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Review Article

Mitigating heat stress in tomato by synergetic effect of trichoderma and organic manures

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ABSTRACT

Tomatoes (*Solanum lycopersicum*) are one of the world's most extensively farmed and economically important crops. Its high nutritional value and flexibility make it a household staple and an important crop for farmers. However, heat stress is a major hazard to tomato output. Temperatures above 30°C have a negative impact on tomato plants' physiological processes, such as germination, flowering, and fruit set, resulting in lower production and quality. With the growing frequency of heat stress caused by global warming, solving this issue is crucial to preserving tomato output. Heat stress has an impact on tomato development and yield by interrupting photosynthesis, reducing pollen viability, and increasing oxidative damage to plant cells. This stress causes decreased fruit set, reduced fruit size, and worse fruit quality. Organic agriculture provides a sustainable solution for mitigating the negative impacts of heat stress. The use of bio-fungicides such as Trichoderma and organic manures has been shown to effectively reduce the effects of heat stress on tomato plants. Trichoderma improves plant resilience by creating systemic resistance, releasing growth hormones, and increasing nutrient intake. Organic manures such as goat manure, poultry dung, and vermicompost improve soil structure, boost water retention, and supply important nutrients that help plants cope with stress. Reduced heat stress is critical for preserving tomato crop output and quality, particularly in the face of global climate change. Promoting the use of Trichoderma and organic manures in tomato growing not only decreases the impacts of heat stress, but also reduces the need for chemical fertilizers, enhancing soil health and protecting the environment. Adopting such sustainable approaches will assure food security and the long-term viability of tomato production.

Keywords: Climate change, Fertilizer, Stress, Yield

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INTRODUCTION

Tomato (Solanum lycopersicum) is one of the world's most economically important vegetable crops, known for its high nutritional content, which includes dietary fiber, vitamins, minerals, and vital amino acids (Hole *et al*., 2005; Banjade *et al*., 2023). It is widely consumed and has an important role in global food security and agricultural economies (Nam *et al*., 2023). Tomatoes are botanically categorized as berries but have a wide range of culinary applications (Murumu *et al*., 2013). However, their cultivation has a number of problems, including environmental stresses that prevent optimal growth and yield.

Heat stress is one of the most harmful environmental conditions to tomato production. High temperatures interfere with the morphological, physiological, and biochemical processes of plants (Emmia Tambarta Kembaren *et al*., 2023). They lower germination rates, inhibit photosynthesis, and impede nutrient intake, resulting in stunted growth and poor fruit quality (Herrera-Téllez *et al*., 2019). In addition, heat stress increases vulnerability to pests and diseases and reduces blooming, fruit set, and total yield (Musa *et al*., 2023). In extreme situations, extended exposure to high temperatures results in unsellable produce and large financial losses (Gharezi & Gharezi, 2012).

A genus of helpful fungi called Trichoderma is well-known for its capacity to reduce stress and encourage plant growth (Rivero *et al*., 2014). Through a variety of methods, Trichoderma improves tomato plants' resistance to heat stress. It controls stress-related hormones like abscisic acid (ABA), strengthens root architecture, and promotes the absorption of nutrients and water (Jackson *et al*., 2018). Additionally, Trichoderma increases the synthesis of antioxidant enzymes, which safeguard cellular structures and functions by assisting in the neutralization of reactive oxygen species (ROS) produced under heat stress (Khanal *et al*., 2024). Additionally, it creates systemic resistance, which makes it possible for plants to more successfully tolerate unfavorable environmental conditions.

Organic manure is a natural fertilizer made from decomposed organic materials that promotes soil fertility and plant health. Farmyard manure, compost, vermicompost, and green manure are among the most commonly utilized organic manures in tomato cultivation (Musa *et al*., 2023; Caccavo *et al*., 2022). These inputs improve soil structure, water retention, and microbial activity in the rhizosphere. Organic manure promotes steady plant growth by steadily releasing nutrients, even when exposed to high temperatures (Sehim *et al*., 2023). Furthermore, better soil health promotes strong root systems, which increases the plant's resistance to high temperatures (La Spade *et al*., 2020).

The justification for this work stems from a compelling need to reduce the impact of heat stress on tomato production in the face of climate change. Organic manure is a natural fertilizer made from decomposed organic materials that promotes soil fertility and plant health (Banjade *et al*., 2023). Farmyard manure, compost, vermicompost, and green manure are among the most commonly utilized organic manures in tomato cultivation (Tang *et al*., 2023). This review investigates the impact of heat stress on tomato physiology and yield, the role of Trichoderma in increasing heat tolerance, and the contribution of organic manure to stress reduction. It also addresses how these approaches affect soil quality metrics and the antioxidative defense mechanism. The goal of this study is to synthesize existing knowledge, emphasize the mechanisms of action for different techniques, and provide integrated approaches to sustainable tomato growing under heat stress.

A review of 63 papers chosen from several scientific databases served as the foundation for

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this manuscript. The publications were selected on the basis of their publication dates (2005 to 2024) and their applicability to the alleviation of stress in tomato (*Solanum lycopersicum* L.). To begin the screening procedure, relevant keywords like "trichoderma," "tomato," "stress response," and "impacts" were searched for in articles. The influence, effectiveness, and most current developments in tomato heat stress response were examined in the chosen articles. An overview of the present state of knowledge in this topic was then provided via a coherent summary of these papers. A qualitative technique was used in the analysis of the chosen papers, and each study's findings were summarized and synthesized. Three key sections—impact, performance, and combined use—organized the idea and conclusions from the chosen articles. The main conclusions of the chosen papers are described in detail in each section, along with how they may affect the creation of tomato cultivars that can withstand high temperatures. Based on a selection of 63 pertinent articles, this document provides an overview of the state of the art regarding the alleviation of heat stress in tomatoes through the application of organic manures and Trichoderma.

Heat stress impact on tomato production in current scenario:

Tomatoes are among the most widely grown crops in the world. The total global production is over 190 million tons annually, with China being the top producer, followed by countries like India, Turkey, and the USA (Coppola Cascone *et al*., 2019). These regions grow tomatoes both for fresh use and processed products like sauces and ketchup (Diretto *et al*., 2019). Tomatoes are grown all over the world, and production is huge—more than 190 million tons each year! China is the biggest producer, growing over 60 million tons annually. Other big players include India, Turkey, and the USA. These countries grow tomatoes for everything from fresh salads to sauces and ketchup. Asia leads in tomato farming, contributing the largest share to global production. China and India dominate the scene, with other countries like Turkey and Iran also being major producers. Tomatoes are adaptable and widely cultivated across different climates in the region. Asia is the heart of tomato farming, producing most of the world's supply. China and India are the top two countries here, with India in second place globally. Other countries like Turkey and Iran also grow a lot of tomatoes. The crop does well in all kinds of climates across the region. In Nepal, tomatoes play a big role in agriculture, especially with techniques like tunnel farming gaining popularity. The country produces and exports tomatoes to neighboring countries, primarily India. However, competition and fluctuating prices present challenges to the market. At the same time, local demand for tomatoes is steadily increasing. In Nepal, tomatoes are really important for farmers, and tunnel farming (growing tomatoes in protected environments) is helping increase production. Nepal mostly exports tomatoes to India, but prices can go up and down. In 2023, the average price for exporting tomatoes was about $1,183 per ton, while imported tomatoes cost around $1,086 per ton. Even though there are challenges like high competition and price fluctuations, local demand is steadily growing.

Heat stress impact on growth and development of tomato:

Heat stress is one of the major factors influencing the morphological and molecular changes in crops that reduce normal growth and yield (El-Mansy *et al*., 2021). When the field capacity is about 70%, the yield of tomato plants and the morphological characteristics of the plants respond better (Nahar & Ullah, 2011). During the heat stress conditions, the vegetative parameters like leaf growth and stem diameter are reduced than the normal conditions (Lee *et al*., 2022). Heat stress slows down the rate of photosynthesis and prevents tomato plants from growing and producing biomass (Altaf *et al*., 2022). When tomato plants are treated with zinc oxide nanoparticles instead of not, the plants' height, stem diameter, and organs such as leaves, stems, and roots all increase (Pérez Velasco *et al.,* 2020). In the presence of Cd, the

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ideal K concentration helps improve root and shoot growth characteristics and lessen Cd translocation from root to shoot (Naciri *et al*., 2021). The vermicompost helps to improve the morphological characteristics of tomato plants, which are affected by heat stress (Lazcano *et al*., 2009). The morphological traits like pericarp thickness and fruit size are highly affected by blue shading (Dissanayake & Wekumbura, 2020). The higher concentration of DLI and Co2 helps to increase the growth and development rates by accelerating the net photosynthesis rate (Huber *et al*., 2021). The optimum rate of GA3 is the best method to decrease the rate of tomatoes under heat stress and enhance their physiological, biochemical, and morphological traits (Guo *et al*., 2022). The application of EBL and ASA helps to improve the root morphological features and root activity under higher temperatures (Khan *et al*., 2014). Tomato yield is increased by 42.18% with organic fertilizers; soluble solids, lycopene, vitamin C, and nitrate levels are also increased, which contributes to the improving the quality of fruits (Gao *et al*., 2023). It helps to increase the protein level in tomato fruit, soil pH, and soil phosphorous and potassium content and reduces tomato nitrate by 14.15% (Fan *et al*., 2023). Vermicompost enhances fruit's ability to photosynthesize and facilitates the movement of carbohydrates, which lowers stress and increases yield and quality (D. Wu *et al*., 2023). Vermicompost helps in the effective growth and development of stem diameter and plant height and increases the fruit yield by 74% (Khanal *et al*., 2024). Combining organic fertilizer and biochar increases the total polyphenols and vitamin C values. Still, it does not affect the amounts of titratable acidity and total soluble solids, which helps improve the quality traits of tomato fruit (Nabaei *et al*., 2021).

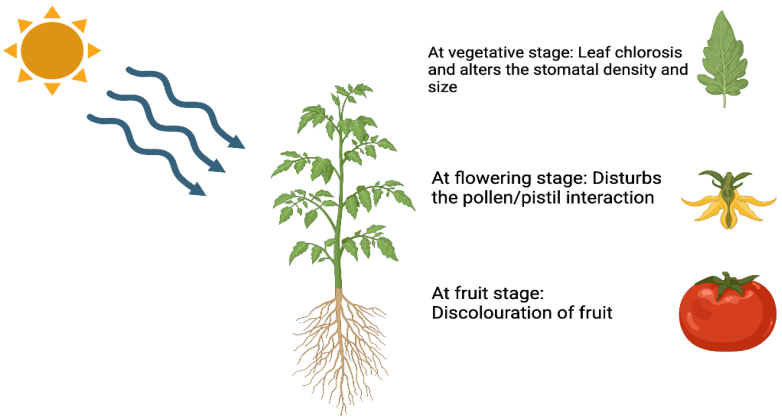

Figure 1: Changes occurs in the different stages of tomato plant due to the heat stress condition

Role of organic manure to mitigate heat stress:

Organic manures improve the soil's ability to retain water and lessen the harmful effects of HS, particularly during the fruit set stage (Silva *et al*., 2017). The tomato yellow curl disease is caused by begomo viruses, which contribute to increased heat and drought tolerance (Sacco Botto *et al*., 2023). Applying nano chitosan and spirulina platensis extract as bio-stimulants are used to skip the heat stress in the tomato plant (Khaled *et al*., 2023). Through the ABA-dependent stimulation of CBFs and HSPs and the antioxidant response, strigo lactones aid tomato plants in enduring heat stress (Dahal *et al*., 2024). The expression of Pht1 family phosphate transporter genes help mitigate heat stress with the help of arbuscular mycorrhizal (Szentpéteri *et al*., 2023). Several metabolites, genes, and microRNAs working in concert regulate the plant heat stress response. Protein denaturation causes HSP, which heat stress induces (Singh *et al*., 2022). A mutant tomato that cannot accumulate jasmonic acid is more

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susceptible to intense light, which is necessary for the tomato to adjust to MFSCs (Pascual *et al*., 2023). Markers like perturbed and DREB1 are the most consistent heat stress markers, which help to indicate the gene expression of heat stress (Tokić *et al.*, 2023). Under the melatonin spray, the heat-tolerant cultivars of tomato performed better than sensitive cultivars (Muhammad Tayyab Khan *et al*., 2024). During the transient exposure to high temperatures, fruit carotenogenesis was affected by altered desaturation (Almeida *et al*., 2021). Organic manure helps plants fight heat stress by improving the soil's ability to retain water and nutrients. When the soil is rich in organic matter—like compost or biochar—it can hold moisture better, which is especially important when temperatures rise. Biochar, for example, not only keeps the soil moisture levels high but also helps lower the soil's surface temperature, giving plants more resilience against heat. The microbes that thrive in healthy, organic-rich soil also help boost plant health by making nutrients more available and improving soil structure. In short, by using organic manure, farmers can help their crops stay cooler, stronger, and better equipped to handle high temperatures, ultimately leading to better yields even in tough conditions.

Role of Trichoderma to mitigate heat stress:

Trichoderma is a biological control agent for agricultural insect pests and aids in mitigating the harmful consequences of stress (Trotta *et al*., 2024). Trichoderma helps to reduce acidity and regulate oxygen utilization by producing stress-resistant chlamydospores (Yao *et al*., 2023). If the temperature is more than 30 degrees Celsius, it weakens the reproductive system of tomato plants and declines the quality and quantity (Bineau *et al*., 2021). In most crops like tomatoes, their reproductive traits are more vulnerable to heat stress than vegetative growth (Lee *et al*., 2022). Trichoderma fungi help plants better withstand heat stress by improving their overall health and protecting them from damage. These fungi enhance plants' ability to retain water, which is especially important during hot weather when water loss can be a significant issue. Trichoderma also helps lower leaf temperatures, allowing the plants to stay cooler even in high heat. It boosts the production of protective compounds like antioxidants and phenolic substances, which help plants deal with the stress caused by excessive heat. Moreover, Trichoderma improves plant defenses by stimulating the production of heat shock proteins and other enzymes that protect plants from the harmful effects of heat. When plants like Arabidopsis or tomato are treated with Trichoderma, they show better heat tolerance, with less damage to essential structures like the parts responsible for photosynthesis. In short, Trichoderma not only helps plants stay healthier during heat stress but also strengthens their natural defense systems, making it an effective tool for farming in hotter climates.

Combined application of organic manures and Trichoderma to mitigate heat stress:

When organic manure and *Trichoderma* are used together, they help plants handle heat stress more effectively. Organic manure enhances soil's ability to retain water and nutrients, which is crucial when temperatures rise. *Trichoderma*, a beneficial fungus, promotes better root growth and shields plants from harmful pathogens. Together, they improve water uptake, strengthen plant defenses, and support healthy growth, making crops more resilient in hot, dry conditions. This combination is a great way to help plants thrive during heat waves. Using organic manure and *Trichoderma* together helps plants withstand heat stress and improves soil health. Organic manure boosts the soil's ability to hold water and provides essential nutrients, while *Trichoderma* strengthens roots and protects plants from disease. This combination enhances the plants' overall resilience, making them more capable of surviving under harsh conditions. It's an excellent strategy for farming in hot climates, ensuring plants have the support they need to grow well and remain healthy during periods of

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extreme heat. The increasing trends of application of chemical fertilizers in the soil lead to low nutrition status of soil (Nduka *et al*., 2019). Different organic fertilizers and biofungicides could be used to improve soil fertility and plant growth at a reduced cost without the negative effects of chemical fertilizers (Abdelhameed & Metwally, 2022). Due to its increased chemical and biological qualities, vermicompost aids in the acceleration of nitrifying bacteria growth and the nitrogen cycle (Huda *et al*., 2024). In the end, organic manures increase the number of microorganisms in the soil by enhancing its bulk density, moisture retention, porosity, and structure (Mayele & Abu, 2023). Organic manures increase microbial diversity and abundance by providing nutrients and organic matter, promoting microbial growth (Huda *et al*., 2024). The enzymatic activity is higher in the soil with organic fertilizers (Tao *et al*., 2015). Organic fertilizers help reduce the ecological risk by mitigating antibiotic resistance gene contamination in agricultural soils (Wu *et al*., 2023).

In tomato roots, the expression of the swollen gene is higher, which improves root colonization and the nutrition uptake process through the positive effects of Trichoderma (Vukelić *et al*., 2021). Trichoderma must resist the poisonous metabolites produced by the plant in reaction to invasion to colonize plant roots (Dutta *et al*., 2023). Due to the manufacture of glucosinolates, a component of plant defense against herbivores, the biomass index of plants treated with Trichoderma was higher than that of untreated plants (Iula *et al*., 2021). Through mycoparasitic and antibiosis mechanisms, Trichoderma helps to solubilize plant nutrients to uplift plant growth (Manzar *et al*., 2022). The performance of Trichoderma is maximized through microencapsulation techniques (Martinez *et al*., 2023). The harmful effects of pathogens can be controlled when the fungus interacts with the pathogen through mycoparasitism, competition, or antibiosis (Guzmán-Guzmán *et al*., 2023).

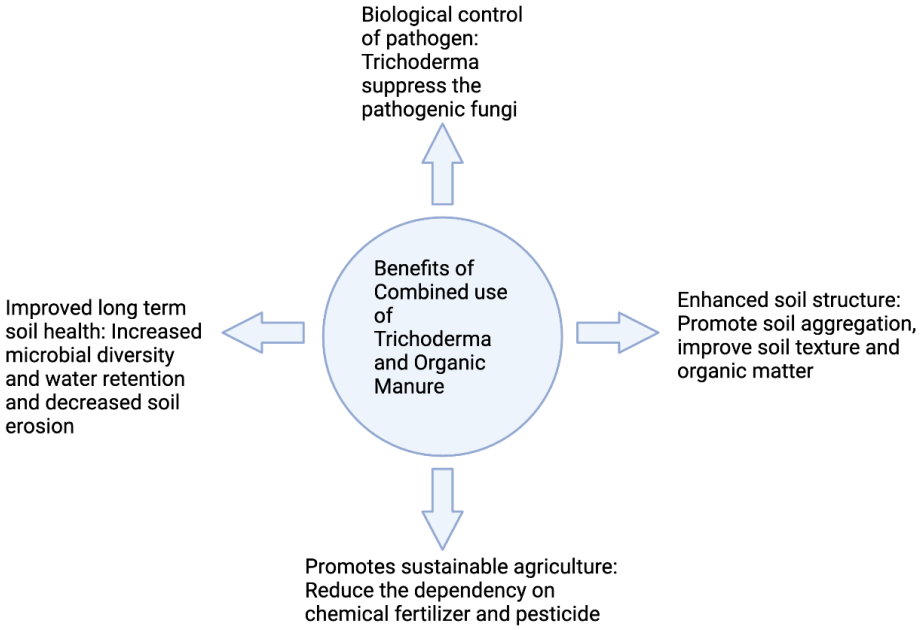

Figure 2: Showing the benefits in the different sectors through the use of Trichoderma and organic manure

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Table 1: Roles and activities of different organic manures and bio-fungicide in tomato plants under heat stress condition

Organic manures and Bio-fungicide	Major function	Reference
Trichoderma asperellum	Promotes the growth of plant; stress resistance; Antifungal activities; Enhance soil fertility	(Yao *et al*., 2023)
Vermicompost	Increase the tomato fruit yield by 65.2% understress; Improve the contain of vitamin C, organic acid and soluble solid; transfer of carbohydrates from leaves to fruits; deep root length	(Alabi *et al*., 2024; D. Wu *et al*., 2023)
Cow manure	Increase the tomato fruits yield by 31.7% understress	(Wu *et al*., 2023)
Poultry manure	Greatly improve tomato plant growth and fruit yield; High accumulation of nitrite in the leaves; reduce the incidence of aphids and white flies	(Aylaj *et al*., 2019; Mayele & Abu 2023b; Rahman *et al*., 2024)
Sheep manure	High dry matter to tomato fruit; longer shelf life; improve the sustainability of soil fertility	(Niassy *et al*., 2010)

CONCLUSION

The rising global temperature caused by climate change poses a substantial threat to tomato production since heat stress has a negative influence on plant growth, reproduction, and yield. This review focuses on the effectiveness of organic manure and Trichoderma treatment in alleviating the effects of heat stress on tomato plants. These measures not only increase the plant's endurance to high temperatures, but they also improve soil health by minimizing the need for synthetic fertilizers. Reducing heat stress is critical to ensure long-term tomato production and food security in the face of global warming. Future study should focus on understanding the processes by which Trichoderma and organic fertilizers improve heat tolerance in tomatoes. Such research is critical to maximize their use and encourage the development of heat-resilient agricultural techniques in increasingly

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Authors' Contributions

Conceptualization and methodology: Dhurba Banjade and Dipak Khanal
Software and validation: Dhurba Banjade and Dipak Khanal
Writing original draft: Dhurba Banjade and Dipak Khanal
Writing revised draft and editing: Dhurba Banjade,
Aman Shrestha, Dipak Khanal, Binod Dahal, Nirajan Banjade, Pratima Regmi
Supervision: Dhurba Banjade and Dipak Khanal
All authors have read and agreed to the publication of this version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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