

Optimizing Cultivation Parameters and Bioactive Potential of *Curcuma longa* L. in Non-Traditional Climates

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Abstract This study evaluated the impact of various soil amendments on turmeric (*Curcuma longa*) biomass production, curcuminoid concentration, and subsequent antibacterial efficacy. Twenty soil treatments, including a control, were applied to raised beds. Post-harvest, total biomass was recorded as fresh weight. Curcumin content was quantified via High-Performance Liquid Chromatography (HPLC), and the resulting extracts were screened for antibacterial activity against *Bacillus cereus* and *Escherichia coli*. Soil amendments applied at a nitrogen concentration of 300 kg/ha significantly enhanced turmeric biomass compared to other treatments. Furthermore, the treatments influenced the secondary metabolite profile, with specific amendments yielding peak curcumin concentrations. These findings suggest that optimized nitrogen-based soil amendments not only maximize physical yield but also enhance the bioactive potential of turmeric, providing a strategic approach for high-quality pharmaceutical-grade cultivation.

Keywords: *Curcuma longa*, Curcuminoids, Nitrogen Management, Secondary Metabolites, Antibacterial Efficacy

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1. Introduction

1.1. Botany

Curcuma longa L. belongs to the family *Zingiberaceae*, which is found in the order *Zingiberales* of monocots. The family is composed of 47 genera and 1400 species of perennial spices [1,2]. The genetic variation of turmeric contributes to rhizome size and orientation [3]. The rhizome of turmeric is the stem that grows underground. As it grows, it branches into the "mother" rhizome and its "fingers" which extend laterally from the "mother". All rhizomes can give rise to a new plant and are known as seedlings. Mother rhizomes are used to give rise to primary rhizomes which can produce aerial shoots. Primary rhizomes can also give rise to secondary and tertiary rhizomes, and these rhizomes do not produce aerial shoots. The mother rhizome and its fingers combined form a three-dimensional ovule shape. Aerial shoots may be produced from the underground bulb consisting of nodes with buds on its axils. Primary fingers may also produce aerial shoots.

1.2. Genetic Variation, Origin, and Production

Turmeric is the most popular yellow colorant in the world [4], also known as the "Indian saffron". Turmeric derives its name from the Latin word *terra merita*, meaning meritorious earth, which is a liquid product resembling a pigment of the color of ground turmeric [5,6]. The Latin name, *Curcuma*, is derived from the Arabic word, Kourkoum, which was the original name for saffron, another yellow dye [7].

Turmeric is widely grown in countries such as India, China, Nigeria, Pakistan, Myanmar, Indonesia, Bangladesh, Sri Lanka, Taiwan (Table 1).

India ranks first in the region and in production among these countries [8]. The origin of turmeric indicates that it could be Southeast Asia [9]. There are several species of *C. longa* found in India; it suggests that its origin is in India, however, it has been reported that there is no conclusive indication indicating it is native to India [10]. India, however, is the largest producer, consumer, and exporter [1], producing in 230 districts in 22 states [5].

Andhra Pradesh, Tamil Nadu, Odisha, Karnataka, and

West Bengal are the major turmeric-producing states in India, contributing 80% of the production in the country [5]. Various *Curcuma* species were identified on a state-wise level in India; about 20 species were identified in Kerala, and about 11 were reported in Karnataka [9] (Table 2).

Turmeric is concentrated with various compounds, including its main bioactive compound, curcumin (Figure 1). Turmeric contains approximately 69.4%

carbohydrates, 6.3% protein, and 5.1% fat. Its primary bioactive compounds are curcuminoids, consisting of curcumin (70–75%), demethoxycurcumin (10–20%), and bisdemethoxycurcumin (5–10%), representing 2–9% of the active components [11].

Among all *Curcuma* species, *Curcuma longa* showed the highest concentration of each compound that was found (Figure 2).

Table 1. *Curcuma longa* distribution worldwide

Country	Approximate number of species
Bangladesh	16–20
China	20–25
India	40–45
Cambodia, Vietnam, and Laos	20–25
Malaysia	20–30
Nepal	10–15
The Philippines	12–15
Thailand	30–40
Total	100–110

Source: [32]

Table 2. *Curcuma longa* species and geographic distribution

Species	Geographic Distribution (State-wise)
<i>C. aeruginosa</i>	West Bengal
<i>C. albiflora</i>	Kerala
<i>C. amada</i>	Throughout India
<i>C. amarissima</i>	West Bengal
<i>C. angustifolia</i>	Uttar Pradesh, Madhya Pradesh, Himachal Pradesh, Northeast India
<i>C. aromatica</i>	Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Odisha, and Biha
<i>C. caesia</i>	West Bengal
<i>C. caulina</i>	Maharashtra
<i>C. comosa</i>	West Bengal
<i>C. petiolata</i>	West Bengal
<i>C. decipiens</i>	Kerala and Karnataka
<i>C. rubescens</i>	West Bengal
<i>C. ferruginea</i>	West Bengal
<i>C. longa</i>	Throughout India
<i>C. montana</i>	Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh
<i>C. oligantha</i>	Kerala
<i>C. pseudomontana</i>	Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh
<i>C. reclinata</i>	Madhya Pradesh
<i>C. xanthorrhiza</i>	West Bengal
<i>C. zedoaria</i>	Throughout India
<i>C. sylvatica</i>	Kerala
<i>C. aurantiaca</i>	Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh
<i>C. sulcata</i>	Maharashtra
<i>C. indora</i>	Gujarat, Maharashtra, and Karnataka
<i>C. ecalcarata</i>	Kerala
<i>C. soloensis</i>	West Bengal
<i>C. brog</i>	West Bengal
<i>C. haritha</i>	Kerala
<i>C. kudagensis</i>	Karnataka
<i>C. thalakaveriensis</i>	Karnataka
<i>C. malabarica</i>	Kerala and Karnataka
<i>C. karnatakensis</i>	Karnataka
<i>C. kannanorensis</i>	Kerala
<i>C. vama</i>	Kerala
<i>C. coriacea</i>	Kerala
<i>C. nilamburensis</i>	Kerala
<i>C. leucorrhiza</i>	West Bengal

<i>C. lutea</i>	Kerala and Karnataka
<i>C. raktakanta</i>	Kerala

Source: [29]

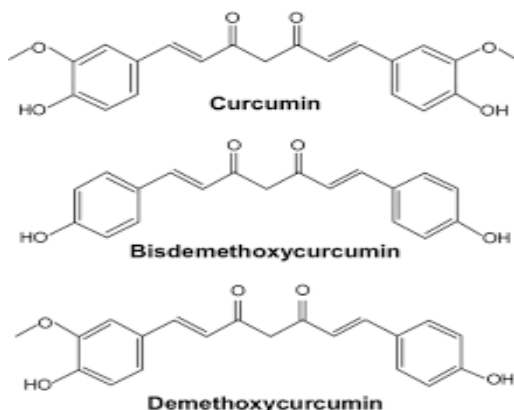


Figure 1. Chemical structures of curcuminoids

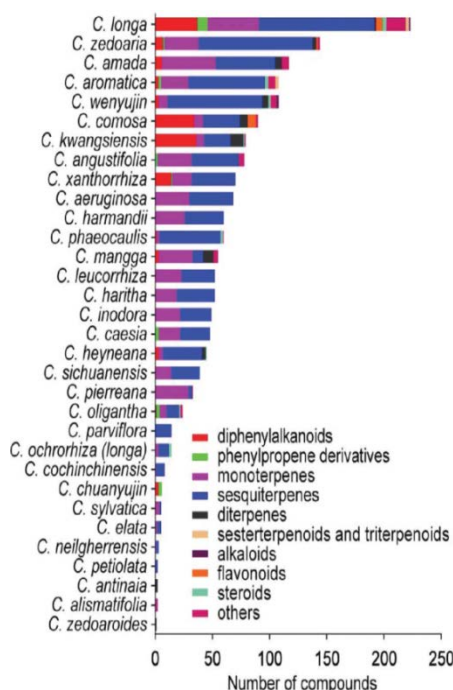


Figure 2. Molecules found in various *Curcuma* species

1.3. Economic Importance, Health, and other Benefits

Turmeric is known for its medicinal properties and its uses span many purposes, including a dye, condiment, and medicine [6,10]. Turmeric has additional properties including choleric, anti-arthritis, antiseptic, and an anti-inflammatory [12]. It contains antimicrobial properties, and is extensively used as stimulant, blood purifier, tonic as a carminative and remedy against the skin diseases, and pain. Among other spices, turmeric holds a prominent position to consumers, and it is believed that turmeric oil has anti-arthritis and anti-inflammatory properties. It is also used as a natural dye of cloth, leather, silk, fibre, wool and cotton. The oil has antimicrobial properties and is very effective against pathogenic bacteria and fungi. Curcumin, volatile oil and essential oil of turmeric prevents tumour formation, improve kidney and liver

functions and they could be used to alleviate diabetic and hepatic disorders [7].

1.4. Cultivation in the USA

Turmeric grows well in southeast Asia and the climate is different than the USA. The USA climate again differs depending on the specific location in the US. Therefore, several growth factors have been altered to soil, planting space, planting duration, and sometimes the growing environment (greenhouses, hydroponic systems, etc.) to increase the overall yield of turmeric throughout its preferred planting season. This study focuses on optimizing these growth factors and evaluating the curcumin contents from trials to determine the optimum growth factors to be applied during the growing season. Optimum growth factors were determined through the analysis of curcumin contents by way of High-Performance Liquid Chromatography (HPLC). Curcumin

contents were tested for antibacterial activity through assay. Samples exhibiting the most curcumin content and microbial inhibition were determined as the elite germplasm, and all growth factors associated with the elite germplasm were available for application and commercial use for small to mid-scale growers.

2. Literature Review

2.1. Investigating *Curcuma longa* Cultivation

Turmeric's medicinally beneficial bioactive compounds in its compact structure is dependent on the presence of nitrogen [13,14,15]. Several studies reported that nitrogen application had significant effect on growth yield and turmeric's yield components [16,17,18,35]. In addition to nitrogen increasing yields, it has been reported that applying nitrogen treatments enhances the quality attributes of turmeric [18]. Nitrogen applications also enhance other nutrient's efficacy (P and K) which improve the yield of turmeric [11,19].

In a study by Mishra et al. (2000), germination, growth, crop yield, yield attributes, and fresh rhizome yield were firmly influenced by planting depth of rhizome [5]. Planting depths were compared at 2-4 cm and 8-10 cm in Japan. It was found that planting at 8-10 cm depth in dark red soil was better to obtain increased yield and decreased weed competition [20]. The ideal soil pH for the growth of turmeric ranges between 4.3 and 7.5. Earlier rhizome development was also reported, coupled with higher shoot biomass and rhizome yield, when planted 8, 12, and 16 cm deep than at 4 cm [10].

Tiwari et al. conducted a study on the growth, yield and quality of turmeric dependent on planting time and fertility levels and found that turmeric variety Rajendra Sonia (RH-10) in June with 150:50:60 kg NPK ha⁻¹ provided better yield and quality [21].

2.2. Curcumin Content

Curcumin, demethoxycurcumin, and bis demethoxycurcumin are the three main bioactive compounds found in turmeric [6,10,22]. Curcumin contents are influenced by nutrient uptake, resulting varying concentrations among turmeric plants of the same germplasm [18,23]. The detection of curcumin may be determined by using high performance liquid chromatography (HPLC). This sensitive method separates compounds found in turmeric. The identification of curcuminoids is detected through retention times. The area produced at the retention time corresponding with each bioactive compound is used to calculate the curcumin content of each sample [24].

Several methods have been employed to separate curcuminoids from turmeric, however, solvent extraction followed by column chromatography is the most common method. In a study by Schieffer found that the prepared standard solutions produced by serial dilution were stable for at least 20 weeks when stored in well-sealed amber vials at -20°C [25]. An HPLC analysis performed by Tayyem et al. reported that the average curcumin content (percentage of the dry weight), in the turmeric powders

was 1.51% [26]. The lowest percentage was reported at 0.58% and the highest at 3.14%. After analysis, the difference between the lowest and highest curcumin content was found to be 5-fold. Monton et al. determined the quantitation of curcuminoid contents and the individual curcuminoid contents in turmeric capsules from three hospitals showed higher contents of curcumin than bisdemethoxycurcumin and demethoxycurcumin, and that the content of bisdemethoxycurcumin and demethoxycurcumin were similar [27]. Content of curcumin, demethoxycurcumin, and bisdemethoxycurcumin of nine lots of turmeric capsules were 6.61-7.67%w/w (average, 7.21%w/w), 2.76-3.33%w/w (average, 3.04%w/w), and 2.64-3.47%w/w (average, 3.10%w/w), respectively. Moreover, the total curcuminoid contents ranged from 12.02%w/w to 14.36%w/w with an average value of 13.35%w/w.

2.3. Investigating Antibacterial Properties of *Curcuma longa*

Chandarana et al. conducted an antibacterial assay on selected species in the *Zingiberaceae* family using the well-diffusion method to compare the antibacterial activities of these species with some synthetic compounds [28]. Turmeric was tested with heated, unheated, and organic solvent extracts, and it was found that the curcumin in turmeric is insoluble in water; therefore, the heated and unheated extracts did not show antibacterial activity. However, it was found that organic extracts such as 1, 4-Dioxan (non-polar) and DMF (polar) did show antibacterial activity. For *B. subtilis*, the zone of inhibition when tested with 1, 4-Dioxan was 3.38 mm, and when tested with DMF (dimethylformamide), the zone of inhibition was 2.78 mm. When tested with *E. coli*, the mean zone diameter was 2 for 1, 4 Dioxan and 0 for DMF.

Turmeric molecule was found to have a photosensitizing agent that kills cancer cells by the cytotoxic reactive oxygen species (ROS) production against both planktonic and biofilm bacterium types [29,30]. Based on data and literature, turmeric has shown its beneficial effects against Gram-negative uropathogens (*Escherichia coli*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, and *Serratia marcescens*) [29,31]. This molecule also has a preventive role in the struvite stones formations associated with the UTIs (urinary tract infections) [32].

3. Objectives

1. To optimize cultivation of Turmeric in Zone 8 to help US farmers.
2. To assess curcumin contents using HPLC analysis.
3. To assess the antibacterial efficacy of turmeric grown with several treatments.

Turmeric is a perennially herbaceous crop, which is cultivated in moist, tropical environments. The production of secondary metabolites produced by turmeric is influenced by several factors such as sunlight, spacing, nitrogen concentrations, and water availability/uptake. Optimizing cultivation practices will stabilize productivity for small to mid-scale farmers through adopted convenient

techniques, implement an intelligible protocol by way of efficiently using available space, while enabling an increase of revenue through obtaining crops which exhibit the highest curcuminoid content. Supplying availability of these elite turmeric crops to consumers provides rationale to conduct and conduct this study.

4. Materials and Methods

4.1. Turmeric Cultivation

The turmeric cultivation was conducted in raised beds with twenty soil treatments [Figure 4] (Table 3). The study was conducted in USDA Zone 8. Raised beds were filled with a 1:2 soil-to-compost mixture (Figure 3. a, c, d). Turmeric seedlings/rhizomes (~50 g) (Figure 3b) were planted 5-7 cm deep (Figure 3c). Soil amendments included manure, coffee grounds, and synthetic fertilizers at concentrations of 100, 200, and 300 kg/Ha. HPLC analysis used a C18 column with UV detection at 425 nm. Antibacterial activity against *B. cereus* and *E. coli* was tested using the well-diffusion method [15].

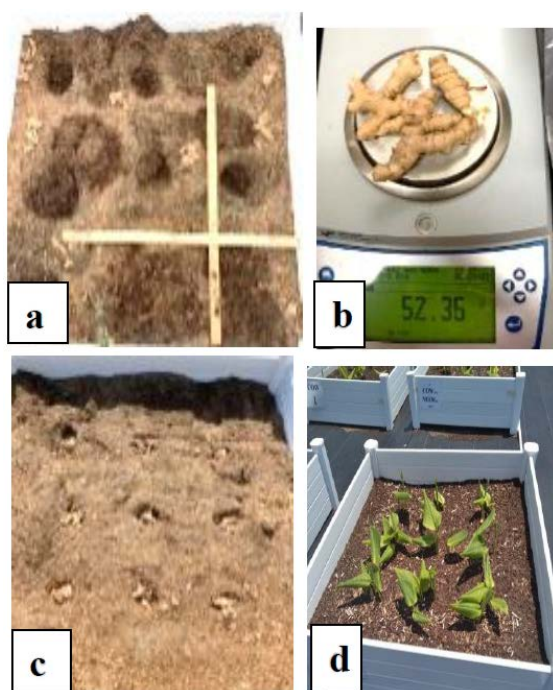


Figure 3. (a) Turmeric rhizome planted with 30 cm equidistance, holes (b) Turmeric rhizome sample weighed ≈50 g and (c) planted per hole, (d) Turmeric plants aerial shoots growing in raised beds after 2 weeks of planting at FVSU

For this cultivation practice, sixty raised beds (122 cm x 122 cm x 45 cm, LxWxH) were constructed and evenly distributed throughout the measured land (Figure 3d). Raised beds were procured from The Home Depot, constructed, and filled with a soil and compost mixture, which were purchased from Julian Cranford in Macon, Ga. A soil drainage test was conducted to determine the optimum soil composition for cultivation.

The drainage/retention test concluded that more soil is required to increase water retention times. Therefore, a 1:2 (soil: compost) composition was used for this study (Figure 3a,b). Turmeric seedlings were purchased from

ORG Nature Life Foundation in Pine Mountain, GA. The number of initial rhizomes were counted for each sample, and the seedlings were weighed to ~50 g prior to planting (Figure 3b). Rhizomes were planted about 5-7 cm deep with 30 cm spacing between each sample. Seedlings were planted on June 23, 2021, and shoot growth was observed within 14 days (Figure 3d). Growth parameters (shoot number, leaf number, leaf length, and leaf width) were examined through recorded monthly observations.



Figure 4. Turmeric plants growing in raised beds at the Fort Valley State University, Fort Valley, GA, USA

Table 3. Soil Amendment Calculations

Treatment (20 types)	Nitrogen (%)	100 kg/Ha (g)	200 kg/Ha (g)	300 kg/Ha (g)
1.Control	-	-	-	-
2.Cow manure	0.5	1,000	2,000	3,000
3.Chicken manure	0.75	333	667	1,000
4.Mushroom	0.5	1,000	2,000	3,000
5.Vermicompost	1.5	333	667	1,000
6.Neem leaf powder Low	2.5 (50 Kg N/H)	100	200	300
7.Neem leaf powder (High)	2.5 (150 Kg N/H)	300	600	900
8.5-10-15 (NPK)	5	100	200	300
9.10-10-10 (NPK)	10	50	100	150
10.Coffee granules	2	250	500	750
11.Neem-L/Neem-H	2.5	100/150	200/300	300/450
12.Cow /Neem	0.5	500/100	1,000/200	1,500/300
13.Chk/Neem	0.75	167/100	334/200	500/300
14.Mush /Neem	0.5	500/100	1,000/200	1,500/300
15.Vermicompost/Neem	1.5	167/100	334/200	500/300
16.Coffee/Neem	2	125/100	250/200	375/300
17.5-10-15/Neem	5	50/100	100/200	150/300
18.10-10-10/Neem	10	25/100	50/200	75/300
19.Fung/Neem	-	5 /100	10/200	15/300
20.Fungicide	-	20	40	

Soil amendments were obtained from various suppliers in middle GA. Manures, synthetic amendments, and composts were purchased from the Minton Lawn and Garden market. Coffee grounds were obtained from the local Dunkin Donut's and Walmart Supermarket. The applied soil amendments were calculated based on each

replication, reflecting nitrogen concentrations. For replication one, the corresponding nitrogen concentration was 100 kg/Ha. The corresponding concentration for replication two were 200 kg/Ha and 300 kg/Ha for replication three. Table 3 shows the appropriate soil amendment applications which were applied to each raised bed. For replication two, soil amendments are doubled, and tripled for replication three.

4.2. Curcumin Content



Figure 5. (a) Freshly harvested turmeric rhizomes from a single spot after rinsed thoroughly, (b) Turmeric rhizomes in 500 mL dH₂O for softening using microwave after skin was scraped, (c) Sliced turmeric rhizome after microwave prior to drying, (d) Turmeric rhizome dried at 60°C for 24 h, (e) Turmeric powder after grinding

The samples used for extraction and HPLC analysis were obtained from each raised bed. Reagents were analytical grade and procured from Fisher Scientific, which was also the primary source for all other lab materials. Each sample was harvested from each raised bed at the FVSU. The rhizomes were rinsed thoroughly of residual soil (Figure 5 a) and the skin was scraped before the fresh weight was taken (Figure 5 b). The rhizomes were then softened in the microwave oven for approx. 10 minutes. Next, the samples were sliced (Figure 5 c) and dried at 60°C for 24 h (Figure 5 d). The dried samples were ground into a fine powder with a grinder procured from CNCEST in Hong Kong (Figure 5 e).

After grinding, the samples were sent to UGA for HPLC analysis. A C18 column was used with a UV detection at 425 nm. The mobile phase was acetonitrile and water (50:50 v/v) at a flow rate of 1.5 mL min⁻¹ [22,24]. The injection volume was 10 µL.

4.3. Efficacy on Bacteria

An antibacterial assay was performed to evaluate the efficacy of turmeric on *B. cereus* and *E. coli*. Methods for antibacterial assay was conducted employing the well diffusion method by Selvam et al. [33]. Fresh samples were harvested, and residual soils were thoroughly rinsed. Fresh weights were taken, and rhizomes were softened in a microwave oven for 10 minutes, sliced, and placed in a Lunaire conventional dryer for 24 h at 60°C, until a constant moisture content was achieved. Samples were then ground with a grinder obtained from CNCEST in Hong Kong, and 10 g was dissolved in a conical flask containing 200 mL H₂O solution. The flasks were low boiled for 5-6 h until, the volume reduced to 25 mL. The slurry was filtered through multiple layers of Whatman paper and centrifuged at 5000 rpm for 15 min at room temperature. The supernatant was collected and autoclaved at 121°C and 15 lb pressure for 20 min. The prepared extracts were sterilized with a 0.5-micron filter before inoculating onto the petri dishes.

Nutrient agar was procured from Carolina Biological and prepared. The agar was heated using a microwave oven and 20 ml was distributed into each plate. A total of 19 plates prepared to culture *E. coli* and 19 plates for *B. cereus*. All Cultures were allowed to grow for 24 h. After the first incubation period, 6mm wells were made using a cork borer and filled with 100 µL of turmeric extract (1.5x10⁸ CFU/ml) and allowed to absorb into the media. The dishes were placed back into the incubator upside down for an additional 24 h incubation period. Inhibition zones were measured to determine the effectiveness of the turmeric extracts on *B. cereus* and *E. coli* and compared to a control antibiotic, chloramphenicol [28,33]. From the assay performed, inhibition zones were measured at 2 to 3 cm for each sample. The positive control measured about 13 to 14 cm. The results show some inhibition against bacteria; however, turmeric extract concentrations may be adjusted to increase inhibition zones.

4.4. Statistics

Three trials (replications) were created, and each soil amendment was randomly assigned within each trial to ensure the randomization of treatments. Data from each bed (leaf length, leaf width, shoot number, and leaf number, curcumin contents, and inhibition zones) were analyzed through MS Excel. Standard deviations and standard errors were used to determine if there is a significant difference in growth between treatments.

5. Results and Discussion

5.1. Turmeric Cultivation

Soil samples were taken in June 2022 and sent to

University of Georgia to test for soil pH and mineral concentrations. Figure 6 shows a graph of the average potassium and phosphorus concentrations for the raised beds. The average potassium concentration is 78% and phosphorus concentration is 114%. Figure 7 shows a graph of the average pH of the raised beds (Figure 7), which was 6.0. An average number of shoots was recorded at 90 (Figure 11), length averaged at 22 cm (Figure 9), width averaged at 9 cm (Figure 10), and leaf number averaged at 262 per bed (Figure 8).

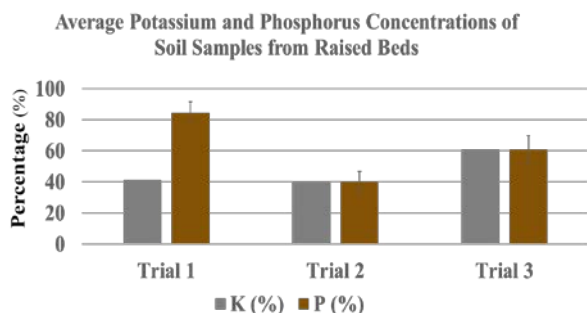


Figure 6. Potassium and Phosphorus Concentrations from Soil Samples

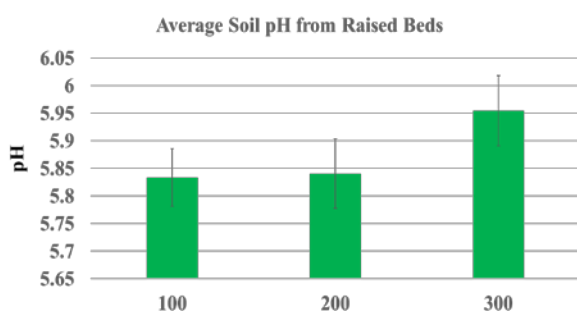


Figure 7. Soil pH of Raised Bed

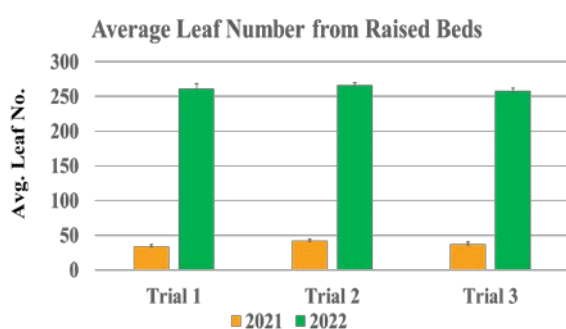


Figure 8. Leaf number for 2021 and 2022

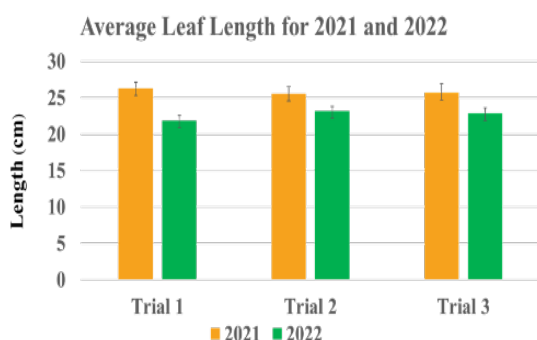


Figure 9. Leaf Length from 2021 and 2022

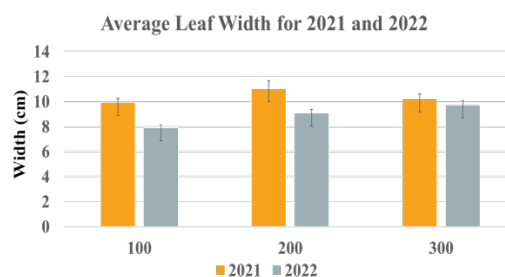


Figure 10. Leaf width from 2021 and 2022

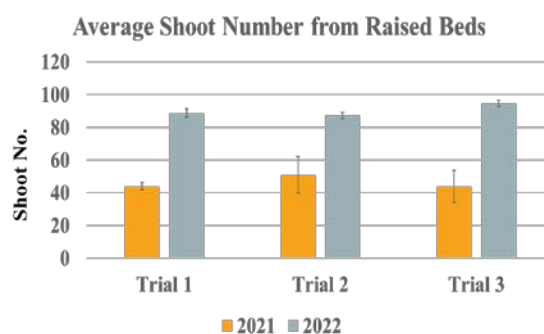


Figure 11. Shoot number from 2021 and 2022

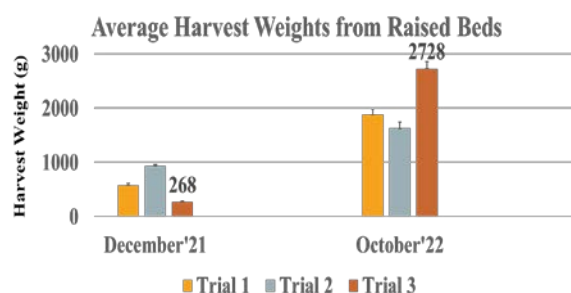


Figure 12. Yield /harvest weightgraphs from 2021 and 2022

Figure 12 shows a graph of the average fresh weights of each trial from both (2021 and 2022) harvests.

Biomass production was evaluated based on the fresh rhizome weights from three harvests. Samples from the first harvest were collected in December of 2021 (Figure 13a). Samples from the second harvest were collected in October of 2022 (Figure 13b). Three samples were harvested from each trial, weighed, and the average harvest weight was calculated. The highest average harvest weight from the first harvest was 743 g, corresponding with the fertilizer 5-10-15/N from the first trial. Results from the second harvest showed the highest average harvest weight corresponded with 10-10-10 fertilizer from trial 3 [25].

It can be determined that using a soil amendment reflecting a nitrogen concentration of 300 Kg ha⁻¹ will produce turmeric with the largest biomass [13,16]. In the graph, it shows that the largest weight obtained from replication three corresponded with the fertilizer 10-10-10 from harvest 3 in October 2022. It was found that using synthetic fertilizers with higher nitrogen concentrations may increase the yield of turmeric as opposed to using manure and composts [18,34]. Figure 13 can also suggest that cultivating for periods longer than 7 to 8 months will produce a larger biomass of turmeric [21,23,35].



Figure 13. Pictures showing yield/hole from 2021(a) and 2022(b)

5.2. Curcumin Content

Chromatographic data were processed to quantify the curcumin content within each sample. Peak areas were calculated and compared to determine which soil amendment yielded the highest curcumin concentration. These results identify the specific soil treatments that, when applied during cultivation, successfully produce turmeric with higher curcumin density.

The average retention time for curcumin was identified at 4.62 minutes at a wavelength of 430 nm. Figure 14 displays the internal standard used for the calculations, while Figure 15(a-b) illustrates the chromatograms for the experimental samples, showing retention times of 4.35 and 4.59 minutes. The curcumin content was calculated by determining the ratio of the sample peak area to the internal standard peak area.

The analysis determined an average curcumin concentration of 1.1% across the samples, compared to 3.27% for the standard. The lower concentration observed in the samples suggests that increasing the sample concentration during preparation may yield a higher curcumin percentage. Additionally, these lower values may indicate potential technical deficiencies or extraction inefficiencies during the experimental process.

5.3. Calculation of Curcumin Concentration

To determine the curcumin content, the ratio of the sample peak area to the internal standard peak area is used. The formula can be represented as follows:

$$\text{Curcumin}\% = A_{\text{sample}} / A_{\text{IS}} \times C_{\text{std}}$$

Where:

- A_{sample} = Area of the curcumin peak in the sample
- A_{IS} = Area of the peak for the Internal Standard
- C_{std} = Concentration factor of the standard (3.27% in this study)

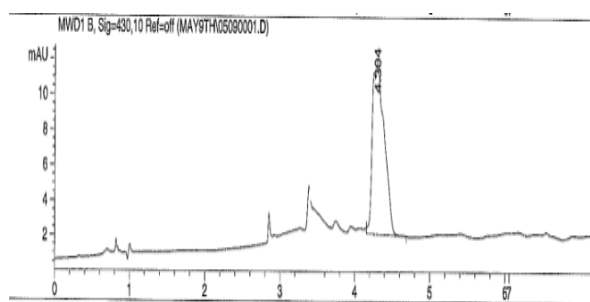


Figure 14. Chromatogram showing detection a retention time of 4.3 minutes at a wavelength of 430 nm for the standard solution. The area for this peak is 108.72 (mAU's)

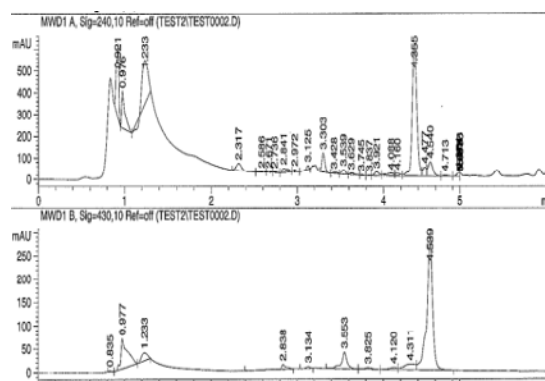


Figure 15(a-b). Chromatogram showing detection a retention time of 4.35 minutes at a wavelength of 240 nm (Figure 15a) and 4.53 minutes at a wavelength of 430 nm (Figure 15b). The area for the peak with a retention time of 4.35 is 2278.1 and the area for the peak with a retention time of 4.53 is 1369.3

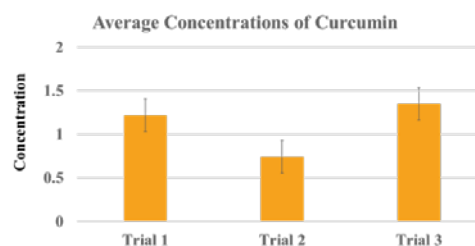


Figure 16. Average concentration of curcumin for trial 1, 2 & 3

5.3. Antibacterial Assay

Each sample was tested to evaluate the effect of curcumin on a gram negative and gram-positive bacterium. The extract was inoculated employing well diffusion method and the antibacterial effects of turmeric was evaluated by measuring (in cm) how much the turmeric has inhibited the growth of bacteria through Inhibition zones. The inhibition zones of gram-negative and gram-positive bacteria were compared to determine if there is any difference in effectiveness between each soil amendment. Figures 17 and 18 show the inhibition zones for turmeric extracts compared to the positive control. The results show that turmeric was able to inhibit bacterial growth by 2 to 3 cm compared to the positive control, chloramphenicol, which inhibited growth up to 13 cm.

6. Conclusions

The content of curcumin is dependent on the availability of nutrients and growth factors. Sunlight, spacing, soil composition, nutrient (NPK) availability, water drainage and logging are all contributing factors in the growth and development of biomass and curcumin contents of turmeric. By increasing nutrient availability, optimizing soil composition, and water supply, turmeric can grow up to 1,000 g in one cultivation period (avg. 7 months). For two years of cultivation, turmeric can double or triple, depending on how these growth factors fluctuate. The highest harvest weight is from the third harvest, which is equivalent to a 16-month cultivation period. Turmeric's antibacterial potential is due to the bioactive compounds present, which may vary by soil amendment.

The effectiveness of turmeric on bacteria may increase when the concentration of curcumin is more potent. Longer cultivation periods, planting depth, and planting time may significantly produce larger biomass, thus increasing the potential to obtain turmeric with larger antioxidant concentrations. Small to mid-scale farmers may adopt these practices to produce turmeric in a convenient and timely manner.

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References

- [1] Abdulrahman, H., L. Misba, S. Ahmad, and A.U. Khan. 2020. Curcumin induced photodynamic therapy mediated suppression of quorum sensing pathway of *Pseudomonas aeruginosa*: An approach to inhibit biofilm in vitro. *Photodiagn. Photodyn. Ther.* 2020, 30, 101645.
- [2] Nair, K. P. 2013. The Agronomy and Economy of Turmeric and Ginger: The Invaluable Medicinal Spice Crops. 3rd Gen.
- [3] Velayudhan, K. C., V. K. Muralidharan, V. A. Amalraj, P. L. Gautam, & S. K. Mandal. 1999. *Curcuma* genetic resources (Scientific monograph no.4, pp. 149). New Delhi: National Bureau of Plant Genetic Resources.
- [4] Singh, P., R. Srivastava, A. Sharma, D. Hore and B. Panwar. 2001. Genetic variability and correlation in turmeric (*Curcuma longa* L.). *Indian J. Hill Farming*, 14: 24-28.
- [5] Cardon, D. 2007. *Natural Dyes: Sources, Tradition, Technology and Science*. Archetype Publications, London. p. 31.
- [6] Mishra, M., S. N. Mishra, & G. J. Patra. 2000. Effect of depth of planting and mulching on rainfed turmeric (*Curcuma longa*). *Indian Journal of Agronomy*, 45(1), 210–213.
- [7] Ravindran, P. N., Babu, K. N., & Sivaraman, K. (Eds.). (2007). *Turmeric: The genus Curcuma* (1st ed.). CRC Press.
- [8] Esatbeyoglu, T., P. Huebbe, I. Ernst, D. Chin, AE Wagner, G. Rimbach. 2012. Curcumin—from molecule to biological function. *Angew. Chem. Int. Ed.* 51: 5308–5332.
- [9] Dhanalakshmi, K., K. Chitra, R. Manimekalai, C. Balisakumar and K.K.Vijayakumari (2018). Production and Economics of Turmeric Cultivation. *Int J CurrMicrobiol App Sci.* 7(11): 3496-3502.8.
- [10] Mishra, M., B. B. Mishra & S. N. Mishra. 1997. Effect of planting dates and varieties on yield of Turmeric. *Indian J. Agron.* 42: 713– 716.
- [11] Nair, K. P. 2019. Turmeric (*Curcuma longa* L.) and ginger (*Zingiber officinale* rosc.) - world's invaluable ... medicinal spices: The agronomy and economy of Turm. SPRINGER NATURE.
- [12] Karthikeyan, P., M. Ravichandran, P. Imas, & M. Assaraf. 2012. Application of potassium and magnesium on turmeric (*Curcuma longa*) to increase productivity in Inceptisols, Arch.
- [13] Ojipong, T.O. 2018. Effect of Planting Dates and NPK (15:15:15) Fertilizer on the Growth and Yield of Turmeric (*Curcuma longa* Linn).SSRG – IJAES. 5(4):42-46.
- [14] Ahmed, S. and S. Muthuswamy. 1981. Studies on the influence of nitrogen on the yield and yield components of turmeric (*Curcuma longa* L.). *Indian Cocoa, Arecanut & Spices J.* 5: 9-10.
- [15] Umate, M.G., A. Latchanna and U.S. Bidgire. 1984. Growth and yield of turmeric varieties as influenced by varying levels of nitrogen. *Indi Coc Are Spi J.* 8: 23- 57.
- [16] Yadav, G. C. 2000. Response of turmeric varieties to dates of planting and fertility levels, Ph.D. Thesis, Department of Veg. Sci., Narendra Deva University of Agriculture & Technology, Kumarganj, Faizabad (U.P.).
- [17] Agere, L. and T. Shiferaw. 2015. Determination of optimum rate of nitrogen and phosphorous fertilizers for the yield and yield components of turmeric (*Curcuma longa* L.) on Nitisols at YakiWoreda Southwestern. *J. Agr. Sci.* 3(10): 289-295.
- [18] Balashanmugam, P.V. and N. Chezhiyan. 1986. Effect of differential application of nitrogen on growth and yield of turmeric (*Curcuma longa* L.). *Madras Agric. J.* 73(8): 439-442.
- [19] Hikaru, A., H. Amzad, I. Yukio and Y. Kenichi, H. Kazuo 2007. Effects of application of N, P and K alone application of N, P and K alone or in combination on growth, yield and curcumin content of turmeric (*Curcuma longa* L.). *Plant Prod Sci.* 10(1): 151-154.
- [20] Qazi, M. A., M. N. Iqbal, M. Ashraf, N. I. Khan, R. Ahmad, F. Umar, U. Naeem, K. M. Mughal, M. Khalid, & Z. Iqbal. 2020. Npk Requirements of Turmeric for Cultivation in Punjab. *Pakistan Journal of Science*, 72(4), 365.
- [21] Shimine, Y., Hossain, M. A., Ishimine, Y., & Murayama, S. (2003). Optimal Planting Depth for Turmeric (*Curcuma longa* L.) Cultivation in Dark Red Soil in Okinawa Island, Southern Japan. *Plant Production Science*, 6(1), 83–89.
- [22] Tiwari, S. K., J. K. Tiwari, and M. K. Pathak. 2014. 'Growth, yield and quality of turmeric (*Curcuma longa* L.) as influenced by planting time and fertility levels', *Journal of Spices & Aromatic Crops*, 23(1), pp. 64–70.
- [23] S.R. Shirsath, S.S. S.G. Sable, S.H. Gaikwad, Sonawane, D.R. Saini, & P.R. Gogate. 2017. Intensification of extraction of curcumin from *Curcuma amada* using ultrasound assisted approach: Effect of different operating parameters, *Ultrasonics Sonochemistry*, 38: 437-445.
- [24] Fu. Hu M., S. M. Chiu, H. I. Liu, M. H. Lai, & S Y Liu. 1996. Effect of planting date and density on the rhizome yield and curcumin content of turmeric plant. *J. Agri. Res. China* 45: 164–173.
- [25] Peram, M. R., S. S. Jalalpure, S. A. Joshi, M. B. Palkar, & Diwan, P. V. 2017). Single robust RP-HPLC analytical method for quantification of curcuminoids in commercial turmeric products, Ayurvedic medicines, and nanovesicular systems. *Journal of Liquid Chromatography & Related Technologies*, 40(10), 487–498.
- [26] Schieffer, G. (2002). Pressurized Liquid Extraction of Curcuminoids and Curcuminoid Degradation Products from Turmeric (*Curcuma longa*) with Subsequent Hplc Assays. *Journal of Liquid Chromatography & Related Technologies*, 25(19), 3033–3044.
- [27] Tayyem, R. F., Heath, D. D., Al-Delaimy, W. K., & Rock, C. L. (2006). Curcumin content of turmeric and curry powders. *Nutrition and Cancer*, 55(2), 126–131.
- [28] Monton, C., Charoenchai, L., Suksaeree, J., & Sueree, L. (2016). Quantitation of curcuminoid contents, dissolution profile, and volatile oil content of turmeric capsules produced at some secondary government hospitals. *Journal of Food and Drug Analysis*, 24(3), 493–499.
- [29] Chandarana, H., Baluja, S., & Chanda, S. V. (2005). Comparison of antibacterial activities of selected species of Zingiberaceae family and some synthetic compounds. *Turkish Journal of Biology*, 29(2), 83–97.
- [30] Adamczak, A., M. Marcin Ożarowski, & T. Karpiński. 2020. Curcumin, a Natural Antimicrobial Agent with Strain-Specific Activity. *Pharmaceuticals*, vol. 13, no. 153, p. 153, viewed 11 August 2022.
- [31] Packiavathy, I.A., S. Priya, S. K. Pandian, and A. V. Ravi. Inhibition of biofilm development of uropathogens by curcumin—An anti-quorum sensing agent from *Curcuma longa*. *Food Chem.* 2014, 148, 453–460.
- [32] Das, P.; G. Gupta, V. Velu, R. Awasthi, K. Dua, and H. Malipeddi. Formation of struvite urinary stones and approaches towards the inhibition—A review. *Biomed. Pharmacother.* 2017, 96, 361–370.
- [33] Selvam, P., Muruges, N., Chandramohan, M., & Hooper, N. M. (2012). Synthesis and antiviral activity of some novel isatin derivatives. *Journal of Applied Pharmaceutical Science*, 2(6), 210–212.
- [34] Suja, G., T.V.R. Nayar and C.S. Ravindran 2006. Influence of nutrient management in arrowroot (*Maranta arundinacea* L.) on biomass production, nutrient uptake and soil nutrient status. *J. Root Crops*. 32: 162-165.
- [35] Chitra, R. 2016. Effect of Planting Material on Growth and Yield of Turmeric, *Madras Agricultural Journal*, 103(10–12), pp. 366–369.

