Research Article

Fungal Strain (Str-1) Extracted From Okra Roots Mitigates Chromate Stress in Maize (*Zea Mays* L.)

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Abstract | Heavy metal contamination in agricultural soils has emerged as a critical global issue, posing serious risks to both crop productivity and human health. Among these contaminants, chromium (Cr^{+3}) is particularly detrimental to maize (*Zea mays* L.) as it negatively affects germination, growth, photosynthesis, and overall plant metabolism, leading to reduced biomass and yield. This study investigated the potential of the endophytic fungal strain (STR-1) of *Talaromyces aurantiacus*, isolated from *Abelmoschus esculentus* L., to alleviate Cr^{+3}-induced stress in maize seedling. Maize plants were stressed with chromium (Cr^{+3}) at varying concentrations (50 ppm and 100 ppm), with or without fungal inoculation growth, physiological, and biochemical characteristics were evaluated to identify strain (STR-1)'s efficacy in reducing heavy metal toxicity. Under Cr^{+3} stress at concentrations of 50 ppm and 100 ppm, maize seedlings exhibited substantial reductions in root length and shoot length compared to the control plants. Fresh and dry weights also declined significantly under Cr^{+3} stress. However, inoculation with fungal strain (STR-1) under non-stress conditions enhanced root length by 51.3% and shoot length by 17.83% relative to the controls. In Cr^{+3}-stressed plants treated with (STR-1), growth parameters were notably restored, approaching control levels. Biochemical analyses revealed that Cr^{+3} stress decreased levels of indole-3-acetic acid (IAA), flavonoids, sugars, and proteins in maize shoots. In contrast, (STR-1) inoculation under non-stress conditions increased the production of these metabolites compared to the controls. In Cr+3-stressed seedlings treated with (STR-1), metabolite levels were partially restored, demonstrating the fungus's ability to mitigate Cr+3-induced phytotoxicity. Additionally, (STR-1) demonstrated resilience to Cr^{+3} stress, maintaining higher metabolite production in its culture filtrate compared to non-inoculated controls. These results suggest that the endophytic fungal strain (STR-1) can alleviate Cr+3-induced stress in maize by promoting growth and restoring essential biochemical components. This highlights its potential as a bioremediation agent for Cr+3-contaminated soils.

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Introduction

For ecological, toxicological, dietary, and environmental reasons, heavy metal toxicity is a major issue that should be taken very seriously (Munir *et al*., 2021). Heavy metals such as Cobalt (Co), Chromium (Cr), and Lead (Pb) are significant environmental pollutants (Briffa *et al*., 2020). Metals can significantly affect a wide range of physiological and biochemical processes in plants, with their toxicity varying based on the plant species, the specific metal, its concentration, and its chemical form (Abbas *et al*., 2018). Many studies have been carried out worldwide to investigate the impact of harmful heavy metals on plants. The process is still ongoing, and it is clear that more research is needed to better understand the toxicity of heavy metals (Gjorgieva Ackova, 2018). Among the heavy metals, hexavalent chromium presents a mutagenic risk to people, animals, and plants (Kapoor *et al*., 2022). Many techniques have been put out over the previous fifty years to identify chromium speciation, extraction and cleaning up of polluted environmental samples (Mondal *et al*., 2021). Higher concentration of Cr in plants has a major effect on seed germination and slows down the growth of roots and shoots, which ultimately affect biomass and yield (Zulfiqar *et al*., 2023). Numerous studies have shown that elevated Cr accumulation in plants has an impact on the chlorophyll content and inhibits photosynthesis (Ugwu *et al*., 2020). Because of the presence of Mn in soil, Cr (III) is oxidized to Cr (VI), which lingers in the soil for a long time and might interfere with plant growth (Srivastava *et al*., 2023). Chromium exposure in maize leads to the development of noticeable interveinal chlorosis lesions, with vein clearing observed in young leaves (Dubey *et al*., 2020). With increasing chromium (Cr) levels, leaves exhibit a papery texture, curled margins, and a gradual loss of pigmentation (Vasilachi *et al*., 2023). Chromium exposure enhanced ribonuclease and phenyl phosphatase activities. Furthermore, chromium exposure led to higher chromium accumulation in the roots and adversely affected grain yield and quality (Sharma and Tripathi, 2003). Besides, the activity of catalase, an iron-porphyrin enzyme, was notably suppressed and amylase activity and production of soluble proteins were markedly reduced (Fan *et al*., 2022). Fortunately, nature is nurturing endophytic fungi that are believed to produce beneficial bioactive compounds within the tissues of their host plants, making the plant-microbe relationship a focal point of extensive research (Vishwakarma *et al*., 2020). These fungi form integral components of the plant micro-ecosystem, contributing significantly to the host's physiological processes (Xie *et al*., 2025). Their roles include hormone production including indole acetic acid, nutrient biosynthesis and acquisition to promote plant growth and development, secretion of stress-adaptive metabolites to protect the host against herbivores and pathogens, and enhancing the host plant's resilience to abiotic stresses (Fan *et al*., 2024). They can produce various bioactive compounds, including molecules with pharmacological activity similar to those from plants (Jin *et al*., 2018). In return, plants provide these fungi with essential shelter and nutrients (Igiehon *et al*., 2021), fostering a mutually beneficial relationship. The use of plant growth-promoting endophytic Fungi is also thought to be an effective and environmentally benign way to treat several biotic and abiotic stresses in plants, including heavy metals (Fahad *et al*., 2015). These fungi help plants resist stressful circumstances and stimulate development by enhancing plant nutrition (N, P, Fe) and producing stress-related metabolites, such as phytohormonal synthesis in maize plants (Dodd and Pérez-Alfocea, 2012). Keeping in view the deleterious effect of Cr on crop and human health and keeping in view the efficacy of endophytic fungi in stress mitigation, we isolated endophytic fungi from okra stem in Toru, Mardan to check its efficacy in Cr stress mitigation in maize. The study aimed to isolate endophytic fungi that can tolerate Cr stress, examine the impact of these endophytes on maize growth and physiological responses and monitor the level of plant metabolite affected by fungi in maize plants grown under chromium stress conditions.

Materials and Methods

Endophytic fungal strain isolation

The endophytic fungal strain (STR-1) was isolated from *A. esculentus* L in the plant-microbe interaction lab of Botany Department, Abdul Wali Khan University Mardan. Okra plant was obtained from a farmer field in Toru, Mardan, and was brought to the Department for isolating endophytic fungi. The stem of the okra was rinsed with distilled water to eliminate surface contaminants, and PDA (Potato Dextrose Agar) media was prepared to facilitate fungal growth. The stem was sliced into thin sections using a sterile blade, and a small segment was sterilized by washing with 70% ethanol, followed by a thorough rinse with

distilled water. This sterilized piece was then placed at the centre of a petri dish containing PDA. The plates were incubated under optimal conditions for fungal growth. The media and glassware (loops, petri dishes, flasks, and beakers) were autoclaved at 121˚C and 15 pounds of pressure for 15 minutes before use.

Endophytic fungal strain identification

BLAST analysis of the ITS sequence of our isolated fungus strain STR-1 showed the highest similarity index (e.g., 99.47%) to *Talaromyces aurantiacus* (GenBank accession number: MH857871.1). Based on sequence similarity, the isolated strain was tentatively identified as *Talaromyces aurantiacus*. The primers ITS5 5' (GGA AGT AAA AGT CGT AAC AAG G) 3' and ITS4 5' (TCC GCT TAT TGA TAT GC) 3′ were used for the PCR.

Preparation of potato dextrose agar (PDA) medium, Poring and Fungi inoculation

To prepare Potato Dextrose Agar (PDA) medium, 250 grams of potatoes were boiled for 20 minutes, and the resulting potato sap was collected. While stirring continuously, 20 grams of dextrose agar were added to the sap, and the mixture was gently heated until fully dissolved. The mixture was then diluted to a final volume of 1 liter with warm distilled water. The medium was sterilized by autoclaving at 121˚C for 15 minutes. After autoclaving, the PDA medium was cooled to 45˚C before being poured into Petri dishes for use. Following a 45-minute cooling period for the flask containing PDA, the medium was distributed into pre-autoclaved glass Petri dishes (25 mL per dish) under sterile conditions. The medium was allowed to solidify within the dishes, after which they were covered with lids. The dishes were stored in the laminar overnight and tested for contamination the next morning. The endophytic fungus was inoculation on non-contaminated plates. The isolated strain (STR-1) of endophytic fungus was sub-cultured on a potato dextrose agar (PDA) medium. To prevent contamination, the petri dishes were adequately covered with aluminium foil. After 24 hours, the clean and contamination-free plates were used to store the pure fungal culture at 4 ˚C for future use.

Preparation of czapek medium

The Czapek Dox liquid medium is used to grow a fungus that can only get nitrogen from sodium nitrate (Abildgren *et al*., 1987). A Czapek medium was prepared by dissolving the following chemicals in 500 mL of sterile distilled water: iron sulfate (0.01 g), magnesium sulfate (0.5 g), potassium chloride (0.5 g), peptones (10 g), and glucose (10 g). The solution was then divided into five flasks, each containing 100 mL of the liquid media.

Seed surface sterilization, soil preparation and sowing

Maize seeds were bought from the local market in Mardan. The seeds were surface-sterilized for 30 seconds with 70% ethanol and were then washed five times with autoclaved distilled water. The soil sample (loamy texture) was collected in clean plastic bags from the garden at a depth of 0 to 20 cm. The soil sample was appropriately labeled, sealed, and transported to the Plant Microbe Interaction (PMI) lab with great care. The soil was first sieved to remove stones and debris, then autoclaved to eliminate microbial contaminants before being packed into clean, pre-labeled plastic bags. After the surface sterilization, four maize seeds were sown randomly per pot. The experimental design used was Completely Randomized Design (CRD) with three replicates. Each pot contained 300 g of sterilized soil, and 3 g (1×10^6 CFU g^{-1}) of fungal biomass was mixed with the soil thoroughly. The experiment was conducted for 40 days under controlled growth conditions: a temperature of 28°C, relative humidity of 34%, and a 16/8-hour light/dark photoperiod.

Preparation of chromium (Cr) stock solution

To prepare the stock solution, we dissolved 1 gram of chromium chloride ($CrCl_3$) as a source of trivalent chromium (Cr^{3+}) in 100 mL of distilled water. To obtain 50 ppm and 100 ppm solutions, we took 0.5 mL and 1 mL of the stock solution, respectively, and diluted them with 99.5 mL and 99 mL of distilled water making the final solution to 100 mL each. The 100 mL working solution was applied to the plant in split. The experimental setup was as follows:

Treatment 1 = 0 ppm of trivalent chromium.
Treatment 2 = 50 ppm trivalent chromium.
Treatment 3 = 100 ppm trivalent chromium.
Treatment 4 = Fungal inoculum.
Treatment 5 = Fungal inoculum + 50 ppm of trivalent chromium
Treatment 6 = Fungal inoculum + 100 ppm of trivalent chromium.

Determination of flavonoids

Total flavonoids were determined in the leaves of

seedlings that had undergone various treatments. The homogenate was centrifuged at 3000 rpm for 10 minutes after grinding a fresh leaf sample (0.5g) in 5 mL of distal water. A clean test tube was used to transfer the supernatants (0.5mL). In the test tube, 0.1 mL of 10% aluminium chloride (AlC13) and 0.1 mL of 10% potassium acetate were added, and the total volume was increased to 5 mL by adding 4.3 mL of 80% methanol. The tubes were vortexed and the absorbance (or optical density) was measured at 415 nm against a blank sample using the reagent (Zishen *et al*., 1999).

Determination of soluble sugar

The soluble sugar content of fresh plant leaves and exudates was calculated through the method used by Muhammad *et al*. (2008). The expanded fresh plant leaves (0.5 g) were mixed with 10 mL of distilled water in a pestle and mortar and then rotated for at least five (5) minutes at 3000 rpm. At room temperature, 1 mL of 80% (w/v) phenol was added to 100 µL of supernatant, and the mixture was incubated. After incubation, 5 mL of concentrated sulfuric acid was added. The resulting mixture was allowed to sit for 60 minutes before the absorbance and O.D of each concentration was calculated at 485 nm. A glucose standard curve was used to calculate the amount of sugar in an unknown sample.

Determination of indole acetic acid (IAA)

For the determination of indole acetic acid (IAA) in plant leaves, 1 mL of the leaf extract supernatant and 2 mL of the salkowski reagent were combined and incubated for 30 minutes in a dark chamber. The density of light was then measured at 540 nm using a Perkin Elmer Lambda 25 spectrophotometer. The experiment was repeated three times for each isolate. Salkowaski reagent was prepared by mixing 1 mL of 0.5M solution of ferric chloride in 50 mL of 35% perchloric acid (Glickmann and Dessaux, 1995).

Determination of protein

A fresh leaf sample of 0.1 g was ground in 1 ml of phosphate buffer, afterward, it was centrifuged at 3000 rpm for 10 minutes. 0.1 mL of supernatant was added to a test tube and diluted with 1 mL of distilled water. After adding 1 mL of reagent C and stirring for 10 minutes, 0.1 mL of reagent D was added. The solution was incubated for 30 minutes, and then the optical density (OD) was measured at 650 nm. Foline reagent was used as a blank (Bradford, 1976).

Statistical analysis

The data were subjected to R statistical software version 4.3.1 for analysis. We used the stats package for ANOVA and the agricolae package for post-hoc tests. All the treatments were tested for significance using ANOVA followed by LSD test. Standard errors of means were calculated and the data were visualized through R. Heat maps and correlation were also visualized through R. Mean data were presented as graphs which were drawn in R statistical package.

Figure 1: *Endophytic fungal strain (STR-1) isolated from A. esculentus L grown on potato dextrose agar (PDA) medium.*

Results

Endophytic fungus (STR-1) enhanced the root and shoot length of maize and compensated for the reduction caused by chromium stress

Endophytic fungal strain (STR-1), was isolated from *Abelmouschus esculentus* L at Microbiology lab, Department of Botany, Abdul Wali Khan University Mardan. The strain was cultured according to the standard protocol and was identified through morphological and molecular analysis as *Talaromyces aurantiacus* (Figure 1). Chromium stress significantly reduced maize seedlings' root and shoot lengths. At 50 ppm chromium stress, root length was decreased by 36.1% and shoot length was decreased by 31.64% while at 100 ppm chromium stress, root length was decreased by 51.1% and shoot length by 42.05%. On the other hand, treatment with the fungal strain (STR-1) significantly enhanced root and shoot growth under non-stress conditions, increasing root length by 51.3% and shoot length by 17.83% compared to the controls. Root and shoot growth was significantly restored when stressed plants were

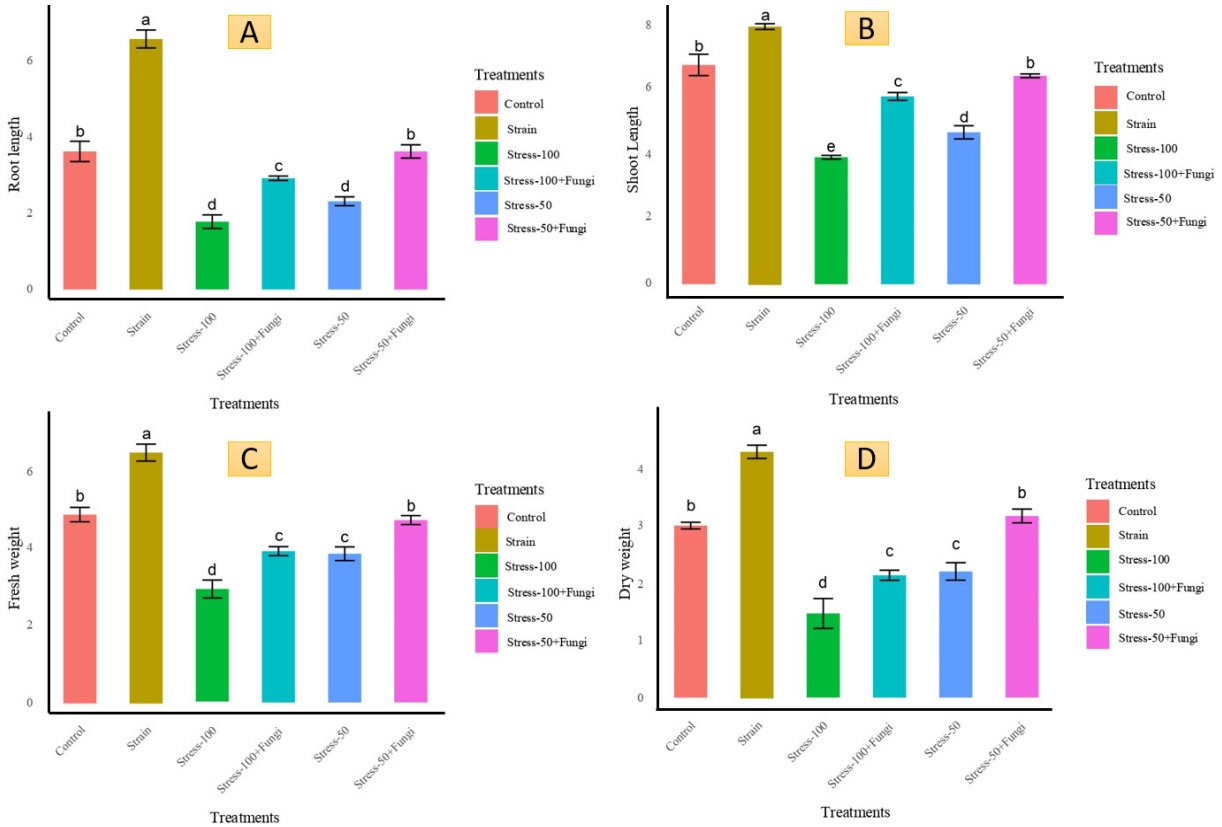

Figure 2: *Effect of association of the endophytic fungal strain (STR-1) on (A) Root length (cm), (B) Shoot length (cm), (C) Fresh weight (g) and (D) Dry weight (g) of maize seedlings grown under chromium stress. Bars represent mean value of triplicates with error bars where different letters indicate significant difference among treatments at p≤0.05.*

treated with the endophytic fungal strain. Compared to plants subjected to 50 ppm chromium stress alone, the application of the fungus resulted in a 41.50% increase in root length and a 27.14% increase in shoot length, effectively counteracting the stress-induced damage. Similarly, under 100 ppm chromium stress, root and shoot lengths were increased by 54.15% and 37.86%, respectively, with the fungal application, relative to chromium stress alone, effectively mitigating the negative effect caused by chromium stress. (Figure 2A and B)

Endophytic fungus (STR-1) enhanced fresh and dry weight of maize grown under chromium stress

Chromium stress significantly reduced the fresh and dry weight of maize seedlings compared to the control. At 50 ppm chromium stress, fresh weight was decreased by 21.23%, while dry weight was decreased by 26.66%, and at 100 ppm chromium stress, fresh weight was decreased by 40.41% and dry weight by 51.4% as compared to the control. In contrast, treatment with the fungal strain (STR-1) significantly enhanced seedling growth under non-stress conditions, increasing fresh and dry weight by 24.87% and 33.33%, respectively, compared to the control. When stressed plants were treated with the endophytic fungal strain, fresh and dry weight was partially restored. Compared to plants subjected to 50 ppm chromium stress alone, the application of the fungus resulted in a 22.60 % increase in fresh weight and a 37.14% increase in dry weight, effectively reducing the stress-induced damage. Similarly, under 100 ppm chromium stress, fresh and dry weights were increased by 29.54 and 38.76 %, respectively, with the fungal application, relative to chromium stress alone, effectively mitigating the negative effect caused by chromium stress. (Figure 2C and D). Moreover, all the agronomic parameters were highly correlated among themselves and with the physiological parameters indicating that all the parameters were equally affected by all the treatments in the same direction (Figure 5). Fungal strain (STR-1) promoted physiological parameters of the maize seedlings

Chromium (Cr) stress significantly reduced the indole-3-acetic acid (IAA) and flavonoid levels in maize seedling shoots. At 50 ppm Cr stress, IAA and flavonoids levels were decreased by 18.20% and

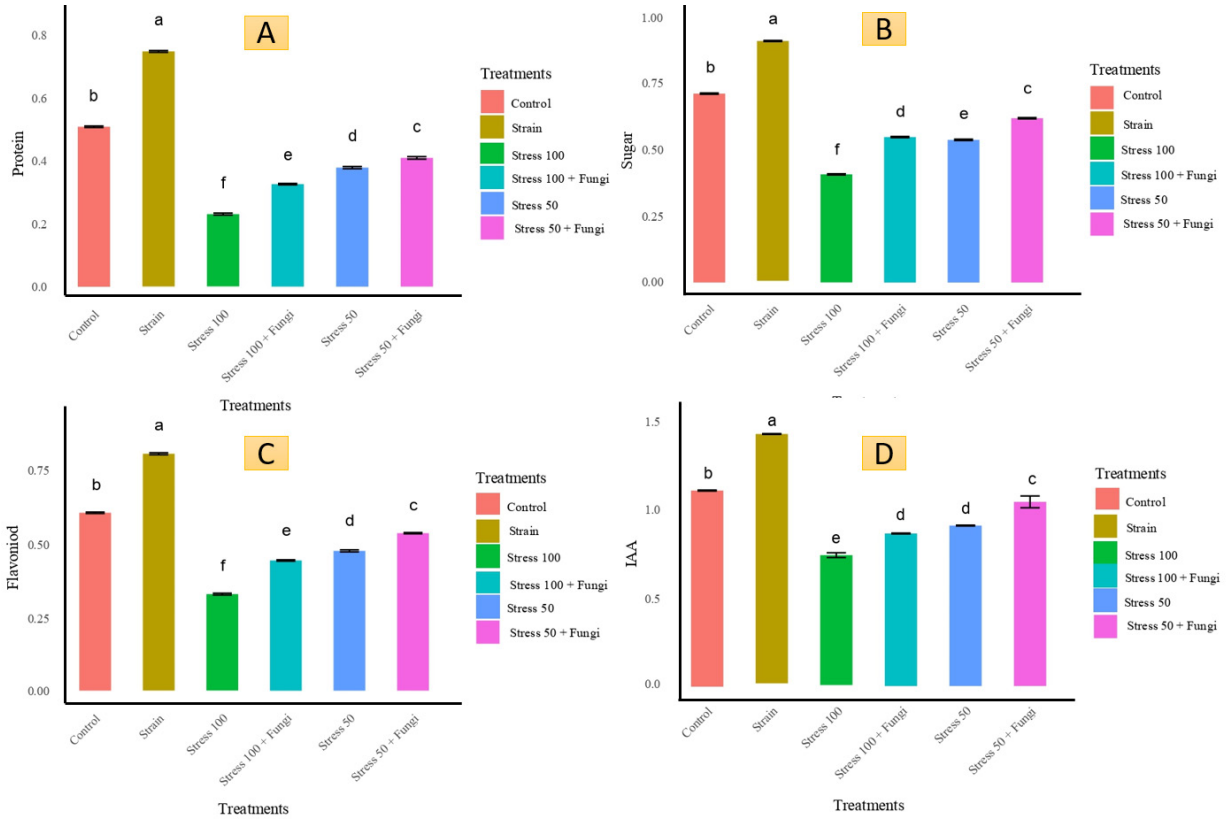

Figure 3: *Effect of association of the endophytic fungal strain (STR-1) on A) Indole acetic acid (µg g^{-1}) B) Flavonoid (mg g^{-1}), (C) Sugar (mg g^{-1}), and (D) Protein (mg g^{-1}), in fresh maize seedlings grown under chromium stress. Bars represent mean value of triplicates with error bars where different letters indicate significant difference among treatments ats p≤0.05.*

21.39 %, respectively, and at 100 ppm Cr stress, they decreased by 33.79% and 45.80 %, respectively. In contrast, treatment with the endophytic fungal strain (STR-1) significantly enhanced seedling growth, as indicated by an increase in IAA and flavonoids levels by 27.10% and 33.13 %, respectively as compared to the control. When stressed plants were treated with the endophytic fungal strain, IAA and flavonoid levels were partially restored. Under 50 ppm Cr stress, IAA and flavonoids levels were increased by 14.15 % and 21.50 % compared to chromium-stressed plants alone mitigating the negative effect of the stress significantly. Similarly, under 100 ppm Cr stress, IAA and flavonoids levels were improved by 22.24% and 25. 40 %, respectively, indicating a significant recovery compared to the chromium stress treatment alone (Figure 3A and B).

Moreover, Chromium (Cr) stress significantly reduced the sugar and protein levels in maize seedling shoots compared to the control. At 50 ppm Cr stress, sugar and levels decreased by 24.44% and 25.60 %, respectively, and at 100 ppm Cr stress, they decreased by 42.76% and 42.21 %, respectively as compared to the control. In contrast, treatment with the endophytic fungal strain (STR-1) significantly enhanced seedling growth, as indicated by an increase in sugar levels by 26.99% and protein level by 29.76 % compared to the control. When stressed plants were treated with the endophytic fungal strain, sugar and protein levels were partially restored. Under 50 ppm Cr stress, sugar levels increased by 13.04 % and protein levels were increased by 15.23 % compared to chromium-stressed plants alone, reducing the hazardous effect of the chromium significantly. Moreover, under 100 ppm Cr stress, sugar levels were improved by 22.98% and protein levels were improved by 24.12 %, indicating significant recovery compared to the chromium stress treatment alone (Figure 3C and D).

Determination of indole acetic acid (IAA), flavonoids, sugar and proteins in their culture filtrate

Chromium (Cr) stress significantly reduced the Sugar levels in the fungal filtrate compared to the control. At 50 ppm Cr stress, Sugar levels decreased by 22.75%, and at 100 ppm Cr stress, they decreased by 37.86% as compared to the control. Chromium (Cr) stress significantly reduced the Protein levels in the fungal

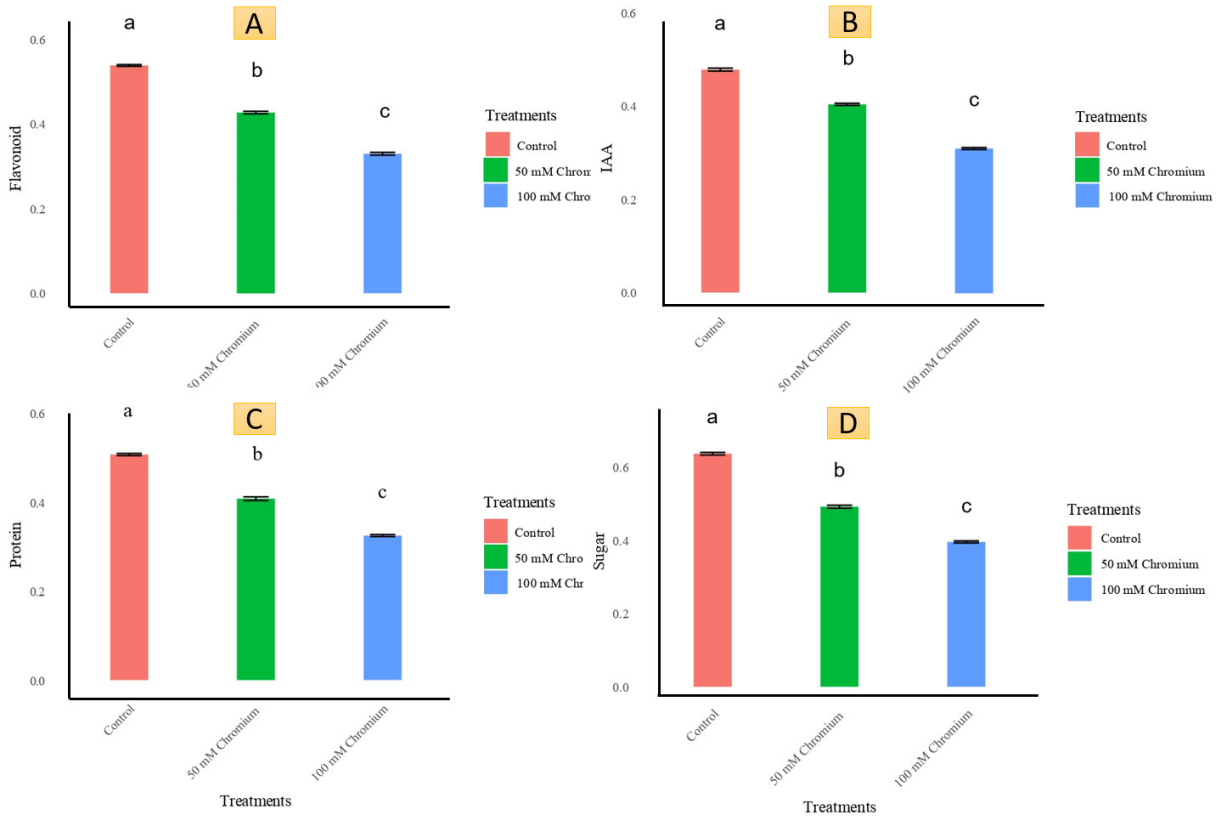

Figure 4: *The endophytic fungal strain (STR-1) (A) Sugar, (B) Protein, (C) IAA contents and (D) Flavonoid In culture filtrate of biomass grown under chromium stress. Bars represent mean value of triplicates with error bars where different letters indicate significant difference among treatments p≤0.05.*

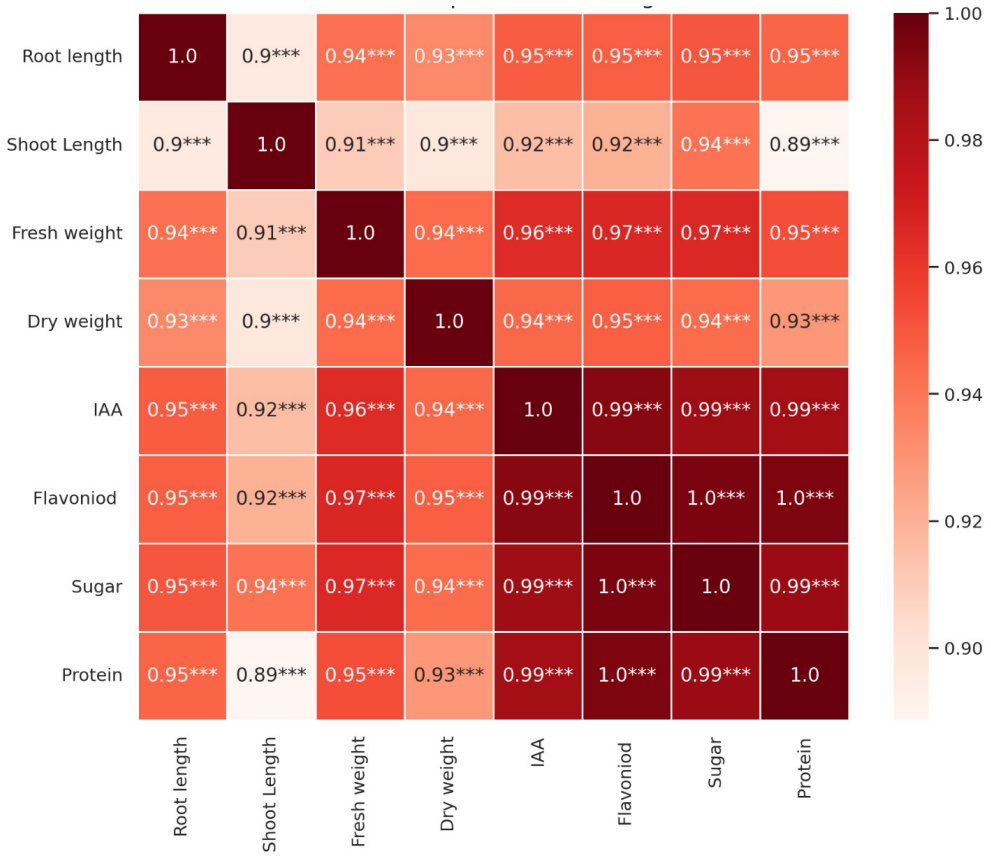

Figure 5: *The correlation among agronomic and physiological parameters in maize plant seedlings under different treatments. Steric on the correlation values represent the significance level of the correlation. All the parameters were highly correlated under different conditions.*

filtrate compared to the control. At 50 ppm Cr stress, Protein levels decreased by 19.56%, and at 100 ppm Cr stress, they decreased by 35.98% as compared to the control. Chromium (Cr) stress significantly reduced the indole-3-acetic acid (IAA) levels in the fungal filtrate compared to the control. At 50 ppm Cr stress, IAA levels decreased by 15.57%, and at 100 ppm Cr stress, they decreased by 35.055% as compared to the control. Chromium (Cr) stress significantly reduced the flavonoid levels in the fungal filtrate compared to the control. At 50 ppm Cr stress, IAA levels decreased by 20.63%, and at 100 ppm Cr stress, they decreased by 38.78% as compared to the control (Figure 4A, B, C and D). Furthermore, all the physiological parameters were highly significantly correlated among themselves indicating that they equally affected by the treatments in the same direction. Furthermore, the physiological parameters were also highly significantly correlated with the agronomic parameters indicated that stress affected them equally and in the same direction Figure 5.

Discussion

The maize plants were grown in 300-gram soil per pot for four weeks and were checked for endophytic fungi (STR-1) and chromium (Cr) stress activity. The plants were taken after four weeks and their root, shoot length, and the levels of primary metabolites (sugar, protein), phytohormones (IAA), and secondary metabolites (flavonoids) were measured. Endophytic fungus (STR-1) and chromium (Cr) stress were applied to the plants alone and in combinations. It was detected that endophytic fungi (STR-1) treated maize plants showed a significant increase in the root and shoot length as compared to the control. It was previously studied that endophytic fungi and rhizospheric fungi are known to enhance plant growth and development under normal and stress conditions (Banhara *et al*., 2015) and the same was observed in our experiment indicating that the strain isolated was belonging to the plant promoting fungi group. Plants produce different types of metabolites such as indole acetic acid (IAA), flavonoids, sugar, and proteins. Plants treated with Endophytic fungus (STR-1) in our experiment produced these metabolites in high concentration as compared to the control. The value of flavonoids (225.35µg/g) and sugar (276.6667µg/g) were increased by endophytic fungus (STR-1) as compared to the control. Indole Acetic Acid (IAA) production has been linked to hardening responses to abiotic stresses in previous literature. The concentration of IAA (328.3768µg/g) was elevated by (STR-1) as compared to the control indicating that this fungus can combat stress if applied to the growers' fields. According to a recent study, endophytic fungi play a significant biological role in the growth of the host plant. This happens as a result of the endophytic microbial populations' defense mechanisms against pathogens or their role in the mineralization of various organic compounds, which give nutrients to the plant (Hinsinger *et al*., 2009). In this research, we found that the heavy metal (Cr), we applied to the maize plant, reduced the root and shoot length. The root length was decreased by 2.0cm as compared to the control. The shoot length is also decreased by 4.33cm as compared to the control. Chromium is a non-essential element for plants. Consequently, there are no carriers for its transport. Chromium (Cr) has toxic effects on plant growth and development, negatively impacting germination, as well as the growth of roots, stems, and leaves as reported (Shanker *et al*., 2005). It was previously noticed that in maize plants, under chromium (Cr) stress, morpho-physiological activities were disrupted, and chromium (Cr) stress severely affected plant growth, yield, and other qualities. Chromium (Cr) delivery to the aboveground part of the plant, which may have a direct effect on cellular metabolism, resulting in growth inhibition and yield penalty, could explain the Cr-induced disruption in plant development and yield (Anjum *et al*., 2005). According to current and earlier research, heavy metal uptake by rhizosphere and endophytic fungi inoculated root differs depending on the nature of the fungus and metal (Shahabivand *et al*., 2012). Besides, it was also noted that chromium stress as well as the application of the endophytic fungi affected all the parameters in the same directions and that none of the parameters was favored either by chromium stress or by the fungi (Figure 5). This indicated that the chromium stress broadly affected the agronomic as well as the physiological processes of the maize seedling. Conversely, the fungi restored the harm caused by the chromium stress up to a significant level. Thus, the study illustrates that more and more fungi need to be used in agricultural research to explore the effect of these fungi in different crops and under different conditions.

Conclusions and Recommendations

Endophytic fungus (STR-1) demonstrated significant

potential in mitigating chromium (Cr) stress in maize plants by enhancing root and shoot length and increasing the production of key metabolites such as sugars, proteins, flavonoids, and indole acetic acid (IAA). The fungus alleviated Cr-induced toxicity, which otherwise negatively impacted plant growth and development. These findings highlight the critical role of endophytic fungi in promoting plant resilience to heavy metal stress through improved nutrient uptake and stress response mechanisms. This research underscores the potential application of endophytic fungi in sustainable agriculture for improving crop performance under abiotic stress conditions.

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Novelty Statement

This study reports, for the first time, the potential of the endophytic fungus Talaromyces aurantiacus strain STR-1, isolated from okra, to alleviate chromium stress in maize seedlings. The novelty lies in the strain's dual ability to promote growth under non-stress conditions while restoring key biochemical parameters such as IAA, flavonoids, sugars, and proteins under chromium toxicity, highlighting its promise as a sustainable bioremediation agent.

Author's Contribution

Abdullah and Ihteram Ullah: Conceptualized the study.
Abdullah and Srataj Aziz: Isolated, cultured, purified and identified the fungal strain (Str-1).
Adbullah, Sajid Ullah and Nurul Haq: Performed the experiments and wrote the draft manuscript.
Maham Jamshed: Visualised the data.
Ihteram Ullah and Habib ur Rehman: Reviewed and revised the manuscript.

Generative AI or AI assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have no conflict of interest.

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