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Phytochemical, nutritional analysis and antibacterial evaluation of leaf of *Coriandrum sativum* L. grown in organic media

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Abstract

The phytochemical composition, nutritional profile, and antibacterial properties of *Coriandrum sativum* L. are comparatively reduced in soilless cultivation systems like Peat-based media compared to traditional soil-based cultivation. Nevertheless, soilless systems offer advantages in terms of increased yield, water use efficiency, and improved nutrient management. A study was conducted to evaluate nine treatments comprising five distinct soilless substrates coconut shell powder-CSP, vermicompost, dried coir pith, rice husk, and perlite in various combinations, compared against soil cultivation in a vertical garden setup. Gas chromatography-mass spectrometry (GC-MS) analysis of methanolic extracts from 45-day-old coriander leaves identified 31 bioactive compounds. The phytochemical profile exhibited significant variability in terms of peak area (PA) percentage and retention time (RT), with notable compounds including tetradecanoic acid and hexadecanoic acid. Biochemical assays revealed that the CSP and P combination yielded significantly higher (p<0.05) total sugar (6.32%) and reducing sugar (2.49%) concentrations compared to other treatments. The dried coir pith and vermicompost combination demonstrated significantly elevated total phenol content (2.46%). Additionally, dried coir pith exhibited a balanced acidity profile (0.59%). The treatments also influenced the concentrations of various nutrients, including ascorbic acid, carotenoids, and starch. Antibacterial susceptibility tests demonstrated that methanolic leaf extracts possess antibacterial activity against both *Escherichia coli* and *Staphylococcus aureus*, with *E. coli* exhibiting marginally larger zones of inhibition (11 mm) compared to *S. aureus* (10 mm). These findings elucidate the potential of soilless cultivation systems for optimizing coriander production while highlighting the plant's phytochemical diversity and antimicrobial properties. These attributes warrant further investigation for potential applications in the pharmaceutical and agricultural sectors.

1. Introduction

Coriander, valued for its culinary and medicinal properties, enhances flavor and aroma in dishes while supporting digestion and alleviating symptoms like indigestion and bloating (Kumar *et al.,* 2018; Singh *et al.,* 2019). Its biochemical profile includes essential oils, fatty acids, sterols, and bioactive compounds such as flavonoids, phenolic acids, and terpenes, contributing to its antioxidant, anti-inflammatory, antimicrobial, and antibacterial properties (Laribi *et al.,* 2015). The therapeutic value of coriander stems from its secondary metabolites. The essential oil from coriander seeds contains linalool (60-70%), γ-terpinene, and α-pinene (Mandal and Mandal, 2015). Antioxidant activity is linked to flavonoids like quercetin and kaempferol, and phenolic compounds such as caffeic and chlorogenic acids (Sreelatha and Inbavalli, 2012). Research has revealed potential health benefits, including antidiabetic, anticancer, neuroprotective, and cardioprotective effects (Prachayasittikul *et al.,* 2018; Pushpangadan, Ijinu and George, 2015).

Coriander's antimicrobial activity is well-documented, with its essential oil and extracts showing strong antibacterial effects against both Gram-positive and Gram-negative species (Silva *et al.,* 2011). Gas chromatography-mass spectrometry (GC-MS) has been crucial in decoding coriander's complex chemical makeup, and identifying compounds responsible for its antibacterial properties (Shahwar *et al.,* 2012; Ashok, 2021). Solid soilless rooting media, such as peat, coconut coir, perlite, and vermiculite, have gained importance in cultivating medicinal plants like coriander. These media enhance growth, yield, and quality by improving nutritional content and concentrations of secondary metabolites (Papadopoulos *et al.,* 2008; Raviv and Lieth, 2008). Soilless media improve aeration, water retention, and nutrient availability, promoting better root development and overall plant health (Dorais *et al.,* 2001; Gruda,

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2009). Coriander grown in soilless systems has shown enhanced production of linalool, broadening its antibacterial efficacy (Mandal and Mandal, 2015; Sriti *et al.,* 2011). However, the effectiveness of soilless media can vary, necessitating further research (Olympios, 1999; Singh *et al.,* 2024).

GC-MS is crucial for identifying and measuring compounds in plant samples, playing a vital role in phytochemical analysis and chemotaxonomic investigation of medicinal plants (Uma and Balasubramaniam, 2012; Hethelyi *et al.,*1987). Biochemical and nutritional analyses are essential for assessing nutritional value, discovering bioactive compounds, and refining agricultural practices (Madhu *et al.,* 2016). The assessment of antibacterial activity in plants is crucial for discovering potential natural antimicrobial agents to address resistant bacterial strains and reduce dependence on synthetic antibiotics. Plants with notable antibacterial properties can provide new compounds with distinct mechanisms, aiding the development of alternative therapeutic agents (Bittner Fialová *et al.,* 2021).

2. Materials and Methods

2.1 Authentication of plant material

The coriander CO_4 variety used in this research work has the authentication number BSI/SRC/5/23/2024-25/Tech./422. This number was issued by the Botanical Survey of India in Coimbatore, confirming that the crop variety is properly identified and certified for research use.

2.2 Plant specimen acquisition

The coriander plant variety CO4 was used for this study. This variety was released in Tamil Nadu Agricultural University in 2002 (TNAU varieties_1971-2003.pdf). It is a pedigree of reselection from germplasm of ATP 77 Guntur collection with an average yield of 600 kg per ha with improved characteristics such as fast growing, high yielding, and short duration (60-65 days), suitable for both kharif and rabi seasons. It is also field tolerant to wilt and grain mold.

2.3 Plant specimen collection

The plant samples for analysis were collected from the vertical herbal garden which was grown in nine different soilless rooting media combination of equal proportions, *viz.,* T1-Control-Soil , T2-CSP-Coconut shell powder, T3-CSP + Vermicompost, T4-CSP + Dried coir pith, T5-CSP + Rice husk, T6-CSP + perlite, T7-CSP + Dried coir pith + Vermicompost, T8-CSP + Rice husk + Vermicompost, T9-CSP+ perlite + Vermicompost and the plants were grown under open condition which was watered twice in a week. At the stage of 45 days after sowing, first harvesting was done and leaf samples were collected. The leaf samples were cleaned in running water, drained and dried in shade. The moisture-free specimen was grounded using a blender to attain the powder of *C. sativum* leaves, which was used as sample for further analysis.

2.4 Specimen setup for GC-MS

5 g of grounded sample was isolated using 50 ml of HPLC-grade methanol (1:10 w/v ratio) for 24 h at room temperature on an orbital shaker adjusted to 150 rpm. After the extraction, the solution was passed through Whatman No. 1 filter paper, and the filtrate was subjected to concentration using a rotary evaporator at 40°C under reduced pressure. The concentrated residue is then reconstituted in 2 ml of methanol and further purified by passing it through a 0.22 ìm syringe filter before being transferred into a GC-MS vial for subsequent analysis.

GC-MS analysis typically involves utilizing a capillary column (*e.g.*, HP-5MS, 30 m × 0.25 mm, 0.25 ìm film thickness) with helium as the carrier gas. The oven temperature program started at 60°C and ramped up to 280°C, with a total run duration of around 40 min. The mass spectrometry parameter includes the ionization source maintained at a temperature of 230°C, with a mass scan range set between m/z 50-550. This approach was to identify and quantify a variety of volatile chemicals in coriander, including essential oils, terpenes, and other secondary metabolites. This was done to get an insight into the plant's chemical makeup and possible biological activity. The analysis was conducted using an Agilent GC 7890A / MS5975C system equipped with an Agilent DB5MS chromatographic column. The column had a length of 30 m, a reference analyte diameter of 0.25 mm, and an adsorbent film depth thickness of 0.25 µm. Sample injection was performed in split mode, with helium serving as the carrier gas. Prior to analysis, the sample extract was dissolved in 100% methanol. Compound identification was achieved by comparing retention times and peak area percentages with the NIST spectral library. This methodology was based on references from Shahwar *et al.* (2012), Mandal and Mandal, (2015).

2.5 Biochemical analysis

2.5.1 Reducing sugars

To estimate the reducing sugars, the Nelson-Somogyi reducing sugar assay was used. The sample was diluted by adding 1 ml to a test tube with 1 ml of alkaline copper tartrate reagent. After heating for 10 min in a water bath and cooling, 1 ml of arsenomolybdate reagent was added and mixed. The solution was then diluted with 7 ml of distilled water, and absorbance was measured at 620 nm. Reducing sugar content was quantified by comparing the absorbance to a glucose standard curve (Gusakov *et al.*, 2011).

2.5.2 Total sugars

The Anthrone method is a colorimetric technique commonly used to measure total sugar content in different samples (Dische, 1962). In this method, sugars react with anthrone reagent, forming a coloured complex that can be quantified using a spectrophotometer . The absorbance of this complex is directly related to the total sugar level, which is figured out by matching the light reading to a reference graph (Dubois *et al.,*1956). Due to its simplicity, sensitivity, and reliability, this method is extensively utilized in various fields, including food science, plant biology, and biochemical.

2.5.3 Carotenoids

To determine the carotenoids content in the leaf sample, the SK ROY method was utilized. 1 g of sample and a petrol ether : acetone mixture (3:2 ratio) were added. The mixture was ground with a pestle and mortar, and the clear upper layer was gathered. The total volume was completed to 50 ml with the petroleum ether: acetone mixture (3:2 ratio). The collected sample was subjected to spectrophotometric analysis at 450 nm. For the blank, a petroleum ether: acetone mixture (3:2 ratio) was used (Negi and Roy, 2003).

2.5.4 Acidity

The acid-base titration method was used to determine the acidity range in a sample. To accomplish this, 5 g of the sample was pulverized and dissolved in 30 ml of distilled water. The mixture was then filtered through filter paper. Next, 5 ml of the filtrate and 2 drops of phenolphthalein indicator were added to the solution. Titration is then carried out using 0.1 N NaOH. The endpoint of the titration is indicated by the appearance of a pink colour (Cookson, 1974).

2.5.5 Phenols

Folin-Ciocalteu assay method was used for extraction and quantifying phenolic compounds from a sample. The sample was ground with 80% methanol to extract the phenolic compounds, which were then separated by centrifugation. The supernatant was diluted with water, and a small aliquot was combined with Folin-Ciocalteu reagent and sodium carbonate. This mixture was heated, and the resulting blue colour was measured using a UV spectrometer at 700 nm. This was useful for characterizing the antioxidant properties in the plant sample (Rover and Brown, 2013).

2.5.6 Starch

A 0.5 g pellet, with total sugars removed, was taken for starch analysis. The sample was combined with 5 ml of cold distilled water and 6.5 ml of 52% perchloric acid (PCA), immersed in an ice bath for 20 min, and subsequently centrifuged at 5,000 rpm for 20 min. The supernatant is collected, and the process was repeated three times. The final supernatant is adjusted to 100 ml with distilled water. A 0.5 ml aliquot of this solution was then combined with 4 ml of pre-cooled Anthrone reagent, while the blank consists of 1 ml of distilled water and 4 ml of Anthrone reagent The test tubes are heated in a boiling water bath for 8 min, producing a green or dark green colour, which was then assessed at 630 nm relative to the blank (Buckan, 2015).

2.5.7 Ascorbic acid

To estimate ascorbic acid using the volumetric method, the first standard ascorbic acid solution was prepared and diluted to a known concentration. Add 10 ml of the sample to a conical flask, followed by 1 ml of a 2% starch indicator solution. Titrate with a standardized iodine solution until a blue-black tint appears, indicating the finish. The ascorbic acid content is then calculated based on the volume of iodine used, as this method depends on the reduction of iodine by ascorbic acid (Ranganna, 1977; AOAC, 1990).

2.6 Antibacterial activity (Kirby-Bauer method)

2.6.1 Inoculum cultivation

Three to five discrete colonies exhibiting homogeneous morphological characteristics were selected from a solidified agar medium. Utilizing an aseptic inoculation loop, the apical portion of each colony was sampled, and the microbial biomass was transferred into a sterile culture vessel containing 4-5 ml of a suitable liquid growth substrate, such as a nutrient-rich broth medium. The broth culture was incubated at 35°C until it reached the desired turbidity level, typically within 2 to 6 h. The cloudiness of the actively proliferating broth culture was subsequently standardized using sterile saline or broth to reach the desired turbidity, resulting in a suspension containing roughly 1 to 2 x 10^8 CFU/m of *E. coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive). This preparation was done in accordance with the Kirby-Bauer protocol (1996).

2.6.2 Culturing on test plates

Ideally, within the next 15 min of standardizing the density of the inoculum solution, a sterile cotton swab was soaked in it. The swab was then twisted multiple times and pressed firmly against the inner surface of the tube above the liquid line to remove any excess inoculum. The dry top of a food-filled plate was rubbed with germs across its whole clean surface. To ensure even distribution of the inoculum, the swabbing was repeated twice, rotating the plate by approximately 60° each time. Finally, the edge of the growth medium was streaked. The dish top was left a bit open for 3 to 5 min, but no longer than 15 min. This lets extra wetness on top dry up before putting the medicine-soaked circles on it. A 6 mm diameter well was made in the medium and filled with 20 µl to 100 µl of the sample. The petri dishes were subsequently inverted to ensure thorough diffusion, and the inhibition zones were evaluated by measuring the diameter (in mm) of the clear areas surrounding the wells after 24 h of incubation at 37°C. The zones were measured using a calibrated ruler (Hi-Media).

2.6.3 Statistical analysis

Each characterization data set's results were derived using the mean technique of three replicates, and a complete randomization design was analysed using GRAPES software for statistical analysis. The statistical analysis of the data on parameters examined during study was conducted following (Gomez and Gomez, 1984) analysis. The crucial difference was calculated at a five percent probability level in cases where the treatment differences were found significant ("F" test). "NS" stands for "non-significant" for treatment differences.

3. Results

3.1 GC-MS profiling

The GC-MS chromatogram of the methanolic extracts of *C. sativum* (Figure 1) displayed a total of 31 peaks, representing bioactive substances. These were identified by evaluating the elution duration and peak intensity percentage through comparison with the NIST spectral database and real-time GC-MS analysis. The identified phytoconstituents are listed in Table 3. The chromatogram clearly demonstrated the presence of multiple phytochemicals in the extract, many of which are known for their phytochemical and pharmacological properties, such as antifungal, antibacterial, anticancer, and anti-inflammatory activities. Notable compounds detected in the methanolic extract of coriander leaves include tetradecanoic acid, hexadecanoic acid, 2-Hydroxy-2,6,10,14-tetramethylpentadecane, oleic acid, octadecanoic acid, heptacosyl acetate, and cyclotetracosane.

3.2 Biochemical analysis and nutritional properties of *C. sativum*

3.2.1 Biochemical analysi

The biochemical analysis of coriander grown under nine different soilless rooting media treatments, analysed using the completely randomized design (CRD) method, revealed significant variations across total sugars, reducing sugars, non-reducing sugars, total acidity, and total phenols. Total sugars ranged from 5.42% in the control-soil media T1 to 6.32% in the CSP + Perlite treatment (T6), with

significant differences among treatments, particularly in T4 - CSP + Dried coir pith, T6, and T7 - CSP + Dried coir pith + Vermicompost. Reducing sugars varied from 2.07% in T1 to 2.49% in T6, with T2 (CSP), T6, and T7 showing significantly higher values. Non-reducing sugars ranged from 3.349% in T1 to 3.781% in T6, but differences were not statistically significant. Total acidity varied significantly, ranging from 0.4485% in T3 - CSP + Vermicompost) to 0.588% in T4, with treatments T2, T4, and T8 - CSP + Rice husk + Vermicompost exhibiting higher acidity. Total phenols ranged from 1.9% in T8 to 2.46% in T7, with T7 showing the highest phenol content, which is beneficial for enhancing the antioxidant properties of coriander. The analysis suggests that CSP + Perlite -T6 is particularly effective in increasing sugars, CSP + Dried coir pith - T4 enhances acidity, and CSP + Dried coir pith + Vermicompost - T7 boosts phenol content, demonstrating that selecting appropriate soilless media can significantly impact the biochemical composition and quality of coriander.

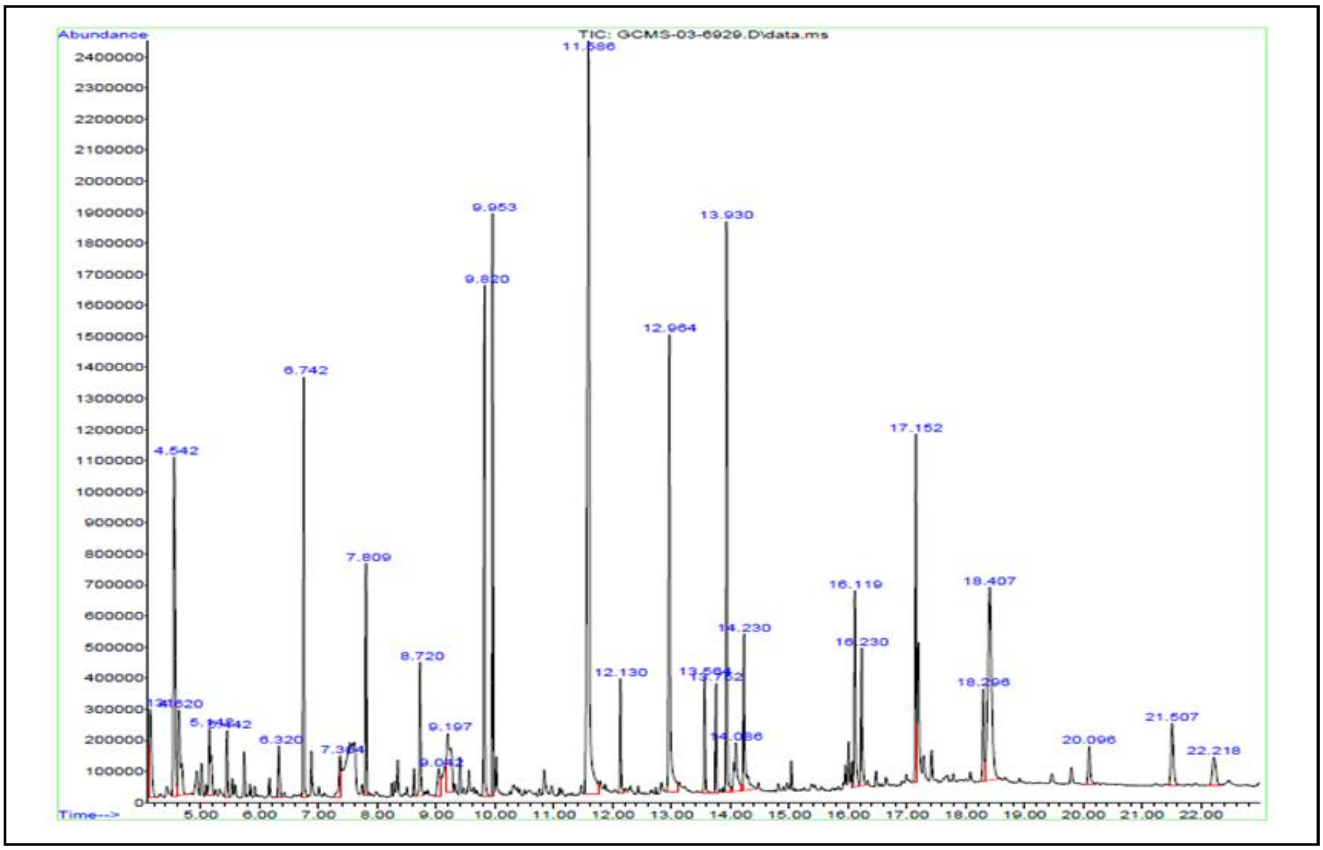
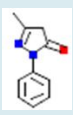
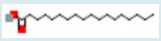
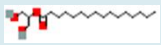
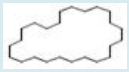
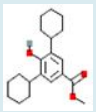
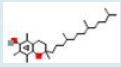
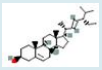
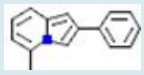


Figure 1: GC-MS chromatogram of methanolic extracts of *C .sativum*.

Table 1: List of major phytochemicals recognized through GC-MS analysis

S. No.	Name of the compound	Molecular formula	Molecular weight g/mol	Structure	PA%	RT time	Functions	Reference
1.	Tetradecanoic acid	$C_{14}H_{28}O_2$	228.37		17.54	11.58	Larvicidal and repellent activity	Sivakumar *et al.*, 2011
2	2,6,6-Trimethyl-bicyclo [3.1.1] heptane	$C_{10}H_{18}$	138.25		1.11	12.130	Pharmacokinetic and physicochemical properties	Frank *et al.*,2022
3	n-Hexadecanoic acid;	$C_{16}H_{32}O_2$	256.42		7.20	12.964	Anti-inflammatory property	Aparna *et al.*,2012
4	3,4-dihydroiso-coumarin;.	$C_{14}H_{16}O_3$	232.27		1.52	13.564	It has isocoumarins property in it	Saddiqa, ÇAKMAK and USMAN, 2017
5	3H-Pyrazol-3-one, 2,4-dihydro-5-methyl-2-	$C_{10}H_{10}N_2O$	174.2		1.26	13.752	Anti-inflammatory activity	Karrouchi *et al.*, 2018.

6	Phytol	$C_{20}H_{40}O$	296.5		6.64	13.930	Anti-inflammatory property	Blum *et al.*,2018
7	oleic acid	$C_{18}H_{34}O_2$	282.5		1.48	14.086	Has cardiovascular health, antidiabetes effects and anti-inflammation activity	Sales-Campos *et al.*,2013
8	1-octadecanoic acid	$C_{18}H_{36}O_2$	284.5		2.74	14.230	Antioxidant activity	Kousalya *et al.*,2023
9	n-Tetracosanol-1; ...	$C_{24}H_{50}O$	354.7		3.04	16.119	Antioxidant activity	Kousalya *et al.*,2023
10	Hexadecanoic acid, 2-hydroxy-1-(hydroxymethyl)ethyl ester; ...	$C_{19}H_{38}O_4$	330.5		2.03	16.230	Antiulcer potential	Kousalya *et al.*,2023
11	Cyclotetracosane	$C_{24}H_{48}$	336.6		4.29	17.152	Anti-microbial activity	Buzón-Durán *et al.*,2023
12	Heptacosyl acetate	$C_{29}H_{58}O_2$	438.8		1.48	18.296	Used for treatment of liver disease	Farghali, Canová and Zakhari, 2015
13	Methyl 3,5-dicycl-ohexyl-4-hydroxy-benzoate	$C_{20}H_{28}O_3$	316.4		7.68	18.407	Antiobesity and anticancer property in it	Subramanian *et al.*, 2020
14	DL-ALPHA-TO COPHEROL	$C_{29}H_{50}O_2$	430.7		0.79	20.096	Free-radical proper ties in it	Al-Ostoot *et al.*, 2021
15	STIGMASTEROL	$C_{29}H_{48}O$	412.7		1.53	21.507	Antiosteoarthritic property	Gabay *et al.*,2010
16	5-Methyl-2-phen-ylindolizine	$C_{15}H_{13}N$	207.27		0.99	22.218	Antioxidant and antimicrobial activity in it	Al-Ostoot *et al.*, 2021

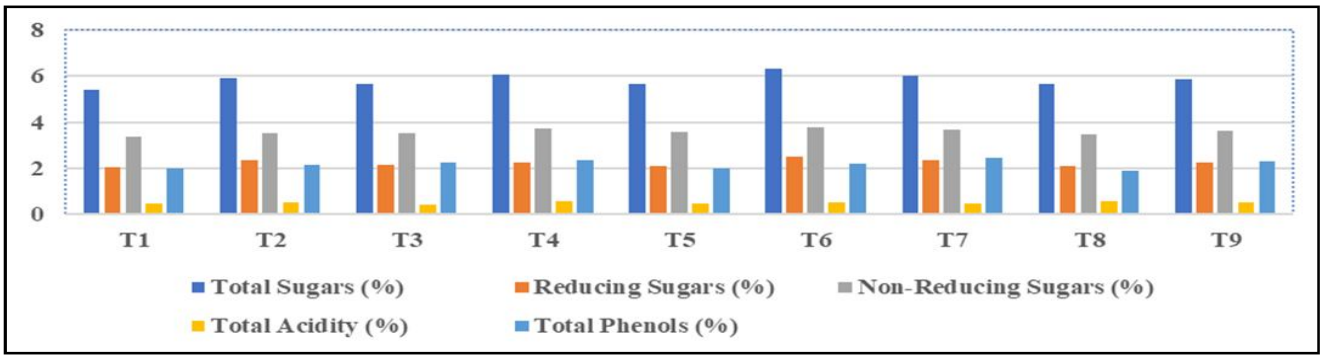


Figure 2: Biochemical properties of coriander grown under different soil less media.

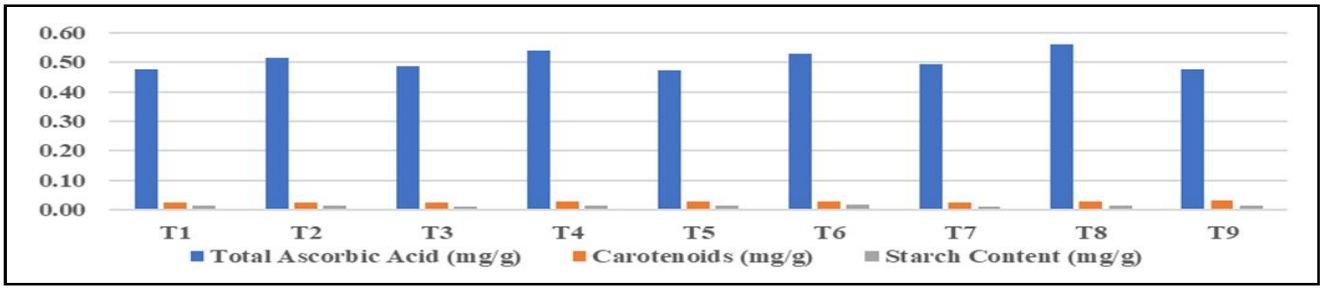


Figure 3: Nutritional properties of coriander grown under different soil less media.

3.2.2 Nutritional analysis

The nutritional data of coriander grown under nine different soilless rooting media, analysed using the completely randomized design (CRD) method, shows significant variation in total ascorbic acid, carotenoids, and starch content. Ascorbic acid content ranged from 0.474 mg/g in T5 - CSP + Rice husk to 0.559 mg/g in T8 - CSP + Rice husk + Vermicompost, with the highest value in T8 indicating the effectiveness of vermicompost in enhancing ascorbic acid levels. Carotenoids varied from 0.024 mg/g in T3 - CSP + Vermicompost to 0.030 mg/g in T9 - CSP + Perlite + Vermicompost, with T9 showing the highest content, suggesting that perlite and vermicompost combinations are beneficial for carotenoid synthesis. Starch content ranged from 0.011 mg/g in T7- CSP + Dried coir pith + Vermicompost to 0.016 mg/g in T6 - CSP + Perlite, where T6 exhibited the highest starch accumulation, likely due to improved aeration and nutrient uptake. The statistical analysis, with critical differences (CD) at the 5% level being 4.15 for ascorbic acid, 0.05 for carotenoids, and 0.16 for starch, confirms that the observed differences among treatments are significant. Overall, the data indicates that vermicompost and perlite are key components in enhancing the nutritional quality of coriander, with treatments like T8, T9, and T6 performing the best across the different parameters.

3.3 Antibacterial assay

The study assessed the antibacterial properties of plant leaf extracts against two bacterial species, *E.coli* (-ve) bacteria and (+ve) *S.aureus* bacteria, utilizing the region of inhibition technique (Musini *et al.,* 2013). The methanolic leaf extract demonstrated antimicrobial efficacy against both bacterial strains tested. The results indicated slightly larger inhibition zones for *E. coli* compared to *S. aureus,* suggesting that the leaf sample exhibits a marginally more potent antibacterial effect on *E. coli* than on *S. aureus.*

The antimicrobial activity of coriander leaves was evaluated against two bacterial strains, *S. aureus* and *E. coli*, and compared to the standard antibiotic gentamicin. The results showed that gentamicin produced a 29 mm zone of inhibition for both *S. aureus* and *E. coli*. In comparison, coriander leaves demonstrated more modest antimicrobial effects, with a 10 mm zone of inhibition against *S. aureus* and an 11 mm zone against *E. coli*. These findings indicate that while coriander leaves do possess some antimicrobial properties, their effectiveness is considerably less than that of the standard antibiotic. The slightly larger inhibition zone for *E. coli* suggests that coriander leaves may be marginally more effective against this gram-negative bacterium compared to the gram-positive *S. aureus*, although the difference is minimal.

4. Discussion

The Gas chromatography-mass spectroscopy (GC-MS) analysis of methanolic leaf extract from *C. sativum* identified thirty-one distinct peaks, as detailed in Table 1 and Figure 1. The chromatogram revealed that 1S-α-pinene was the first compound detected, with a retention time of 4.31 min. Notably, 5-methyl-2-phenylindolizine showed the largest peak area, with a retention time of 22.218 min. Previous studies have highlighted the medicinal properties of coriander oil, including its antimicrobial activity against certain pathogens (Ishikawa *et al.,* 2003; Martins *et al.,* 2003), antioxidant properties (To Quynh *et al.,* 2009), and its potential as an antidiabetic (Pourmortazavi and Hajimirsadeghi, 2007), anticancer, and antimutagenic agent (Shavandi *et al.,* 2012). The substantial presence of oleic acid (38.55%) suggests that *C. sativum* could be an excellent source of this compound, which can be extracted from its fruit using soxhlation Shahidi (2009) emphasized the importance of the synergistic effects of phytochemicals from various sources in the development of functional foods and the selection of a balanced diet, highlighting their collective beneficial impact.

4.1 Phytochemical analysis

4.1.1 Sugar content

The plant growth in T6 CSP + Perlite produced the highest total sugar content (6.32%) and reducing sugar content (2.49%). This result is consistent with the findings of (Zheng *et al.,* 2010), who observed that perlite-based substrates boost

carbohydrate accumulation in leafy vegetables. The increased sugar content is likely due to perlite's superior aeration and water retention properties, which enhance root respiration and nutrient absorption. Additionally, Mirseyed *et. al*. (2023) reported that coconut shell powder - CSP improves soil structure and microbial activity, which may contribute to enhanced sugar synthesis. The variation in sugar content across different treatments highlights the significant impact of substrate composition on carbohydrate metabolism in coriander. For example, the coriander plant grown T4 CSP + Dried coir pith showed second-highest total sugar content (6.08%), this is supported by findings of Xiong *et al.* (2017) Mohanalakshmi *et al*. (2024) shows that coir pith improves nutrient retention and microbial activity, potentially enhancing photosynthetic efficiency and sugar accumulation.

4.1.2 Phenolic compounds

The coriander plant grown under treatment T7 - CSP + Dried coir pith + Vermicompost showed the highest total phenol content (2.46%), consistent with the findings of (Pandey *et al.,* 2016), who noted that vermicompost significantly boosts phenolic compound production in medicinal plants. The increase in phenol content can be attributed to vermicompost's contribution to enhanced soil fertility, microbial diversity, and the presence of plant growth regulator. Also, T4 -CSP + Dried coir pith also exhibited high phenol concentrations (2.35%), possibly due to coir pith inducing mild stress conditions that trigger phenolic synthesis as a defensive response. This notion is supported by Sharma *et al.* (2019), who observed increased phenolic production in plants subjected to moderate stress conditions.

4.1.3 Ascorbic acid and carotenoids

The ascorbic acid content varied across treatments, with T8 - CSP + Rice husk + Vermicompost showing the highest concentration at 0.559 mg/g. This finding is consistent with Kumar *et al.* (2012), who observed that soils amended with rice husk improved vitamin C content in leafy vegetables. The synergistic effect of rice husk and vermicompost likely enhanced nutrient availability and stress tolerance, thereby promoting ascorbic acid synthesis. Carotenoid levels were highest in T9-CSP + Perlite + Vermicompost at 0.030 mg/g, aligning with research by Wang *et al.* (2015), who found that perlite-based substrates boosted carotenoid accumulation in leafy greens. The combination of improved aeration and water retention from perlite, along with the nutrient-rich properties of vermicompost, may have optimized conditions for carotenoid biosynthesis.

4.1.4 Starch content

Treatment T6 -CSP + Perlite yielded the highest starch content (0.016 mg/g). This finding aligns with research by Wang *et al.* (2009), Maragatham *et al.* (2014), who reported increased starch accumulation in plants grown in perlite-amended substrates. The improved starch content can be attributed to enhanced carbon fixation and allocation, resulting from the optimized root environment provided by perlite. This environment likely promotes better root respiration and nutrient uptake, which are critical for starch biosynthesis.

4.1.5 Interrelationships and physiological implications

The observed variations in biochemical and nutritional profiles across treatments underscore the intricate interplay between plant physiology and substrate properties. For instance, the increased sugar and starch content in T6 - CSP + Perlite suggests improved photosynthetic efficiency and carbon allocation. This aligns with research by Zhang Hui Meng *et al.* (2017), who found that perlite-based substrates enhance chlorophyll content and photosynthetic rates in leafy vegetables. Moreover, the elevated levels of phenolic compounds in treatments containing vermicompost T7, T9 may indicate a priming effect on the plant's defence mechanisms. This is consistent with findings by Olivares *et al.* (2015), who reported that humic substances derived from vermicompost can activate systemic resistance pathways in plants, leading to increased synthesis of secondary metabolites like phenolics.

The varied ascorbic acid and carotenoid levels across treatments suggest differential activation of antioxidant systems, likely influenced by substrate-induced stress or varying nutrient availability. This aligns with findings by Rouphael *et al.* (2018), who reported that substrate composition significantly affects the synthesis of antioxidant compounds in leafy greens by modulating oxidative stress and nutrient uptake. The results indicate that the choice of substrate can play a crucial role in enhancing the nutritional quality of crops by influencing their biochemical pathways and stress responses.

4.1.6 Antibacterial activity

The methanolic leaf extract exhibited antibacterial efficacy against both *E. coli* and *S. aureus*, with slightly larger inhibition zones observed for *E. coli*. This observation is consistent with the findings of Saeed and Tariq (2007), who noted that coriander extracts demonstrate stronger antibacterial activity against gram-negative bacteria like *E. coli* compared to Gram-positive bacteria such as *S. aureus*. The differential effectiveness is likely due to the variations in cell wall structure between these bacterial types, along with the specific phytochemical composition of the coriander extract. The antibacterial activity observed in this study correlates with the bioactive compounds identified in the GC-MS analysis, including fatty acids and phenolic compounds. These results support the traditional use of coriander as a natural antimicrobial agent and highlight its potential applications in food preservation and pharmaceutical industries.

5. Conclusion

This in-depth study on *C. sativum* highlights the profound impact of substrate composition on the plant's biochemical properties and potential applications. The research concluded that combinations of coconut shell powder (CSP) with substrates like perlite, vermicompost and dried coir pith significantly enhance the plant's sugar content and overall nutritional profile. Notably, the CSP + Perlite treatment yielded the highest total sugar content, suggesting that the optimal aeration and water retention provided by perlite may facilitate greater carbohydrate accumulation. The integration of vermicompost was found to significantly elevate phenolic compound production, which could enhance the plant's antioxidant capabilities. The highest phenolic content was observed in the CSP + Dried coir pith + Vermicompost treatment, indicating that vermicompost's contribution to soil fertility and microbial activity may stimulate secondary metabolite synthesis.

Additionally, variations in ascorbic acid and carotenoid levels across different treatments reflect the influence of substrate composition on vitamin biosynthesis. Further, the antibacterial activity against both *E. coli* and *S. aureus*, with a slightly higher efficacy against *E. coli*, pointing to the broader antibacterial potential of coriander. These findings are further corroborated by GC-MS analysis, which identified a diverse range of bioactive compounds, including fatty acids and phenolic compounds. Collectively, this research not only validates the traditional medicinal uses of coriander but also underscores its potential applications in food preservation and natural medicine. The study's outcomes provide essential insights for optimizing coriander cultivation to enhance specific nutritional or bioactive properties, paving the way for targeted production strategies in the nutraceutical and functional food industries.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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