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Phytochemical analysis of turmeric (*Curcuma longa* L.) grown in Uzbekistan

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Abstract: Turmeric (*Curcuma longa* L.), a well-documented medicative plant, is used as a foodstuff, cosmetic, and medicine. The objective of this study was to assess the influence of mineral fertilizers on the phytochemical evaluation, curcumin, flavonoids, and total protein contents of turmeric (*Curcuma longa* L.) rhizomes grown in different regions of Uzbekistan. The experiments were carried out in a randomized block design with three replications: a mini plot experiment at the Institute of Genetics and Plant Experimental Biology in the Kibray district, Tashkent region, and a field experiment at the Surkhandarya Scientific Experimental Station of the Vegetable, Melon Crops, and Potato Research Institute, Uzbekistan. The experimental treatments included: T1 - control (without fertilizer), T2 - NPK treatment (application rate 75:50:50 kg/ha), T3 - NPK treatment (application rate 125:100:100 kg/ha), and T4 - NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha). At harvest, after eight months, the phytochemical properties, curcumin, flavonoids, and total protein content of the turmeric rhizomes were determined. The results revealed the presence of alkaloids, terpenoids, tannins, flavonoids, steroids, carbohydrates, and saponins in the methanolic extract of turmeric rhizomes grown in different regions (Tashkent and Surkhandarya). The chloroform extract showed the presence of six phytochemicals, including alkaloids, terpenoids, flavonoids, steroids, carbohydrates, and saponins in the rhizomes of turmeric collected from both regions, Tashkent and Surkhandarya. However, the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the curcumin, rutin, and quercetin contents of turmeric rhizomes grown in the Tashkent and Surkhandarya regions. The highest total protein content was recorded in the NPK kg/ha treatment (application rate 125:100:100 kg/ha), showing a significant increase compared to the control. It was concluded that the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the curcumin and flavonoid contents of turmeric rhizomes grown in the Tashkent and Surkhandarya regions compared to the control.

Key words: Turmeric, phytochemical analysis, curcumin, flavonoids, total protein, carbohydrate content

1. Introduction

Curcuma longa L. belongs to the family Zingiberaceae. It is a perennial herb, approximately 60–90 cm in height (Monaghesh and Hajizadeh, 2020). The crop requires a hot and moist climate, a substantial water supply, and well-drained soil (Mirjanaik and Vishwanath, 2020). It flourishes in any soil that is loamy, loose, and friable. It is a native crop of South Asia and is extensively grown in tropical and subtropical zones worldwide (Gudade et al., 2015). Curcumin, the major constituent of turmeric, is widely used in the treatment of numerous serious diseases such as cancers (Zoi et al., 2021; Sharifi-Rad et al., 2020; Mansouri et al., 2020), neurodegenerative diseases such as Alzheimer's disease, skin infection, intestinal gas formation, and allergies (Maiti and Dunbar, 2018; Fu et al., 2021; Fuloria et al., 2022). It is also an essential ingredient in several cosmetics (Maiti and Dunbar, 2018). Recent studies have revealed the clinical applications of curcumin for treating SARS-CoV-2 by targeting the cellular entry and replication of the virus (Fuloria et al., 2022). *Curcuma longa* L. has been widely used for its therapeutic activities, including antiinflammatory (Fuloria et al., 2022), antimicrobial properties (Fuloria et al., 2022), antidiabetic properties (Fuloria et al., 2022), and antioxidants effects

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(Fuloria et al., 2022), as well as its protective effects on the gastrointestinal (Micucci et al., 2013) and cardiovascular systems (Zadeh and Kor, 2014).

The sources of plant-based protein include soybeans, a variety of pulses, nuts, tofu, seeds, peas, and even certain grains. Nowadays, consumers and researchers are increasingly interested in plant-based diets due to their potential health advantages as well as their positive environmental impact. These plant proteins, which have positive health benefits, are associated with numerous vitamins, minerals, dietary fiber, and various phytochemicals. For example, plant proteins such as pea and soya have been used to improve biomarkers associated with disease risk, including blood pressure and, in some cases, serum lipids (Ahnen et al., 2019).

Flavonoids are aromatic compounds that play vital roles in plant growth and development. Researchers today are investigating how flavonoids facilitate the relationship between host plants and their microorganisms.

Several studies have also indicated that flavonoids mediate interactions between plants and plant growth promoting rhizobacteria. Interpreting the full range of plant-microbe interactions mediated by flavonoids is crucial, as it could provide scientists with new and sustainable approaches to improving plant health (Wang et al., 2022).

Turmeric is a long duration crop with an extended gestation period, which quickly depletes soil fertility and requires additional minerals and fertilizers for revitalization. In order to maintain the soil fertility, NPK fertilizers are frequently added, either alone or in combination. Occasionally, Mg is also added to the soil as a secondary nutrient due to its potential role in the photosynthetic fixation of CO_2 (Adekiya et al., 2019). Turmeric has been reported to respond positively to both NPK 15:15:15 fertilizer (Ojikpong, 2018) and poultry manure (PM) (Ihenacho et al., 2015).

Mineral fertilizers can significantly affect the protein, flavonoids, curcumin, and phytochemical content of turmeric. Turmeric contains a relatively low amount of protein, with an average protein content of approximately 6%. However, mineral fertilizers containing nitrogen can help increase the protein content of turmeric. Flavonoids are a group of plant secondary metabolites with antioxidant and antiinflammatory properties. Studies have shown that the use of mineral fertilizers can increase both the flavonoid and curcumin content in turmeric. Overall, mineral fertilizers can positively impact the phytochemical content of turmeric, including protein, flavonoids, curcumin, and other phytochemicals. We aimed to test the following three hypotheses: (1) mineral fertilizers can improve the phytochemical evaluation of curcumin in turmeric rhizomes; (2) mineral fertilizers can increase the flavonoid content of turmeric; and (3) mineral fertilizers can enhance the total protein content of turmeric rhizomes grown in various regions of Uzbekistan.

2. Materials and methods

2.1. Experimental design

Turmeric (*Curcuma longa* L.) rhizome was used in both lysimeter and field experiments. A field experiment was conducted to study the effects of mineral fertilizers on the phytochemical screening, curcumin content, flavonoid content, and protein content of turmeric rhizomes. The experiment was carried out in a randomized block design with three replications. The lysimeter experiment was conducted at the Institute of Genetics and Plant Experimental Biology in the Kibray district, Tashkent region (41°23'22.99"N, 69°27'54.00"E), and a field experiment was carried out at the Surkhandarya Scientific Experimental Station of the Vegetable, Melon Crops and Potato Research Institute, Uzbekistan (37°13'44"N, 67°16'34"E) (Figures 1 and 2). Experimental treatments included: T1 - control (without fertilizer), T2 - NPK treatment (application rate 75:50:50 kg/ha), T3 - NPK treatment (application rate 125:100:100 kg/ha), and T4 - NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha). Rhizomes were sown in March for the years 2020–2022. The harvesting process was initiated eight months after the sowing of the seeds, in November.

2.2. Collection of turmeric fresh rhizome

Curcuma longa L. rhizomes were collected from the Institute of Genetics and Plant Experimental Biology in the Kibray district of the Tashkent region, at the Surkhandarya Scientific Experimental Station of the Vegetable, Melon Crops and Potato Research Institute, Uzbekistan. The fresh rhizomes were thoroughly washed with distilled water. Then, the rhizomes were dried for three days and ground using a sterile blender to prepare a fine powder.

2.3. Preparation of turmeric rhizome extract

Twenty grams of air-dried powdered rhizome was macerated with 150 mL of 96% methanol stored overnight under shaking conditions. The liquid was decanted, the solid material was pressed, and the liquid was clarified. The filtrates were then air-dried at room temperature in a vacuum oven at 50 to 52 °C. The dried extracts were dissolved in dimethyl sulfoxide (DMSO) and stored in a refrigerator for future use (Shihabudeen et al., 2010).

2.4. Alkaloid detection test

A solution of 0.5 mL of plant extract was prepared by diluting with 10 mL of acid alcohol. This solution was then boiled and filtered, and 5 mL of the resulting filtrate was added to 2 mL of diluted ammonia and 5 mL of chloroform. The solution was shaken gently to extract the alkaloidal base. The chloroform layer was then extracted

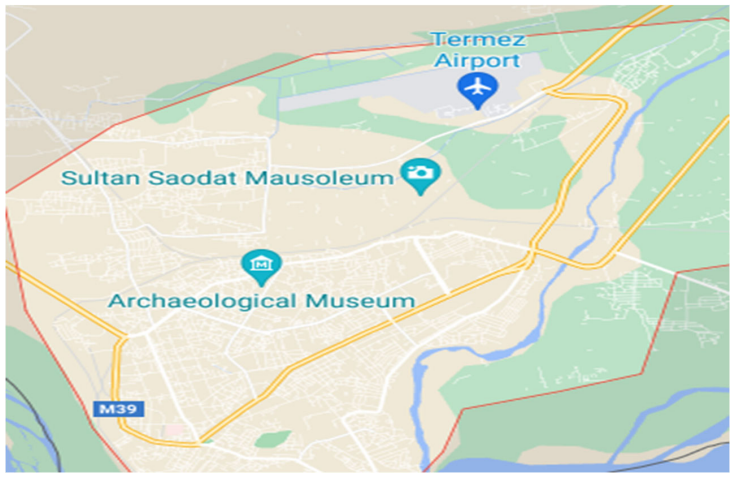

Figure 1. Map showing the locations of sampling sites in the Termez district, Surkhandarya region, Uzbekistan.

Figure 2. Map showing the locations of sampling sites in the Kibray district, Tashkent region, Uzbekistan.

with 10 mL of acetic acid. Mayer's reagent was added, and the formation of a cream or reddish-brown precipitate was considered positive for the presence of alkaloids.

2.5. Terpenoid detection: Salkowski test

Two milliliters of chloroform were added to 0.5 g of each extract. To this mixture, 3 mL of concentrated H_2SO_4 were carefully added to form a distinct layer. The presence of terpenoids is indicated by a reddish-brown coloration at the interface.

2.6. Tannin detection: Braemar test

Three milliliters of the extract was added to 1 mL of 10% alcoholic ferric chloride solution. A dark blue or greenish-grey coloration of the solution indicated the presence of tannins in the sample.

2.7. Flavonoid detection test

To perform the NaOH test, a few drops of aqueous NaOH and a few drops of HCl were treated with 2 mL of the plant extract. The formation of a yellow-orange color indicates the presence of flavonoids.

2.8. Sterol detection: H_2SO_4 test

A few milliliters of ethanol and 1 mL of H2SO4 were treated with 1 mL of plant extract. The formation of a violet or green color indicates the presence of sterols.

2.9. Carbohydrate detection test

To perform the Molisch's test, a few drops of Molisch's reagent were added to 1 mL of plant extract, followed by the addition of 1 mL of concentrated H_2SO_4 along the side of the test tube. The mixture was then allowed to stand for 2

min and subsequently diluted with 5 mL of distilled water. The formation of a red or dull violet color at the interface of the two layers indicates the presence of carbohydrates.

2.10. Saponin detection test

To perform the foam test, 3 mL of water was added to 2 mL of plant extract, and the mixture was shaken vigorously. The formation of foam indicates the presence of saponins.

2.11. Glycoside detection: Keller–Kiliani test

A few drops of glacial acetic acid and ferric chloride were added to the test solution. A few drops of H_2SO_4 were then added. The formation of two layers was observed: the lower layer appeared reddish, while the upper layer was bluish-green in color.

2.12. Determination of total protein content

Turmeric rhizome was accurately weighed and extracted with chloroform. The extraction was performed in a water bath equipped with a reflux condenser for 5–6 h at a temperature of 40 °C. The extraction process was repeated 3–4 times until the complete extraction of lipophilic compounds and chlorophyll. Subsequently, the resulting raw material was air-dried until the chloroform had completely evaporated. The dried raw material was extracted with 40% ethyl alcohol in a ratio of 1:5 (raw material to extracting solvent). This extraction process was repeated twice. The resulting extraction was then concentrated using a rotary evaporator until only one-third of the initial weight remained. Distilled water was added to the residue obtained after alcohol extraction. Furthermore, all processes were carried out in the same manner as during alcohol extraction. Finally, the two extracts were dried using a freeze dryer. Total protein content was determined using the Kjeldahl method.

2.13. Determination of carbohydrate content

The composition of carbohydrates in the rhizome of turmeric cultivated under the climatic conditions of Surkhandarya and Tashkent was determined (Kochetkov, 1967). The aim of our research is to study the content of these carbohydrates, depending on the local conditions of the Tashkent and Surkhandarya regions. The object of the study is air-dried crushed rhizome powders. To isolate lipophilic substances, the raw material was treated with a boiling mixture of chloroform and methanol (1:1) for 1 h at a ratio of 1:5. The plant residue was then treated with 82% alcohol to isolate alcohol-soluble sugar (ASS). The monosaccharide composition includes arabinose, glucose, and fructose. The remaining raw material was extracted three times with water at room temperature for 3–4 h, with a hydro modulus of 1:5, 1:4, and 1:3. The extracts were combined, centrifuged, concentrated, and precipitated with three times the volume of alcohol. The formed precipitate was separated, washed with alcohol, dehydrated with acetone, and dried under vacuum using P_2O_5.

Isolation of pectic substance (PS): After isolating water-soluble sugar (WSS), the residue was treated twice with a mixture of equal volumes of 0.5% solutions of oxalic acid and ammonium oxalate (1:1) at a temperature of 70 °C for 3 h. The extracts were dialyzed against running water, evaporated, and then precipitated with ethanol (1:3). The precipitate was separated, washed with alcohol, and dried with acetone. It was subsequently dried under vacuum using P_2O_5.

Isolation of hemicellulose (HC): The remaining raw material after isolating HC were extracted twice with a 5% KOH solution (1:5) at room temperature for 3 h. The alkaline extracts were combined, dialyzed against running water for 48 h (until a neutral pH was achieved). The extracts were then concentrated using a rotary evaporator and precipitated with alcohol. The resulting precipitate was separated, washed with alcohol, dehydrated with acetone, and dried under vacuum using P_2O_5. The monosaccharide composition of the water-soluble polysaccharide (WSP) samples was hydrolyzed with 1 N H_2SO_4 at 100 °C for 8 h, while HP and HMC samples were hydrolyzed with 2 N H_2SO_4 for 24 h, respectively. The hydrolysates were neutralized with barium carbonate, and the filtrates were treated with KU-2 (H^+) cation exchanger, evaporated to a syrup, and analyzed for paper chromatography (PC) and gas chromatography (GC).

2.14. Statistical analysis

All the experiments were performed in five replicates, and the mean values of these replicates were considered. The data were statistically analyzed using one-way analysis of variance (ANOVA). The significance of the effects of various treatments on plant growth parameters, plant nutrients, crop yield, and soil nutrients was determined based on the p-value ($p < 0.05$ and $p < 0.001$).

3. Results

The data on phytochemical screening of methanol and chloroform extracts of turmeric rhizomes collected from the Surkhandarya region, Termez district were presented in Table 1. The results revealed the presence of alkaloids, terpenoids, tannins, flavonoids, steroids, carbohydrates, and saponins in the methanolic extract of turmeric rhizomes in all treatments. The chloroform extract indicated the presence of six phytochemicals—alkaloids, terpenoids, flavonoids, steroids, carbohydrates and saponins—in the turmeric rhizomes in all treatments (Table 1).

In the present study, the phytochemical evaluation of turmeric rhizome revealed the absence of glycosides. However, the methanol extracts of turmeric rhizomes collected from the Tashkent region, Kibray district revealed the presence of alkaloids, terpenoids, tannins, flavonoids, steroids, carbohydrates, and saponins in all treatments

Table 1. Phytochemical screening of methanol and chloroform extracts of *Curcuma longa* L. cultivated in the Surkhandarya region.

Treatment	Compounds	Methanol extract	Chloroform extract
T1 - control	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T2 - NPK (application rate 75:50:50 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T3 - NPK (application rate 125:100:100 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T4 - NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–

+ Positive = detected, – negative = not detected.

(Table 2). Phytochemical screening of the chloroform extract of turmeric rhizomes indicated that alkaloids, terpenoids, tannins, flavonoids, steroids, carbohydrates, and saponins were present in the samples collected from the Tashkent region, Kibray district, in all treatments (Table 2).

The curcumin content in turmeric rhizomes significantly increased with the NPK (application rate 125:100:100 kg/ha) and the NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha) treatments in both the Surkhandarya and Tashkent regions (Figure 3). In the Surkhandarya region, the rhizome curcumin content was higher compared to turmeric grown in the Tashkent region. In both regions, Surkhandarya and Tashkent, the NPK treatment (application rate 125:100:100 kg/ha) significantly increased the curcumin content by 90% and 78%, respectively, compared to the control. The maximum curcumin content was recorded in the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha), indicating a significant increase in curcumin content, particularly in the Surkhandarya region compared to the control.

The data in Table 3 indicate that in both the Surkhandarya and Tashkent regions, the NPK treatment (application rate 125:100:100 kg/ha) significantly enhanced the rhizome robinin content by 30%–35% and the rutin

Table 2. Phytochemical screening of methanol and chloroform extracts of *Curcuma longa* L. cultivated in the Tashkent region.

Treatment		Methanol extract	Chloroform extract
T1 - control	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T2 - NPK (application rate 75:50:50 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T3 - NPK (application rate 125:100:100 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–
T4 - NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha)	Alkaloids	+	+
	Terpenoids	+	+
	Tannins	+	–
	Flavonoids	+	+
	Steroids	+	+
	Carbohydrates	+	+
	Saponins	+	+
	Glycosides	–	–

+ Positive = detected, – negative = not detected.

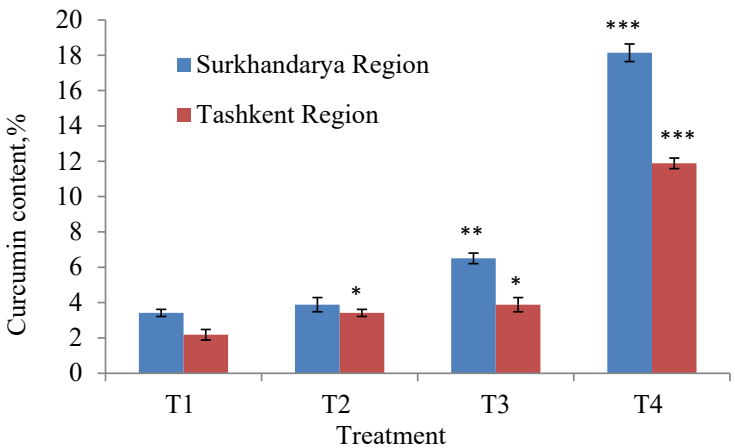

Figure 3. Effect of various mineral fertilizers on curcumin content of medicinal plant turmeric rhizomes cultivated in the Surkhandarya and Tashkent regions.

Table 3. Effect of various mineral fertilizers on flavonoid content of medicinal plant turmeric rhizomes cultivated in the Surkhandarya and Tashkent regions.

Land cultivated	Treatment	Flavonoid content, mg/100g			
		Robinin	Rutin	Quercetin	Hypolaetin, gallic acid
Surkhandarya region	T1 - control	5.51 ± 0.07	0.14 ± 0.05	0.071 ± 0.03	–
	T2 - NPK (application rate 75:50:50 kg/ha)	6.49 ± 0.08	0.16 ± 0.06	0.077 ± 0.04	–
	T3 - NPK (application rate 125:100:100 kg/ha)	7.46 ± 0.1	0.17 ± 0.07	0.128 ± 0.06	–
	T4 - NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha)	8.76 ± 0.09	0.18 ± 0.06	0.129 ± 0.05	–
Tashkent region	T1 - control	3.66 ± 0.07	0.12 ± 0.05	0.082 ± 0.06	–
	T2 - NPK (application rate 75:50:50 kg/ha)	4.21 ± 0.08	0.14 ± 0.05	0.082 ± 0.05	–
	T3 - NPK (application rate 125:100:100 kg/ha)	4.77 ± 0.09	0.15 ± 0.06	0.085 ± 0.06	–
	T4 - NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha)	4.61 ± 0.1	0.19 ± 0.07	0.087 ± 0.05	–

content by 21%–25% compared to the control (no fertilizer). Compared to the control, the NPK treatment (application rate 125:100:100 kg/ha) also increased the quercetin content by 80% in the Surkhandarya region. The combination of macro- and microelement treatments, NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha), significantly increased the rhizome robinin content by 26%–59% and the rutin content by 28%–58% compared to the control in both the Kibray and Termez districts. Additionally, the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the quercetin content by 82% compared to the control in the Surkhandarya region.

The lowest level of protein content in the rhizome was observed in plants without mineral fertilizer control treatment and with the NPK treatment (application rate 75:50:50 kg/ha) in both the Surkhandarya and Tashkent regions. In the Surkhandarya region, the highest level of protein content in the rhizome was found compared to the Tashkent region. Compared to the control, the maximum protein content was observed in the NPK treatment (application rate 125:100:100 kg/ha) and the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha). These treatments significantly increased protein content in the Surkhandarya region. In the Surkhandarya region, the NPK treatment (application rate 125:100:100 kg/ha) and the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the protein content by 17% and 14%, respectively (Figure 4). In the Tashkent region, treatments with NPK application rate (125:100:100 kg/ha) and the NPK + BZnFe application rate (100:75:75:3:6:6 kg/ha) increased the protein content by 11% and 10%, respectively, compared to the control.

The yields of polysaccharides and their monosaccharide composition are presented in Table 4. Glucose predominated in the hemicellulose composition. The lowest level of monosaccharide content in the rhizomes was observed in plants without mineral fertilizer control treatment and with the NPK treatment (application rate 75:50:50 kg/ha) in both the Surkhandarya and Tashkent regions. In the Surkhandarya region, the rhizomes have the highest level of monosaccharide content compared to those in the Tashkent region. Compared to the control, the maximum monosaccharides content was observed with the NPK treatment (application rate 125:100:100 kg/ha) and

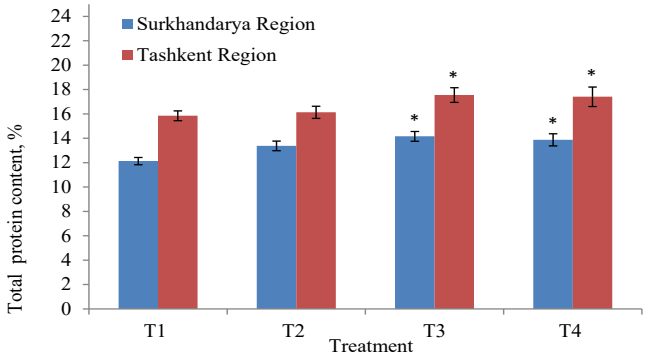

Figure 4. Effect of various mineral fertilizers on total protein content of medicinal plant turmeric rhizomes cultivated in the Surkhandarya and Tashkent regions.

Table 4. Monosaccharide composition of polysaccharides extracted from the rhizome of *Curcuma longa* L.

Region	Treatments	Polysaccharides	Yield,%	The ratio of monosaccharide residues							
				Rham	Ara	Xyl	Man	Glu	Gal	Ura	Fru
Surkhandarya	T1	ASS	8.5	–3.9	+	–	–	+	–	–	+
		WSP	2.4	1.0	1.0	6.0	7.1	8.1	–	–	–
		PS	9.8	0.9	2.8	2.5	–	25.8	–	+	–
		HC	23.3		1.6	1.1	–	21.0	1.7	+	–
	T2	ASS	9.1	–	+	–	–	+	–	–	+
		WSP	2.7	4.1	1.1	5.8	6.9	8.8	–	–	–
		PS	11.2	0.9	2.5	3.1	–	27.1	–	+	–
		HC	25.5	1.3	1.5	1.9	–	29.0	–	+	–
	T3	ASS	10.1	–	+	–	–	+	–	–	+
		WSP	3.0	5.0	1.3	6.1	7.1	7.9	–	–	–
		PS	10.9	1.3	2.1	3.3	–	21.7	–	+	–
		HC	20.7	1.7	1.4	2.0	–	30.1	0.6	+	–
	T4	ASS	10.9	–	+	–	–	+	–	–	+
		WSP	4.4	6.1	1.7	6.7	7.7	8.1	–	–	–
		PS	12.1	2.0	2.5	3.9	–	25.1	–	+	–
		HC	25.8	2.4	1.3	3.6	–	29.7	–	+	–
Tashkent	T1	ASS	5.3	–	+	–	–	+	–	–	+
		WSP	2.5	2.8	0.9	3.4	3.7	18.5	2.3	–	–
		PS	8.6	3.1	1.0	1.4	–	11.9	–	+	–
		HC	20.2	1.7	1.2	0.9	0.8	37.1	2.6	+	–
	T2	ASS	4.1	–	+	–	–	+	–	–	+
		WSP	2.7	2,1	1.1	3.1	2.8	7.9	–	–	–
		PS	9.6	3.3	1.7	1.9	–	13.1	–	+	–
		HC	19.8	2.0	1.9	1.6	1.1	36.1	2.9	+	–
	T3	ASS	5.1	–	+	–	–	+	–	–	+
		WSP	2.1	2.5	1.6	3.8	2.6	8.4	–	–	–
		PS	9.8	4.0	2.0	2.2	–	15.2	–	+	–
		HC	21.9	1.9	2.3	2.1	1.7	31.6	1.1	+	–
	T4	ASS	9.9	–	+	–	–	+	–	–	+
		WSP	3.0	3.1	2.2	4.1	3.3	9.0	–	–	–
		PS	10.8	5.0	2.4	2.7	–	17.1	–	+	–
		HC	23.4	2.1	3.0	2.1	2.1	33.0	1.7	+	–

ASS: alcohol-soluble sugar; HC: hemicellulose; PS: pectic substance; WSP: water-soluble polysaccharide.

the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha), resulting in a significant increase monosaccharide content in the Surkhandarya region.

4. Discussion

Herbal plants are important have been used in both traditional and modern medicine (Egamberdieva and Jabborova, 2018; Jabborova et al., 2019; Egamberdieva and Jabborova, 2020; Jabborova et al., 2020; Mamarasulov et al., 2020; Jabborova et al., 2021a; Sarabekov et al., 2021).

Micronutrients, particularly nitrogen and phosphorus, play a crucial role in nutrient uptake, growth, and overall development of plants (Elemike et al., 2019). The rhizome of the turmeric plant is one of the best and most utilized sources of macro- and micronutrients (Jabborova et al., 2021b). When mineral fertilizers are applied externally to the rhizome of the turmeric crop, they enhance nutrient uptake, which can ultimately result in higher and more potential yield of the crop (Jabborova et al., 2021c). Many case studies have been conducted on turmeric grown in various regions of the world (Prasad et al., 2014); however, none have focused on the Tashkent and Surkhandarya regions. Several studies conducted in different parts of the world have investigated the effect of mineral fertilizers on turmeric's protein and other phytochemicals. These studies found that the application of nitrogen, phosphorus, and potassium fertilizers significantly increased the protein content of turmeric compared to the control group. Specifically, the application of nitrogen fertilizer was found to increase the total phenolic and flavonoid content in turmeric by 25% and 21%, respectively (Verma et al., 2019). A study conducted in Thailand found that applying nitrogen fertilizer increased the curcumin content in turmeric by 16%, while applying potassium fertilizer increased the volatile oil content in turmeric (Akamine et al., 2007). Overall, these studies suggest that the use of mineral fertilizers can significantly impact the protein and other phytochemical contents of turmeric in different regions. However, it is important to note that the optimal fertilizer application rate may vary depending on factors such as soil type, climate, and turmeric cultivar.

This experiment revealed a substantial enhancement in the nutrient content in turmeric. The results clearly indicate the presence of alkaloids, terpenoids, flavonoids (which reduce cardiovascular mortality rate), steroids, carbohydrates and saponins (amphipathic glycosides exhibiting both hydrophilic and lipophilic properties) in the methanolic extracts of turmeric rhizomes in all treatments, with samples collected from the Surkhandarya and Tashkent regions. Tannins, recognized for enhancing glucose uptake and considered a potential drug for diabetes, were found in the methanol extract of all four sets under investigation but were absent in the chloroform extract. In contrast, glycosides were reported to be absent in all experimental treatments.

In addition, a higher curcumin content was reported when crops were treated with NPK fertilizers in the Surkhandarya region compared to those in the Tashkent region. The NPK treatment (application rate 125:100:100 kg/ha) substantially boosted rhizome robinin content by 30%–35% and rutin content by 21%–25% compared to the control group, which received no fertilizer. The studies also revealed that the quercetin content was increased by 80% in the Surkhandarya region following the NPK treatment (application rate 125:100:100 kg/ha) compared to the control. Additionally, the quercetin content also showed a drastic increase of 82% in the same region with the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha). The combination of macro- and microelement treatments, NPK + BZnFe (application rate 100:75:75:3:6:6 kg/ha), significantly enhanced the rhizome robinin composition by 26%–59% and the rutin content by approximately 28%–58% compared to the control in both the Kibray and Termez districts.

This was the first time that the NPK treatment (application rate 125:100:100 kg/ha) and the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) increased the overall protein content in the Surkhandarya region by 17% and 14%, respectively. Similarly, studies conducted in the Tashkent region reported an increase in protein content by approximately 10% following the application of the same NPK combinations. The polysaccharides extract of the rhizome in *Curcuma longa* L. revealed that glucose is predominantly accumulated in the hemicellulose composition. This analysis clearly demonstrated that the NPK (application rate 100:75:75 kg/ha), in combination with BZnFe (application rate 3:6:6 kg/ha), significantly enhanced the curcumin and flavonoid contents in turmeric rhizomes grown in the Tashkent and Surkhandarya regions.

5. Conclusion

For the first time in Uzbekistan, the phytochemical evaluation of turmeric rhizomes grown in the country was conducted. The evaluation revealed the absence of glycosides but the presence of alkaloids, terpenoids, tannins, flavonoids, steroids, carbohydrates, and saponins in the methanol extracts of turmeric rhizomes collected from Termez and Kibray districts, in all treatments. However, the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the curcumin, rutin, and quercetin contents of turmeric rhizomes grown in the Tashkent and Surkhandarya regions. The highest total protein content was recorded in the NPK treatment (application rate 125:100:100 kg/ha), which significantly increased the total protein content compared to the control. It was concluded that the NPK + BZnFe treatment (application rate 100:75:75:3:6:6 kg/ha) significantly increased the curcumin and flavonoids contents of turmeric rhizomes grown in the Tashkent and Surkhandarya regions compared to the control.

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