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FIZA IJAZ

SU92-MSBNW-F23-008

FOS

Synthesis of Biochar from Rice Husk and its Applications on *Solanum lycopersicum* L.



SUPERIOR UNIVERSITY

Thesis Submitted to

The Superior University Lahore

In Partial Fulfillment of the

Requirement for the Degree of

MS Botany

By

FIZZA IJAZ

Roll No. SU92-MSBNW-F23-008

Session: 2023-2025

Faculty of Sciences

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No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the Faculty of Sciences, The Superior University, Lahore in partial fulfillment of the requirements for the degree of Master of Science/Master of Philosophy in the field of **“MS Botany”** in the Faculty of Sciences at The Superior University, Lahore.

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Dedication

I dedicate this thesis to my parents, whose unwavering support, enduring sacrifices, and belief in my potential have been the foundation of my academic and personal achievements.

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In the name of Allah, the Most Gracious, the Most Merciful.

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List of Abbreviations

T1	Control
T2	Treated with 60g of NPK
T3	5g biochar+9g NPK
T4	7.5g biochar+9g NPK
T5	10g biochar+9g NPK
T6	12.5g biochar+9g NPK
T7	15g biochar+9g NPK
EC	Electrical Conductance
WHC	Water Holding Capacity
BD	Bulk Density
NPK	Nitrogen Potassium Phosphorus
TPC	Total Phenolic Content
TFC	Total Flavonoid Content
ANOVA	Analysis of Variance
NaOH	Sodium Hydroxide
HCl	Hydrochloric Acid
AlCl ₃	Aluminum Chloride
ds/m	DE Siemens per meter
G/cm ³	Gram per cubic centimeter
mScm ⁻¹	Milli siemens per meter
%	Percentage
UV- Spectrophotometer	Ultraviolet spectrophotometer
cm ³	Centimeter Cube
mL	Milliliter
G	Gram
°C	Degrees Celsius
Mg	Microgram
Mg	Milligram
H ₂ SO ₄	Sulphuric Acid
v/v	Volume/volume

Nm	Nanometer
μL	Microliter
DPPH	2,2-diphenyl-1-picrylhydrazyl
PCSIR	Pakistan Council of Scientific and Industrial Research
RH	Rice Husk
RHB	Rice Husk Biochar
FTIR	Fourier Transform Infrared
SEM	Scanning Electron Microscope
DAP	Di-Ammonium Phosphate
DAG	Day after Germination
RCBD	Randomized Complete Block Design

ABSTRACT

Pakistan ranks among major rice producer countries, due to which is abundance availability of rice husk as waste materials. Production of biochar using rice husk promotes sustainability and avoids environmental problems. Over and over use of inorganic fertilizers has caused rapid soil erosion. Conversion of rice husk (RH) residue into rice husk biochar (RHB) could be used as a soil amendment and its application on vegetable crops could promote organic farming. It has high adsorptive and nutrient retention capacity with high silica content. RHB can improve soil fertility and improve the effectiveness of fertilizer when mixed due to its composition. The present experimental study was designed to synthesize RHB through the process of pyrolysis at 350°C. *Solanum lycopersicum* L (cherry tomato) was used as an experimental plant, as is beneficial to human health due to its composition, such as vitamins A, C, and several minerals. It was cultivated in seven different treatments (T1-T7), T1 was left untreated and T2 NPK (60%), while T3-T7 were kept as experimental crops and were treated with different concentrations of biochar: NPK (5:9,7.5:9,10:9,12.5:9 and 15:9). The impact on the nutrient content of soil, which is considered important for the growth of vegetable crops, was assessed before and after application of RHB. The physicochemical characterization of biochar showed that the RHB was alkaline pH (8.7), water holding capacity (5 mL), and electrical conductivity (602 dSm⁻¹), and FTIR analysis revealed the presence of functional groups such as C=C, C-F, which are attributable to the organic compounds present in the rice husk (RH) employed as the feedstock. SEM analysis of rice husk biochar revealed a porous and heterogeneous surface structure favorable for nutrient retention and microbial colonization. Finally, the produced biochar's showed promising results for the growth of plants, highest plant height (151.67cm), were recorded in T4 with higher number of leaves (259), number of branches (48.33), stem girth (20.667), number of fruits (309)/plant, leaf area (320.33), number of flowers (314), and total yield per plant (6.45 kg /plant). Recorded results suggested that the application of biochar with a better ratio of NPK (5:9,7.5:9,10:9,12.5:9, and 15:9). could effectively improve soil fertility and significantly enhance the growth and productivity of the crop. The moisture, ash, fiber, fat, protein, and carbohydrate contents of each of the seven treatments were assessed by

nutritional analysis. T2 had the highest moisture content, ranging from 89.13 % to 94.9 %. T3 had the lowest ash concentration (0.16 %), whereas T1 had the highest (0.87 %). While fat stayed low in all treatments, T5 had the highest fiber content (7.92 %), and T4 had the highest protein content (4.17 %). While T2 had the highest carbohydrate amount (80.61 %). Although the amount of lycopene varied by treatment, T4 had the highest amount (3.179 mg/g), suggesting a notable improvement over other treatments. The long-term impacts of biochar should be investigated in future studies to promote sustainable tomato production and improve the nutritional values of vegetable crops.

Keywords: Rice Husk biochar, Pyrolysis, Soil amendment, SEM, FTIR, yield.

CHAPTER 1

INTRODUCTION

The tomato, or *Solanum lycopersicum* L., is a member of the Solanaceae family and one of the most important vegetable crops in the world in terms of both economic and nutritional value. It ranks as the second most extensively cultivated and consumed vegetable globally. The increasing demand for tomatoes is primarily driven by their rich nutritional composition, which includes high concentrations of carotenoids, dietary fiber, essential vitamins, and minerals. Consequently, tomatoes have been the focus of extensive research under both controlled environmental conditions and open-field cultivation systems. The overall quality of tomatoes is influenced by both external and intrinsic variables. Texture, sweetness, acidity, flavor, scent, and nutritional value are examples of internal characteristics that are considered intrinsic qualities. Extrinsic factors include external characteristics such as color, shape, size, and firmness, all of which contribute significantly to consumer preference and marketability [1]. Tomatoes play a vital role in Mexico's agricultural economy, which is the world's leading exporter of tomatoes, contributing approximately 25.11% to the global export market value [2]. Servicio de Información Agroalimentaria y Pesquera (SIAP) claims that Mexico's tomato exports are projected to reach 3.84 million tons in 2024 [3]. Tomatoes are recognized for their health-promoting properties, as they are rich in essential nutrients, including vitamins A and C, as well as various minerals [4]. Over the past five decades, the tomato has become one of the most important and extensive horticulture crop cultivations, both globally and within the Mediterranean region. In 2019, global tomato production surpassed 180 million tons, with approximately 42 million tons produced in Mediterranean countries alone [5].

Phytochemicals and vital elements such as lycopene, potassium, iron, folate, and vitamin C are abundant in *Solanum lycopersicum* L. [6,7]. Apart from lycopene and vitamin C, tomatoes also include a variety of phenolic chemicals, including flavonoids, hydroxycinnamic acid, chlorogenic acid, homovanillic acid, and ferulic acid, as well as β -carotene, which are antioxidants [6,7,8]. Tomatoes are a great addition to any diet because of their high nutritional content. They may be eaten raw or cooked, and many of their health-promoting qualities are preserved after processing [6]. Interestingly, more

than 80% of tomatoes grown for commercial purposes are used to make processed foods like ketchup, soup, and juices [9]. Due in large part to their high antioxidant content, diets high in tomatoes and tomato-based products have been linked to several health advantages [6,10,11].

One of the most significant horticultural crops in terms of economic impact is the tomato (*Solanum lycopersicum* L.) [12]. Originally from South America, tomatoes are now widely grown in a variety of agroecological zones. Determinate cultivars, characterized by their compact growth habit and the production of multiple flower clusters within a limited growth period, are commonly cultivated in open-field systems and are well-suited for mechanical harvesting. These varieties are primarily utilized in the processing industry for products such as canned tomatoes, tomato sauce, and ketchup. In contrast, tomatoes intended for fresh market consumption are predominantly grown in protected environments. For this purpose, indeterminate cultivars are preferred due to their extended growth potential, often exceeding 6 meters in length over a production cycle of 6 to 9 months [13,14].

Historically, tomato cultivation in greenhouses was conducted using soil-based systems; however, this traditional method posed several agronomic challenges, including accelerated soil erosion, suboptimal nutrient availability, and a heightened incidence of soil-borne pests and diseases. To mitigate these issues, soilless cultivation systems were introduced, wherein plants are grown in inert substrates and supplied with nutrient solutions tailored to their developmental needs. This approach allows for precise regulation of mineral nutrition, thereby enhancing plant health and productivity [15]. Among the various substrates tested, Rockwool emerged as the first widely adopted medium in soilless cultivation due to its favorable physical properties, including high pore volume, consistent quality, ease of system management, and superior crop yields when compared to conventional soil-based cultivation systems [16].

Perlite is another commonly used inert substrate for tomato cultivation and is typically utilized in plastic grow bags or Bato buckets [13]. However, as mineral-based materials, both perlite and Rockwool raise environmental concerns due to their non-biodegradable nature and contribution to agricultural waste. As a more sustainable alternative, coco peat

derived from the fibrous husk of coconuts has gained popularity in soilless cultivation systems. It is often employed in grow bags similar to those used for perlite and Rockwool. Unlike mineral substrates, coco peat is biodegradable and can be composted after use, reducing environmental impact. Comparative studies have demonstrated that tomato yields produced in coco peat, perlite, and Rockwool substrates are nearly equivalent [17,18]. In contrast to Rockwool and perlite, which possess negligible cation exchange capacity (CEC), coco peat exhibits a substantial CEC, ranging from 320 to 950 mmole·kg⁻¹, which contributes to its ability to buffer and retain nutrients more effectively [19].

Tomato plants exhibit dynamic nutrient requirements that vary across different stages of growth and development. For instance, elevated calcium levels are essential during the vegetative phase, particularly for optimal leaf development. In contrast, during the fruit development stage, the demand for potassium increases markedly. An abundant supply of potassium during fruit ripening has been shown to enhance yield, prolong shelf life, and improve fruit flavor; however, excessive potassium can also elevate the risk of physiological disorders such as blossom end rot [16]. Furthermore, nitrogen demand remains high during the fruit ripening stage, as tomato fruits are rich in free amino acids, most notably glutamate, which is crucial in the overall flavor profile of the fruit [20,21]. The concentration of glutamate and other amino acids is considered a key factor influencing taste and consumer acceptability [22,23].

The application of chemical fertilizers has become a widespread and integral component of modern intensive agriculture [24,25]. However, the long-term and extensive reliance on synthetic fertilizers has led to several unintended environmental and agronomic consequences. Notably, the relationship between fertilizer input and crop productivity is not linear, often resulting in substantial inefficiencies and waste of mineral resources. A significant proportion of applied nutrients is not absorbed by plants; it is estimated that up to 90% of phosphorus and 50% of nitrogen introduced into agricultural systems are lost through leaching, runoff, or volatilization. These losses contribute to soil salinization, eutrophication of aquatic ecosystems, and the emission of greenhouse gases [25,26]. Additionally, the excessive use of chemical fertilizers can adversely affect food safety and

quality, including the accumulation of nitrates in edible plant tissues. In contrast, organic farming systems, which prohibit the use of synthetic fertilizers, have been shown to mitigate many of these negative effects. Numerous studies indicate that organically produced crops often possess superior nutritional qualities compared to those cultivated under conventional systems [27].

In contemporary agriculture, the use of chemical fertilizers has become a common practice to achieve high crop yields in the short term. However, the detrimental environmental impacts associated with excessive chemical fertilizer application have prompted the exploration of alternative approaches. Over-application of synthetic fertilizers is linked to various food safety and quality concerns, including the accumulation of nitrates in plant tissues, which poses potential risks to human health [28]. In contrast, organic amendments such as crop residues, animal manures, and compost have been shown to provide substantial improvements in both the physical and biological properties of soils, in addition to supplying nutrients traditionally provided by chemical fertilizers. These organic resources are increasingly recognized as essential components in sustainable agriculture, enhancing soil health and improving grain yields within agroecosystems [29].

Moreover, organic and bio-organic amendments offer an effective means of waste utilization, contributing to more sustainable agricultural practices [30]. To facilitate the broader adoption of these technologies, various factors need to be optimized, including the type and dosage of organic amendments [29], the optimal ratio when mixed with chemical fertilizers [30], the timing of nitrogen applications [30], and the integration of organic amendments with different soil organisms. Studies have explored these variables across different crops and vegetables in various regions, investigating interactions with microorganisms such as phosphate-solubilizing bacteria, free-living nematodes, and epigenic earthworms. However, relatively few studies have examined the combined effects of two or more factors concurrently, and the potential interactions among these factors have often been overlooked [30]. Additionally, there is a lack of comprehensive evaluations that span from soil properties to plant outcomes, including morphological and

physiological traits, yield, and quality, which remain insufficient in the current literature [4].

Biochar, a solid with high carbon content, is produced by pyrolyzing agricultural waste biomass at elevated temperatures. It is characterized by its black color, high porosity, fine grain, lightweight nature, and large surface area, all of which contribute to its beneficial effects when incorporated into soil [31]. Compared to the original biomass, biochar decomposes significantly more slowly, allowing its positive impacts to persist for extended periods. Numerous studies have demonstrated the agronomic benefits of biochar, including its ability to enhance water and nutrient retention in the growing medium, thereby boosting crop productivity [32]. Additionally, it has been demonstrated that biochar alters soil pH [33] and improves cation exchange capacity, which facilitates better potassium availability and retention in soilless substrates [34]. It has been discovered that adding biochar to peat moss substrates improves the growth of tomatoes and marigold plants [35] while also stimulating physiological responses and increasing fruit yield in pea plants grown in similar conditions [36]. Biochar is formed when biomass, or feedstock, is subjected to pyrolysis at temperatures with low oxygen levels between 300 °C and 1000 °C, resulting in a formation of recalcitrant and generally stable organic carbon molecules [37]. A key chemical characteristic that differentiates biochar from other organic materials is the presence of fused aromatic carbon structures [38]. These aromatic structures contribute to biochar's high stability, making it resistant to microbial degradation and utilization by soil microorganisms. As a result, biochar's long-term stability allows it to enhance and sustain soil quality over extended periods [38]. Soil amended with biochar has been shown to significantly improve tomato plant growth, including increases in plant height, stem girth, leaf production, flower production, fruit yield, and weight [1].

The increasing global demand for energy, coupled with environmental and sustainability concerns, has led to a greater focus on sustainable energy, with biomass becoming a viable strategic substitute for fossil fuels [39,40]. The term biomass refers to organic materials that come from non-food sources, such as wood, organic household and industrial waste, algae, energy crops, and agricultural waste. The production of rice, corn, eucalyptus,

sugarcane, and other agricultural byproducts has shown a great deal of promise for power generation [41,42,43].

Growing rice has a lot of negative effects on the environment, such as polluting the soil and water and contributing significantly to greenhouse gas (GHG) emissions, especially methane (CH_4). An estimated 5% to 19% of anthropogenic methane emissions are attributed to rice cultivation [44]. Furthermore, a significant amount of husk is produced throughout the rice-growing process. This husk makes up around 20% of the rice crop's weight. An important source of energy in the agro-industrial industry is this husk [44]. However, rice husks contribute to eutrophication and disturb aquatic and terrestrial ecosystems when they are dumped in landfills, where they become a source of pollution. Additionally, because of their higher phenolic content and sluggish pace of biodegradation, rice husks that are dumped in rural areas release significant volumes of methane [45]. Uncontrolled burning, also known as open-field combustion, is another popular disposal technique. This method poses health and environmental hazards since it produces crystalline silica (quartz and cristobalite) as airborne suspended particles [46]. Because of the material's low density and again transportation costs, rice husk incineration continues even though it is an improper disposal method. However, rice husks become more economically and environmentally feasible biofuels when they go through a regulated thermochemical conversion process, increasing their energy density [47].

Among the most economical types of biochar is rice-husk biochar [48]. Rice husks, hard outer shells surrounding rice grains, are typically discarded during the milling process, making them a byproduct of rice production [49]. Rice husks produce about 35% of the initial feedstock material as biochar [50]. Rice husk biochar has been shown in numerous studies to have favorable agronomic effects on crop productivity [51]. For example, it has been demonstrated that adding rice husk biochar to alkaline soils enhances soil quality and lentil plant growth [52]. Applying 5% biochar to soils from recovered tidal land has produced the highest maize yields [53]. Additionally, applying 25 tons/ha of rice husk biochar and 15 tons/ha of cattle dung together has been shown to increase tomatoes yields in terms of both fruit weight and number. Biochar made from the rice husks has been shown to have beneficial effects on peanuts and soybeans. The positive effects of rice

husk biochar on rice productivity and fertilizer management have been the subject of more recent studies [53,54].

Rice residue management is crucial to halting environmental deterioration. Additionally, many arable lands have seen a significant decline in soil quality due to the ongoing usage of inorganic fertilizer. A sustainable method of producing rice is to turn rice husk debris into rice husk biochar (RHB), which is then reapplied as a soil supplement. When combined with soil, RHB can improve soil fertility and boost fertilizer efficacy because of its high silica content, nutrient retention capabilities, and high adsorptive ability. Rice husk biochar's high silica concentration enhances soil structure, plant turgidity, and nutrient retention. [55]. RHB treatment has shown great promise in lowering nitrate leaching; however, the magnitude of this impact is contingent upon the rate at which biochar is applied as well as the soil's biogeochemical properties. Additionally, RHB use exhibits a promising mitigating effect on greenhouse gas emissions, especially in paddy fields. after pyrolysis, heating rate and residence duration affect RHB's features. Pyrolysis temperature adjustment can maximize RHB's performance for certain uses (such as carbon sequestration and PH amendment) [55].

Torrefaction, gasification, flash carbonization, hydrothermal carbonization, and pyrolysis are common thermochemical processes used to produce biochar [56]. Pyrolysis is the most commonly used technique among these for producing biochar. The organic molecules found in biomass break down at particular temperatures in an oxygen-limited atmosphere during pyrolysis. Process temperatures, residence duration, biomass type, and heating rate are some of the variables that affect the properties of the biochar generated by pyrolysis [57].

The process of making biochar from rice husk (RH), characterizing it, and evaluating its impact on crop and soil characterization have all been the subject of extensive research. Few research has explicitly examined the effect of applying rice husk biochar to soil, despite the fact that there are numerous reviews on the characterization of biochar and its use in soil [58]. Additionally described are the effect of RHB on plant development, carbon sequestration, stabilization of heavy metals in soil, and enhancement of soil chemical, biological and physicochemical properties [58]

Aims and Objectives

The following are the Aims and Objectives of the present experimental study

1. The synthesis of biochar using rice husk
2. Evaluation of the impact of biochar on growth of *S. lycopersicum*
3. To analyze the nutritional profile of *S. lycopersicum* fruits before and after application of biochar

CHAPTER 2

REVIEW LITERATURE

Salim et al., 2020 stated that one of the most significant and widely consumed fruits and vegetables worldwide is the tomato (*S. lycopersicum* L.). With chromosome number $2n = 2x = 24$, it is an annual crop that self-pollinates and is a member of the Solanaceae family. (Jenkins, 1948; Peralta et al., 2008). The genus *Lycopersicon* has been reintegrated into the genus *Solanum* with its new nomenclature, as part of a recent revision to the evolutionary taxonomy of the family Solanaceae. When it comes to cooking, tomatoes are a really useful vegetable. While unripe green tomatoes are used for pickles and preserves and are eaten after cooking, mature tomato fruit is eaten fresh and used to make a variety of processed foods, including paste, powder, ketchup, sauce, soup, and canned entire fruits. Lycopene, a phytochemical that shields cells from oxidative damage, which has been connected to cancer, is abundant in it. This crop is cultivated all over the world for a variety of reasons [59].

Bjarnadottir et al., 2019 reported that the tomato, which produces more than 100 million tons of fresh fruit a year, is important for both emerging agricultural research and global cuisines (Food and Agriculture Organization). The tomato, scientifically known as *Solanum lycopersicum*, provides a wealth of nutrients in a variety of dishes and preparations. Tomatoes are considered a fruit, specifically a berry, despite their use as vegetables [60]. Costa and Heuvelink 2018 Along with other vegetable crops, including bell peppers, potatoes, and eggplants, it is a member of the Solanaceae or nightshade family [61]. Moore 2021; Reimers and Keast 2016). With a growing list of over 10,000 cultivars, tomatoes are grown in great quantities all over the world and account for around 20% of the consumption of all vegetable crops. Although most tomatoes are consumed fresh, most are processed into tomato paste or canned tomatoes, which increases the fruit's range of applications [62].

Bjarnadottir et al., 2019 conveyed that tomatoes are 95% water, with the remaining 5% consisting of fiber and carbs. The tomato is still a great source of vitamins and minerals that support bone health, tissue growth, cell function, blood pressure regulation, and more. Additionally, tomatoes are the primary source of lycopene, an antioxidant that has been

shown to support cell communication and shield significant biomolecules from deterioration [60]. Elango et al. 2017 According to recent research, lycopene has some anticancer properties and is important in preventing cardiovascular and Alzheimer's disorders [63].

Branthome 2022 demonstrated that China is the world's top producer of fresh tomatoes, followed by India, Turkey, and the US. In 2017, approximately 170 million tons of tomatoes valued at tens of billions of dollars were produced worldwide, or around 60% of the total (Nag 2020). In 2020, over 180 million tons of tomatoes were produced worldwide, with over 35% of the fresh fruit coming from China [64]. Keast and Reimers, 2019 The United States produces more than \$2 billion worth of commercial tomatoes a year, with Florida leading the way in fresh tomato production and California leading the way in processing tomato production. [65].

Seun Owolabi Adebajo et al., 2022 reported that tomatoes are beneficial for human health because they contains such as A and C as well as several minerals. However, tomato production needs to be improved to satisfy the demands of the growing population. Thus, this study examined how rice-husk biochar affected the microbial biomass of carbon, nitrogen, and phosphorus in various tomato growth stages as well as the agronomic performances of tomato plants. Four different rates of soil amendment were applied to the rice husk biochar that had been pyrolyzed at 350 °C: 0, 2.5, 5.0, and 7.5 t/ha. Mid-Infrared Reflectance Spectroscopy was used to ascertain the physicochemical characteristics of the soil. Fumigation extraction was used to study the effects of biochar on Microbial Biomass Carbon, Microbial Biomass Nitrogen, and Microbial Biomass Phosphorus. Three functioning stages were observed. The application of biochar significantly improves the physicochemical characteristics of the soil, including pH, Ca, Na, H⁺, S, P, B, C, Zn, and cation exchangeable capacity, as compared to the control. Tomato weight, blooms, fruit yields, stem girth, leaf area, and height were all markedly improved by soil supplemented with biochar. B3 had the greatest number of fruits and the highest fruit weight (3 and 40%, respectively), despite having the smallest leaf area. For biochar added soil at 7.5 t/ha (B3), the microbial biomass C:N:P ratio was 302.30:18.81:11.75 µg/g, while the control was 242.12:18.30:11.49 µg/g. According to this study, tomato plant yields and microbial

biomass were significantly ($p < 0.05$) boosted by biochar treatments. In conclusion, adding 7.5 t/ha of rice-husk biochar to soil is thought to be an effective way to increase tomato yield and growth [66].

Singh et al., 2017 explained that vegetables must receive enough nutrients in order to grow and develop correctly. Fertilizer applications must follow ideal guidelines to yield respectable results. At the Department of Horticulture, Allahabad School of Agriculture, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, the current study researches the effect of foliar zinc and boron application, and the quality of cherry tomatoes employing nine treatments in a randomized block pattern, each of which was triple-replicates. According to the results of the study, foliar sprays of zinc (ZnSO_4) and boron (Bo) at 1.25g and 2.0g per liter have been found to affect cherry tomatoes. Treatment T9 (B=2.0g/l) produced the highest plant height (62.74cm, 94.44cm, 144.29cm, 146.55, and 148.44cm) at every stage of growth (30, 60, 90, 120, and 150 DAT) according to the study's significant findings. There were 19.41, 29.76, 43.05, 46.89, and 54.09 leaves per plant, 7.04, 12.04, 15.29, and 16.77 clusters per plant, and 22.21, 26.72, 30.15, and 36.65 flowers per cluster. T9 (B=2.0g/l+ Zn= 2.0g/l) was used to record the following: higher TSS (13.100 Brix), vitamin C (14.10MG/100g fruit pulp), fruit set (%) (57.84, 77.78, and 85.76), fruit weight (14.87g), fruit number per plant (244.15), fruit yield per plant (4.98kg), fruit yield per ha (4.98 t ha⁻¹) and the maximum number of fruits per cluster (28.22, 30.33, and 32.80). These findings showed that the combined foliar application of zinc and boron had a greater impact on cherry tomato growth, yield, and quality than either fertilizer alone [67].

Joung et al., 2025 reported that There were significant variations in lycopene concentration between maturity stages. The deep red stage was the primary time for lycopene accumulation. Total antioxidant status (TAS), a measure of tomato fruit's antioxidant qualities, increased steadily over the ripening process and had a significant linear association with the quantity of hydroxymethyl furfural, polyphenol, and lycopene. The amount of lycopene and the production of hydroxymethyl furfural were shown to be significantly correlated [68].

Wang et al., 2019 explained that biochar, a material rich in carbon, can be made from a range of organic waste feedstocks, such as agricultural waste and municipal sewage sludge. Biochar has gained increasing interest due to its unique properties, including its stable structure, large specific surface area, high carbon content, and cation exchange capacity. Based on more than 200 papers published in the last ten years, this review methodically examined and compiled the production, characterization, modification, and most importantly, environmental use of biochar to give a general overview of the material with an emphasis on its use in the environment. The varieties of feedstocks have an impact on the physicochemical characteristics of biochar. Common techniques for creating biochar include hydrothermal carbonization, gasification, and pyrolysis. Biochar can be changed by acid, alkali, oxidizing agents, metal ions, and carbonaceous. The environmental application fields determine which modification techniques are used. We went into great length on the various applications of biochar, encompassing soil remediation and amelioration, carbon sequestration, purification of water and wastewater, composting of organic solid waste, catalysts, and activators. electrode modifiers. Further studies on the application of biochar in carbon sequestration should be carried out under similar experimental conditions in order to obtain reliable results. Further studies on the effects of biochar on soil microorganisms are necessary to identify the main factor contributing to the increase in soil fertility, depending on different soil and feedstock conditions. Furthermore, when utilizing biochar for environmental restoration, greater consideration should be devoted to heavy metal release and polycyclic aromatic hydrocarbons (PAHs) into the environment. To learn more about how biochar activates persulfate when it is utilized as an activator, more research should be done on the connection between biochar structure and activation competence [69].

Allohverdi et al., 2021 reported that further research on the effects of biochar on soil microorganisms is necessary to determine the primary cause of the increase in soil fertility, which varies based on the conditions of the soil and feedstock. To provide food for an expanding global population, innovative and practical solutions are needed as climate change intensifies drought and desertification worldwide. The productivity of agricultural soils has long been increased by the use of synthetic fertilizers, some of which release greenhouse gases (GHG) into the atmosphere. When applied as a soil amendment,

biochar appears to improve soil nutrient density, crop yields, soil microbiology, fertilizer needs, and water-holding capacity. The use of biochar also has numerous economic and environmental advantages, as well as the possibility of being incorporated into carbon credit schemes. Biochar, sometimes referred to as biocarbon, might provide the solution to these basic needs [70].

Ippolito et al., 2020 described that the highest treatment temperature (HTT) for pyrolyzing a variety of biochar types made from feedstocks such as woody residues, agricultural straw, animal manures, sewage sludge, and food wastes ranges from about 350°C to more than 750°C. Biochar's properties vary widely and are primarily determined by feedstock, HTT, residence period at HTT, and pre- and post-pyrolysis treatments. According to a review of 5400 studies, biochar with the highest surface area was typically formed by wood-based feedstocks, the highest cation exchange capacity (CEC) by straw-based feedstocks, and the highest N and P content by manure-based feedstocks. Biochar produced by HTTs above 500°C had greater ash contents and pHs and was more persistent in soil [71].

Kumar and Bhattacharya, 2021. Numerous hazardous issues have encircled the planet since the late 20th century. Climate change, the depletion of fossil resources, and various types of pollution, such as heavy metal contamination, have all had a negative influence on humanity. One workable solution to heavy metal pollution is the use of biochar. Any biomass-containing item can be pyrolyzed to create biochar, a carbonaceous product. The kind of feedstock utilized and the pyrolysis temperature at which it is produced determine the chemico-physical characteristics of biochar. It is a great substrate for eliminating heavy metals from contaminated soil and water because of its exceptional qualities, which include high adsorption capacity, large surface area, excess surface functional groups, and high porosity. By storing carbon and reducing the use of fossil fuels through the production of bio-oil and syngas, it can simultaneously address the new problems of climate change and prove to be an economical and environmentally beneficial approach. The review was designed to ascertain whether biochar may be a sustainable solution to address the numerous threatening challenges [72].

Gabhane et al., 2020 explained that the production of biochar from organic waste has gained popularity in recent years due to its more effective manufacturing technique, accessibility, and broader range of uses. Biochar production methods are always being improved to boost output speed and quality. Even though several methods have been described recently, a systematic classification of them has not yet been investigated. We have divided all of the main manufacturing processes of biochar into two main classes based on the development of the techniques now in use and the modification of traditional methods. While modern approaches incorporate several state-of-the-art technologies such as gasification, torrefaction, hydrothermal carbonization, and electro-modification, the traditional approach consists of the conventional pyrolysis technique (slow and fast pyrolysis) and modified traditional methods such as flash pyrolysis, vacuum pyrolysis, and microwave pyrolysis. Additionally, the goal of the systematic review was to assess the possibility of producing biochar from a variety of feedstock types, including paper waste, aquatic biomass, forest/woody biomass, agricultural biomass, and urban garbage. It was noted that the feedstock containing high cellulose was found to be effective in increasing the overall features of biochar, including better adsorptive activity and retention of nutrients [73].

According to Rombel et al. 2022, the globe is currently dealing with number of environmental issues. Due to the ever-growing size of the population, it is required to produce more and more food. The result of such high food demand is overfertilization of soils, frequently without proper control. An overview of many types of biochar(BC) fertilizer. A protective layer, a coating of BSs, or a mixture of BCs and commercial fertilizers can be applied. Despite the fact that applying these innovative fertilizers enhances soil properties and agricultural output, simple inorganic fertilizers are still widely manufactured and used. Given that composts are still the most widely utilized products by farmers, using BC-compost systems as an effective soil amendment could be the first step in reversing this trend. Two varieties of BC-compost soil additives were outlined in the review: BC co-composted with compost raw material and BC mixed with pre-made compost. These kinds of soil amendments allow for a high production of safe food while significantly reducing the need of commercial inorganic fertilizers and, consequently, environmental degradation. [74].

Goldan et al.,2023 explained that the handling of organic waste is a significant issue for communities and companies alike. For a number of reasons, including lowering greenhouse gas emissions, encouraging sustainability, and enhancing public health, proper management is essential. An excellent source of organic matter and nutrients, composted manure can be applied as a soil amendment in agricultural settings. Utilizing composted manure in agriculture has several significant advantages, such as increasing soil fertility, improving soil structure, decreasing soil erosion, preventing plant diseases, and lowering the need for synthetic fertilizers. One of the best strategies for maximizing the value of organic waste is composted manure. At different application rates, its macronutrient and micronutrient concentration can boost plant output without having any known harmful or detrimental impacts on the soil or plants. Inappropriate usage of farmyard manure, however, can harm the ecosystem by causing nitrate and phosphate contamination of surface and groundwater, acidification of the soil, and air pollution from greenhouse gas emissions. The structure and composition of manure can increase the soil's aeration, density, porosity, pH, water retention capacity, and other characteristics. Proper plant growth can be determined by the slow-release source of nutrients that compost's nutritional content provides. To avoid over-applying nutrients, which can harm plants and the environment, it is essential to use compost sparingly and evaluate the soil frequently. [75].

Zahra et al.,2021 illustrated that by changing the physical and chemical characteristics of the soil, organic soil amendments can improve crop yields and have an impact on soil health. There isn't many research, though, on how compost and biochar affect crop productivity and soil health in the field. Thus, the goal of the current study was to assess the positive effects of compost and biochar on the nutritional composition of soil and maize yield. Biochar and compost were made using cow manure as a biomass. The pyrolysis temperature was maintained at 480 °C for the formation of biochar. At a rate of 5 tons ha⁻¹, the experiment included four treatments: (1) Control; (2) Biochar; (3) Compost; and (4) Biochar plus Compost. Grain yield and biological yield increased by 46.29% and 13.4%, respectively, in the biochar and compost-containing treatment compared to the untreated control. Similarly, the combined action of compost and biochar has resulted in an 80.52% increase in soil organic carbon. However, applying compost

and biochar together caused the pH of the soil to drop. In conclusion, compost and biochar have the potential to improve crop productivity through improved soil nutrient and property management [76].

Bello et al., 2021 reported that as an alternate strategy to address soil fertility, soil degradation, and climate change, some researchers have reported utilizing a mixture of biochar and compost to improve the physicochemical qualities of soil and lower greenhouse gas emissions. However, there hasn't been much research done on how it affects the soil microbiota. The effects of a combined application of biochar and compost on soil physicochemical characteristics, fungal community composition, function, and network patterns in maize during the seedling, reproductive, and maturity stages (SS, RS, and MS) were examined in this study. Five treatments make up the study design: compost (CMP), composted biochar (CMB), compost fortified with biochar (CFWB), biochar (BCH), and control (CNT). The findings demonstrated that, in comparison to BCH and CNT, CFWB, CMB, and CMP raised the fungal diversity indices (Shannon, Sobs, and Chao) at the RS and MS stages, respectively. The fungal community was found to be considerably and favorably impacted by the pH, available nitrogen, and soil organic matter at SS; available phosphorus at RS; and Mg, Mn, Fe, and Zn at MS, according to distance-based redundancy analysis (db-RDA) at the genus level. The only MS biomarkers with a substantial CFWB enrichment were *Cystofilobasidiaceae* and *Guehomyces*. Comparing organic amendments (CFWB, CMB, CMP, and BCH) to CNT, the FUN Guild study showed that the former reduced the abundance of plant pathogenic fungi. This study showed that the co-occurrence network pattern and soil fungal communities were positively impacted by the application of compost, biochar, and a combination of the two in a single cropping season. As a result, adding them to soil could improve the soil's health and quality, slow down climate change, and strengthen the ecosystem of soil fungi.

Pandit et al., 2020 showed that organic nutrient transformation techniques based on locally accessible materials (manure, green waste, and advanced biochar) can increase fertilizing substrate by a factor of three when compared to other organic amendments without biochar. To examine the processes of organic nutrient transformations, we

employed three distinct composting techniques: i) conventional composting, which involves turning the piles without turning the compost; ii) aerobic composting, which involves turning the piles by hand; and iii) bokashi composting, which involves anaerobic lacto-fermentation. Both the absence (compost only) and the addition (co-compost) of biochar were used for composting. Locally, biochar was made from "Eupatorium adenophorum," an invasive woodland species. In order to compare the agronomic effects of the three aforementioned composting techniques with traditional mineral fertilizers (NPK), a pot trial involving maize grown on silty loam soil was conducted. Co-composted bokashi-biochar (60 t ha^{-1}) had significant effects on maize growth, increasing biomass by 243%. When compared to mineral NPK. It also shows superior growth effects when compared to aerobic and conventional composting additives. Better soil nutrients (available P) and other exchangeable base cations (K^+ , Ca^{2+} , and Mg^{2+}) caused co-composted bokashi-biochar to have a better growth effect [78].

Karam et al., 2022 explained that to prevent environmental issues, the amount of rice residue in rice-producing nations needs to be managed responsibly. Furthermore, these arable lands have seen significant soil deterioration due to the frequent application of inorganic fertilizers. A sustainable method of producing rice may involve turning rice husk leftovers into rice husk biochar (RHB) and reusing it as a soil supplement in paddy fields. RHB can increase soil fertility and fertilizer efficacy when combined with other fertilizers because of its high silica content, nutrient retention capacity, and adsorptive ability. Rice husk biochar's high silica concentration improves the plant's turgidity, structure, and nutrient retention. The purpose of this review article is to compile information on the properties of rice husk biochar, the factors that affect it, and its application in Asian agriculture [79].

Asadi et al., 2021 reported that the production of rice husk biochar (RHB) and its effects on soil characteristics, plant growth, immobilization of heavy metals, decrease of nutrient leaching, and mitigation of greenhouse gas emissions were critically examined in this work. Compared the characteristics of biochar produced from various agro-industrial wastes with RHBs produced at various temperatures. RHBs with a lower hydrogen/carbon ratio, which suggests the presence of more aromatic carbon molecules, are

produced at higher pyrolysis temperatures. RHBs that have a bigger surface area, lower yield, and higher ash content are also produced when the pyrolysis temperature is raised. When compared to biochar made from other feedstocks under the same pyrolysis conditions, RHB often contains less carbon and more silicon and ash. The amount of organic carbon in the soil, its cation exchange capacity, its accessible K concentration, its bulk density, and its microbial activity can all be enhanced by applying RHB, albeit this varies on the kind of soil. The primary determinant of RHB's impact on soil aggregation is soil texture. The growth of different crops is also enhanced by the application of RHB. RHB addition to soil can immobilize heavy metals and herbicides and reduce their bioavailability. RHB application shows a significant capacity in reduction of nitrate leaching, although its magnitude depends on the biochar application rate and soil biogeochemical characteristics. RHB utilization exhibits a promising mitigation effect on greenhouse gas (CH_4 , CO_2 , and N_2O) emissions, particularly in paddy fields. The performance of RHB for particular applications (such as carbon sequestration or pH amendment) can be controlled by varying the pyrolysis temperature, even if its properties are also influenced by other variables, including the pyrolysis heating rate and residence time. Additional research on long-term field uses is necessary to fully understand the advantages and disadvantages of RHB as a soil amendment.

According to Bushra et al., 2024 biochar derived from various biomass types has been widely used in environmental applications due to its ability to immobilize or eliminate contaminants from soil, water, and air. The present research offers an overview of the several pyrolysis techniques utilized to produce biochar from rice husk, modify biochar, and use it in the environment. By pyrolyzing rice husk, biochar is produced with a high volatile matter content (70.2–78.5 %) and carbon content (35.2–44.7 %). When compared to other process variations, microwave-assisted hydrothermal carbonization yielded the most biochar from rice husk (57.9%), while wet pyrolysis yielded the most carbon-rich biochar (71.2%). Compared to CO_2 activation, steam activation of rice husk biochar produced a wider pore size distribution with notable micropores. While metal impregnation resulted in a decrease in surface area, alkali activation significantly increased both surface area and microporous volume when compared to acid activation. With or without modification, rice husk biochar has been used to adsorb contaminants

such as tetracycline, dyes, cations, and nutrients. The cation exchange capacity and soil fertility were enhanced by the nutrient-rich rice husk biochar. According to the investigations, selecting an appropriate pyrolysis variant and biochar modification technique is essential to enhancing the rice husk biochar's adsorption capacity and potential for nutrient release [81].

Li et al., 2023 It has been discovered that rice husk biochar (RHB), a cheap and renewable material, works very well for cleaning up soil and aquatic ecosystems. By altering the preparation process's variables, including the heating rate, pyrolysis temperature, and carrier gas flow rate, its yield, structure, composition, and physicochemical characteristics can be changed. Its functional groups and specific surface area can also be altered chemically, physically, and biologically. Although RHB can be altered for better adsorption, it performs poorly in solutions with coexisting metals when compared to biochar made from other feedstocks. By controlling soil characteristics and releasing advantageous components, RHB has been shown to be successful in adsorbing organic matter and heavy metals from polluted soils, lowering pollutant availability, and improving crop development. To completely comprehend its mechanisms and efficacy in environmental restoration, more research is necessary as its efficacy in complicated contexts is yet unknown [82].

Sahoo et al., 2022 explained that black carbon, a primary cause of air pollution in megacities like Delhi, is released when agricultural waste, such as crop residues, is burned. On the other hand, cellulose, hemicellulose, and lignin are abundant in crop wastes. Using microwave pyrolysis, the current study examined the impact of heating time (HT) and MW power (P) on the output of biochar from rice husk, an agricultural waste. At HT 18 minutes and P 500 W, the yield of biochar was 68%; at HT 15 minutes and P 900 W, it was 39%. The yield of biochar was predicted using a second-order polynomial model, indicating that the maximum yield of biochar was positively impacted by microwave power and the combination of heating time and microwave power. When compared to rice husk (12.43 MJ/kg and 0.06), biochar's high heating value and fuel ratio (25.46 MJ/kg and 2.82) shown improvement. Additionally, the fixed carbon content of biochar increased from 4.78% in rice husk to 52.2% in biochar as a result of the MW

pyrolysis of rice husk. The characteristics of rice husk and biochar showed that the pH increased from 6.71 to 8.75, the surface area improved from 2.4 to 190 m²/g, and the O/C ratio decreased from 1.5 to 0.66. Additionally, it was discovered that the energy production and density in MW pyrolysis were 99.28% and 1.46, respectively. As a consequence, MW pyrolysis of rice husk produced high-quality biochar that may be utilized as a soil amendment, nutrient-capturing media, or energy source [83].

Rahmat et al., 2023 explained that for Indonesians, rice is the staple diet. Large volumes of rice husk are generated as waste during the manufacturing process. Because of their strong fibers, rice husks take a long time to naturally decompose. Making biochar from rice husk waste is one way to utilize it and give it value. One substance that is good for the soil is biochar, which is made by pyrolyzing organic waste. The temperature of pyrolysis affects the quality of biochar. The purpose of this study was to examine the properties of biochar at different pyrolysis temperatures. The findings demonstrated that the element concentration of SiO₂ (ash fraction) increases with an increase in pyrolysis temperature. The biochar output, calorific value, carbon and hydrogen content, and the concentration of K₂O, CaO, P₂O₅, MnO, and TiO₂ are all reduced when the pyrolysis temperature is raised. SiO₂ is the predominant ingredient in biochar (ash fraction), accounting for 85.35–89.47 % of the total. The yield of the biochar ranged from 37.4 to 68.18 %, and its carbon, hydrogen, and nitrogen contents ranged from 31.77 to 38.11, 1.67 to 3.61, and 0.63 to 0.73 %, respectively. The biochar's calorific value ranged from 14.48 to 11.61 MJ/Kg, and the highest yield was obtained using the lowest pyrolysis temperature of 250°C. Fourier transform infrared (FTIR) analysis revealed that the functional groups in the biochar were O-H, C=O, and C-OH. The results of the X-ray diffraction (XRD) analysis showed that the amorphous biochar of rice husk decreases as the pyrolysis temperature increases, and vice versa. The rice husk biochar has excellent potential to form silicate crystals [84].

Linam et al., 2023 reported that the impact of adding husk, biochar, and charcoal to rice paddy soil on its chemistry of dissolved organic matter (DOM), greenhouse gas emissions, and soil organic carbon (SOC) levels is investigated. The study found that non-flooded

conditions increased CO₂ and NO₂ emissions, husk and biochar additives increased CH₄ emissions, and SOC storage [85].

Calcan et al., 2022 illustrated that the study assessed how soil physicochemical characteristics and tomato plant growth were affected by biochar (BC) made from vine pruning residue. Strongly alkaline BC dramatically increased tomato plant growth in acidic soil, according to a greenhouse experiment. In addition to decreasing soil bulk density and improving root development, BC also raised pH, electrical conductivity, and the concentration of soluble and accessible nutrients, improving water and nutrient uptake. As a result, BC from vine pruning residues can improve tomato plant development and soil quality [86].

Oladele et al., 2019 reported that it has been demonstrated that the co-application of biochar with inorganic N fertilizer is an environmentally sound and sustainable method of increasing crop output and soil fertility. Nevertheless, little research has been done on how they combine to affect nutrient availability and rain-fed rice productivity in the tropics' various soil types. The effects of applying N fertilizer at varying rates and rice husk biochar on rain-fed rice output and soil nutrient distribution in the 0-20 cm soil layer were examined in a field study. In addition to N fertilizer (urea) applied at four rates (0, 30, 60, and 90 kg/ha⁻¹) to two distinct soil types (sandy clay loam Oxic-Paleustalf and sandy loam Oxic-Paleustult), biochar was applied at four rates (0, 3, 6, and 12 t/ha⁻¹). The study discovered that in Oxic-Paleustult and Oxic-Paleustult soil types, rain-fed rice yield and soil nutrient availability can be enhanced by charcoal amendment and N fertilizer. While lowering soil nitrate leaching, the combination of biochar and N fertilizer enhanced panicles/m² and straw yields. According to the study, nitrate leaching can be reduced and rain-fed rice output increased with the use of biochar amendment and N fertilizer [87].

El-Hassanin et al., 2020 explained that using accepted techniques, the physicochemical characteristics of the soil, rice husk, biochar, and biochar soil were assessed both before and after planting. Morphological and biochemical characterizations were used to isolate and identify the plant's rhizospheric microorganisms. Plant height, stem girth, leaf area, number of leaves, blooms, fruits, and fruit weight were among the agronomic parameters that were measured. The results showed that the unamended soil had the lowest

constituents, whereas rice husk biochar (40 t/ha) had the greatest physical and chemical properties. *Bacillus subtilis* and *Aspergillus niger* are the two most common bacteria and fungi. At every stage of growth, the amended soil outperformed the control in all agronomic measures, including plant heights, stem girths, leaf areas, number of leaves, flowers, fruits, and fruit weight. At the tenth week, the treated soil produced an average fruit weight of $34.95\text{g} \pm 8.76$ and $21.53\text{g} \pm 5.16$ at 20 t/ha and 40 t/ha, respectively, while the unamended soil produced no fruit. According to this study, tomato plant growth and yield could be enhanced by using biochar made from rice husk [88].

Veloso et al., 2025 described that a significant amount of agricultural waste contributes to serious pollution issues in many developing nations. Additionally, heavy metal pollution of agricultural soils necessitates the development of an environmentally benign method for disposing of agro-wastes while simultaneously increasing the amount of soil available for farming. In the current study, biochar was produced using rice straw for use in soil remediation. A variety of techniques, including X-ray diffraction, Fourier transform infrared, and scanning electron microscopy, were used to analyze the biochar made by pyrolyzing rice straw at 450 degrees Celsius. Rice straw biochar (RSB) is mostly made up of silicates and has an amorphous porous structure with several functional groups, according to the characterization data. After that, RSB was looked at as a soil remediation material for a silty clay soil. Here, a synthetic polluted soil was created with cadmium and lead concentrations of 10 and 500 mg/kg, respectively. At the following (w/w) rates, rice straw biochar (RSB) was added to the soil: 0 % (control), 1.25 % (T1), 2.50 % (T2), 5.00 % (T3), and 10.00 % (T4). The soil samples underwent analysis following a 30-day incubation period. The findings demonstrated that the addition of biochar significantly raised the pH, EC, CEC, total organic matter, total carbon, and moisture content of the soil. The amount of accessible N, P, and K was marginally increased by the application of biochar. All biochar treatments had considerably lower levels of plant-available Pb and Cd than the control treatment. Therefore, it can be said that biochar made from agricultural waste has both economic and environmental benefits, particularly in underdeveloped nations. With ongoing soil property monitoring, rice straw biochar may be investigated further for the remediation of different kinds of soil contaminants [89].

CHAPTER 3

METHODOLOGY

3.1 Experimental Site

The current experimental study was conducted during the growing year (2025) at the Pakistan Council of Scientific and Industrial Research Institute (PCSIR) Lahore, Punjab, Pakistan (latitude $31^{\circ} 32' N$, longitude $74^{\circ} 19' E$) (Figure 3.1).



Figure 3.1 Map of PCSIR study site at (Right), District Punjab; city Lahore, and Tehsil Boundary Model town (Left)

3.2 Synthesis of Biochar from Rice Husk

3.2.1 Collection and Preparation of Rice Husk

Rice husk (RH) collected from Data Rice Mill, Lahore, Pakistan ([Data Rice Mills, Lahore, Punjab 54921 Pakistan](#)) was used for the preparation of experimental biochar. Collected rice husk was dried in the sun for 2-3 days to reduce moisture content (Figure 3.2 A) and then ground to make uniform particle size using a hammer mill [4]. Experimental biochar was prepared using the standard protocol of Mukherjee [90] with little modification through the process of Pyrolysis at $550-600^{\circ} C$ for 3-4 h (Figure 3.2 B, and C). The yield of biochar was determined by calculating the ratio of the mass of the biochar to the mass of the biomass of rice husk initially used for the pyrolysis by the given formula.

Yield of biochar (%) = Mass of biochar (g) / Mass of the feedstock (g) × 100.....(Eq A)

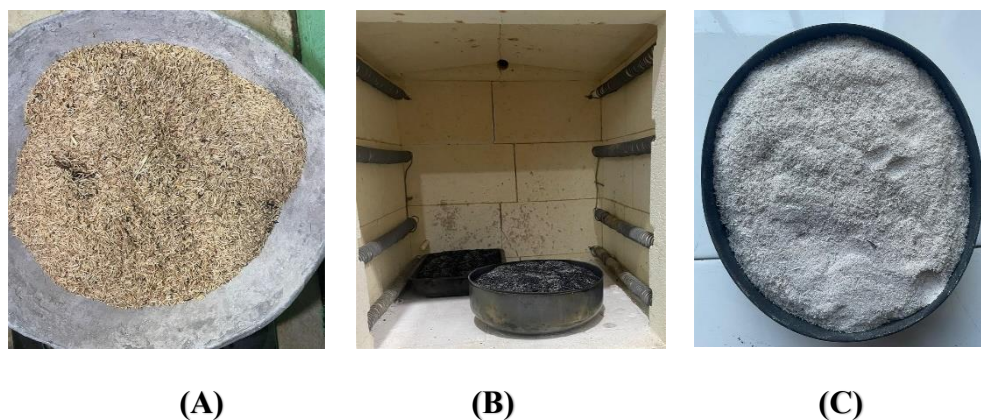


Figure 3.2 Pyrolytic conversion of rice husk into biochar

Where: (A): Feedstock rice-husk; (B): Pyrolysis at 550 °C; (C): Biochar produced from rice-husk

3.3 Characterization of Biochar

Rice husk feedstock (RHF) and synthesized experimental rice husk biochar (RHB) were assessed for their pH, water-holding capacity, electrical conductivity, nitrogen content, bulk density, moisture, and ash content. Further, these samples were assessed through FTIR to determine their functional groups, and SEM provided high-resolution images of the surface structure and morphology of the samples [91].

3.3.1 pH analysis

Mixture of both (RHF, RHB) and water was prepared at a ratio 1:2 (w/v) (Figure 3.7 A) and the samples were shaken continuously for 1 hour and left for 15 minutes, which were stirred after filtration and the value of pH was recorded by using a pH meter (Figure 3.7 B, and C) (China TXL/08”) [94].

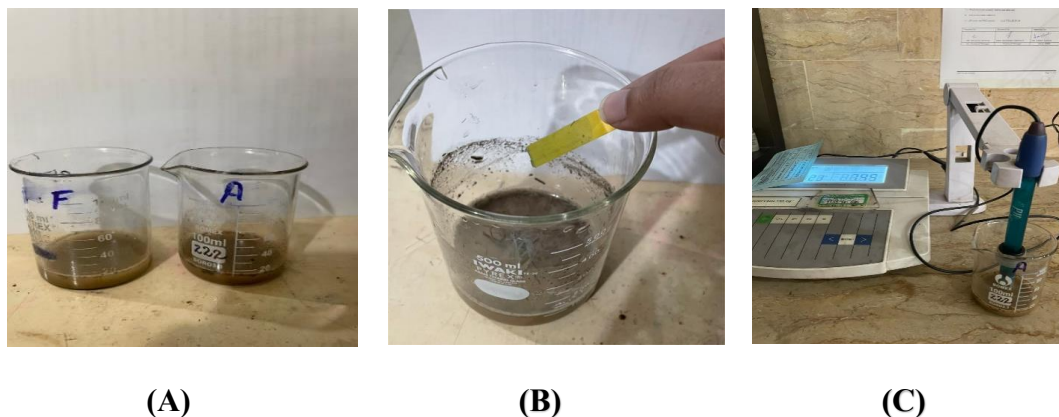


Figure 3.3 Evaluation of pH levels in soil and Biochar

3.3.2 Water holding capacity

Water holding capacity of both (RHF and RHB) sample were assessed through the following method of Singh [93] with little modification. For those 50 grams of sample were weighed and poured into the bottom of the titration apparatus along with the cotton. Each sample was poured into an apparatus using funnel, and then 50 ml of water was added. The mixture was left for 20 - 30 minutes, then the collected filtrate (Figure 3.9 A and B) was measured, and the reading was recorded.

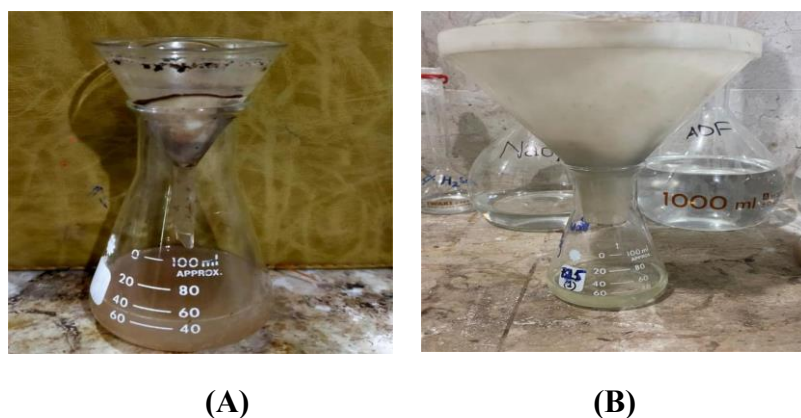


Figure 3.4 Determination of water holding capacity of soil and Biochar

3.3.3 Electrical conductivity (S/m)

Electrical conductance of both (RHF and RHB) samples was checked (Figure 3.8 A and B) by following the method described by Jindo [94] with little modifications. Two grams of biochar sample were weighed and added to a beaker with 100 ml of distilled water, and the suspension was allowed to settle for 5 minutes. After filtration, the suspension was transferred to another beaker. The reading of EC was recorded by using an electrical conductivity meter (HI98304 DIST4).



Figure 3.5 Determination of Electrical conductance of soil and Biochar

3.3.4 Total Protein content analysis (%)

Total protein content of both (RHF and RHB) was checked by following the standard method described by Aller [92] with a few modifications. For that, 0.5g of biochar was taken in a digestion flask with 30 mL H_2SO_4 and 2 grams of digestion mixture (Selenium tablet). Swirl them to mix the contents thoroughly (Figure 3.5). Each flask was kept on heat for digestion, and the reaction mixture was transferred to a volumetric flask after cooling. 25 mL of volume was made with distilled water. Boric acid (2%) solution was added to a 100 mL beaker and connected with the tip of the distillate condenser. A digested sample (5-10 mL) was taken in a distillation flask with 30 mL of sodium hydroxide solution, and the change in color of the boric acid solution was recorded. Further, the collected solution was titrated with standard HCl. Three concise readings were taken during titration to ensure accuracy, and the percent of protein content was calculated by using the following formula.

$N\% = \text{Titrated reading} \times 100 / 5 \times 100 \dots \dots \dots (\text{Eq D})$



Figure 3.6 Sample preparation for protein

3.3.4.1 Phosphorus (%)

For the determination of phosphorus content of both (RHF and RHB), and soil were used in order to process the standard protocol of Sigh [93] with minor modifications. 0.5g from each sample was further weighed with the addition of 3 mL of 6N HCl and 10 mL of water. Prepared mixture was heated for 5 minutes and the volume was adjusted to 50 mL water after filtration (Figure 3.6 A). And was assessed through UV Spectro-photometer at 213 nm for the calculation of phosphorus content (Figure 3.6 B).



(A)



(B)

Figure 3.7 (A) sample preparation for phosphorus, (B) UV Spectrophotometer

3.3.4.2 Potassium (%)

The potassium content of both (RHF and RHB) and soil were determined using the standard protocol of Sigh [93] with minor modifications. 0.5g of sample from ash was weighed, followed by the addition of 3 mL of 6N HCl and 10 mL of water for biochar.

Similarly, 0.5g from each sample was weighed with the addition of 3mL of 6N HCl and 10 mL of water for the soil sample. The mixture was heated for 5 minutes. The volume was adjusted to 50 mL with water after filtration. The prepared solution was then analyzed using a flame photometer at 766.5 nm for the potassium content.

3.3.5 Moisture content analysis (%)

The moisture content of both (RHF and RHB) were assessed through following standard method of Tasim [91] with little modifications. For that one gram of the sample was weighted using an analytical balance (9TXL/15) in a clean dry crucible (Figure 3.3 A) and heated at 100°C in oven for 6-12 hours (Figure 3.3 B). Crucibles were then left in the desiccator for 30 minutes, each sample was weighed again (Figure C), and the moisture content was calculated by following formula.

$$\text{Moisture} = \frac{W_1 - W_2}{W} \times 100$$

Where, W = weight of empty crucible

W₁ = weight of crucible + sample, W₂ = weight of crucible + dried sample.....(Eq B)

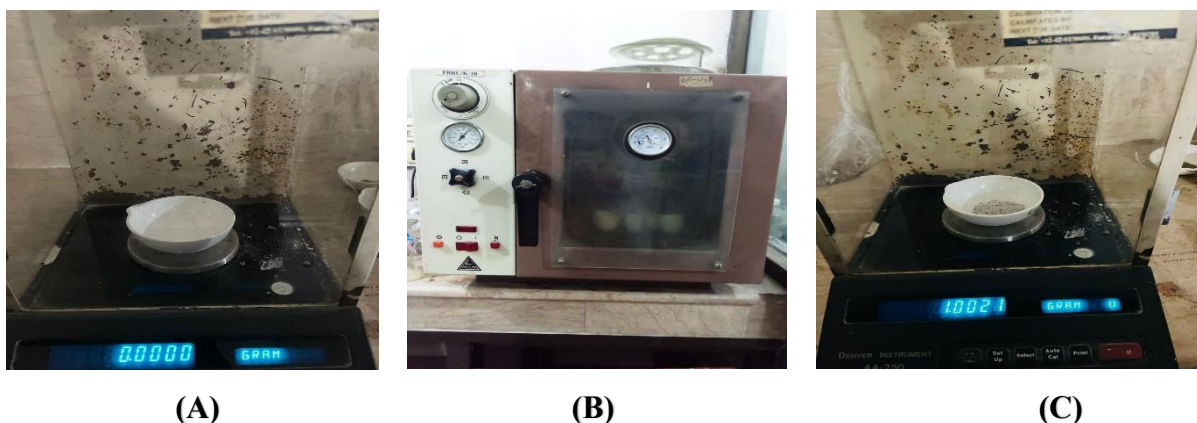


Figure 3.8 Moisture content analysis of prepared biochar

3.3.6 Ash analysis

Clean, empty crucibles were heated in a muffle furnace at 600°C to calculate the amount of ash they contained, and weight of the crucibles were recorded after cooling in the desiccator. In order to proceed further, one gram of the sample of RHF and RHB were

placed in each crucible and burned until it was charred completely (Figure 3.4 A) and kept in desiccator for 30 minutes. Further, samples were heated in a muffle furnace (Figure 3.4 B) at 550°C for 2-4 hours for oxidation and the change in color was noted. After cooling, samples were weighed again (Figure 3.4 C) to calculate the ash content [91] by following formula.

$$\text{Ash} = \frac{W_1 - W_2}{W} \times 100 \dots \dots \dots (\text{Eq C})$$

Where W = Weight of sample

W₁ = initial weight of sample

W₂ = final weight of sample

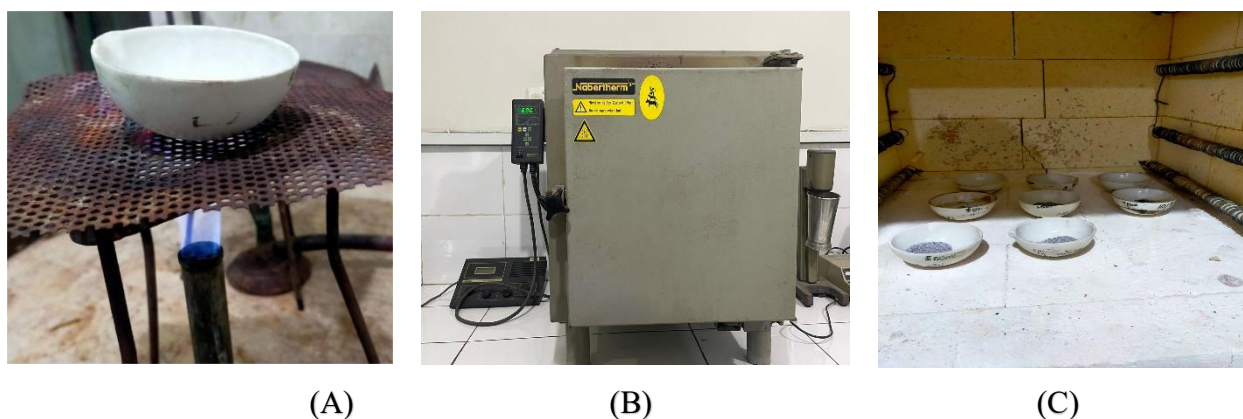


Figure 3.9 Analysis of ash content of biochar samples (A) Charring of sample (B) muffle furnace (C) Sample in muffle furnace

3.3.7 Analysis of Mineral Content

The mineral analysis of both (RHF and RHB), and soil was determined using the standard protocol of Sigh [93] with minor modifications. Approximately 0.5g of ash was accurately weighed, followed by the addition of 3 mL of 6N HCl and 10 mL of water. The mixture was heated for 5 minutes (Figure 3.10 A), then filtered (Figure 3.10 B). The volume was adjusted to 50 mL using distilled water. The resulting solution was then analyzed using a flame photometer.

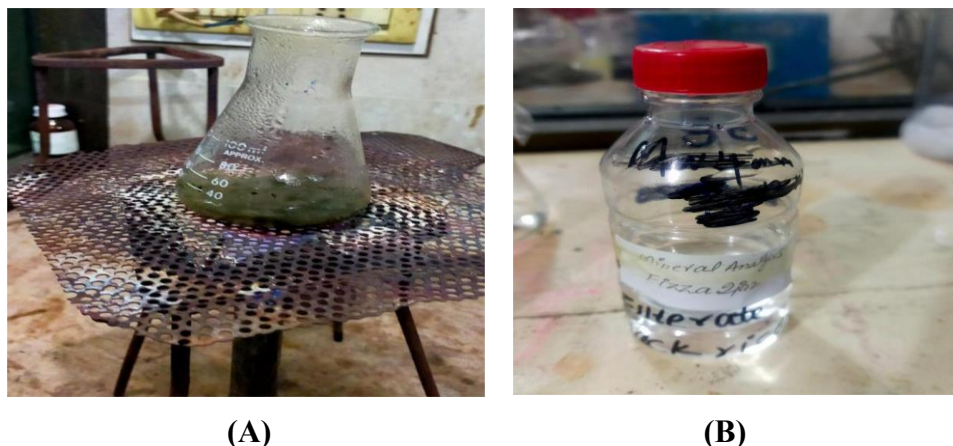


Figure 3.10 (A) Sample preparation for Mineral analysis (B) Filtration

3.3.8 Fourier Transform Infrared (FTIR)

The structural makeup and the existence of functional groups on the surface of biochar were investigated using FTIR spectroscopy (Model Prestige-21 Shimadzu, Japan) [95].

3.3.9 Scanning Electron Microscope (SEM)

Using a Scanning Electron Microscope (JEOL Model JSM-5910 SEM) set to an accelerating voltage of 20 kV, the sample's surface morphology study was done using SEM, and localized carbon content was examined using SEM with EDX capabilities [96].

3.4 Application of Biochar on *S. lycopersicum* L

3.4.1 Experimental Plant

Certified seeds of *S. lycopersicum* (Cherry) were bought from Punjab Seeds Cooperation, Lahore, Pakistan. Then the seeds were soaked in water for 3 days and then cultivated in the field until 2-3 cm long seedling was produced and then shifted into control and experimental plots.

3.4.2 Field Experiment Design

Experimental crop was planted in RCBD at an area of 9 m² (Figure 3.11 A, B). There were seven different treatments (T1-T7), two out of seven were kept as controls, T1 (left untreated) and T2 (treated with 60 g of NPK), while the other five were experimental, treated with biochar and NPK. T3 (5 g biochar+9 g NPK), T4 (7.5 g biochar+9 g NPK),

T5 (10 g biochar+9 g NPK), T6 (12.5 g biochar+9 g NPK), and T7 (15 g biochar+9 g NPK). Nine plants were planted in each treatment, keeping a 0.2 m plant-to-plant distance, and three random plants were selected from each treatment for the collection of data regarding growth and yield. Experimental treatments were applied twice (once at the seedling stage and a second time at flowering) during whole life of the plant.

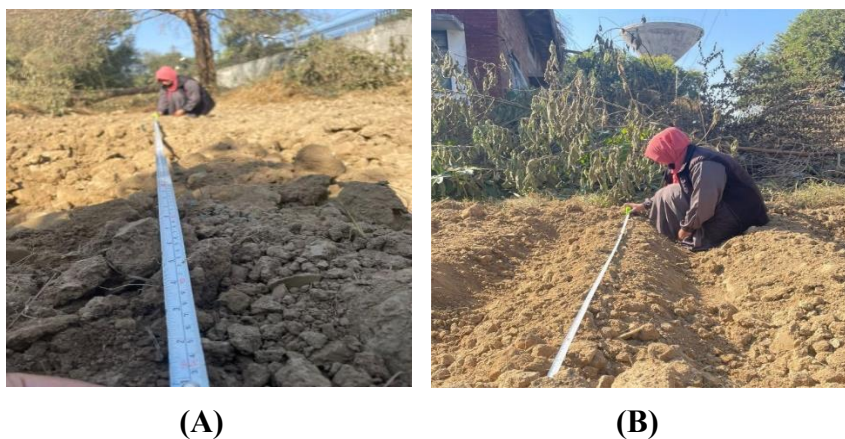


Figure: 3.11 Measurement and Spatial Arrangement of the Experimental Site

3.4.3 Soil Preparation

The soil was collected from the Pakistan Council of Scientific and Industrial Research Institute (PCSIR), Lahore and was dried and passed through 2 mm sieve and the sample from that solution was submitted to the soil and water testing Laboratory Thokar Niaz Beig Lahore for testing while some tests were performed at PCSIR, Lahore.



Figure 3.12 Preparation of the Experimental Site (T1-T7)

3.5 Soil Testing

The collected soil sample was assessed for the assessment of macro-nutrients (N, P, K), soil texture and organic matter, pH, electric conductivity, and soil saturation. Similarly, soil was collected again from the post-treated crop to evaluate the residual effects of the applied biochar on soil properties and nutrient availability.

3.5.1. pH

A soil slurry (1:2) was prepared by mixing 25 g of soil with 50 ml of distilled water and stir vigorously until dissolved completely. Soil was settled down for 30 minutes and filtrated the solution with help of filter paper. Electrodes of pH meter were placed in the slurry, swirl carefully, and the pH value was recorded [97].

3.5.2. Electric conductivity

Slurry of soil (1:5) was prepared by mixing 20 g of soil with 100 ml of distilled water and stirring for one hour and the value of EC was calculated using electrical conductivity meter model (MW805 MAX) [98].

3.5.3 Saturation

50 g of soil was taken and added distilled water until complete saturated with distilled water. The saturated soil was weighted with analytical balance. The saturated soil sample was oven dried at 105 °C for 24 hours. The oven dried soil was weighted [99].

Saturation percentage = $\frac{\text{Saturated soil} - \text{Oven dried soil}}{\text{Oven dried soil}} \times 100$(Eq E)

3.6 Data Collection

Data regarding growth and yield attributes were collected manually after 30,60,90,120, and 150 days of germination (DAG). Plant height was measured with a graduated ruler in centimeters (cm), stem girth was measured by vernier Calipers [4], leaf area was measured in centimeters square (cm²). Numbers of leaves were counted manually [4]. The number of branches, flowers, and fruits were counted manually [4]. Fruit diameters were measured using a vernier caliper. Fruit weight was calculated by using the weighing

balance. Fruit yield was calculated based on the amount of fruit produced per unit area [4].

3.7 Proximate Analysis

Freshly harvested fruits from all the treatments were collected at the maturity stage and the proximate analysis was performed by following the standard protocols already explained in the previous sections, such as ash, moisture, and protein [100]. UV-Vis Spectrophotometry was used to check the lycopene content and ascorbic acid [101,102].

The proximate analysis was estimated by using the following Association of Official Analytical Chemists (AOAC 1990) method.

3.7.1 Fat Analysis

For fat extraction, a separating funnel was used. 5 mL of tomato samples and 10 mL of hexane was added flask was covered and placed in orbit shaker for 24 hours for proper extraction then the solution was transferred in separating funnel to separate the fat layer from the solution Pre weighted china dish was taken to collect fat layer from separating funnel and then placed on hot plate to evaporate all hexane from it (Figure 3.13). It was again allowed to cool down and was weighted again [100].

Loss in weight was calculated.

Loss in weight = wt. of thimbles + de moisture sample - (wt. of thimble-tat free sample)

Weight of sample was calculated by: $[\text{Loss in wt. (g)} / \text{total sample (g)}] 100 \dots \dots \dots (\text{Eq F})$



Figure 3.13 Analysis of fat content of *S. lycopersicum*

3.7.2 Fiber Analysis

Fiber is the loss of ignition of dried residue after the digestion of sample with H_2SO_4 (Sulphuric Acid) and NaOH (Sodium Hydroxide). Sample of 5 mL was taken in a conical flask and 100 mL of 1.25 % H_2SO_4 was added in it. It was cooked on burner for 45 minutes until bubbles were formed (Figure 3.14 A). The sample solution was filtered out with silk cloth by rinsing the flask with 100 mL of distilled water (Figure 3.14 C).

After that, filtrate from silk cloth was added in another flask and was cooked by 1.25 % NaOH for 45 minutes. It was allowed to cool down (Figure 3.13 B) and again filtered with silk cloth by rinsing the flask with 100mL distilled water (Figure 3.14 C). A pre weighed china dish was used to pour out filtrate in it. Now the sample was placed in electrical oven at 100°C for 24 hours for drying and weighed it [100].

Percentage of fiber was calculated as:

Loss in weight = (wt. of china dish with oven dried sample - weight of china dish)

% of fiber = [loss in weight (g)/ wt. of sample (g)] x100.....(Eq G)

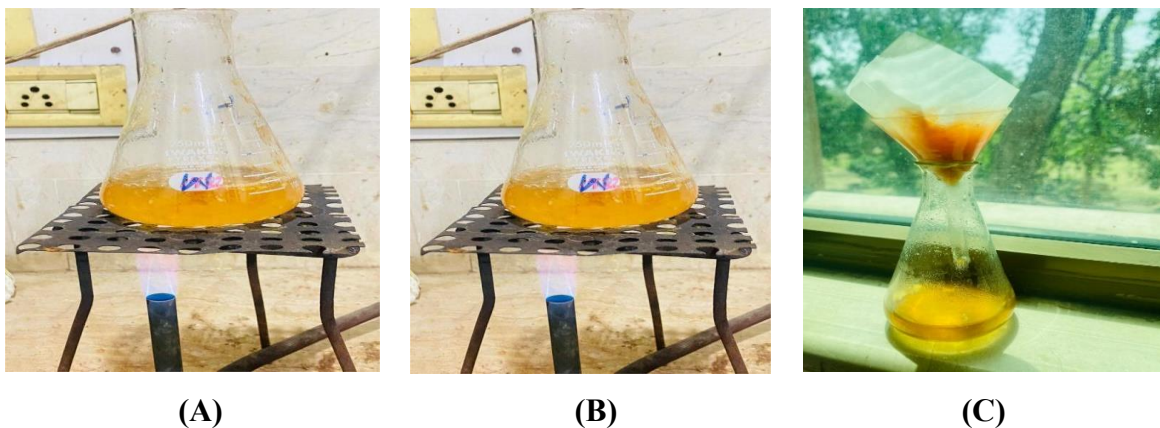


Figure 3.14 Analysis of Fiber content of content of *S. lycopersicum*

(A) heated with acid H_2SO_4 , (B) heated with base NaOH , (C) filtrate

3.7.3 Carbohydrate analysis

Carbohydrate content was calculated after the evaluation of % of moisture, % of ash, %

of fat, % of fiber, and % of protein by using the Carbohydrate formula. The sum of the percentage Moisture, Ash, Crude Lipid, Crude Protein, and Crude Fiber was subtracted from 100 [100].

$$\% \text{ Total Carbohydrate} = 100 - (\% \text{ Moisture} + \% \text{ Ash} + \% \text{ Fat} + \% \text{ Protein} + \% \text{ Fiber} \dots) \text{ (Eq H)}$$

3.8 Lycopene Content Determination

Five grams of tomato puree was weighed (Figure 3.15 A). Acetone was added to the pestle mortar several times until the residue was colorless (Figure 3.15 B). Pour the acetone extract into the separating funnel with 10-15 mL of petroleum ether and stir carefully. Dilute the lower phase of acetone with water to absorb the carotenoid colors in the petroleum ether (Figure 3.15 C). Transfer the petroleum ether extract containing the carotenoid pigments to an amber- coloured bottle and the bottom phase to another separating funnel (Figure 3.15 D). Use petroleum ether to extract the acetone phase once more in a similar manner until it turns colorless. The acetone step was discarded. Add a tiny amount of anhydrous Na_2SO_4 to the petroleum ether extract as a blank, dilute an aliquot to 50 mL, and use the spectrometer to detect the color in a 1 cm cell at 503 nm (Figure 3.15 F).

Calculate the lycopene content of the sample as given below using the relationship that an optical density (OD) of 1.0 = 3.1206 μg of lycopene per mL [101].

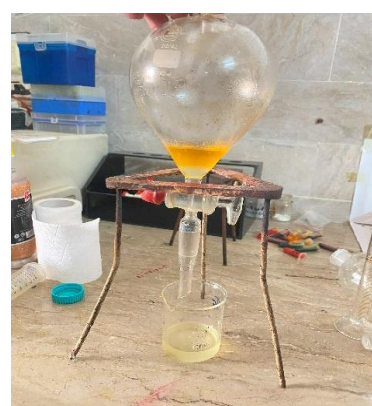
$$\mu\text{g of lycopene per 5g} = \frac{3.1206 \times \text{OD of sample} \times \text{volume made up} \times \text{Dilution}}{1 \times \text{wt of sample} \times 1000} \text{ (Eq I)}$$



(A)



(B)



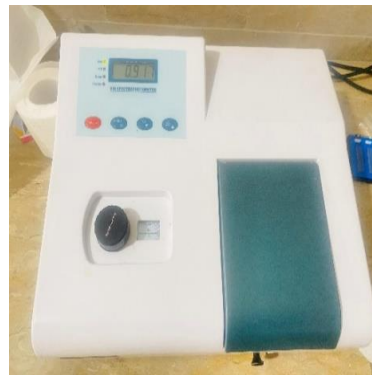
(C)



(D)



(E)



(F)

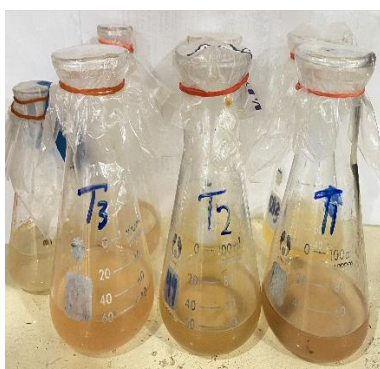
Figure 3.15 Crushing the samples, (A) extraction with acetone, (B) separating the upper phase from the lower phase, (C) collecting the upper phase, (D) preparing dilutions, (E) spectroscopy, (F).

3.9 Ascorbic Acid (Vitamin C)

For the estimation of Ascorbic acid, a 5g sample was mixed with 50 mL of EDTA-oxalic acid solution and shaken for 3 hours. The extract was then treated with 1 M 5 % H_2SO_4 , 0.5 mL of metaphosphoric acid, and 2 mL of 5% ammonium molybdate solution (Figure 3.16 A). After standing for 15 minutes to allow color development, to clarify the solution, distilled water was added until the level reached 25 mL (Figure 3.16 B). The absorbance was then measured at 760 nm (Figure 3.16 C) [101].



(A)



(B)



(C)

Figure 3.16 Determination of Ascorbic acid content of *S. lycopersicum*

3.10 Antioxidant activity

3.10.1 DPPH Analysis

1mL of extract was mixed with 1 mL of 1 mM 2, 2-diphenyl-1- picrylhydrazyl radical solution. The test tubes were wrapped in aluminum foil and set aside for 30 minutes in the dark (Figure 3.17). A double-beam spectrophotometer was used to measure the color intensity (optical density) of each solution at 517 nm. Similarly, a blank solution was made for the test sample. The equation was used to calculate the percentage of DPPH inhibition [101].

$$\% \text{ DPPH inhibition} = (A_c - A_s / A_c) 100 \dots \dots \dots (\text{Eq J})$$

Where A_c is the absorption of methanol and DPPH, A_s is the absorption of the sample and DPPH

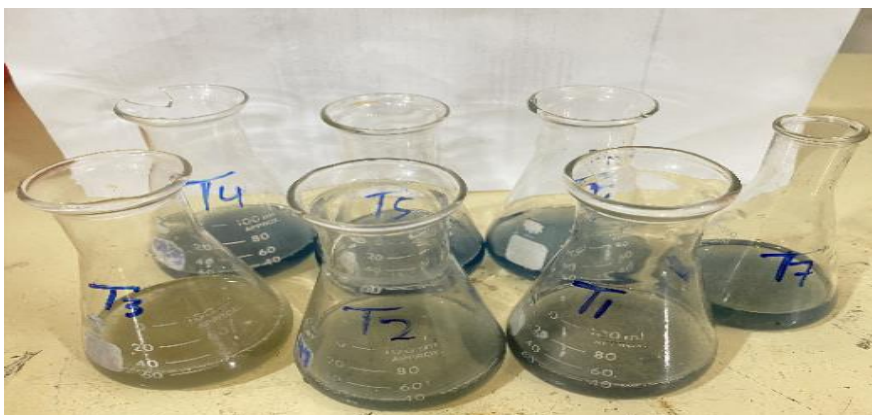


Figure 3.17 Determination of Flavonoid content of *S. lycopersicum*

3.10.2 Phenolic Analysis

1.25 mL plant extract was mixed with 1.25 mL of Folin-Ciocalteu reagent and 1.25 mL of 7 % Na_2CO_3 , and the volume was adjusted to 3 mL with distilled water (Figure 3.18). After incubation in the dark for 90 minutes, the absorbance at 760 nm was measured [101].



Figure 3.18 Determination of Phenolic content of *S. lycopersicum*

3.11 Chlorophyll Content Analysis (mg/g)

For the determination of chlorophyll of each sample, the protocol of Evensen with a few modifications was followed [102]. Furthermore, 1 gram of leave sample was weighed and ground with a pestle and mortar, made a 10-12 mL solution of hexane and acetone (6:4), the solution was shaken on a magnetic stirrer for 2 hours, and then filtered with a Whattam filter paper. The solution was diluted with a solvent mixture (hexane and acetone) (Figure 3.19), then the optical density of the supernatant was recorded at 663 and 645 nm. The results were calculated by the following equations [102].

$$\text{Chlorophyll A (mg/100 ml)} = 0.999 A_{663} - 0.0989 A_{645}$$

$$\text{Chlorophyll B (mg/100 ml)} = 0.999 A_{663} + 0.0989 A_{645} \dots\dots\dots (\text{Eq K})$$



Figure 3.19 Determination of lycopene content of *S. lycopersicum*

3.12 Statistical Analysis

Analysis of variance ANOVA (Statistix 8.1) was used to examine data about growth and yield variables, and the means of calculated values were compared based on the least significant difference (LSD) test at the 0.05 probability level. To visualize the data, graphs were created of the results 8.2.

CHAPTER 4

RESULTS

4.1 Synthesis of Biochar from Rice Husk

Biochar was successfully synthesized using rice husk as raw material through pyrolysis. The process was carried out under limited oxygen conditions at a temperature suitable for carbonization, resulting in a fine, porous, granular, and powdery material with a grey color. The final product had no smell, and the production of biochar was satisfactory. The synthesis process proved efficient and environmentally friendly, offering a sustainable way to convert waste into a valuable soil amendment (Table 4.1).

4.2 Characterization of Biochar

The size, texture, and potential functional qualities of the produced biochar were assessed. The pH values of both (RHF and RHB) were assessed. pH value was recorded higher in rice husk biochar (8.7) % as compared to rice husk feedstock (6.85) %, as illustrated in Table 4.1. The recorded water holding capacity was higher in RHB (5) mL compared to RHF (3) mL (Table 4.1). The EC was recorded higher 602 in RHB (dS/m^{-1}) as compared to RHF 567 (dS/m^{-1}) (Table 4.1). The protein content of both (RHF and RHB) was evaluated. The protein content, which is directly related to total nitrogen, was significantly higher in RHB (1.9) % compared to RHF (0.28) %. Phosphorus content was recorded as higher in RHF (0.13) % compared to RHB (0.039) %. The recorded potassium content was slightly higher in RHF (211) mg/Kg as compared to RHB (205) mg/ Kg. Moisture content was recorded higher in rice husk biochar (0.645) % as compared to rice husk feedstock (0.27) %, as illustrated in Table 4.1. Compared to rice husk feedstock (4.98) %, rice husk biochar (5.85) % had a greater ash content (Table 4.1). Compared to rice husk feedstock (4.98) %, rice husk biochar (5.85) % had a greater ash content (Table 4.1).

Table 4.1 Characterization of Biochar

Sr No	Parameters	RHF	RHB
1	pH	6.85	8.7
2	Water holding capacity (%)	3	5
3	EC (dSm ⁻¹)	567	602
4	Moisture content (%)	0.27	0.645
5	Ash content (%)	4.98	5.85
6	Total Nitrogen content (%)	0.28	1.9
7	Phosphorus (%)	0.13	0.039
8	Potassium (%)	211	205
9	Total C (%)	33	60.8

where, %: Percentage; EC: Electrical Conductivity; mg: milligram; kg: kilogram; dS/m⁻¹

4.2.1 FTIR

FTIR identifies functional groups present in biochar, affecting their adsorption capacity, reactivity, and interaction with soil nutrients. The analysis revealed several key functional groups in the biochar sample. These peaks at 1628.8 cm⁻¹ and 1539.4 cm⁻¹ are attributed to the C=C stretching vibrations, which are typically observed in alkenes or aromatic rings. The presence of these bands indicates the existence of unsaturated carbon-carbon bonds, likely due to conjugated or aromatic systems within the molecular structure. The peaks at 1397.8 cm⁻¹, 1315.8 cm⁻¹, and 1043.7 cm⁻¹ correspond to the C-F stretching vibrations, suggesting the presence of fluorinated functional groups in the sample. The multiple C-F stretch peaks at different wavenumbers may result from different chemical environments or degrees of substitution within the fluorinated moieties.

Table 4.2 FTIR Peaks of experimental biochar

FTIR	
Peaks	Functional groups
1628.8	C=C Stretch
1539.4	C=C Stretch
1397.8	C-F stretch
1315.8	C-F stretch
1043.7	C-F stretch

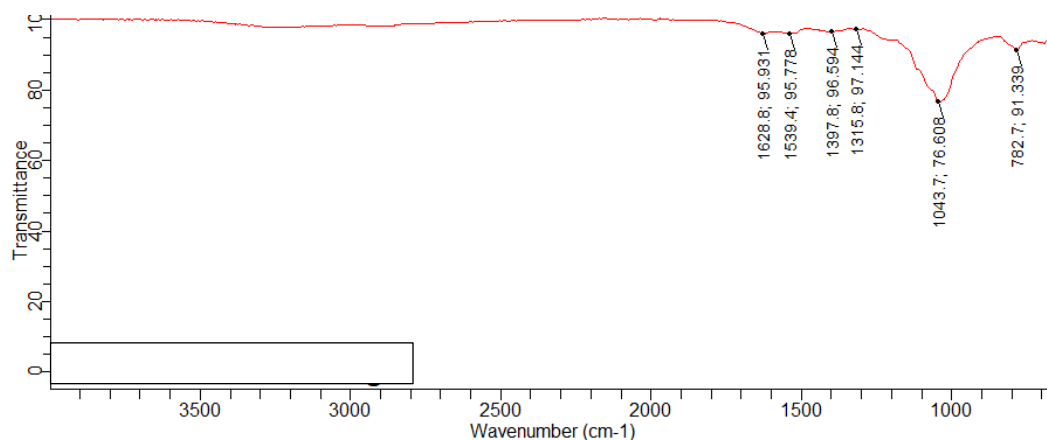


Figure 4.1 FTIR Analysis of Experimental Biochar

4.2.2 Scanning Electron Microscope (SEM) Analysis

At very high magnification, the surface appears rough, highly irregular, and composed of agglomerated fine particles. Some spherical particles are embedded within flake-like structures, suggesting partial porosity development. This indicates the presence of high surface roughness and potential microporosity, which are desirable properties for enhancing the material's surface area, especially in applications such as adsorption or soil amendment. This morphology suggested that the particles of biochar were highly porous and rough (Figure 4.3 A) at a magnification of 50,000x with a scale of 1 μm . Photographs taken at 25,000x magnification and a scale of 2 μm reveal densely packed, irregularly shaped particles. Some regions display sheet-like, layered structures that are carbonaceous in appearance, indicating a heterogeneous surface morphology. The presence of such layered structures suggests a stable carbon framework and points to the material's structural integrity and potential for nutrient retention and gradual release in agricultural applications (Figure 4.3 B). However, particles viewed at 10,000x magnification, scale: 5 μm , the SEM micrograph reveals larger particle aggregates with a broad size distribution. While the overall texture appears compact, visible porosity is still retained. This balance of compactness with porosity indicates the formation of a continuous network structure, which can enhance both mechanical strength and permeability, making the material suitable for soil conditioning and water retention (Figure 4.3 C). At 1,000x magnification, scale: 50 μm , highlights a structure with fused particles, micro-cracks, and interconnected cavities. The interconnected porous network

is visible, contributing to enhanced capillarity and air-water balance, which are critical in plant root respiration and nutrient absorption. The material's spongy and rough texture further supports its suitability in agricultural soil amendments or environmental remediation (Figure 4.3 D). While photographs taken at a magnification of 100,000x and a scale of 500 μm , the particles appear to be in the submicron range. The surface is comparatively smooth, suggesting that the biochar particles are highly refined and potentially stable. Such morphology is indicative of high-purity material, which is advantageous in high-precision applications, such as catalysis or nano-composites (Figure 4.3 E). Photograph captured at 5,000x magnification with a scale of 10 μm , displays partially fractured, porous particles with visible macrovoids and open pores. The morphology reflects good structural rigidity combined with accessible porosity, making it suitable for slow-release fertilizers or carrier systems for beneficial microbes in sustainable agriculture. The roughness and open architecture may also aid in the adsorption of heavy metals or organic pollutants in environmental clean-up efforts (Figure 4.3 F).

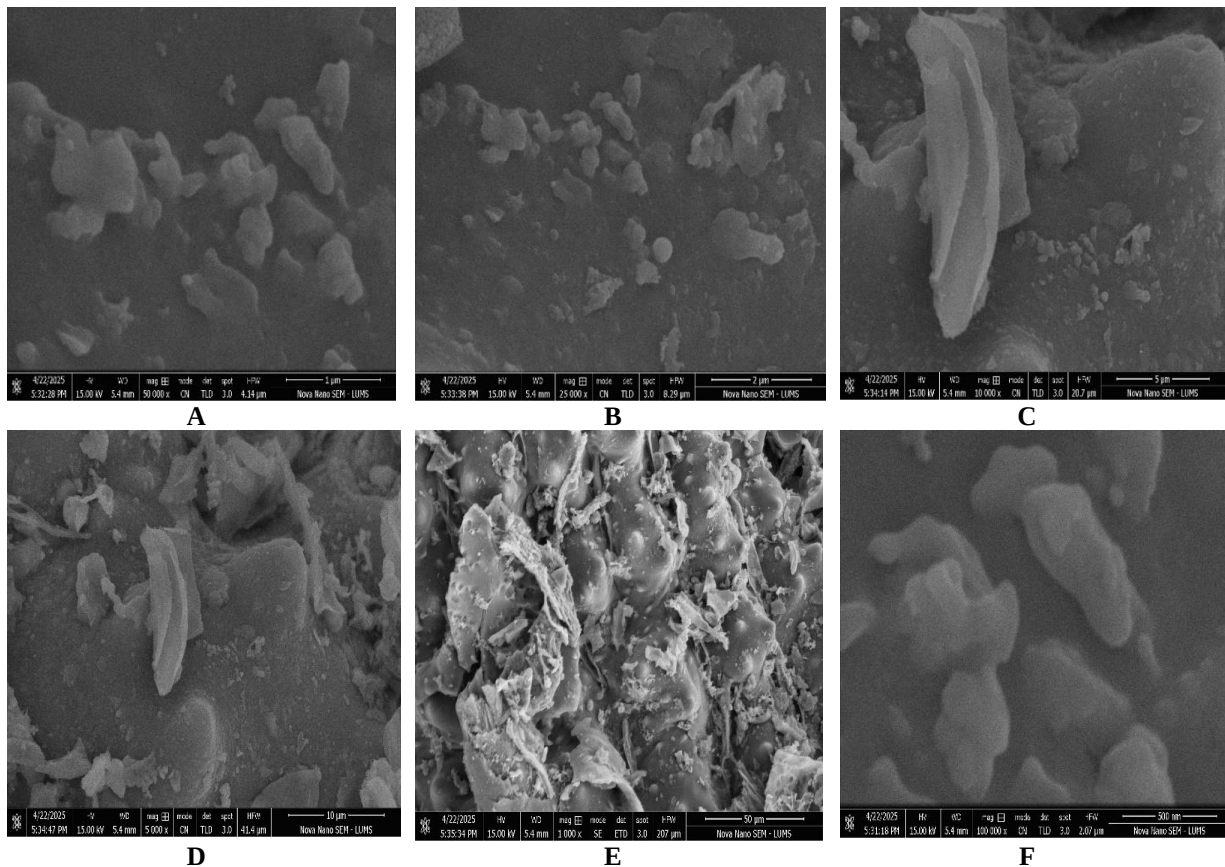


Figure 4.2 SEM analysis of experimental Biochar assessed at various magnifications such as 1, 2, 5, 10, and 50 μm and 500 nm (A-F).

4.3 Soil analysis of experimental field

The pH of the field experimental soil was 7.6 %, which is within the acceptable range of typical soils (7.0-8.0), and the texture was loam. The Soil sample had a saturation level of 36 % aligned near the acceptable range of regular soil (7.0-8.0). However, the moisture content at 1.39 % was significantly below the optimal range of 20-40 %; further, the ash content was 7.2 % greater than the ideal range of 2-5 % (Table 4.2). The nitrogen content of the soil sample was 0.96 % within the normal range of 0.01-0.04 %, and the amount of potassium was recorded at 232 mg/kg within the normal range of 43-278 mg/kg. Additionally, the phosphorus level of the soil was 7.1% higher than the average value (0.01-0.04) %. The bulk density was measured at 1000 kg/m³, which was lower than the normal range (1300-1400 kg/m³).

Table 4.3 Physicochemical properties of pre-soil collected from the experimental field

Sr. No	Properties	Soil
1	Moisture content (%)	1.39
2	Ash content (%)	7.2
3	pH	7.6
4	Total N (mg/kg)	0.96
5	Total P (mg/kg)	7.1
6	Total K (mg/kg)	232
7	EC mScm-1	324
8	Saturation (%)	36
9	Texture	Loam
10	Bulk density (g/cm ³)	1000

Where E.C = Electrical Conductance, % = percentage, mg/kg = milligram per kilogram, mScm-1 = miliSiemens per meter

Table 4.3.1 Post-Soil Analysis

Treatment	Moisture (%)	EC (dS/m)	pH	Organic Matter (%)	Phosphorus (mg/kg)	Potassium (mg/kg)	Saturation (%)	Texture
T1	1.42	2.90	8.2	0.21	13.6	216	36	Clay loam
T2	1.54	2.76	8.2	0.35	11.1	111	32	Clay loam
T3	1.501	3.17	8.4	0.21	9.0	99	34	Loam
T4	1.611	2.73	8.5	0.07	6.6	62	38	Clay loam
T5	1.520	3.75	8.4	0.49	8.4	105	44	Clay loam
T6	1.510	1.29	8.1	0.35	13.7	73	32	Clay loam
T7	1.59	2.29	8.4	0.23	2.20	56	40	Clay loam

Where, %: Percentage; EC: Electrical Conductivity; mg: milligram; kg: kilogram; dS/m¹

4.4 Growth attributes

Data regarding plant height (cm) was recorded two weeks after each application of treatments.

4.4.1 Plant Height

The results showed that plant height varied across treatments at different stages of growth, measured in days after germination (DAG). At 30 DAG, a statistically significant difference was observed among the treatments ($P = 0.0113$). The tallest plants were recorded in T7 ($28 \pm 4.041a$ cm) and T6 ($27 \pm 2.516ab$ cm), while the shortest were in T1 and T5 ($17 \pm 2.082c$ and $17 \pm 0.577c$ cm, respectively). This suggests that treatments T6 and T7 provided favorable early growth conditions, possibly due to better nutrient availability or enhanced seedling vigor. At 60 DAG, although T4 ($44 \pm 4.509a$ cm) showed the highest plant height and T1 ($33 \pm 1.732c$ cm) the lowest, the difference was statistically non-significant ($P = 0.1143$), indicating a relatively uniform growth phase across treatments, likely due to plant acclimatization and similar nutrient uptake during this period. By 90 DAG, the treatments showed highly significant differences in plant height ($P = 0.0005$),

with T4 ($74 \pm 4.582a$ cm) and T3 ($71 \pm 1.527ab$ cm) showing the greatest growth, while T1 ($55 \pm 6.027d$ cm) remained the lowest. These results reflect a stronger vegetative response in T3 and T4, likely due to improved nutrient uptake and physiological activity at this mid-growth stage. At 120 DAG, the difference among treatments was marginally significant ($P = 0.0531$). T4 ($107 \pm 2.516a$ cm), T5 ($105 \pm 8.386a$ cm), and T6 ($106 \pm 3.511a$ cm) recorded the highest plant heights, whereas T1 again showed the least growth ($72 \pm 7.505b$ cm). this stage marks the transition to reproductive growth, where nutrient-rich treatments appeared to support continued elongation and biomass accumulation. At 150 DAG, plant height differences were not statistically significant ($P = 0.1925$), although T4 ($115 \pm 7.637a$ cm), T5 ($114 \pm 7.211a$ cm), and T6 ($113 \pm 3.6055a$ cm) continued to exhibit higher plant heights compared to T1 ($78 \pm 8b$ cm). Despite the lack of statistical significance, the sustained growth in T4, T5, and T6 indicates the prolonged beneficial effects of these treatments throughout the crop cycle. It had been concluded that rice husk biochar, particularly in T4, significantly enhances tomato productivity. Overall, T4 consistently resulted in the tallest plant at most stages, highlighting its effectiveness in promoting growth. The control treatment (T1) consistently resulted in the shortest plants, suggesting limited nutrient support or suboptimal growth conditions. These findings underscore the importance of treatment selection in enhancing plant height and overall growth performance.



30 DAG



60 DAG



90 DAG



120 DAG



150 DAG

Figure 4.3 Plant Height of *Solanum lycopersicum* L.

Table 4.4 Effect of treatments (T1-T7) on plant height

Treatments	Plant height 30days(cm)	Plant height 60days(cm)	Plant height 90days(cm)	Plant height 120days(cm)	Plant height 150days(cm)
T1	17±2.082	33±1.732	55±6.027	72±7.505	78±8
T2	22±2.516	38±7.767	67±1.527	80±9.165	84±3.785
T3	21± 5.773	40±1.732	71±1.527	101±1.527	112±10.408
T4	26± 4.041	44±4.509	74± 4.582	107±2.516	115±7.637
T5	17± 0.577	41±2.645	68±1.527	105±8.386	114±7.211
T6	27±2.516	42±3.464	68±2.645	106±3.511	113±3.6055
T7	28±4.041	35±5.507	64±0.577	99±0.577	108±2.886
Max Value	28.3	44.6	74	107.3	151.6
Mini Value	17.3	35.3	64.6	99.6	108.3
% for C1	37	26	24	32	48
% for C2	21	13	9	25	44
P Value	0.0113 S	0.1143 NS	0.0005 S	0.0531 S	0.1925 NS
CV	6.4902	8.261	5.7624	9.9037	8.8241

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

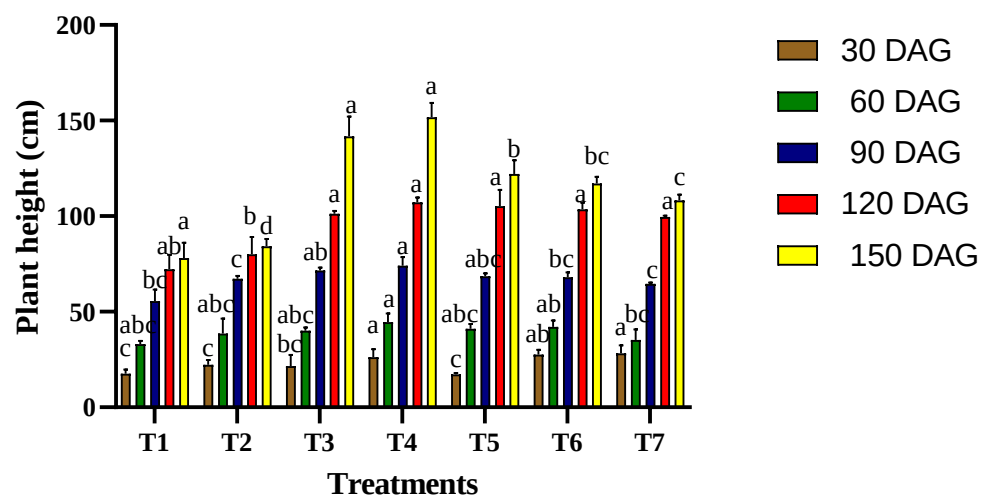


Figure 4.4 Plant height (cm) after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.2 Number of Leaves

The number of leaves per plant was significantly influenced by different treatments at several growth stages, measured in days after germination (DAG). At 30 DAG, the difference among treatments was statistically significant ($P=0.0767$), where T4 ($14\pm8.082a$) produced the highest number of leaves, followed by T3 ($12.667\pm2.645b$), while the lowest number was observed in T7 ($10\pm6.429f$) and T6 ($10.667\pm10.969e$). This early variation suggests that T4 supported better initial vegetative growth, possibly due to improved nutrient availability or enhanced photosynthetic activity. At 60 DAG, although T4 ($27\pm6.429a$) maintained a slight advantage in leaf number, the differences among treatments were statistically non-significant ($P=0.6686$). This indicates a phase of uniform leaf development likely due to stabilization in environmental or physiological condition by 90 DAG, a highly significant difference was observed ($P=0.0015$). T4 again recorded the highest number of leaves ($207.33\pm21a$), followed by T5 and T3, while T1 ($105\pm8.083d$) and T7 ($135.33\pm1.154d$) had the fewest. This suggests that T4 consistently enhanced vegetative growth, possibly through improved uptake of macronutrients essential for leaf formation. At DAG, differences in leaf numbers were again statistically

significant ($P=0$), with T4 ($259\pm259a$) clearly outperforming all other treatments. Treatments T1 ($158.67\pm158.66d$) and T7 ($160.67\pm160.66c$) exhibited the lowest leaf counts. The results emphasize the sustained effect of T4 in promoting robust vegetative development throughout the growth cycle. At 150 DAG, significant differences persisted ($P=0.0004$), where T4 maintained the highest leaf number ($320.33\pm44.162a$), indicating strong foliage retention and continued vegetative vigor. In contrast, T1 ($209.67\pm9.504e$) showed the least number of leaves, reflecting weaker long-term growth. It had been concluded that rice husk biochar, particularly in T4, consistently exhibited the highest number of leaves at all stages, indicating its superior vegetative growth potential compared to the other treatments. This could be attributed to improved soil conditions, better moisture retention, or nutrient-enriched treatment composition. On the other hand, T1 and T7 repeatedly showed poor performance, indicating suboptimal growth conditions or limited nutrient support. (Table 4.4).

Table 4.5 Effect of treatments (T1-T7) on number of leaves

Treatments	No. of leaves per plant 30days	No. of leaves per plant 60days	No. of Leave per plant 90days	No. of leaves per plant 120days	No. of leaves per plant 150days
T1	$11.333\pm0.577f$	$26.333\pm5f$	$105\pm8.083d$	$158.67\pm158.66d$	$209.67\pm9.504e$
T2	$11\pm3.214c$	$25.667\pm10.408de$	$133.33\pm8.083c$	$171.33\pm171.33b$	$283\pm14.731b$
T3	$12.667\pm2.645b$	$27\pm18.037bc$	$148.67\pm14.011c$	$185.67\pm185.66b$	$25.027ab$
T4	$14\pm8.082a$	$27\pm6.429a$	$207.33\pm21a$	$259\pm259a$	$320.33\pm44.162a$
T5	$12\pm11.532d$	$25.333\pm25.514b$	$155\pm23.066b$	$192\pm192b$	$269\pm3.606b$
T6	$10.667\pm10.969e$	$26.667\pm23.515cd$	$116\pm2.01b$	$177.33\pm177.33b$	$276.67\pm2.087c$
T7	$10\pm6.429f$	$24\pm31.069ef$	$135.33\pm1.154d$	$160.67\pm160.66c$	$260.67\pm1.155d$
Max Value	14	58.6	207.3	259	320.3
Mini Value	10	26.6	116	160.6	260.6
% for C1	19	55	49	38	34
% for C2	21	56	35	33	11
P Value	0.0767 S	0.6686 NS	0.0015 S	0 S	0.0004 S
CV	2.5848	4.0654	37.026	26.126	31.292

Where mean values were separated ($P=0.05$) and represented in the table along with $\pm$ standard error.

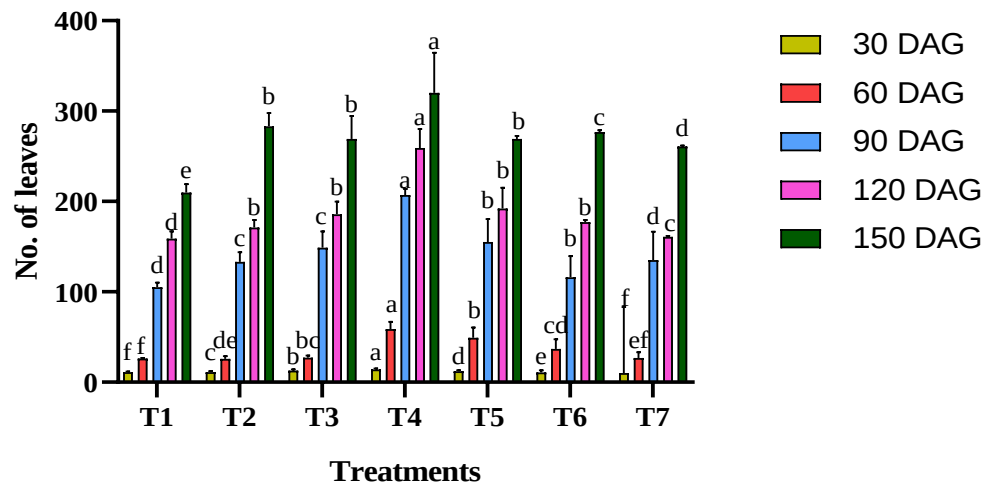


Figure 4.5 Number of leaves after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.3 Number of branches per plant

The number of branches per plant was significantly influenced by the different treatments across most stages of growth, measured in days after germination (DAG). At 30 DAG, a highly significant difference ($P = 0.0001$) was observed among treatments. The maximum number of branches was recorded in T4 ($12.333 \pm 1.154a$), followed by T6 ($11.667 \pm 0.577ab$) and T5 ($11 \pm 1abc$), indicating their superior early vegetative branching potential. In contrast, the lowest branching was seen in T1 ($7.667 \pm 0.577e$), suggesting limited initial growth and vigor under this treatment. At 60 DAG, significant differences persisted ($P = 0.0051$) with T4 ($19 \pm 1a$) again outperforming others.

Treatments T2 and T5 also showed relatively higher branch numbers, while T1 remained the least productive ($14.667 \pm 0.577c$). These findings indicate that T4 consistently promotes early-stage vegetative development, possibly due to improved nutrient uptake and hormonal stimulation, enhancing lateral bud formation. By 90 DAG, no statistically significant difference was observed ($P = 0.9843$). However, numerically, T4 ($24.667 \pm 1.527a$) maintained the lead, followed closely by T6 and T7, implying a continued influence of favorable treatment effects. Significant differences re-emerged at

120 DAG ($P=0.0003$), with T4 ($48.333\pm2.887a$), T6 ($47.667\pm2.082a$), and T5 ($46.667\pm2.095a$) producing the highest number of branches. This trend continued through 150 DAG, where T4 sustained the highest value ($48.333\pm2.886a$), and T1 remained the lowest ($27.333\pm2.081b$). It had been concluded that rice husk biochar, particularly in T4, Overall, exhibited the highest number of branches throughout the growth period, suggesting superior branching capacity. The consistent performance of T4 can be attributed to optimal nutrient availability or growth-promoting components within the treatment. T1 consistently recorded the fewest branches, indicating comparatively weaker vegetative development.

Table 4.6 Effect of treatments (T1-T7) on number of branches

Treatments	No. of branches per plant 30days	No. of branches per plant 60days	No. of branches per plant 90days	No. of branches per plant 120days	No. of branches per plant 150days
T1	$7.667\pm0.577e$	$14.667\pm0.577c$	$19.667\pm0.577b$	$27.333\pm2.081b$	$27.333\pm2.081b$
T2	$8.667\pm0.577de$	$18\pm1.732a$	$21.333\pm0.577ab$	$43.333\pm2.081a$	$43.333\pm2.081a$
T3	$10.333\pm0.577bc$	$17.667\pm0.577a$	$22.333\pm0.577ab$	$46.333\pm3.785a$	$46.333\pm3.785a$
T4	$12.333\pm1.154a$	$19\pm1a$	$24.667\pm1.527a$	$48.333\pm2.887a$	$48.333\pm2.886a$
T5	$11\pm1abc$	$18.667\pm0.577a$	$23\pm1ab$	$46.667\pm2.085a$	$46.667\pm2.081a$
T6	$11.667\pm0.577ab$	$17.333\pm1.527ab$	$23.667\pm2.081ab$	$47.667\pm2.082a$	$47.667\pm2.082a$
T7	$9.667\pm1.154cd$	$15.333\pm1.527bc$	$23.667\pm4.725a$	$46.333\pm8.504a$	$46.333\pm8.504a$
Max Value	12.3	19	24.6	48.3	48.3
Mini Value	9.6	15.3	22.3	46.3	46.3
% for C1	37	22	20	43	43
% for C2	29	5	13	10	10.
P Value	0.0001 S	0.0051 S	0.9843 NS	0.0003 S	0.0003 S
CV	1.3907	2.1145	3.9463	7.0164	7.0164

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

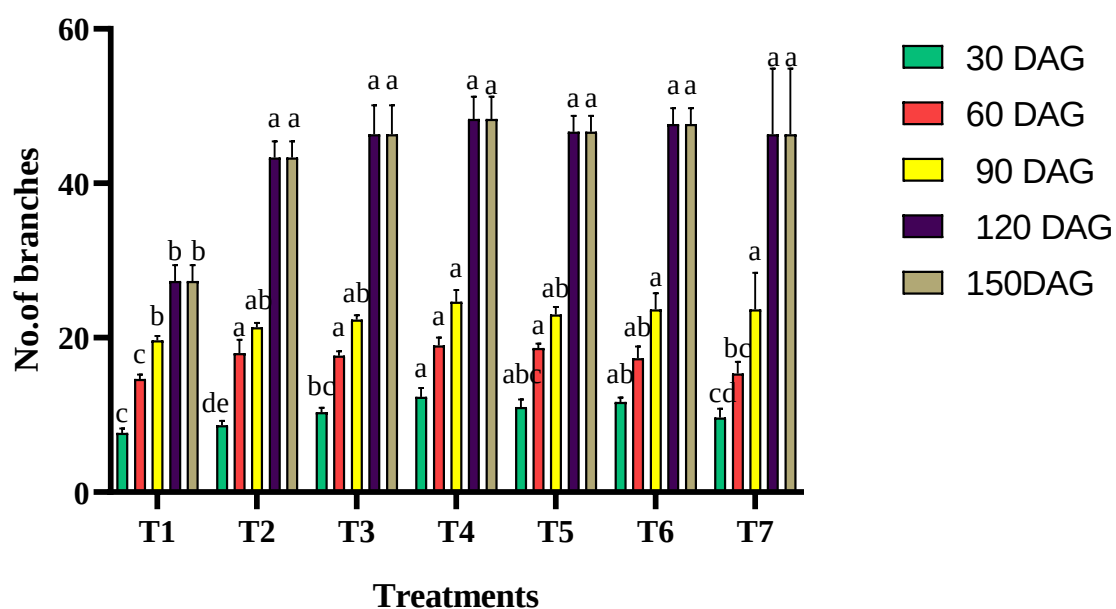


Figure 4.6 Number of branches after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.5 Stem Girth

At 30 days, there was no statistically significant difference among treatments ($P = 0.1502$). This suggests that the early-stage growth was not markedly influenced by the applied treatments, possibly due to limited root establishment or initial slow nutrient uptake. From 60 days onwards, the differences became statistically significant ($P \leq 0.05$). At 60 days, T4 showed the highest stem girth (7.33 ± 8.08 mm), significantly greater than T1 (5 ± 0.557 mm). Treatments T4, T5, and T7 generally showed superior performance compared to others, suggesting that these treatments may have provided more favorable conditions for stem development, potentially through improved nutrient availability or water retention. By 90 to 150 days, this trend increased. T4 and T5 consistently recorded the largest stem girths, with T4 reaching 20.67 ± 44.16 mm and T5 reaching 20.33 ± 3.605 mm at 150 days, significantly higher than the control (T1: 12 ± 9.504 mm). The results imply that treatments T4 and T5 had a sustained positive effect on stem girth expansion. In contrast, T1 maintained the lowest values throughout the growth periods, indicating

that the absence of treatment limited stem development. It had been concluded that rice husk biochar, particularly in T4, consistently showed the highest stem girth across all growth stages, indicating robust stem development, while T1 consistently exhibited the least stem thickening, reflecting comparatively weaker structural growth.

Table 4.7 Effect of treatments (T1-T7) on stem girth

Treatments	Stem girth(mm) 30 days	Stem girth(mm) 60 days	Stem girth(mm) 90 days	Stem girth(mm) 120 days	Stem girth(mm) 150 days
T1	1.3333±0.577b	5±0.577d	10±5d	12±8.082d	12±9.504d
T2	1.5±1b	5.3333±3.214cd	10.408cd	14.667±8.082c	14.667±14.731c
T3	2.6667±1.527ab	6.6667±2.645bcd	14±18.037b	19±14.011ab	19±25.027ab
T4	3±1a	7.3333±8.082a	16.333±6.429a	20.667±21a	20.667±44.162a
T5	2.3333±1ab	6±11.532bcd	16.667±25.514a	20.333±23.065a	20.333±3.605a
T6	2.3333±2.516ab	6.3333±10.969abc	12.667±23.515bc	17.333±2.081b	17.333±2.081b
T7	2.6667±78.329ab	7±6.429ab	12.333±31.069bc	17±1.154b	17±1.154b
Max Value	3	7.3	16.6	20.6	20.6
Mini Value	2.3	6	12.3	17	17
% for C1	55	31	40	41	41
% for C2	50	27	30	29	29
P Value	0.1502 NS	0.0197 S	0.0000 S	0.0000 S	0.0000 S
CV	34.00	11.86	8.02	6.99	6.99

Where mean values were separated (P = 0.05) and represented in the table along with ± standard error.

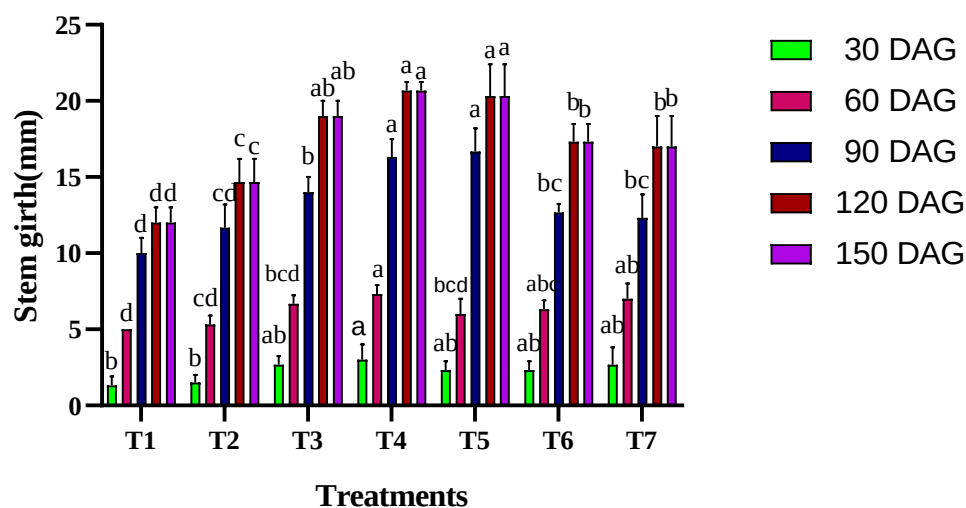


Figure 4.7 Stem girth after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.6 Leaf Area

At 30 DAG, although the P value (0.0767) indicated a statistically significant difference at the 10 % level, the variations among treatments were relatively small. T4 exhibited the largest mean leaf area ($14 \pm 8.082 \text{ cm}^2$), while T7 recorded the lowest ($10 \pm 6.429 \text{ cm}^2$). These early differences suggest that T4 may have positively influenced initial vegetative growth, possibly by enhancing early nutrient availability or root development. At 60 DAG, there was no statistically significant difference among treatments ($P = 0.6686$, NS), indicating a uniform leaf area expression during this period. This could be due to similar growth conditions during the mid-vegetative stage, where differences in treatment effects were not yet strongly expressed. However, from 90 DAG onwards, the treatments had a statistically significant impact on leaf area ($P \leq 0.05$). At 90 days, T4 again showed the highest leaf area ($207.33 \pm 21 \text{ cm}^2$), significantly outperforming all other treatments, while T1 (control) remained the lowest ($105 \pm 8.083 \text{ cm}^2$). This suggests that the effect of treatment T4 was cumulative, likely due to sustained nutrient release or better soil conditioning. At 120 and 150 DAG, the difference became more pronounced. T4 recorded the highest leaf area at both stages (259 ± 259 and $320.33 \pm 44.162 \text{ cm}^2$, respectively),

followed by T5 and T2. These results reflect the superior long-term efficacy of T4 in promoting vegetative growth. In contrast, T1 consistently lagged, indicating that the control treatment was insufficient to support maximal leaf development.

Table 4.8 Effect of treatments (T1-T7) on leaf area

Treatments	Leave area 30days	Leave area 60days	Leave area 90 days	Leave area 120days	Leave area 150days
T1	11.333±0.577f	26.333±5f	105±8.083d	158.67±158.66d	209.67±9.504e
T2	11±3.214c	25.667±10.408de	133.33±8.083c	171.33±171.33b	283±14.731b
T3	12.667±2.645b	27±18.037bc	148.67±14.011c	185.67±185.66b	25.027ab
T4	14±8.082a	27±6.429a	207.33±21a	259±259a	320.33±44.162a
T5	12±11.532d	25.333±25.514b	155±23.066b	192±192b	269±3.606b
T6	10.667±10.969e	26.667±23.515cd	116±2.01b	177.33±177.33b	276.67±2.087c
T7	10±6.429f	24±31.069ef	135.33±1.154d	160.67±160.66c	260.67±1.155d
Max Value	2.16	2.97	3.69	4.93	6.06
Mini Value	1.01	2.08	2.92	3.53	4.62
% for C1	53.38	34.13	20.84	35.78	29.41
% for C2	20.30	24.10	14.80	8.03	7.20
P Value	0.0767 S	0.6686 NS	0.0015 S	0 S	0.0004 S
CV	2.5848	4.0654	37.026	26.126	31.292

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

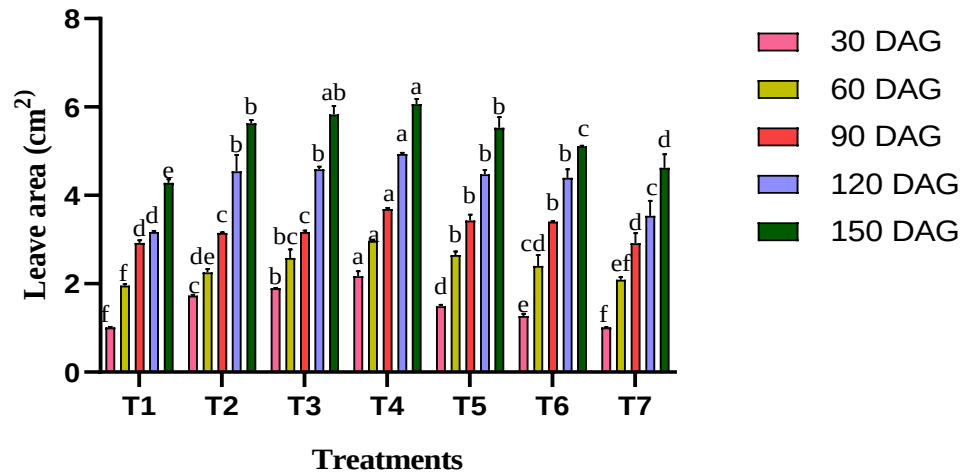


Figure 4.8 Leaf area after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean $\pm$ standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.7 Number of Flowers

At 30 and 60 DAG, no statistically significant differences were observed among treatments ($p=0.4961$ and 0.3797 , respectively). All treatments produced relatively lower flower production at these early stages. T1 recorded 7.67 and 35.67 flowers at 30 and 60 days, respectively, while T4 recorded 10 and 52.67 flowers, the highest among all the treatments at these stages. At 90 DAG, significant differences appeared ($P = 0.000$). T4 produced the highest number of flowers (99 ± 1), followed by T5 and T2 (both 85.33). T1 produced the lowest (65 ± 5.296), indicating that treatments began to show distinct effects on flowering at this stage. At 120 DAG, the number of flowers continued to differ significantly among treatments ($P = 0.000$). T4 again showed the maximum number (170 ± 2), while T1 remained the lowest (94 ± 5). Treatments T1, T2, and T5 ranged between 111.67 to 158.67, indicating moderate improvement over the control. At 150 DAG, T4 recorded the highest flower count (314.33 ± 12.89), followed by T5 (239.67 ± 34.645) and T2 (193.33 ± 4.932). the control T1 remained the lowest at 151.67 ± 27.537 . It had been concluded that rice husk biochar, particularly, Overall, T4 emerged as the most floriferous treatment, maintaining the highest flower count at every interval beyond 30 DAG. In contrast, T1 and T7 consistently demonstrated reduced floral output, indicating comparatively lower reproductive vigor.

Table 4.9 Effect of treatments (T1-T7) on the number of flowers

Treatments	No. of flowers 30days	No. of flowers 60days	No. of flowers 90days	No. of flowers 120days	No. of flowers 150days
T1	7.667±2.517f	35.667±3.055f	65±5.296d	94±5d	151.67±27.537e
T2	7.333±4.415c	49±5.033de	85.333±4.932c	111.67±7.638b	193.33±4.932b
T3	11.667±4.932b	58±4.041bc	83±5c	158.67±8.082b	185±5ab
T4	10±1.732a	52.667±0.578a	99±1a	170±2a	314.33±12.89a
T5	11.333±3.215d	50±7.637b	85.333±2.081b	128.33±5.77b	239.67±34.645b
T6	8±1.732e	39.333±6cd	77.667±2.087b	107.33±11.846b	189.67±9.504c
T7	10.667±8.144f	51.667±5ef	68.333±2.897d	104.67±5.682c	154.67±23.459d
Max Value	11.66	69.66	99	170	314.3
Mini Value	8	45	68.3	104.6	154.6
% for C1	34.28	48.80	34.34	44.70	51.74
% for C2	37.14	21.53	13.80	34.31	38.49
P Value	0.4961 NS	0.3797 NS	0.00 S	0.00 S	0.00 S
CV	5.7668	22.22	7.0361	12.169	34.935

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

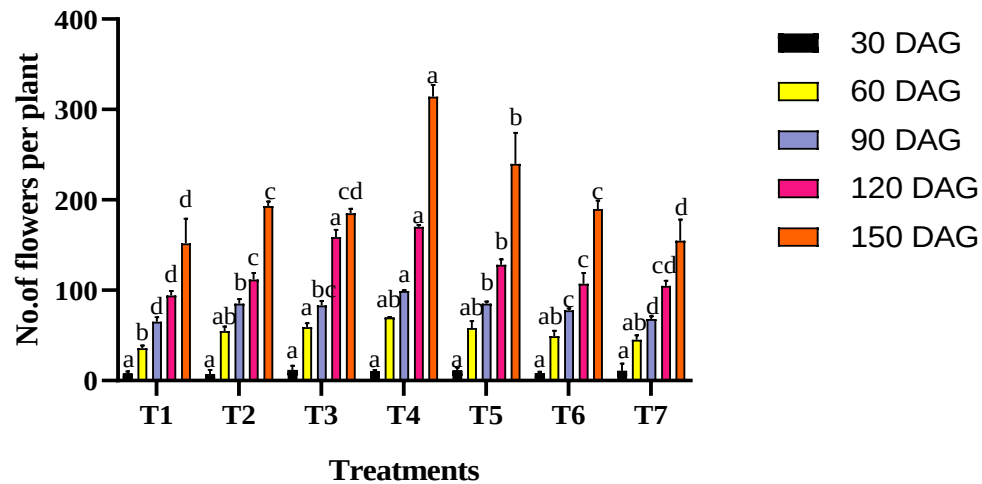


Figure 4.9 Number of flowers after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean $\pm$ standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.8 Number of Fruits

The number of fruits per plant was recorded at 150 DAG to assess the final reproductive performance under different treatments. The results showed a highly significant difference among treatments ($P = 0.000$), indicating that the treatments had a strong influence on fruit production. Treatment T4 produced the highest number of fruits per plant (309 ± 13.892), markedly outperforming all other treatments. This suggests that T4 created the most favorable conditions for sustained flowering, fruit set, and retention. T5 followed with 221 ± 28.513 fruits per plant, while T2 and T3 also demonstrated strong performance with (182.67 ± 4.618 and 180 ± 1) fruits, respectively. T6 recorded a similar value to T3 (179 ± 8.44 fruits), indicating comparable reproductive output. In contrast, the lowest fruit numbers were observed in T1 (124 ± 39.849) and T7 (148 ± 2.645), suggesting limited fruiting potential under these treatments. Recorded results were also checked through ANOVA. It was concluded that rice husk biochar, particularly, Overall, T4 emerged as the most effective treatment in enhancing fruit production, nearly doubling the fruit count observed in T1. Treatments T2, T3, T5, and T6 also showed robust performance, while T1 and T7 exhibited comparatively reduced fruit-bearing capacity.

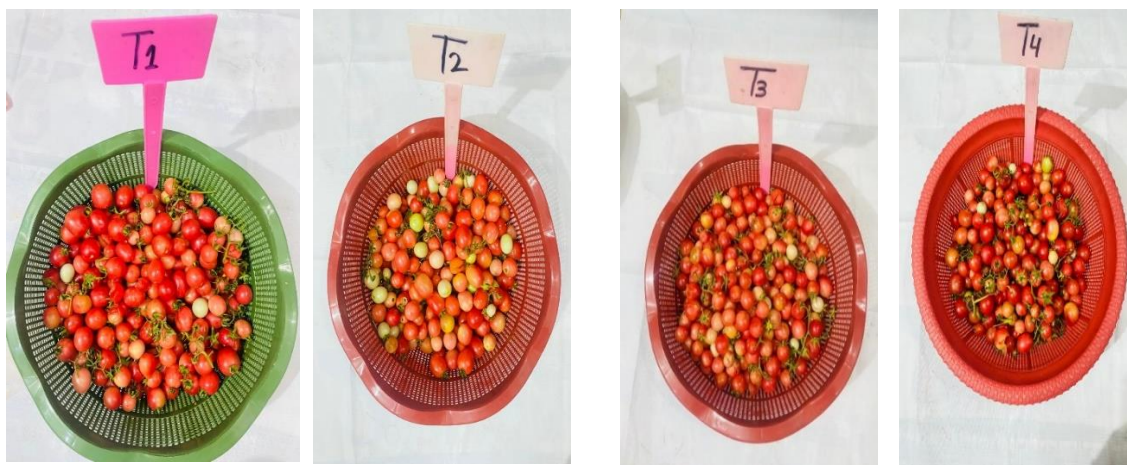




Figure 4.10 Number of fruits of *Solanum lycopersicum* L.

Table 4.10 Effect of treatments (T1-T7) on number of fruits

Treatments	No. of Fruit (150) DAG
T1	124±39.849e
T2	182.67±4.618c
T3	180±1cd
T4	309±13.892a
T5	221±28.513b
T6	179±8.544cd
T7	148±2.645d
Max Value	309
Mini Value	148
% for C1	59.87
% for C2	40.88
P Value	0 S
CV	34.248

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

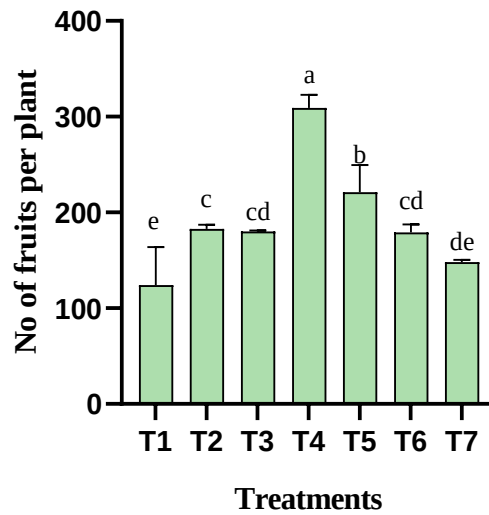


Figure 4.11 Number of fruits per plant after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.9 Fruit weight

At 90 DAG, fruit weight ranged from ($2.67 \text{ g} \pm 0.58\text{c}$) in T1 to ($4.67 \text{ g} \pm 0.578\text{a}$) in both T4 and T5, reflecting an early difference in yield accumulation. T3 also exhibited relatively high fruit weight ($4.33 \text{ g} \pm 0.578\text{ab}$), while T2, T6, and T7 each recorded ($3.00 \text{ g} \pm 1\text{bc}$), indicating moderate fruit development. By 120 DAG, treatment T4 showed the highest weight ($27.33 \text{ g} \pm 2.087\text{a}$), followed by T5 ($24.00\text{g} \pm 1\text{ab}$) and T6 and T7 ($20.67\text{g} \pm 3.055$) each. T1 maintained the lowest fruit weight ($15.00\text{g} \pm 1\text{e}$), suggesting limited yield accumulation under this treatment. At 150 DAG, T4 recorded the maximum fruit weight ($47.67 \pm 2.309\text{a}$), signifying superior cumulative fruit yield. T5 ($42.33\text{g} \pm 2.517\text{b}$) and T3 ($40.00 \text{ g} \pm 2\text{b}$) followed, indicating strong reproductive output. In contrast, T1 ($31.00 \text{ g} \pm 1.732\text{d}$) and T7 ($31.33 \text{ g} \pm 1.528\text{d}$) remained the lowest, consistent with their lower fruit number. Recorded results were also checked through ANOVA, and results revealed a significant effect of different treatments on the growth parameters of tomato, with a p-value of less than 0.05 indicating strong evidence against the null hypothesis. It had been concluded that rice husk biochar, particularly, Overall, T4 emerged as the most productive treatment in terms of fruit weight, consistently outperforming other treatments at all

observation stages. T5 and T3 also demonstrated strong performance, whereas T1 showed comparatively lower yield potential, as evidenced by its consistently lower fruit weight across all intervals.



Figure 4.12 Fruit weight of *Solanum lycopersicum* L.

Table 4.11 Effect of treatments (T1-T7) on fruit weight

Treatments	Fruits weight(g) 90 days	Fruits weight(g) 120 days	Fruits weight(g) 150 days
T1	2.6667±0.58c	15±1e	31±1.732d
T2	3±1bc	16.667±3.512de	35.333±0.578c
T3	4.3333±0.578ab	19±1cd	40±2b
T4	4.6667±0.578a	27.333±2.087a	47.667±2.309a
T5	4.6667±0.577a	24±1ab	42.333±2.517b
T6	3±1bc	20.667±3.055bc	32.667±3.0551cd
T7	3±1bc	20.667±1.155bc	31.333±1.528d
Max Value	4.66	27.33	47.66
Mini Value	3	19	31.33
% for C1	42.85	45.12	34.96
% for C2	35.71	39.02	25.87
P Value	0.0197 S	0.0003 S	0 S
CV	1.3725	3.9494	3.9335

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

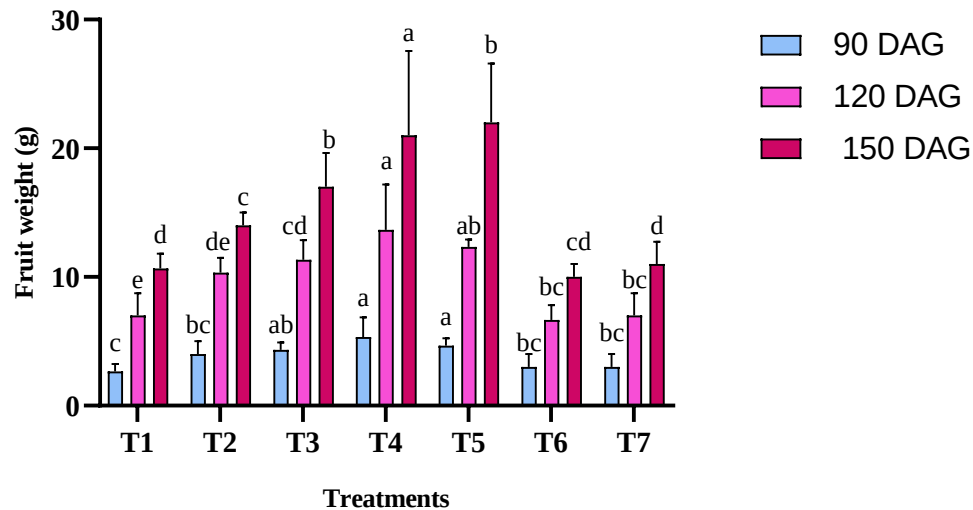


Figure 4.13 Fruit weight after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean $\pm$ standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.9 Fruit diameter

The smallest fruit diameter was recorded in T1, with an average of (12.72 mm $\pm$ 2.486c), significantly lower than all other treatments, suggesting limited fruit expansion under this treatment. In contrast, the largest fruit diameter was observed in T2 (28.05 mm $\pm$ 1.393a), followed closely by T4 (26.52 mm $\pm$ 0.095ab), T6 (26.42 mm $\pm$ 0.351ab), and T5 (26.37 mm $\pm$ 0.288ab). these treatments demonstrated superior fruit development, likely due to more favorable physiological or environmental responses. Treatments T3 and T7 recorded slightly smaller average fruit diameters (25.23 mm $\pm$ 1.148b and 25.04 mm $\pm$ 1.148b, respectively) compared to the leading treatments, but were still substantially higher than T1. Recorded results were also checked through ANOVA, and results revealed a significant effect of different treatments on the growth parameters of tomato, with a p-value of less than 0.05 indicating strong evidence against the null hypothesis. It had been concluded that rice husk biochar, particularly, Overall, T4 produced the largest fruit by diameter, indicating a strong positive influence on fruit enlargement. Treatment T2, T5,

and T6 also supported substantial fruit growth, while T1 consistently under formed, suggesting it was the least effective in promoting fruit size.



Figure 4.14 Fruit diameter of *Solanum lycopersicum* L.

Table 4.12 Effect of treatments (T1-T7) on fruit diameter

Treatments	Fruit diameter (mm)
T1	12.72±2.486c
T2	28.05±1.393a
T3	25.227±1.148b
T4	26.517±0.095ab
T5	26.37±0.288ab
T6	26.417±0.351ab
T7	25.037±0.028b
Max Value	26.51666667
Mini Value	25.03666667
% for C1	52.0301697
% for C2	5.782526713
P Value	0 S
CV	2.0034

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

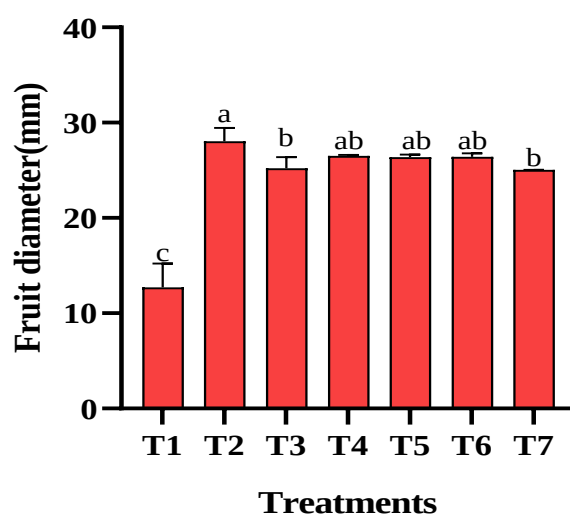


Figure 4.15 Fruit diameter after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean±standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).

4.4.10 Fruit Yield per plant

Treatment T4 recorded the highest yield, with an average of (6.45 Kg±1.831a) per plant, significantly surpassing all other treatments. This suggests a highly favorable effect of T4 on fruit set, development, and final productivity. T5 ranked second with a yield of (4.78 Kg±0.390b), followed by T3 (3.06 Kg±0.463c) and T2 (2.55 Kg±0.133cd), all of which demonstrated moderate to high yield performance. Conversely, the lowest yields were observed in T1 (1.31 Kg±0.380d), T7 (1.63 Kg±0.025a), and T6 (1.78 Kg±0.096cd), indicating relatively poor fruit production under these treatments. The notably low yield in T1 aligns with its reduced performance in other reproductive parameters, such as fruit number and fruit size. Recorded results were also checked through ANOVA, and results revealed a significant effect of different treatments on the growth parameters of tomato, with a p-value of less than 0.05 indicating strong evidence against the null hypothesis. It had been concluded that rice husk biochar, particularly overall, T4 emerged as the most productive treatment. These results highlight the superior efficacy of T4 in enhancing fruit yield under the experimental conditions.

Table 4.14 Effect of treatments (T1-T7) on fruit yield

Treatments	Fruit Yield (Kg)
T1	1.307±0.35d
T2	2.553±0.133cd
T3	3.057±0.463c
T4	6.447±1.831a
T5	4.776±0.380b
T6	1.783±0.096cd
T7	1.626±0.025a
Max Value	6.44
Mini Value	1.62
% for C1	79
% for C2	60
P Value	0 S
CV	25.21

Where mean values were separated ($P = 0.05$) and represented in the table along with $\pm$ standard error.

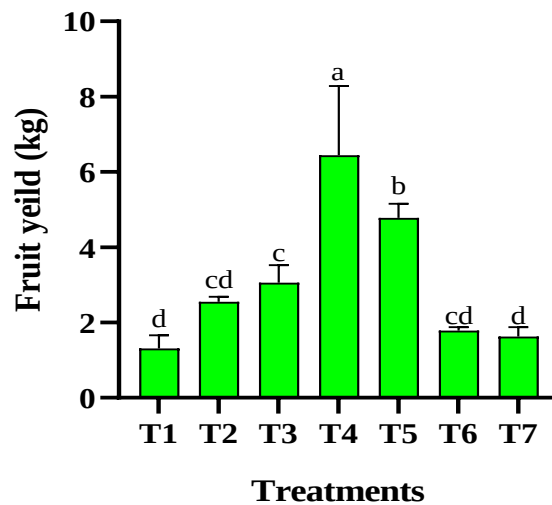


Figure 4.16 Fruit Yield after the application of biochar

Where DAG: days after germination; T1-T2: Control crop; T3-T7: experimental crop treated with biochar, data were expressed as mean $\pm$ standard deviation (SD). Statistical significance as NS ($P>0.05$), N ($P<0.05$).



Figure 4.17 Fruit Yield of *Solanum lycopersicum* L

4.5 Proximate Analysis

Table 4.14 Proximate Analysis of (T1-T7) on *Solanum lycopersicum* L.

Treatments	Moisture Analysis %	Ash Analysis %	Fiber Analysis %	Fat Analysis%	Protein Analysis %	Carbohydrates Analysis %
T1	92.833	0.867	4.763	0.081	2.676	79.921
T2	94.9	0.26	6.419	0.065	2.726	80.612
T3	89.13	0.157	7.301	0.009	2.390	79.806
T4	91.733	0.367	6.901	0.087	4.172	78.751
T5	94.6	0.673	7.919	0.004	3.59	76.974
T6	92.9	0.483	7.345	0.091	2.584	78.634
T7	92.067	0.413	6.829	0.091	2.526	80.091
Max	94.6	0.67	7.99	0.09	4.17	80.09
Mini	89.13	0.16	6.83	0.004	2.3	76.97
% for C1	1.8	28	39	10	35	0.2
% for C2	0.3	61	18	28	34	0.6

4.5.1 Moisture Analysis

The moisture content of cherry tomato fruits varied significantly among the different treatment groups. The highest moisture content was recorded in treatment T2 (94.9%), followed closely by T5 (94.6%) and T6 (92.9%). Treatment T1 and T7 exhibited moderately high moisture levels, with values of 92.833% and 92.067%, respectively. A relatively lower moisture percentage was observed in T4 (91.733%) and T3 (89.13%).

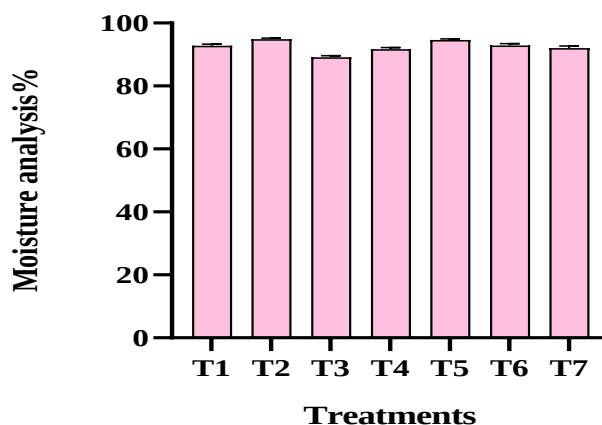


Figure 4.18 Moisture analysis of *Solanum lycopersicum* L.

where T1-T2: Control crop; T3-T7: experimental crop treated with biochar.

4.5.2 Ash Analysis

Treatment T1 exhibited the highest ash content at 0.867%, indicating a greater concentration of inorganic matter. This was followed by T5 and T6, with ash contents of 0.673% and 0.483%, respectively. Treatment T7 showed a moderate value of 0.413%, while T4 recorded a slightly lower ash content of 0.367%. In contrast, treatments T2 and T3 exhibited the lowest ash contents, with values of 0.260% and 0.157%, respectively.

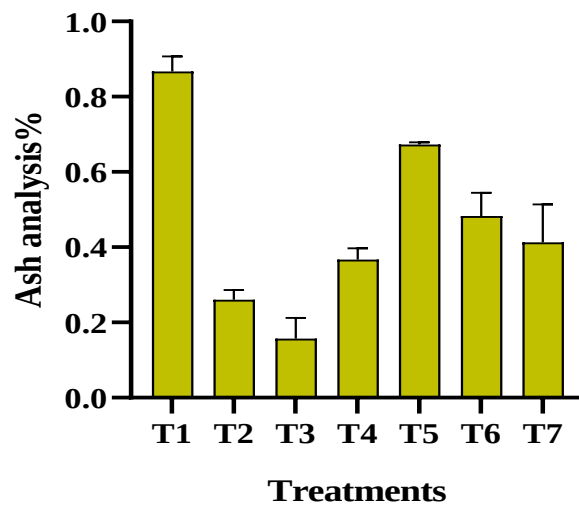


Figure 4.19 Ash analysis of *Solanum lycopersicum* L.

4.5.3 Fat Analysis

T7 and T6 recorded the highest fat contents at 0.0917% and 0.0907%, respectively, while treatments T1 and T4 each exhibited fat contents of 0.0817%. Treatment T2 showed a moderately lower value at 0.0653%. Notably, treatments T3 and T5 presented substantially lower fat contents, with values of 0.0097% and 0.0037%, respectively.

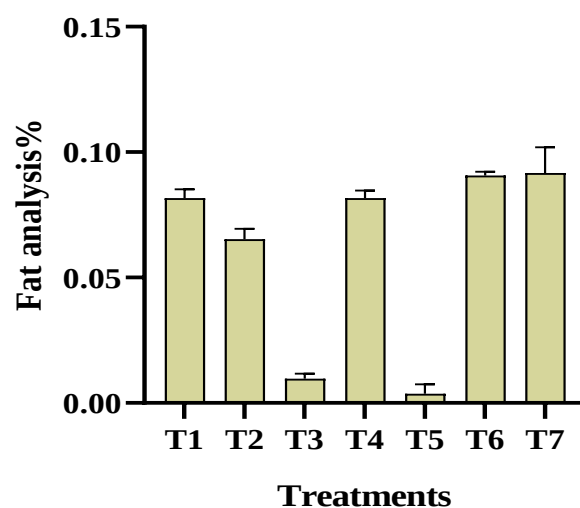


Figure 4.20 Fat analysis of *Solanum lycopersicum* L.

4.5.4 Fiber Analysis

The highest fiber content was observed in treatment T5, with a value of 7.919%, followed closely by T6 (7.345%) and T3 (7.302%). Treatment T4 also showed a relatively high fiber content at 6.901%, while T7 and T2 recorded slightly lower values of 6.829% and 6.419%, respectively. The lowest fiber content was recorded in treatment T1, with a value of 4.763%, which was notably lower than all other treatments.

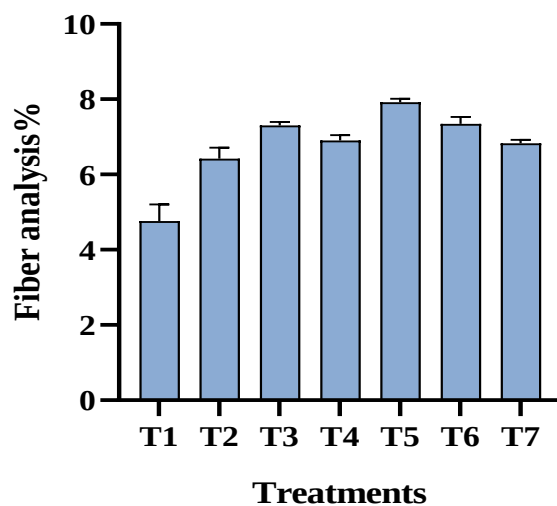


Figure 4.21 Fiber analysis of *Solanum lycopersicum* L.

4.5.5 Protein Analysis

Treatment T4 exhibited the highest protein content at 4.172%, significantly exceeding the values recorded for the other treatments. This was followed by T5 with a protein content of 3.590%. Moderate levels were observed in T2 (2.725%) and T1 (2.676%). T6, T7, and T3 recorded the lowest protein contents at 2.584%, 2.526% and 2.390%, respectively.

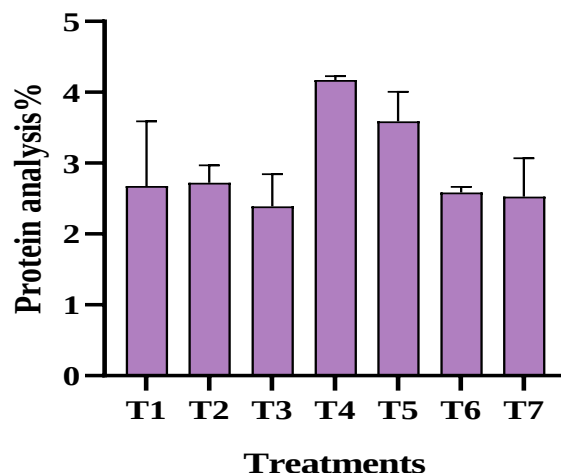


Figure 4.22 Protein analysis of *Solanum lycopersicum* L.

4.5.6 Carbohydrate Analysis

The highest carbohydrate content was recorded in Treatment T2, with a value of 80.612%, followed closely by T7 (80.091%) and T1 (79.921%). Treatment T3 also exhibited a comparable value of 79.806%, while slightly lower contents were observed in T4 (78.751%) and T6 (78.634%). The lowest carbohydrate content was found in treatment T5, which was 76.974%.

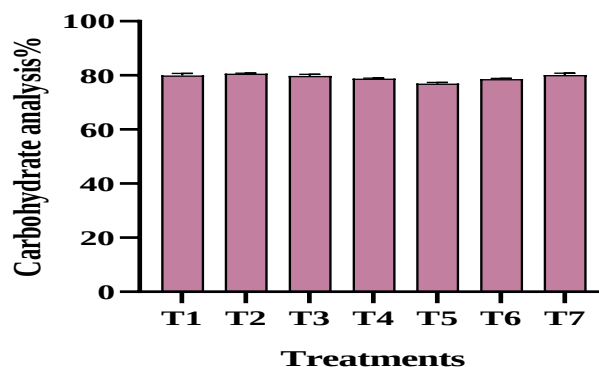


Figure 4.23 Carbohydrate analysis of *Solanum lycopersicum* L.

4.6 Lycopene Content

The lycopene content in cherry tomato fruits varied significantly among the different treatments. The maximum lycopene concentration was recorded in treatment T4 (3.179 mg/100g FW), indicating a substantial enhancement in carotenoid biosynthesis under this condition. Treatments T3 and T5 showed equal lycopene levels (1.625 mg/100 g FW), followed closely by Treatment T6 (1.517 mg/100g FW). Treatment T2 had a moderate lycopene content of 1.354 mg/100g FW. Lower lycopene levels were observed in Treatments T7 (1.231 mg/100g FW) and T1 (1.163 mg/100g FW). These results suggest that the conditions applied in Treatment T4 were most effective in promoting lycopene accumulation in cherry tomato fruits, whereas T1 and T7 exhibited comparatively lower lycopene contents.

Table 4.15 Lycopene content of *Solanum lycopersicum* L.

Treatments	Lycopene content
T1	1.163
T2	1.354
T3	1.625
T4	3.179
T5	1.625
T6	1.517
T7	1.231
Max Value	3.179
Mini Value	1.231
% for C1	63
% for C2	57

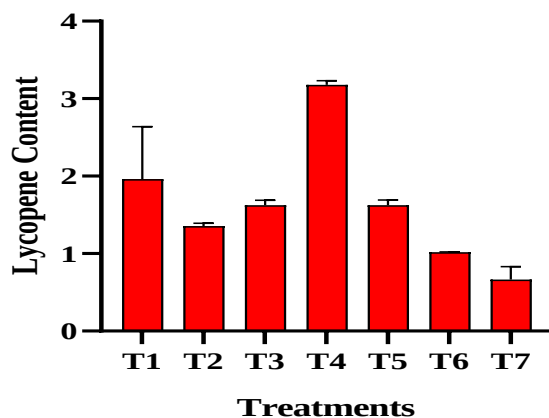


Figure 4.24 Lycopene content of *Solanum lycopersicum* L.

4.7 Ascorbic Acid Content

T2 exhibited the highest ascorbic acid content at 0.287 mg/g, moderate levels of ascorbic acid were found in T5 (0.098 mg/g) and T7 (0.077 mg/g), while the remaining treatments showed relatively low concentrations. Specifically, treatments T3, T4, T6, and T1 recorded values of 0.033 mg/g, 0.047 mg/g, 0.033 mg/g, and 0.023 mg/g, respectively, with T1 exhibiting the lowest vitamin C content.

Table 4.16 Ascorbic Acid Content *Solanum lycopersicum* L.

Treatments	Ascorbic Acid (Vitamin C)
T1	0.023
T2	0.28
T3	0.03
T4	0.047
T5	0.098
T6	0.032
T7	0.076
Max Value	0.098
Mini Value	0.032
% for C1	76
% for C2	92

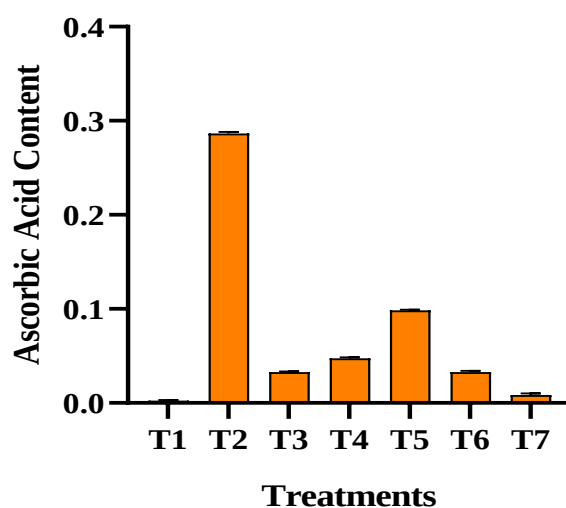


Figure 4.25 Ascorbic Acid Content *Solanum lycopersicum* L.

4.8 Total Flavonoid Content

Spectrophotometric analysis revealed considerable variation in flavonoid content across the treatments. The highest absorbance value was observed in T5 (0.345), indicating elevated flavonoid concentration. This was followed by T4 (0.259) and T7 (0.191), which showed moderate flavonoid levels. Treatments T3 (0.164), T2 (0.112), and T6 (0.112) had comparatively lower flavonoid content, while T1 exhibited the lowest absorbance (0.107). These data suggest that the treatments have a significant effect on flavonoid biosynthesis.

Table 4.17 Total Flavonoid Content (T1-T7) of *Solanum lycopersicum* L.

concentration (Ug/mL)	Sample	Absorbance	x(Q conc.ug/mL)	x(Q conc.mg/mL)	A(TFL mg /g extract)	Mean	SD	Mean+SD
0.1	T1	0.107	12.80203546	0.012802	25.6040709	25.6	0	25.6±0
0.1	T2	0.112	12.80703546	0.012807	25.6140709	25.61	0	25.61±0
0.1	T3	0.164	12.85903546	0.012859	25.7180709	25.71	0	25.71±0
0.1	T4	0.259	12.95403546	0.012954	25.9080709	25.91	0	25.91±0
0.1	T5	0.345	13.04003546	0.01304	26.0800709	26.08	0	26.08±0
0.1	T6	0.112	12.80703546	0.012807	25.6140709	25.65	0	25.65±0
0.1	T7	0.191	12.88603546	0.012886	25.7720709	25.77	0	25.77±0

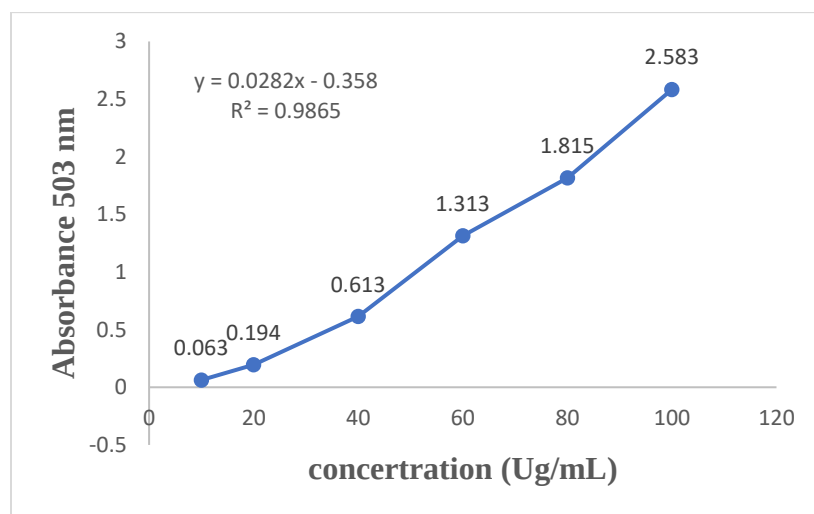


Figure 4.26 Standard curve of Total Flavonoid Content

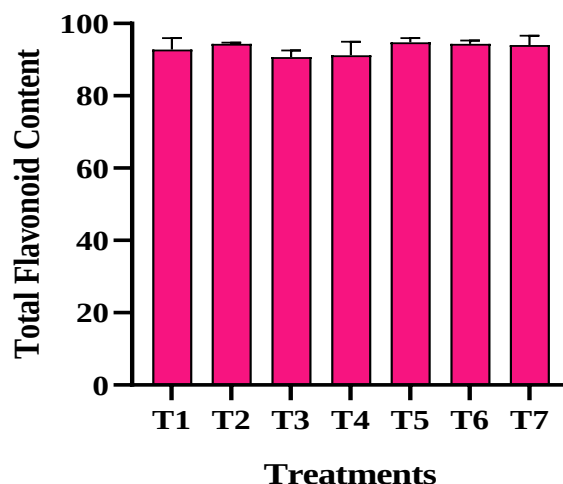


Figure 4.26.1 Total Flavonoid Content *Solanum lycopersicum* L.

4.8.1 Total Phenolic Content

The absorbance values indicative of phenolic content varied across the treatments. The highest phenolic concentration was observed in T5 (0.385), followed by T2 (0.351), T1 (0.349), and T7 (0.336). Moderate levels were recorded in T4 (0.276) and T6 (0.269), while the lowest value was found in T3 (0.184). These variations suggest differential phenolic accumulation under the applied treatments.

Table 4.1.1 Total Phenolic Content (T1-T7) *Solanum lycopersicum* L.

Sample	Absorbance	x(conc.ug/mL)	x(conc.mg/mL)	A (mg GAE/g extract)	Mean	SD	Mean± SD
T1	0.349	11.89956	0.0119	5.949781	5.94	0.02	5.94±0.02
T2	0.351	11.90156	0.011902	5.950781	5.95	0.021	5.95±0.021
T3	0.184	11.73456	0.011735	5.867281	5.86	0.061	5.86±0.061
T4	0.276	11.82656	0.011827	5.913281	5.91	0.015	5.91±0.015
T5	0.385	11.93556	0.011936	5.967781	5.96	0.038	5.96±0.038
T6	0.269	11.81956	0.01182	5.909781	5.91	0.019	5.91±0.019
T7	0.336	11.88656	0.011887	5.943281	5.94	0.014	5.94±0.014

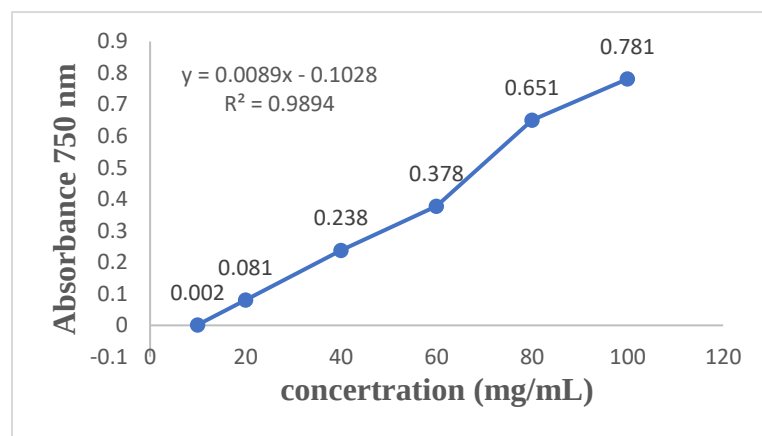
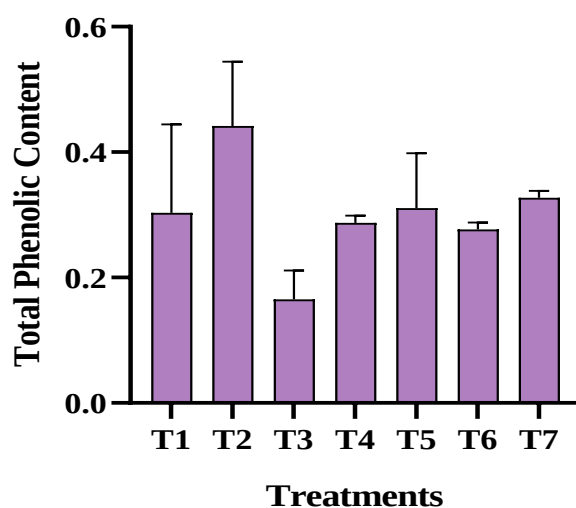


Figure 4.27 Standard curve Total Phenolic Content



Graph 4.27.1 Total Phenolic Content of *Solanum lycopersicum* L.

4.9 Chlorophyll Content

Among all treatments, the highest chlorophyll a content was observed in T6 (1.776 mg/g), followed closely by T3 (1.751 mg/g) and T1 (1.728 mg/g). Conversely, the lowest chlorophyll a content was recorded in treatment T7, at 1.490 mg/g. In terms of chlorophyll b content, the highest value was found in treatment T4 (3.938mg/g), followed by T1 (3.832 mg/g) and T2 (3.641 mg/g). The lowest chlorophyll b concentration was observed in treatment T5 (2.883 mg/g).

Table 4.19 Chlorophyll Content (T1-T7) *Solanum lycopersicum* L.

Treatments	Chlorophyll a	Chlorophyll b
T1	3.832	1.728
T2	3.641	1.543
T3	3.585	1.751
T4	3.938	1.711
T5	2.883	1.555
T6	3.522	1.776
T7	3.608	1.49
Max Value	3.938	1.776
Mini Value	2.883	1.49
% for C1	2	2
% for C2	7	13

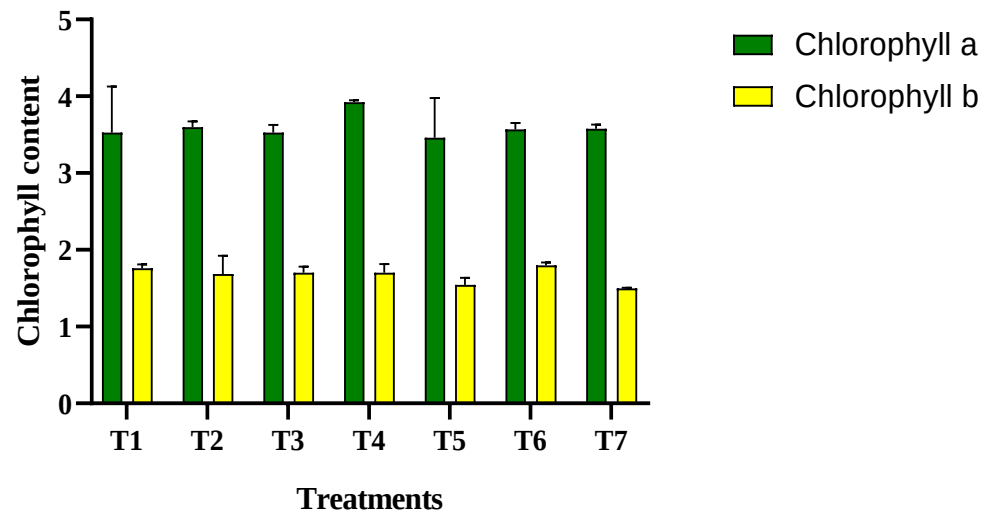


Figure 4.28 Chlorophyll Content analysis of leaves of *Solanum lycopersicum* L.

CHAPTER 5

DISCUSSION

As a soil amendment, biochar, a carbon-rich substance made by pyrolyzing organic feedstock like rice husk, has shown significant advantages. In the present study, the use of biochar made from rice husk significantly improved soil physicochemical properties, particularly by reducing soil acidity. This finding aligns with the work of Ghorbani et al., 2019 [103] and Wu et al., 2020 [104], who reported that biochar's inherent alkalinity and buffering capacity contribute to stabilizing soil pH. The increased pH not only mitigates soil acidity but also fosters favorable conditions for root development and nutrient uptake, thereby enhancing plant growth (Changxun et al., 2016 [105]).

Compared to conventional lime, biochar has shown greater efficacy in ameliorating acidic soils, improving soil quality, and promoting fruit yield and quality Wu et al., 2020 [104]. This superiority is attributed to biochar's high organic carbon content, surface functional groups, and porous structure, which collectively enhance its interaction with soil constituents. Additionally, biochar has the ability to adsorb and immobilize toxic metal ions, thereby reducing their bioavailability and improving overall soil health Khan et al., 2017 [106].

The effectiveness of biochar is influenced by the conditions under which it is produced. According to the International Biochar Initiative and studies by Yu et al., 2013 [107]. and Rawat et al. 2019 [108], pyrolysis temperatures between 300 °C and 500 °C under limited oxygen are optimal for producing high-quality biochar. This temperature range, also supported by Lee et al., 2014 [109], promotes slow pyrolysis, yielding biochar with a stable structure and high functionality.

Following biochar application, the current study observed increased effective cation exchange capacity (E.CEC), along with higher concentrations of basic cations and improved micronutrient availability. This is particularly important, as the high CEC of biochar enhances nutrient retention, reduces leaching losses, and improves soil water-holding capacity Kharel et al., 2019 [110]. These changes collectively contribute to better nutrient use efficiency and sustainable crop production.

All growth parameters at every subsequent growth stage were dramatically changed by the therapy. At every subsequent growth stages (30, 60, 90, 120 and 150 DAT), the treatment T4 (7.5g biochar) showed the height plant height (26cm, 44cm, 74cm, 107 and 115cm), number of leaves per plant (14, 27, 207, 259 and 320), Leave area (2.17cm², 2.97cm², 3.69 cm², 4.94 cm² and 6.06cm²). Number of branches per plant (12.33, 19, 24.667, 48.333 and 48.333). Stem girth (3mm, 7.333mm, 16.333mm, 20.667mm, and 20.667mm), which was superior compared to the control. The enhanced growth performance in T4 can be attributed to the beneficial properties of biochar, which raise nutrient availability, strengthen soil structure, and promote water retention. Biochar's porous structure facilitates better root aeration and microbial activity, creating a more favorable rhizosphere for plant development. These results were corroborated by She *et al.*, 2018 [111], who reported that biochar application improved plant biomass, leaf development, and stem thickness due to improved soil fertility and microbial dynamics.

treatment T4 (7.5g biochar) produced the most flower per cluster (10, 52.667, 99, 170 and 314.33) at (30, 60, 90, 120 and 150 DAT) and extreme number of fruits per plant (309) was also found with treatment T7 as compare to control the enhanced floral production in T4 may be attributed to the biochar's ability to improve soil physicochemical characteristics, such as nutrient availability (especially phosphorus and potassium), moisture retention and soil aeration. These improvements support better vegetative vigor, leading to increased assimilate production and allocation towards reproductive organs. The high fruit set in T7 further suggests that biochar not only promotes flower progress but also boosts pollination success and fruit retention, likely due to improved plant physiological status and hormonal balance. These observations are consistent with the earlier studies by She *et al.*, 2018 [111], Faloye *et al.*, 2020 [112] and Ronga *et al.*, 2020 [113], who reported that biochar positively influences flowering, fruiting, and yield by improving nutrient cycling, stimulating beneficial soil microbes, and optimizing root zone conditions. Such enhancements create a conducive environment for reproductive growth, leading to higher productivity in horticultural crops.

The treatment T4 (7.5g biochar) observed maximum weight of fruit (47.667g), Ronga *et al.*, 2020 [113], and maximum fruit diameter (26.517cm), closely followed by T6 (26.417)

and T5 (26.37), Khayyat *et al.*, 2007 [114]. Fruit diameter significantly increased by a foliar spray composed of essential micronutrients boron, zinc, magnesium sulfate, potassium sulfate, and sulfur was applied uniformly across the entire field. It is manifest from the table that maximum fruit yield per plant (6.446kg) and maximum fruit yield per ha (107.5 t ha⁻¹) was recorded with T4 (7.5g biochar) followed by T6 (10g biochar) (4.776kg) and (79.67 t ha⁻¹) respectively reported by [4] *et al.*, 2022. Boron and zinc are necessary blocks of several enzyme systems that produce energy and synthesize proteins by preserving the entire complement of chloroplasts reported by Chaudhary, M.I., 2006 [115]. So, Foliar application of considerable boron, zinc, magnesium sulfate, potassium sulfate, and sulfur increased the number of fruits and fruit yield reported by Khayyat *et al.*, 2007 [114]

The use of biochar resulted in the highest chlorophyll content compared to the control treatment. This result is in line with earlier research by Pathak 2017 [116] and Zara-Maiyan 2017 [117], who reported increased chlorophyll levels following biochar amendments. Mycorrhizal inoculation has also been shown to enhance chlorophyll content and photosynthetic efficiency in various crops of nutritional and economic importance Zhang, 2018 [118]. However, as observed by Mena-Violante, chlorophyll content in mycorrhized plants and their fruits may decline during the ripening process, a stage characterized by the interruption of chlorophyll and the synthesis of carotenoids and other pigments. The elevated chlorophyll levels observed in biochar-treated plants may be attributed to enhanced chloroplast development or stability in the foliage [119]. Similar mechanisms have been reported in mycorrhizal plants, where the symbiotic interaction promotes chloroplast biogenesis and function Rajasekaran, 2016 [120]. Therefore, the synergistic effect of biochar and microbial inoculants likely contributes to improved chlorophyll retention and photosynthetic capacity in treated plants.

The moisture content of treated with biochar was high (94.6%) as compared to control. Pinela *et al.*, 2012 [121] reported maximum moisture content which indicates its low shelf life. As the high moisture makes it susceptible to microbial attack and it suggested better water uptake and retention in the fruit indicating improved physiological activity under these treatments

The ash content of treated with biochar was low (0.367%) as compared to control. The results of Bello *et al.*, 2008 [122]; Atasié *et al.*, 2009 [123] also showed minimum ash content. When compared to every other proximate composition, the ash concentration of both fruits is typically low, despite being high in the pulp.

Treated with biochar recorded the highest fat contents at 0.0917% - 0.0907%, respectively as compared to control. The results agreed with the observation made by Oboulbiga *et al.*, 2012 [124] explained that fruits which have a high water content (85 % on average) are not a suitable source of fat and are therefore advised as part of diets aimed at losing weight.

When compared to control, the fiber content of the treated biochar was 7.919%. dietary fiber is a crucial part of nutritious components, according to buttress *et al.*, 2008 [125]. Although it can only generate a small amount of energy and is not digested and absorbed by the gastrointestinal tract, it plays essential physiological roles, increases intestinal peristalsis, absorbs water swelling, improves the microbial composition of the intestine, and stimulates the production of digestive juices.

The protein content of treated with biochar was 4.172%, which was a little bit higher than compared to the control group. The results approved with the observation made by Oboulbiga *et al.*, 2012 [124] low protein content is a general low in tomatoes

The carbohydrate content of treated biochar was 78.751% which was lower as compared to range of mean values obtained by control group. Patients with diabetes and hypertension who need to follow low-sugar, low-fat diets have been found to benefit greatly from fruits with low carbohydrate content Fizza *et al.*, 2025 [126].

The total phenolic content treated with biochar was higher compared to the control. The main ingredient that gave DPPH its antioxidant and free radical scavenging properties was phenol. These substances may be able to scavenge the body's harmful free radicals and lower the risk of numerous illnesses brought on by oxidative stress Abreu *et al.*, 2019 [127]

Total phenolic content treated with biochar was higher compared to the control. Antioxidant activity inhibits cell proliferation, potentially reducing the risk of chronic diseases. The obtained results align with findings reported by [101].

The ascorbic acid content of T2 was high (0.286mg/1g) as compared to the control. karima 2019 [128] discovered that, depending on the harvest season, cherry tomatoes' total ascorbic acid content ranges from 31 to 71 mg/100g. In comparison to colored cherry tomatoes, red cherry tomatoes had a higher overall ascorbic acid level.

T4 demonstrated the highest lycopene concentration, with the mean value of 3.179mg/100g, representing a significant enhancement compared to the treatments, particularly the control (1.963mg/100g). This increase aligns with the findings of Khan 2019 [105], who observed elevated levels of lycopene, titratable acidity in response to biochar application as a soil amendment. Additionally, biochar-treated plants exhibited greater concentrations of both trans- and cis-lycopene, along with improved titratable acidity and total soluble solids, relative to untreated controls. The observed enhancement in lycopene accumulation may be attributed to increased nitrogen (N_{tot}) and potassium ion concentrations in the rhizosphere of biochar-amended soils, which have been previously associated with elevated lycopene content Massa 2019 [129], titratable acidity, and soluble solid levels in tomato fruit wang 2014 [130].

CHAPTER 6

CONCLUSION

The present study demonstrated that the incorporation of biochar at the rate of 7.5g significantly improved tomato yield compared to all other treatments. This increase may be attributed to moderate biochar application, which likely enhanced soil properties and nutrient availability, increasing the growth and yield production of *Solanum lycopersicum* L.

Appendices

Area required for Plots

Length of Ridge = 200cm = 2m

Width of Ridge = 30cm = 0.3m

Area of Ridge = $2 \times 0.3 = 0.6\text{m}$

Area of 7 Ridge = $0.6\text{m} \times 7 = 4.2\text{m}$

space of furrows = 40cm = 0.4m

Area of furrows = $0.4 \times 2 = 0.8\text{m}$

$$0.8 \times 6 = 4.8\text{m}$$

Total Area = $4.2\text{m} + 4.8\text{m} = 9\text{m}^2$

Space b/w two plants = $200\text{cm} / 9 = 22.22\text{cm}$

$$22.22\text{cm} / 100 = 0.2\text{m}$$

Distance b/w two adjacent plots = 0.2m

CHAPTER 7

REFERENCES

1. Amr A, Raie W. Tomato components and quality parameters. A review. Jordan Journal of Agricultural Sciences. 2022;18(3):199-220.
2. Tello AF. Desempeño comercial del trigo Mexicano en los mercados internacionales, 2012-2021. ITSI ECHERI Revista de Divulgacion de Estudios Económico Agroalimentario y del Desarrollo Rural. 2024;2(4):9-15.
3. Maeda-Gutiérrez V, Galvan-Tejada CE, Zanella-Calzada LA, Celaya-Padilla JM, Galván-Tejada JI, Gamboa-Rosales H, Luna-Garcia H, Magallanes-Quintanar R, Guerrero Mendez CA, Olvera-Olvera CA. Comparison of convolutional neural network architectures for classification of tomato plant diseases. Applied Sciences. 2020;10(4):1245.
4. Adebajo SO, Oluwatobi F, Akintokun PO, Ojo AE, Akintokun AK, Gbodope IS. Impacts of rice-husk biochar on soil microbial biomass and agronomic performances of tomato (*Solanum lycopersicum* L.). Scientific Reports. 2022;12(1):1787.
5. Panno S, Davino S, Caruso AG, Bertacca S, Crnogorac A, Mandic A, Noris E, Matic S. A review of the most common and economically important diseases that undermine the cultivation of tomato crop in the Mediterranean basin. Agronomy. 2021;11(11):2188.
6. Parmar M, Rajput H, Johri S. *Solanum lycopersicum*, a Reservoir of Antioxidants. In Antioxidant-based therapies for disease prevention and management 2021 (pp. 253-268). Apple Academic Press.
7. Collins EJ, Bowyer C, Tsouza A, Chopra M. Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. Biology. 2022;11(2):239.
8. Ahmed R, Uddin MK, Quddus MA, Samad MY, Hossain MM, Haque AN. Impact of foliar application of zinc and zinc oxide nanoparticles on growth, yield, nutrient uptake and quality of tomato. Horticulturae. 2023;9(2):162.

9. Kiralan M, Ketenoglu O. Utilization of tomato (*Solanum lycopersicum*) by-products: An overview. *Mediterranean Fruits Bio-Wastes: Chemistry, Functionality and Technological Applications*. 2022;799-818.
10. Khan UM, Sevindik M, Zarrabi A, Nami M, Ozdemir B, Kaplan DN, Selamoglu Z, Hasan M, Kumar M, Alshehri MM, Sharifi-Rad J. Lycopene: food sources, biological activities, and human health benefits. *Oxidative medicine and cellular longevity*. 2021;(1):2713511.
11. Collins EJ, Bowyer C, Tsouza A, Chopra M. Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*. 2022;11(2):239.
12. Panno S, Davino S, Caruso AG, Bertacca S, Crnogorac A, Mandić A, Noris E, Matić S. A review of the most common and economically important diseases that undermine the cultivation of tomato crop in the mediterranean basin. *Agronomy*. 2021;11(11):2188.
13. Zheng Y, Fields JS, Bragg N, Caron J, Michel JC, Zaccheo P, Crippa L, Giuffrida F, Mauro RP, Tüzel Y, Balliu A. *Advances in horticultural soilless culture*. Burleigh Dodds Science Publishing; 2021.
14. Bak A, Nihranz CT, Patton MF, Aegerter BJ, Casteel CL. Evaluation of aminoethoxyvinylglycine (AVG) for control of vector-borne diseases in solanaceous crops. *Crop Protection*. 2021;145:105640.
15. Rehan M, Al-Turki A, Abdelmageed AH, Abdelhameid NM, Omar AF. Performance of plant-growth-promoting rhizobacteria (PGPR) isolated from sandy soil on growth of tomato (*Solanum lycopersicum* L.). *Plants*. 2023;12(8):1588.
16. Gruda NS, Bragg N. Developments in alternative organic materials for growing media in soilless culture systems. In *Advances in horticultural soilless culture 2021* (pp. 73-106). Burleigh Dodds Science Publishing.
17. Thiessen ME, Fields JS, Abdi DE. Physical Properties and Crop Performance of Four Substrate Fibers in Greenhouse Petunia Production. *Horticulturae*. 2024;10(3):279.

18. Zantanta N. *Crop yields, secondary metabolites and anti-fungal activities of extracts of Helichrysum cymosum and Helichrysum odoratissimum cultivated in aquaponics* Doctoral dissertation, Cape Peninsula University of Technology 2022
19. Chowdhury M, Espinoza-Ayala A, Samarakoon UC, Altland JE, Yang T. Substrate Comparison for Tomato Propagation under Different Fertigation Protocols. *Agriculture*. 2024;14(3):382.
20. Alfosea-Simón M, Simón-Grao S, Zavala-Gonzalez EA, Cámara-Zapata JM, Simón I, Martínez-Nicolás JJ, Lidón V, García-Sánchez F. Physiological, nutritional and metabolomic responses of tomato plants after the foliar application of amino acids aspartic acid, glutamic acid and alanine. *Frontiers in plant science*. 2021;11:581234.
21. Ghazanfari N, Fallah S, Vasiee A, Yazdi FT. Optimization of fermentation culture medium containing food waste for l-glutamate production using native lactic acid bacteria and comparison with industrial strain. *LWT*. 2023;184:114871.
22. Wang S, Qiang Q, Xiang L, Fernie AR, Yang J. Targeted approaches to improve tomato fruit taste. *Horticulture Research*. 2023;10(1):uhac229.
23. Felföldi Z, Ranga F, Roman IA, Sestras AF, Vodnar DC, Prohens J, Sestras RE. Analysis of physico-chemical and organoleptic fruit parameters relevant for tomato quality. *Agronomy*. 2022;12(5):1232.
24. Nadarajan S, Sukumaran S. Chemistry and toxicology behind chemical fertilizers. *In* Controlled Release fertilizers for sustainable agriculture 2021 (pp. 195-229). Academic press.
25. Jote CA. The impacts of using inorganic chemical fertilizers on the environment and human health. *Org. Med. Chem. Int. J*. 2023;13:555864.
26. Richardson AE, George TS, Hens M, Delhaize E, Ryan PR, Simpson RJ, Hocking PJ. Organic anions facilitate the mobilization of soil organic phosphorus and its subsequent lability to phosphatases. *Plant and Soil*. 2022;476(1):161-80.
27. Suswana S, Maulana DD. Residual Effect of Rice Husk Biochar on Growth and Yield of Aerobic Rice. *Agrotechnology Research Journal*. 2022;6(2):87-94.
28. Durmuş M, Kızılkaya R. The effect of tomato waste compost on yield of tomato and some biological properties of soil. *Agronomy*. 2022;12(6):1253.

29. Liu X, Zhang D, Li H, Qi X, Gao Y, Zhang Y, Han Y, Jiang Y, Li H. Soil nematode community and crop productivity in response to 5-year biochar and manure addition to yellow cinnamon soil. *BMC ecology*. 2020;20:1-3.
30. Hasnain M, Chen J, Ahmed N, Memon S, Wang L, Wang Y, Wang P. The effects of fertilizer type and application time on soil properties, plant traits, yield and quality of tomato. *Sustainability*. 2020;12(21):9065.
31. Polzella A, Terzaghi M, Trupiano D, Baronti S, Scippa GS, Chiatante D, Montagnoli A. Morpho-physiological responses of *Pisum sativum* L. to different light-emitting diode (led) light spectra in combination with biochar amendment. *Agronomy*. 2020;10(3):398.
32. Khan S, Irshad S, Mehmood K, Hasnain Z, Nawaz M, Rais A, Gul S, Wahid MA, Hashem A, Abd Allah EF, Ibrar D. Biochar production and characteristics, its impacts on soil health, crop production, and yield enhancement: A review. *Plants*. 2024;13(2):166.
33. Jia M, Yu J, Li Z, Wu L, Christie P. Effects of biochar on the migration and transformation of metal species in a highly acid soil contaminated with multiple metals and leached with solutions of different pH. *Chemosphere*. 2021;278:130344.
34. Amery F, Debode J, Ommeslag S, Visser R, De Tender C, Vandecasteele B. Biochar for circular horticulture: Feedstock related effects in soilless cultivation. *Agronomy*. 2021;11(4):629.
35. Younis A, Ahsan M, Akram A, Lim KB, Zulfiqar F, Tariq U. Use of organic substrates in sustainable horticulture. Hasanuzzaman, M., Hawrylak Nowak, B., Islam, T. and Fujita M. *Biostimulants for Crop Production and Sustainable Agriculture*. 2022:122-38.
36. Simiele M, Argentino O, Baronti S, Scippa GS, Chiatante D, Terzaghi M, Montagnoli A. Biochar enhances plant growth, fruit yield, and antioxidant content of cherry tomato (*Solanum lycopersicum* L.) in a soilless substrate. *Agriculture*. 2022;12(8):1135.
37. Pelagalli, V., Langone, M., Matassa, S., Race, M., Papirio, S., Lens, P.N., Lazzazzara, M., Frugis, A., Petta, L. and Esposito, G., 2024. Pyrolysis of municipal

- sewage sludge: challenges, opportunities and new valorization routes for biochar, bio-oil, and pyrolysis gas. *Environmental Science: Water Research & Technology*.
38. Zhang C, Zhang Z, Zhang L, Li Q, Li C, Chen G, Zhang S, Liu Q, Hu X. Evolution of the functionalities and structures of biochar in pyrolysis of poplar in a wide temperature range. *Bioresource technology*. 2020;304:123002.
 39. Vieira FR, Luna CM, Arce GL, Ávila I. Optimization of slow pyrolysis process parameters using a fixed bed reactor for biochar yield from rice husk. *Biomass and Bioenergy*. 2020;132:105412.
 40. Terlouw T, Bauer C, Rosa L, Mazzotti M. Life cycle assessment of carbon dioxide removal technologies: a critical review. *Energy & Environmental Science*. 2021;14(4):1701-21.
 41. Barot S. Biomass and bioenergy: resources, conversion and application. *Renewable Energy for Sustainable Growth Assessment*. 2022:243-62.
 42. Chen R, Congress SS, Cai G, Duan W, Liu S. Sustainable utilization of biomass waste-rice husk ash as a new solidified material of soil in geotechnical engineering: A review. *Construction and Building Materials*. 2021;292:123219.
 43. Akhter F, Soomro SA, Jamali AR, Chandio ZA, Siddique M, Ahmed M. Rice husk ash as green and sustainable biomass waste for construction and renewable energy applications: a review. *Biomass Conversion and Biorefinery*. 2021:1-1.
 44. Ariani M, Hanudin E, Haryono E. Greenhouse Gas Emissions from Rice Fields in Indonesia: Challenges for Future Research and Development. *Indonesian Journal of Geography*. 2021 Jan 1;53(1).
 45. Shukla SS, Chava R, Appari S, Bahurudeen A, Kuncharam BV. Sustainable use of rice husk for the cleaner production of value-added products. *Journal of Environmental Chemical Engineering*. 2022;10(1):106899.
 46. Ran C, Gulaqa A, Zhu J, Wang X, Zhang S, Geng Y, Guo L, Jin F, Shao X. Benefits of biochar for improving ion contents, cell membrane permeability, leaf water status and yield of rice under saline-sodic paddy field condition. *Journal of Plant Growth Regulation*. 2020;39(1):370-7.

47. Sun Y, Chen X, Yang J, Luo Y, Yao R, Wang X, Xie W, Zhang X. Biochar Effects Coastal Saline Soil and Improves Crop Yields in a Maize-Barley Rotation System in the Tidal Flat Reclamation Zone, China. *Water*. 2022;14(20):3204.
48. Li Z, Zheng Z, Li H, Xu D, Li X, Xiang L, Tu S. Review on rice husk biochar as an adsorbent for soil and water remediation. *Plants*. 2023;12(7):1524.
49. Kaur G, Kaur P, Kaur G, Kaur J. Valorization of Rice Straw and Husk for Food Packaging. In *Agro-Wastes for Packaging Applications 2024* (pp. 42-65). CRC Press.
50. Sahoo D, Remya N. Influence of operating parameters on the microwave pyrolysis of rice husk: biochar yield, energy yield, and property of biochar. *Biomass Conversion and Biorefinery*. 2022;12(8):3447-56.
51. Asadi H, Ghorbani M, Rezaei-Rashti M, Abrishamkesh S, Amirahmadi E, Chengrong CH, Gorji M. Application of rice husk biochar for achieving sustainable agriculture and environment. *Rice Science*. 2021;28(4):325-43.
52. Ebido, N.E., Edeh, I.G., Unagwu, B.O., Nnadi, A.L., Ozongwu, O.V., Obalum, S.E. and Igwe, C.A., 2021. Rice-husk biochar effects on organic carbon, aggregate stability and nitrogen-fertility of coarse-textured Ultisols evaluated using *Celosia argentea* growth. *SAINS TANAH-Journal of Soil Science and Agroclimatology*, 2021; 18(2), pp.177-187.
53. Sun Y, Chen X, Yang J, Luo Y, Yao R, Wang X, Xie W, Zhang X. Biochar Effects Coastal Saline Soil and Improves Crop Yields in a Maize-Barley Rotation System in the Tidal Flat Reclamation Zone, China. *Water*. 2022;14(20):3204.
54. Ephraim W, Paul NN, Rebecca Y. Rice husk biochar for carbon sequestration, soil fertility and plant health improvement: A review. *African Phytosanitary Journal*. 2024;4(2):54-84.
55. Pan SY, Dong CD, Su JF, Wang PY, Chen CW, Chang JS, Kim H, Huang CP, Hung CM. The role of biochar in regulating the carbon, phosphorus, and nitrogen cycles exemplified by soil systems. *Sustainability*. 2021;13(10):5612.
56. Do PT, Nguyen LX. A review of thermochemical decomposition techniques for biochar production. *Environment, Development and Sustainability*. 2024:1-57.

57. Amenaghawon AN, Anyalewechi CL, Okieimen CO, Kusuma HS. Biomass pyrolysis technologies for value-added products: a state-of-the-art review. *Environment, Development and Sustainability*. 2021;1-55.
58. Razzaghi F, Obour PB, Arthur E. Does biochar improve soil water retention? A systematic review and meta-analysis. *Geoderma*. 2020;361:114055.
59. Salim MM, Rashid MH, Hossain MM, Zakaria M. Morphological characterization of tomato (*Solanum lycopersicum* L.) genotypes. *Journal of the Saudi Society of Agricultural Sciences*. 2020;19(3):233-40.
60. Bjarnadottir A. Strawberries 101: Nutrition facts and health benefits. Red Ventures, Health line Media. <https://www.healthline.com/nutrition/foods/strawberries>. 2019.
61. Costa JM, Heuvelink EP. The global tomato industry. In *Tomatoes 2018* (pp. 1-26). Wallingford UK: CABI.
62. Reimers KJ, Keast DR. Tomato consumption in the United States and its relationship to the US Department of Agriculture food pattern: results from What We Eat in America 2005–2010. *Nutrition Today*. 2016;51(4):198-205.
63. Tang S. Tracing Tomato Timelines: The Domestication of *Solanum lycopersicum*. *Prized Writing*. 2021.
64. Elango P, Asmathulla S. A Systematic Review on Lycopene and its Beneficial Effects”. *Biomedical and Pharmacology Journal*. 2017;10(4):2113-20.
65. Branthôme FX. Worldwide (total fresh) tomato production exceeds 187 million tonnes in 2020. *Tomato news*. 2022;28.
66. Allohverdi T, Mohanty AK, Roy P, Misra M. A review on current status of biochar uses in agriculture. *Molecules*. 2021;26(18):5584.
67. Ippolito JA, Cui L, Kammann C, Wrage-Mönnig N, Estavillo JM, Fuertes-Mendizabal T, Cayuela ML, Sigua G, Novak J, Spokas K, Borchard N. Feedstock choice, pyrolysis temperature and type influence biochar characteristics: a comprehensive meta-data analysis review. *Biochar*. 2020;2:421-38.
68. Joung M, Kim YJ, Shin Y. Assessment of lycopene, polyphenols, antioxidant compounds, and activities in colored cherry tomato cultivars harvested in Korea. *Food Science and Biotechnology*. 2025 Mar;34(5):1161-70.

69. Gabhane JW, Bhange VP, Patil PD, Bankar ST, Kumar S. Recent trends in biochar production methods and its application as a soil health conditioner: a review. *SN Applied Sciences*. 2020;2:1-21.
70. Rombel A, Krasucka P, Oleszczuk P. Sustainable biochar-based soil fertilizers and amendments as a new trend in biochar research. *Science of the Total Environment*. 2022 10;816:151588.
71. Goldan E, Nedeff V, Barsan N, Culea M, Panainte-Lehadus M, Mosnegutu E, Tomozei C, Chitimus D, Irimia O. Assessment of manure compost used as soil amendment—A review. *Processes*. 2023;11(4):1167.
72. Zahra MB, Aftab ZE, Akhter A, Haider MS. Cumulative effect of biochar and compost on nutritional profile of soil and maize productivity. *Journal of Plant Nutrition*. 2021;44(11):1664-76.
73. Bello A, Wang B, Zhao Y, Yang W, Ogundeji A, Deng L, Egbeagu UU, Yu S, Zhao L, Li D, Xu X. Composted biochar affects structural dynamics, function and co-occurrence network patterns of fungi community. *Science of the Total Environment*. 2021;775:145672.
74. Pandit NR, Schmidt HP, Mulder J, Hale SE, Husson O, Cornelissen G. Nutrient effect of various composting methods with and without biochar on soil fertility and maize growth. *Archives of Agronomy and Soil Science*. 2020 Jan 28.
75. Karam DS, Nagabovanalli P, Rajoo KS, Ishak CF, Abdu A, Rosli Z, Muharam FM, Zulperi D. An overview on the preparation of rice husk biochar, factors affecting its properties, and its agriculture application. *Journal of the Saudi Society of Agricultural Sciences*. 2022;21(3):149-59.
76. Asadi H, Ghorbani M, Rezaei-Rashti M, Abrishamkesh S, Amirahmadi E, Chengrong CH, Gorji M. Application of rice husk biochar for achieving sustainable agriculture and environment. *Rice Science*. 2021;28(4):325-43.
77. Bushra B, Remya N. Biochar from pyrolysis of rice husk biomass—characteristics, modification and environmental application. *Biomass Conversion and Biorefinery*. 2024;14(5):5759-70.
78. Li Z, Zheng Z, Li H, Xu D, Li X, Xiang L, Tu S. Review on rice husk biochar as an adsorbent for soil and water remediation. *Plants*. 2023;12(7):1524.

79. Sahoo D, Remya N. Influence of operating parameters on the microwave pyrolysis of rice husk: biochar yield, energy yield, and property of biochar. *Biomass Conversion and Biorefinery*. 2022;12(8):3447-56.
80. Rahmat A, Nissa RC, Nuraini L, Nurtanto M, Ramadhani WS. Analysis of rice husk biochar characteristics under different pyrolysis temperature. In *IOP Conference Series: Earth and Environmental Science 2023* (Vol. 1201, No. 1, p. 012095). IOP Publishing.
81. Linam F, Limmer MA, Ebling AM, Seyfferth AL. Rice husk and husk biochar soil amendments store soil carbon while water management controls dissolved organic matter chemistry in well-weathered soil. *Journal of Environmental Management*. 2023;339:117936.
82. Oladele SO, Adeyemo AJ, Awodun MA. Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in two contrasting soils. *Geoderma*. 2019;336:1-1.
83. Adebajo SO, Oluwatobi F, Akintokun PO, Ojo AE, Akintokun AK, Gbodope IS. Impacts of rice-husk biochar on soil microbial biomass and agronomic performances of tomato (*Solanum lycopersicum* L.). *Scientific Reports*. 2022;12(1):1787.
84. Singh B, Kasera S, Mishra SK, Roy S, Rana S, Singh D. Growth, yield and quality of cherry tomato (*Lycopersicon esculentum* var. *cerasiforme*) as influenced by foliar application of Zinc and Boron. *Journal of pharmacognosy and phytochemistry*. 2017;6(6S):911-4.
85. Helyes L, Lugasi A. Formation of certain compounds having technological and nutritional importance in tomato fruits during maturation. *Acta alimentaria*. 2006;35(2):183-93.
86. Wang J, Wang S. Preparation, modification and environmental application of biochar: A review. *Journal of Cleaner Production*. 2019;227:1002-22.
87. Calcan SI, Pârvulescu OC, Ion VA, Răducanu CE, Bădulescu L, Madjar R, Dobre T, Egri D, Moț A, Iliescu LM, Jerca IO. Effects of biochar on soil properties and tomato growth. *Agronomy*. 2022;12(8):1824.

88. El-Hassanin AS, Samak MR, Radwan SR, El-Chaghaby GA. Preparation and characterization of biochar from rice straw and its application in soil remediation. *Environment and Natural Resources Journal*. 2020;18(3):283-9.
89. Veloso VD, Silva FB, Araújo PR, Paraizo TD, Souza ER, Nascimento CW. Rice straw biochar mitigates metal stress in corn and assists in the phytoattenuation of a slag-contaminated soil. *Revista Brasileira de Ciência do Solo*. 2025;49:e0240171.
90. Mukherjee A, Patra BR, Podder J, Dalai AK. Synthesis of biochar from lignocellulosic biomass for diverse industrial applications and energy harvesting: effects of pyrolysis conditions on the physicochemical properties of biochar. *Frontiers in Materials*. 2022;9:870184.
91. Tasim B, Masood T, Shah ZA, Arif M, Ullah A, Miraj G, Samiullah M. Quality Evaluation of Biochar Prepared from Different Agricultural Residues. *Sarhad Journal of Agriculture*. 2019;35(1).
92. Aller D, Bakshi S, Laird DA. Modified method for proximate analysis of biochars. *Journal of analytical and applied pyrolysis*. 2017;124:335-42.
93. Singh H, Northup BK, Rice CW, Prasad PV. Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis. *Biochar*. 2022;4(1):8.
94. Jindo, K., H. Mizumoto, Y. Sawada, M.A. SanchezMonedero and T. Sonoki. 2014. Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosci*. 11: 6613-6621.
95. Amin MN, Rehman KU, Shahzada K, Khan K, Wahab N, Alabdullah AA. Mechanical and microstructure performance and global warming potential of blended concrete containing rice husk ash and silica fume. *Construction and Building Materials*. 2022;346:128470.
96. Amin MN, Hissan S, Shahzada K, Khan K, Bibi T. Pozzolanic reactivity and the influence of rice husk ash on early-age autogenous shrinkage of concrete. *Frontiers in Materials*. 2019 2;6:150.
97. Adamchuk VI, Morgan MT, Ess DR. An automated sampling system for measuring soil pH. *Transactions of the ASAE*. 1999;42(4):885-92.

98. Slavich PG, Petterson GH. Estimating the electrical conductivity of saturated paste extracts from 1: 5 soil, water suspensions and texture. *Soil Research*. 1993;31(1):73-81.
99. Richards LA, editor. *Diagnosis and improvement of saline and alkali soils*. US Government Printing Office; 1954.
100. Ahmed MJ, Iya IR, Dogara MF. Proximate, mineral and vitamin content of flesh, blanched and dried tomatoes (*Lycopersicon esculentum*). *Asian Food Sci. J.* 2020;18(4):11-8.
101. Joung M, Kim YJ, Shin Y. Assessment of lycopene, polyphenols, antioxidant compounds, and activities in colored cherry tomato cultivars harvested in Korea. *Food Science and Biotechnology*. 2025;34(5):1161-70.
102. Huang P, Yang P, Yang L, Xiao F, Feng Y, Wang Y. Non-Destructive Detection and Visualization of Chlorophyll Content in Cherry Tomatoes Based on Hyperspectral Technology and Machine Learning. *Agriculture*. 2024;14(12):2247.
103. Ghorbani M, Asadi H, Abrishamkesh S. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. *International soil and water conservation research*. 2019;7(3):258-65.
104. Wu S, Zhang Y, Tan Q, Sun X, Wei W, Hu C. Biochar is superior to lime in improving acidic soil properties and fruit quality of Satsuma mandarin. *Science of The Total Environment*. 2020;714:136722.
105. Changxun G, Zhiyong P, Shu'ang P. Effect of biochar on the growth of *Poncirus trifoliata* (L.) Raf. seedlings in Gannan acidic red soil. *Soil Science and Plant Nutrition*. 2016;62(2):194-200.
106. Khan H, Shamim G, Gul B, Misbah M, Tasawar AC, Adnan A. Biochar and manure influences tomato fruit yield, heavy metal accumulation and concentration of soil nutrients under groundwater and wastewater irrigation in arid climatic conditions. 2019
107. Yu, O. Y., Raichie, B. & Sink, S. Impact of biochar on the water holding capacity of loamy sand soil. *Int. J. Energy Environ. Eng.* 41(1), 44–53 (2013).

108. Rawat J, Saxena J, Sanwal P. Biochar: a sustainable approach for improving plant growth and soil properties. In Biochar-an imperative amendment for soil and the environment 2019.
109. Lee Y, Park J, Gang KS, Ryu C, Yang W, Jung JH, Hyun S. Production and characterization of biochar from various biomass materials by slow pyrolysis. Tech Bull J Food Fertil Technol Center. 2013;197:1-1.
110. Kharel G, Sacko O, Feng X, Morris JR, Phillips CL, Trippe K, Kumar S, Lee JW. Biochar surface oxygenation by ozonization for super high cation exchange capacity. ACS Sustainable Chemistry & Engineering. 2019;7(19):16410-8.
111. She D, Sun X, Gamareldawla AH, Nazar EA, Hu W, Edith K, Yu SE. Benefits of soil biochar amendments to tomato growth under saline water irrigation. Scientific reports. 2018;8(1):14743.
112. Faloye OT, Ajayi AE, Alatis MO, Ewulo BS, Horn R. Nutrient uptake, maximum yield production, and economic return of maize under deficit irrigation with biochar and inorganic fertilizer amendments. Biochar. 2019;1:375-88.
113. Ronga, D. *et al.* Using digestate and biochar as fertilizers to improve processing tomato production sustainability. *Agronomy* 10, 138–145 (2020).
114. Khayyat M, Tafazoli E, Eshghi S, Rajaei S. Effect of nitrogen, boron, potassium and zinc sprays on yield and fruit quality of date palm. Am Eurasian J Agric Environ Sci. 2007;2(3):289-96.
115. Chaudhary MI. Horticulture, 5 ed. National Book Foundation Islamabad, 2006, 275.
116. Pathak D, Lone R, Koul KK. Arbuscular Mycorrhizal fungi (AMF) and plant growth-promoting Rhizobacteria (PGPR) Association in Potato (*Solanum tuberosum* L.): A brief Review. Probiotics and plant health. 2017;401-20.
117. Zare-Maivan H, Khanpour-Ardestani N, Ghanati F. Influence of mycorrhizal fungi on growth, chlorophyll content, and potassium and magnesium uptake in maize. Journal of plant Nutrition. 2017;40(14):2026-32.
118. Zhang H, Xu N, Li X, Long J, Sui X, Wu Y, Li J, Wang J, Zhong H, Sun GY. Arbuscular mycorrhizal fungi (*Glomus mosseae*) improves growth, photosynthesis

- and protects photosystem II in leaves of *Lolium perenne* L. in cadmium contaminated soil. *Frontiers in plant science*. 2018;9:1156
119. Mena-Violante HG, Ocampo-Jiménez O, Dendooven L, Martínez-Soto G, González-Castañeda J, Davies FT, Olalde-Portugal V. Arbuscular mycorrhizal fungi enhance fruit growth and quality of chile ancho (*Capsicum annum* L. cv San Luis) plants exposed to drought. *Mycorrhiza*. 2006;16:261-7.
 120. Rajasekaran S, Nagarajan SM. Effect of dual inoculation (AM fungi and *Rhizobium*) on chlorophyll content of *Vigna unguiculata* (L.) Walp. var. Pusa 151.
 121. Pinela J, Barros L, Carvalho AM, Ferreira IC. Nutritional composition and antioxidant activity of four tomato (*Lycopersicon esculentum* L.) farmer varieties in Northeastern Portugal homegardens. *Food and chemical toxicology*. 2012;50(3-4):829-34.
 122. Bello MO, Falade OS, Adewusi SR, Olawore NO. Studies on the chemical compositions and anti nutrients of some lesser known Nigeria fruits. *African Journal of Biotechnology*. 2008;7(21).
 123. Atasie VN, Akinhanmi TF, Ojiodu CC. Proximate analysis and physico-chemical properties of groundnut (*Arachis hypogaea* L.). *Pakistan journal of Nutrition*. 2009;8(2):194-7.
 124. Oboulbiga EB, Parkouda C, Sawadogo-Lingani H, Compaoré EW, Sakira AK, Traoré AS. Nutritional composition, physical characteristics and sanitary quality of the tomato variety Mongol F1 from Burkina Faso. *Food and Nutrition Sciences*. 2017;8(4):444-55.
 125. Buttriss JL, Stokes CS. Dietary fibre and health: an overview. *Nutrition Bulletin*. 2008;33(3):186-200.
 126. Ijaz F, Ashfaq A, Ahmed A, Afzal A. Assessment of antioxidants and Nutritional analysis of persimmon and Grapefruit juice. *Phytum*. 2025;1(1):01-11.
 127. Abreu AC, Fernández I. NMR metabolomics applied on the discrimination of variables influencing tomato (*Solanum lycopersicum*). *Molecules*. 2020;25(16):3738.

128. Hamid KA, Mustafa AE, Salem HM, Ismaiel SM, Amin MA. Effect of salinity and ascorbic acid treatments on growth, yield and antioxidant enzymes activity of barley plants. *Al-Azhar Journal of Agricultural Research*. 2024;49(1):117-29.
129. Massa D, Bonetti A, Cacini S, Faraloni C, Prisa D, Tuccio L, Petruccelli R. Soilless tomato grown under nutritional stress increases green biomass but not yield or quality in presence of biochar as growing medium. *Horticulture, Environment, and Biotechnology*. 2019;60:871-81.
130. Wang Y, Pan F, Wang G, Zhang G, Wang Y, Chen X, Mao Z. Effects of biochar on photosynthesis and antioxidative system of *Malus hupehensis* Rehd. seedlings under replant conditions. *Scientia Horticulturae*. 2014;175:9-15.

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