample was extracted by adding 150 uL of 80% methanol and centrifuged at 10,000 xg for 10 min, 200 uL of supernatant was removed and read at 470 nm.

2.4 ICP Analysis of Ion Uptake

The ion uptake was determined using a previously described method [27]. In a microwave, freeze-dried powdered plant samples of 0.1 g were mixed with 3 ml of nitric acid and 2 ml of H_2O_2. The samples were injected using inductively coupled plasma mass spectrometry (ICP-MS).

2.5 Statistical Analysis

The experiment was repeated thrice, and each replicate contained 20 plants. GraphPad Prism was used for graphical representations. One-way ANOVA in MS Excel determined the statistical difference between treatment means. Duncan's multiple range test (DMRT) was used to determine critical values for comparison between the mean of treatments at a significance level of $p < 0.05$. Statistical Analysis System (SAS 9.1) was used for the DMRT Analysis. For the graphical representation, we used GraphPad Prism software (version 6.0, San Diego, CA, USA).

3 Results

3.1 Physiochemical Properties of the Soil

The results of the current study indicate that the application of food waste significantly improved soil electrolytic conductivity. As shown in Fig. 1a significant increase in EC was found in FW4 (1.4 mS/m) and decreased in FW2 (0.8 mS/m: No, FW2 was lower than the control) treated plants when compared to control plants. Moreover, further addition of *Chlorella* slightly increases the EC level by (0.7 mS/m) when compared to the control. However, the combined application of FW and CR significantly increases the EC level by 133.3%, compared to the control plant followed by the sole application of FW and chlorella (Fig. 1A). Similarly, the application of FW lowers the soil pH to 3.0–3.5, when compared to control plants, while the combined application of FW + CR significantly balances soil pH to optimum ranges between 3.8–4.0, which is the optimum level for the availability of most nutrients. These parameters further improve the soil's physiochemical properties and nutrient availability (Fig. 1B).

3.2 Inoculation of Chlorella Regulates Pepper Physiological Growth under Food Waste Treatment

The current results showed that food waste application (FW2 and FW4) reduced pepper plants' growth characteristics (Table 1). As plants treated with FW4 significantly decreased the shoot length (15.9 ± 2.50 cm), root length (21.9 ± 2.65 cm) shoot fresh weight (11.6 ± 3.13 g), dry weight (1.8 ± 0.68 g), and stem thickness (4.4 ± 0.43 mm), when compared to control plants (Fig. 2). While, combine inoculation of *Chlorella* along with food waste enhances the morphological features in red pepper plant such as increases in shoot length (28 ± 0.91 cm), root length (30 ± 3.37 cm), fresh shoot weight (15.6 ± 1.60 g), shoot dry weight (2.7 ± 0.44 g) and stem thickness (5.7 ± 0.31 mm).
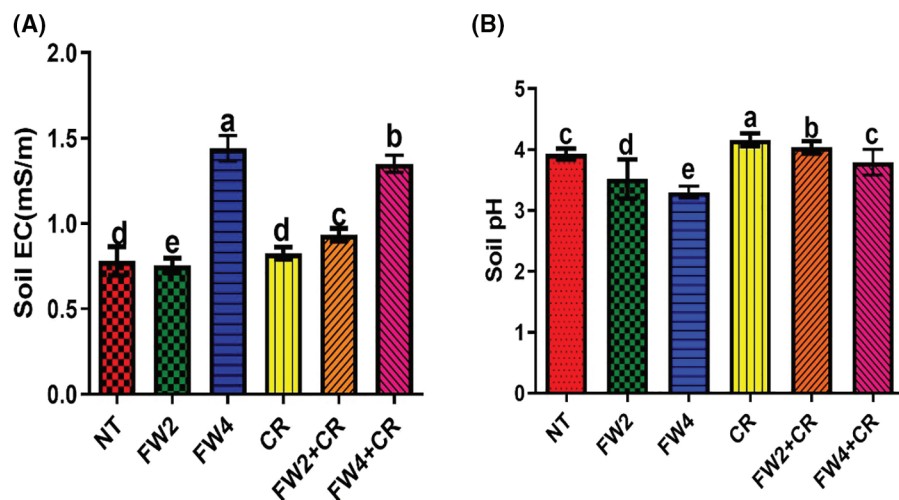
Figure 1: Effect of FW + CR on physiochemical properties of soil. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. (A) Effect of food waste and *Chlorella* on soil electrolytic conductivity (B) Effect of food waste and *Chlorella* on soil pH. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p \leq 0.05$ between two replicates

Table 1: Growth survey for each treatment

	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Stem thickness (mm)
NT	25.4 ± 1.49b	30.3 ± 5.91b	17.5 ± 2.22a	22.1 ± 1.13b	2.6 ± 0.36a	2.0 ± 0.19c	6.1 ± 0.97a
FW2	23.0 ± 1.78c	26.8 ± 3.30c	15.9 ± 0.37b	23.5 ± 0.59b	2.4 ± 0.19ab	2.2 ± 0.15b	5.4 ± 0.21c
FW4	15.9 ± 2.50d	21.9 ± 2.65d	11.6 ± 3.13d	16.1 ± 1.48c	1.8 ± 0.68d	1.2 ± 0.76d	4.4 ± 0.43d
CR	26.1 ± 0.56ab	32.5 ± 2.65a	13.90 ± 0.98c	27.8 ± 0.88a	2.3 ± 0.18b	2.8 ± 0.17a	5.8 ± 0.32b
FW2 + CR	26.2 ± 0.85ab	29.8 ± 3.40b	16.29 ± 1.81ab	27.4 ± 4.34a	2.1 ± 0.11c	2.0 ± 0.54c	5.8 ± 0.33b
FW4 + CR	28 ± 0.91a	30 ± 3.37b	15.6 ± 1.60b	26.3 ± 2.64a	2.4 ± 0.44ab	2.7 ± 0.44a	5.7 ± 0.31b

3.3 Effect of Food Waste on Endogenous ABA

Red pepper plants treated with food waste alone and in combination with *Chlorella* were further investigated to quantify endogenous ABA. The current results show that sole FW2 and FW4 cause a significant increase in the ABA content by 41.8% and 67.5%, when compared to control plants. However, the sole CR and FW2 + CR application shows a significant reduction in ABA content by 39.7% compared FW4 treated plant, followed by the combined application of FW4 + CR (Fig. 3).

3.4 Antioxidant Quantification in Red Pepper Plants Treated with Food Waste

Major ROS-scavenging enzymes, such as SOD, PPO, MDA, and DPPH, and phytochemicals, such as flavonoids and phenolics, were investigated to assess their influence on food waste and on the regulation of the endogenous antioxidant defense system of red pepper. The current results indicate that a slight increase in the SOD, MDA, El, and DPPH content was found in the plant treated with sole CR application, whereas a

significant decrease was found in the total flavonoids and phenolic content by sole CR application when compared to control plants (Figs. 4–7). On the other hand, FW2 and FW4 application cause significant increases in the SOD (21.5%), MDA (8.6% and 17.3%), EL (9.8% and 14.1%), DPPH (24.1%), total flavonoids (15.5%), and phenolic content (19.6%) compared to control plants. Were the combined application FW2 + CR and FW4 + CR significantly reduced this increase in the SOD (9.1% and 13%), MDA (15.4% and 7.3%), EL (13.2% and 7.1%), total flavonoids (11.2% and 16.1%), and phenolic content (8.6% and 12.4%) when compared to sole FW application. However, in the case of DPPH, the FW2 + CR significantly increased its content by 12.1% and 22.4% compared to FW-treated and control plants, while the FW4 + CR shows a significant reduction in the DPPH content by 7.5% and 16.7% when compared to control and FW treated plants (Fig. 6B).
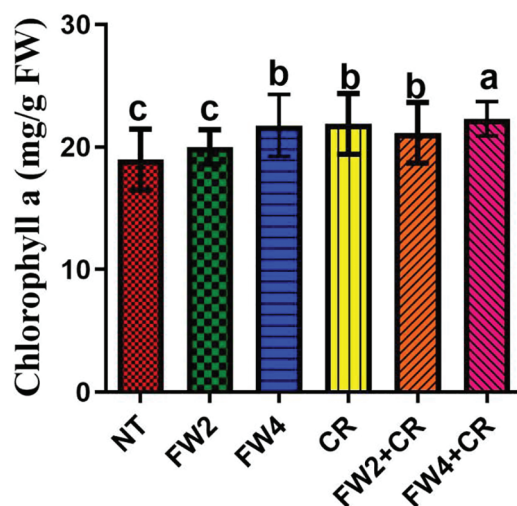

Figure 2: Effect of FW + CR on Chlorophyll *a* content. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at *p ≤ 0.05* between two replicates
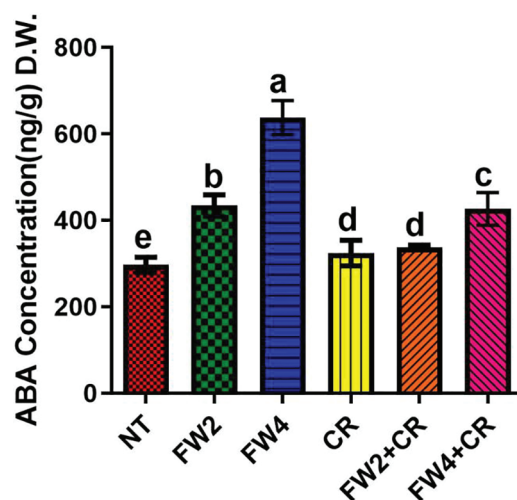

Figure 3: Effect of FW + CR on ABA content. NT as control, FW2 and FW4 as food waste, CR as *Chlorella* and FW2 + CR, FW4 + CR as combinations. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at *p ≤ 0.05* between two replicates
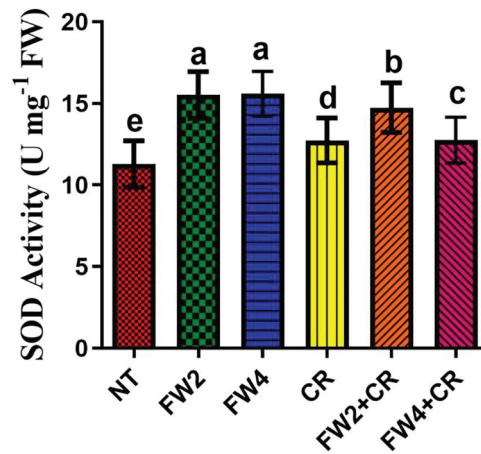
Figure 4: Effect of FW + CR on antioxidant activity. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. (A) Effect of food waste and *Chlorella* on SOD content. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p ≤ 0.05$ between two replicates
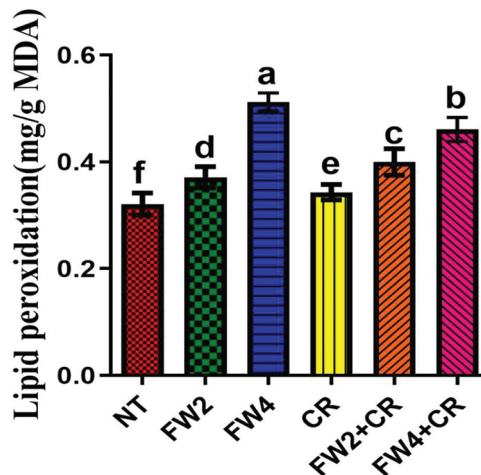

Figure 5: Effect of FW + CR on MDA content. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p ≤ 0.05$ between two replicates

3.5 ICP Analysis of Na, K, P, and Ca Content

The accumulation of different elements such as Ca, Na, and K was investigated through ICP analysis (Fig. 8). The current results show a significant increase in the Na content by FW2 (21.5%) and FW4 (48.6%) compared to control plants, where the sole CR and combine FW2 + CR application shows a slight decrease in Na content compared to control plant (Fig. 8A). in the case of K content, its level was significantly reduced in the FW4 (19.3%), CR (11.2%), and FW4 + CR (11.6%) treated plant compared to control plants, where the FW2 + CR application cause a significant increase in the K content by 13.8% compared to control plants (Fig. 8B). Moreover, the Ca content shows a significant increase by the FW2 (10%) and FW4 (8.6%) treated plants compared to control plants, where the sole CR and combine application of FW and CR cause significant reduction in the Ca content by 8% and 12% when compared to a sole FW treated plants (Fig. 8C).
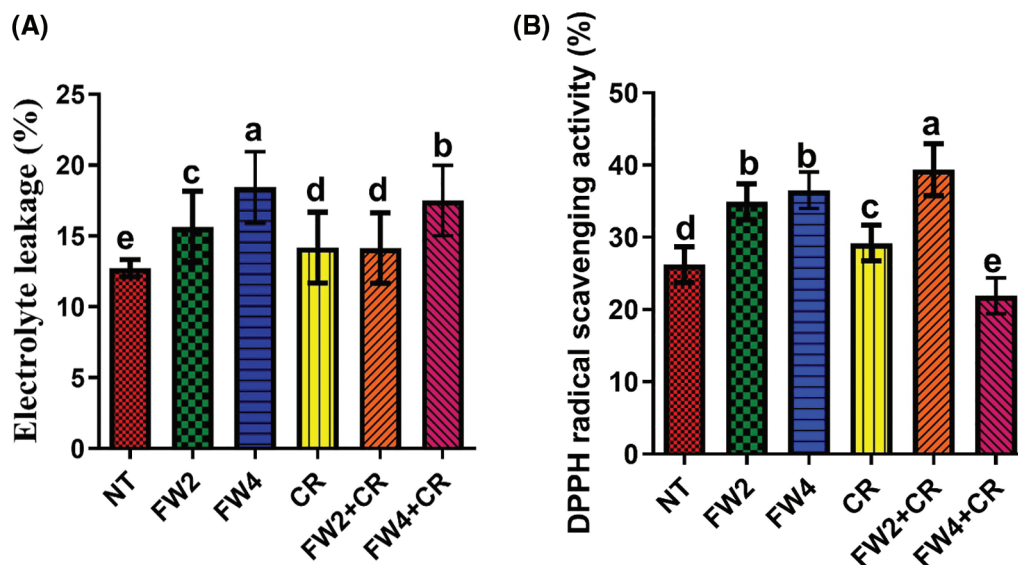
(A)

(B)

Figure 6: Effect of FW + CR on Electrolytic leakage NT as control, FW2 and FW4 as food waste, CR as *Chlorella* and FW2 + CR, and FW4 + CR as combinations. (A) Effect of food waste and *Chlorella* on soil electrolytic leakage (B) Effect of food waste and *Chlorella* on free radical scavenging. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p \leq 0.05$ between two replicates
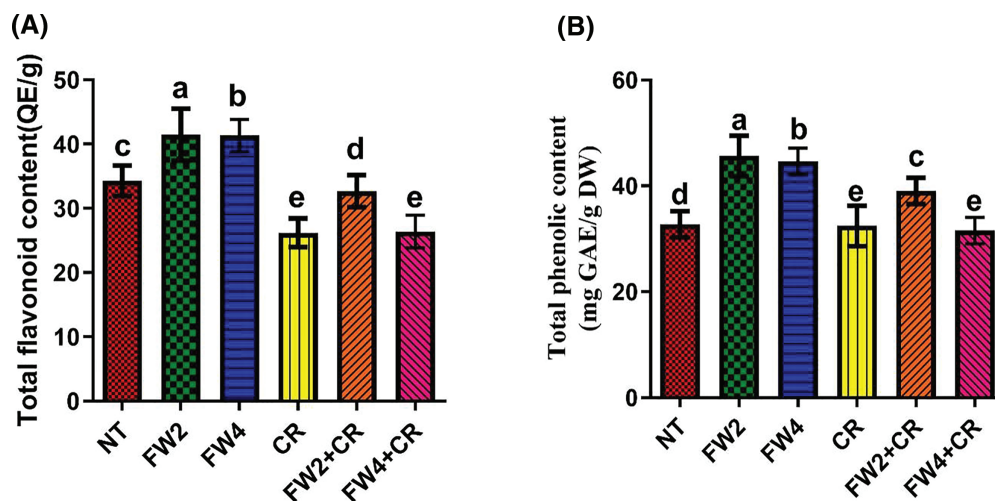
(A)

(B)

Figure 7: Effect of FW + CR on phytochemical contents. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. (A) Effect of food waste and *Chlorella* on total flavonoid contents (B) Effect of food waste and *Chlorella* on total phenolic contents. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p \leq 0.05$ between two replicates

Figure 8: Effect of FW + CR on **Na, Ca, and K content**. NT as control, FW2 and FW4 as food waste, CR as *Chlorella*, and FW2 + CR, FW4 + CR as combinations. (A) Effect of food waste and *Chlorella* on sodium content (B) Effect of food waste and *Chlorella* on potassium content (C) Effect of food waste and *Chlorella* on calcium content. Each bar represents the mean (±SE) with two replicates. Means with different letters are significantly different at $p \leq 0.05$ between two replicates

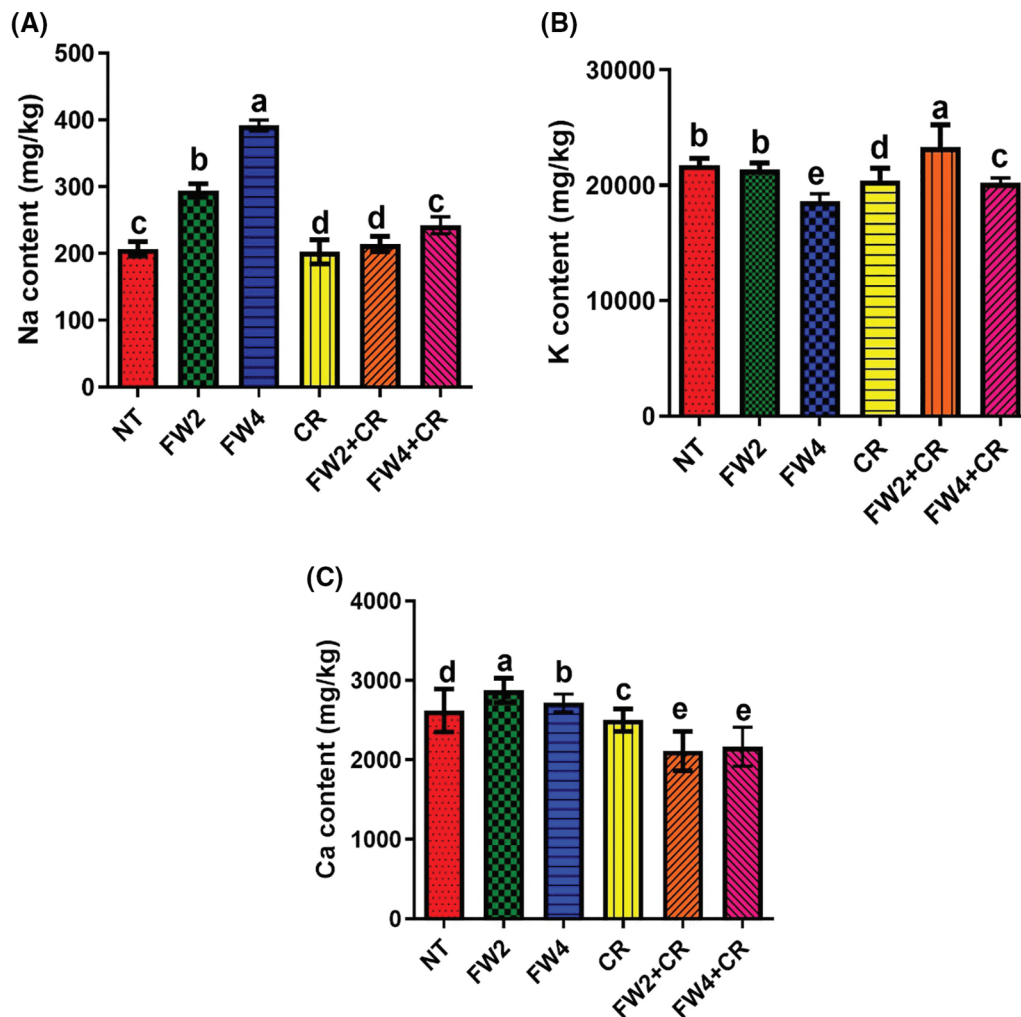## 4 Discussion

Although cities and households generate food waste in significant quantities, proper management remains a challenge [28–30]. Hence, turning food waste into resources and energy may help achieve economic and environmental sustainability [31]. Organic waste has been reported to facilitate *Chlorella* growth, which is consequently used for various bio-resource products and aids with plant growth [32–34]. Our experimental results suggested that the combination treatment of *Chlorella* and food waste dry powder considerably improved the morphological and physiological features of crops. Our findings align with those of Chew et al. [35], who reported that food waste compost could be used as an organic medium for microalgae cultivation, which could aid organic matter in the soil. These findings demonstrated the feasibility of using food waste as a fertilizer source. However, there are several disadvantages, such as the high salt content in food, which can cause salinity stress and soil sodification

[36,37]. As a result, we used *Chlorella*, a microbe that we believe could protect the crop against salt stress and soil sodification. Counterintuitively, when monitoring the mineral content of pepper plants, we discovered that *Chlorella* treatment with food waste powder reduced the Na content in the plants while improving other metabolic features, including endogenous phytohormones, antioxidants, and critical nutrient elements such as Ca^{++} and K^+. Composting produces stable organic matter rich in humic compounds and essential plant nutrients that can be utilized as organic fertilizers [38]. Food waste can be a vital source of composting materials and organic fertilizers to aid organic components in the soil [21]. In the current study, we observed that the combined application returned the pH level of the soil to a normal state. Furthermore, the application of *Chlorella* marginally reduced the soil EC content. These findings highlight the importance of food waste and *Chlorella* treatment in soil health management, which might be owing to enhanced organic matter and humic substances.

Long-term management solutions require a comprehensive understanding of the physiological context of crops [39]. Our research revealed that the combined application increased the chlorophyll *a* content of crops, possibly improving photosynthetic activity and, thus, crop growth. Moreover, the ABA content was substantially reduced by combination therapy. In general, ABA elevation above a specific threshold level can cause severe plant stress, which can be harmful [40]. The ABA level was significantly increased by using only food waste. This could be attributed to an increase in Na inflow. However, the ABA concentration was reduced considerably after inoculation with *Chlorella*. Excessive salt prevents critical nutrients from being absorbed, and PGPM improves the compartmentalization and exclusion of harmful ions by absorbing and transferring soil nutrients. Therefore, understanding the interaction of Na^+/K^+ and Ca^{++} ions is crucial for understanding plant physiology [41,42]. Similarly, ABA has been linked to the regulation of stomatal conductance in plant cells for water balance, signaling, and osmotic adjustment [43]. Our results are supported by numerous studies [44–46] reporting that the accumulation of Na^+ ions would elevate ABA levels. Similarly, our findings corroborate those of Arkhipova et al. [47] and Mohamed et al. [48], who reported a high efflux rate of Na^+ ions and low ABA levels upon inoculation with plant growth-promoting microorganisms, consequently improving plant growth.

The interactions among antioxidant activity, ionic balance, and phytohormones are critical to improving plant metabolomics. Under diverse environmental conditions, plants activate their intrinsic antioxidant defense system to help with ROS detoxification [49,50]. DPPH, SOD, flavonoid, and phenolic content are considered vital components that regulate the antioxidant activities of crops. Typically, superoxide dismutase converts O_2 to H_2O_2, which catalyzes the conversion of $2H_2O_2$ to $O_2 + 2H_2O$ [51]. DPPH scavenges toxic radicals, flavonoids, and phenolic compounds known as metal chelators and scavenges H_2O_2. In addition, flavonoids also act as signaling molecules in plant-microbe interactions [52]. The present experimental study suggested that the exogenous application of food waste and *Chlorella* mostly significantly enhance the phenolic content and DPPH, SOD, and flavonoid levels. These antioxidants are thought to neutralize vulnerable oxygen radicals, known as ROS. Moreover, our results also suggested that the combined application of FW2/CR plants exhibited lower electrolytic leakage compared to sole FW2 and FW4, which validates the possible low levels of ROS in these plants. Collectively, the lower content of these scavenging radicals and electrolytic leakage indicates the potential growth and development of red pepper seedlings. Overall, the co-inoculation of CR and FW enhanced the morphological features of the plant by maintaining the soil pH and EC, improving the chlorophyll *a* content, and maintaining the ABA regulation at a steady level, along with stabilizing the antioxidant potential and nutrient uptake. Through extensive research, this combination can be used to combat diverse types of environmental stress in the future.

Previously, our team also determined the effect of food waste on the growth of Chinese cabbage [5] and the mitigation of commercial food waste-related salinity stress with the help of halotolerant isolate *Bacillus*

pumilus MAK9 [21]. The present study validated the effect of food waste on the growth of red pepper via the activation of the antioxidant defense system and regulation of endogenous abscisic acid.

5 Conclusion

In this study, red pepper was treated with different concentrations of food waste along with the plant growth-promoting agent *Chlorella*. An increase in the morphological growth parameters was observed. The study demonstrated that physio-morphological features improved owing to the activation of endogenous ABA and the antioxidant defense system.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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