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Full Length Article

Lysine Priming Improved Cadmium Stress Tolerance and Nutraceutical Potential of Bitter Melon (*Momordica charantia*)

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Abstract

Uncontrolled increase in population and pathogen resistance underscores the need to develop nutraceutical-rich plants that can serve as food and medicine. Heavy metal contamination remains a major impediment in achieving this goal. It was hypothesized that lysine could influence the metabolism of bitter melon (*Momordica charantia* L.) to enhance stress tolerance and nutraceutical quality. A pot experiment was conducted, where seeds of bitter melon were primed for 24 h with lysine (0, 0.01, 0.1 and 1 m*M*) and grown under cadmium (Cd) stress (control, 2 and 5 mg $CdCl_2$/kg soil). Morphological traits, primary metabolites, antioxidants and antibacterial activities against *Staphylococcus aureus* and *Pseudomonas aeruginosa* were analyzed. The fruit was evaluated for biomass, nutritional content and phenolic profile. Bitter melon showed inherent potential to inhibit both species. Stress reduced growth, chlorophyll, sugars and proteins contents, while phytate, hydrogen peroxide and malondialdehyde contents were increased. Lysine positively influenced all these attributes. Antibacterial activity against *S. aureus* was further improved in primed plants, with a positive correlation to nutritional parameters, peroxidase activity and the contents of flavonoids, p-coumaric acid, gallic acid, chlorogenic acid, quercetin, kaempferol and hydroxybenzoic acid. Therefore, lysine priming can be recommended as a safe and effective strategy to enhance the daily diet and improve production in Cd stress.

Keywords: Lysine; Bitter melon; Antioxidant; Phenolics; Primary metabolites; Antibacterial

Introduction

Cadmium contamination poses a significant challenge to human and plant health. It continues to pollute the environment because of unregulated economic and agricultural growth. It harms plant tissues, disrupts nutrient uptake, affects plant structure and function and reduces crop yields (Mfarrej and Al-Huqail 2025; Masood *et al.* 2025).

Plants naturally produce various primary and secondary metabolites that help them respond to environmental challenges. The antioxidant capacity of these metabolites helps plants to scavenge stress-induced peroxidation products, thereby boosting stress tolerance. Many of these compounds are bioactive, known for their nutritional and medicinal benefits, and are referred to as nutraceuticals. These metabolites with the above significance include nutrients, vitamins, carotenoids, chlorophylls and phenols (Gerola *et al.* 2011; Hadidi *et al.* 2024; Hussain *et al*. 2024). Incorporating these metabolites into daily food is considered a cost-effective and sustainable approach to enhancing food security and reducing reliance on synthetic medicines.

There is a dire need to find new antimicrobial sources to combat microbes that develop resistance to existing antibiotics over time. Relying only on current antibiotics is expected to cause 10 million deaths worldwide by 2050 (Pulingam *et al.* 2021). For targeted research into microbes, the World Health Organization (WHO) has identified some critical and concerning pathogens, including *Staphylococcus aureus* and *Pseudomonas aeruginosa* (WHO 2024).

Manipulation of plant metabolism to overproduce metabolites of interest is a popular strategy. It is being employed to improve food quality and tolerance to environmental stresses. Plants engineered for high lysine content have demonstrated improved accumulation of proteins, nutritional components and stress tolerance in previous studies (Rathore *et al.* 2025). Engineering can be expensive and technical, requiring some cost-effective alternatives. Seed priming is amongst the most widely adopted simple, inexpensive and user-friendly approaches among them.

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Bitter melon (*Momordica charantia* L.) is a popular vegetable grown in tropical, subtropical and warm-temperate regions worldwide. Its leaves, seeds and peels are commonly used due to their nutritional and medicinal benefits (Hussain *et al*. 2024). These benefits are associated with natural metabolites. Phenolics are considered the most significant for such functions (Hayakawa *et al.* 2022; Hadidi *et al.* 2024). It was hypothesized that lysine priming could influence bitter melon metabolism to enhance antioxidant, nutritional and antibacterial properties (against *S. aureus* and *P. aeruginosa*). Successful outcomes may lead to better food production, characterized by higher levels of natural compounds involved in ROS management and a diet rich in nutraceuticals.

Materials and Methods

Experimental details

Seed of Safeena variety of bitter melon (*M. charantia*) was taken from the Ayub Agricultural Research Institute (AARI), Faisalabad, Punjab, Pakistan. Surface-sterilized (0.1% $HgCl_2$) seeds for 5 min, were primed (unprimed, 0, 0.01, 0.1 and 1 m*M* Lysine) for 24 h using sterilized materials. Seeds were sown in natural climatic conditions in a Completely Randomized design with three replicates and three Cd levels (control, 2 and 5 mg $CdCl_2$/kg soil). Three harvests were taken first at the seedling stage, second at the vegetative stage and finally at the mature yield stage for the following studies.

Photosynthetic pigments

Chlorophyll content was determined by the method of Arnon (1949). A 0.5 g of fresh leaf sample was extracted in 80% of acetone and the volume was brought up to 10 mL. Absorbance was read at 663 nm and 645 nm on a spectrophotometer to determine the values of leaf total chlorophyll using the following formula:

$$\text{Total Chl. (mg/g)} = [20.2(OD645+8.02(OD663)] \times V1000 \times W$$

Where *V*, volume of the acetone used; *W*, weight of leaf used.

Nutritive and antinutritive components

Crude fiber: Ash and crude fiber were determined by the method of Chopra and Kanwar (1991). For crude fiber, 0.5 g of fruit and peel was treated with 25 mL of 1.25% NaOH, washed and treated with 25 mL of 1.25% diluted sulfuric acid (H_2SO_4), washed with hot water and then treated with 1% HNO_3 before being rinsed once more with hot water. The residue was combusted in an EYELA-TMF-2100 muffle furnace (Japan) and the weight of ash was recorded. Percent variation in weight was interpreted as a crude fiber.

Ash: Dry plant sample (5 g) was converted into ash at 350°C using a muffle furnace.

Crude fat: From the dry fruit sample, crude fat was determined following the official method (AOAC 1990).

Total soluble sugar: Irigoyen *et al.* (1992) described the method of soluble sugar. 0.25 g of leaf sample was extracted in 80% methanolic solution. A 0.1 mL of methanolic extract was added to 3 mL of anthrone reagent (0.15 g anthrone reagent in 100 mL of 72% sulphuric acid). It was then placed in a water bath at 95°C for 15 min. Absorbance was measured at 625nm on the spectrophotometer.

Total soluble proteins: Following Bradford (1976), A 1.5 mL of 1 M Phosphate buffer (pH of 7.0) was used to extract 0.5 g of the sample in an ice-chilled mortar pestle. A supernatant was obtained by centrifuging the sample at 12000 rpm for approximately 15 min. The Bradford reagent (50 mL ethanol, 0.1 g Coomassie blue dye and 100 mL orthophosphoric acid) was diluted to 1000 mL, filtered and then diluted to 1L. The 100 µL extract was used for the reaction and absorbance was measured at 595 nm using a spectrophotometer.

Tannin: Fruit tissue (0.12 g) and 2.5 mL of distilled water were shaken well for 1 h. Thereafter, 5 mL of filtrate, 2 mL of 0.1 M $FeCl_3$ (in 0.1 N HCl) and 0.008 *M* potassium ferrocyanide were allowed to react. At 725 nm, determinations were made following Buren and Robinson (1981).

$$C_T = A_T \times C_s / A_s$$

Where CT is tannin concentration (mg GAE/g), AT is the absorbance of the sample, CS is the concentration of tannin in the standard and AS is the absorbance of the standard.

Phytate: The Method of Young and Greaves (1940) was used for phytate determination. Extraction of 4 g/100 mL HCL (2%) was filtered. To 5 mL of filtrate, 1 mL of ammonium thiocyanide (0.3%) and 10.6 mL of distilled water were added; titrated against 0.01 M ferric chloride ($FeCl_3$) till the yellow-brownish color appeared A 1.19 mg per mL solution of phytin was used.

$$\text{Phytate content (mg \%)} = \text{TV (mL)} \times \text{phytin phosphorous (1.19 g)} \times 3.55$$

Oxidants and antioxidants

Peroxidase activity: Estimation was made following the method of Sadasivam and Manickam (1991) using H_2O_2 and guaiacol as substrates. A 0.5 g of leaf was homogenized in 3 mL of 0.1 M phosphate buffer at pH 7 in a chilled mortar. The sample was then transferred into the centrifuge machine to centrifuge the samples at 18000 rpm at a temperature of 5°C for 15 min. Supernatant was used as the enzyme and kept at an ice-chilled condition for 4 h. Thereafter, 3 mL of phosphate buffer and 0.05 mL of guaiacol were infused into 100 µL of enzyme in a cuvette. Vortexed the mixture and read the absorbance at 430 nm in a spectrophotometer at every 20s interval:

$$\text{The specific activity units } (g^{-1} \text{ f.wt.}) = [500\Delta t] \times [11000] \times [TVVU] \times [1\text{f.wt.}]$$

Where: Δt*:* Change in time (min); *TV:* Total volume of extract (mL); *UV:* Volume used (mL); *f. wt.:* Weight of fresh leaf tissue (g).

Malondialdehyde (MDA): As described by Cakmak and Horst (1991), 0.25 g of leaf sample was homogenized in 3% trichloroacetic acid (TCA). To 500 µL, 3 mL of 0.5% thiobarbituric acid in 20% TCA solution was added, followed by heating at 95°C for 55 min. Absorbance was measured at 532 nm and 600 nm for the following calculations.

MDA (nmol) = Δ (A 532 nm-A 600 nm)/1.56×105

Hydrogen peroxide: Using the method proposed by Velikova et al. (2000) 0.25 g of fresh leaf was ground with 6% TCA. Then, 0.5 mL of TCA extract was mixed with 0.5 mL of 10 mM phosphate buffer at pH 7.0. After that, 1 mL of 1 M KI (potassium iodide) was added. The mixture was vortexed and absorbance was measured at 390 nm on a spectrophotometer.

Phenolics: To measure phenolics, 0.25 g of leaf sample was homogenized in 80% methanol. Then 100 µL of the sample, 500 µL of Folin reagent and 20% of 2.5 mL Na_2CO_3 was allowed to react. Absorbance was measured at 750 nm on a spectrophotometer (Julkenen-Titto 1985).

Flavonoids: Leaf tissue was extracted in 80% methanol and 1 mL of the sample was added to 0.3 mL of 5% Na_2CO_3. After incubation for 5 min, 0.3 mL of 10% $AlCl_3$ was added, followed by 2 mL of 1 M NaOH and the volume of the solution was made up to 10 mL. The absorbance was read at 510 nm using a spectrophotometer (Karadeniz *et al.* 2005).

Antimicrobial potential: This was measured in terms of minimum inhibitory concentration (MIC) of the extract. Three extractions (water, acetone and methanol) were prepared from 0.1 g of the sample in 1 mL of solvent. The micro dilution tray was prepared by volumetrically diluting the extract several times; a new pipette was used for every step. Cultures of *S. aureus* and *P. aeruginosa* were obtained from the Department of Microbiology, Government College University, Faisalabad, Pakistan and were inoculated as 0.01 mL bacterial suspensions in each microdilution. The inoculated microdilution tray was checked for density (not extended to 10%). Inoculated suspensions were incubated (35±2ºC) for 16–20 h. Finally, the minimum concentration with the potential to inhibit bacteria was noted as MIC (Cheruiyot *et al.* 2009).

Phenolic profile (HPLC): The freeze-dried sample was prepared using liquid nitrogen. A 1.5 g of the sample was homogenized with 2.5 mL of HPLC-grade methanol. The HPLC analysis was conducted at the Central Hi-Tech Laboratory of GCUF, Pakistan, following the method of Penarrieta *et al.* (2007) employing gradient reverse-phase HPLC (Shimadzu, Japan). Two solvents were used: acetonitrile (A) and 0.1% phosphoric acid (B). Using standard phenolics, individual phenolics were estimated in leaf and fruit samples. A SPD-10AV detector was used and a computer-generated chromatogram was utilized to evaluate the comparative composition of phenolics. The HPLC system was equipped with a C18 column.

Statistical analysis

For Analysis of Variance and mean comparison (LSD) Costat coHort 6.4 software was used.

Results

Morphological attributes

Higher Cd stress (5 mg $CdCl_2$/kg soil) significantly reduced germination percentage, leaf area and leaf dry weight. All lysine levels increased the germination percentage under this stress. At lower levels of Cd (2 mg $CdCl_2$/kg soil), there was an almost non-significant effect of both factors (Fig. 1).

Nutritive value

Total soluble sugars decreased under high stress in untreated plants, whereas total soluble proteins decreased at both stress levels. Each level of lysine improved these parameters. Stress decreased crude fiber and percent ash. Higher concentration of lysine improved these attributes as a priming agent (Fig. 2).

Antinutritive value

Phytate and tannin levels increased with stress. None of the priming levels significantly affected tannin content under stress. However, under controlled conditions, priming reduced its level. For phytate, lysine priming was effective in decreasing its accumulation in stressed plants (Fig. 2).

Oxidants and antioxidants

Cd stress increased MDA accumulation at higher levels and H_2O_2 at both stress levels. Priming reduced their accumulation under stress. Total phenolic content increased due to Cd stress. Regarding the effect of priming, at a lower stress level, the impact was almost non-significant; however, at a higher level, priming enhanced its effect. Total chlorophyll content and POD activity decreased significantly; however, lysine priming improved their values (Fig. 3).

Fruit yield

Final fruit yield in terms of fruit and seed dry mass decreased under Cd stress. However, the number of fruits per plant and fruit fresh weight remained the same across all growth conditions for unprimed plants. The highest concentration of lysine increased this attribute in primed plants. Average seed weight, fruit fresh and dry weights improved with lysine priming too (Fig. 4).

Antibacterial activity

Antibacterial activities (MIC) varied depending on the plant's

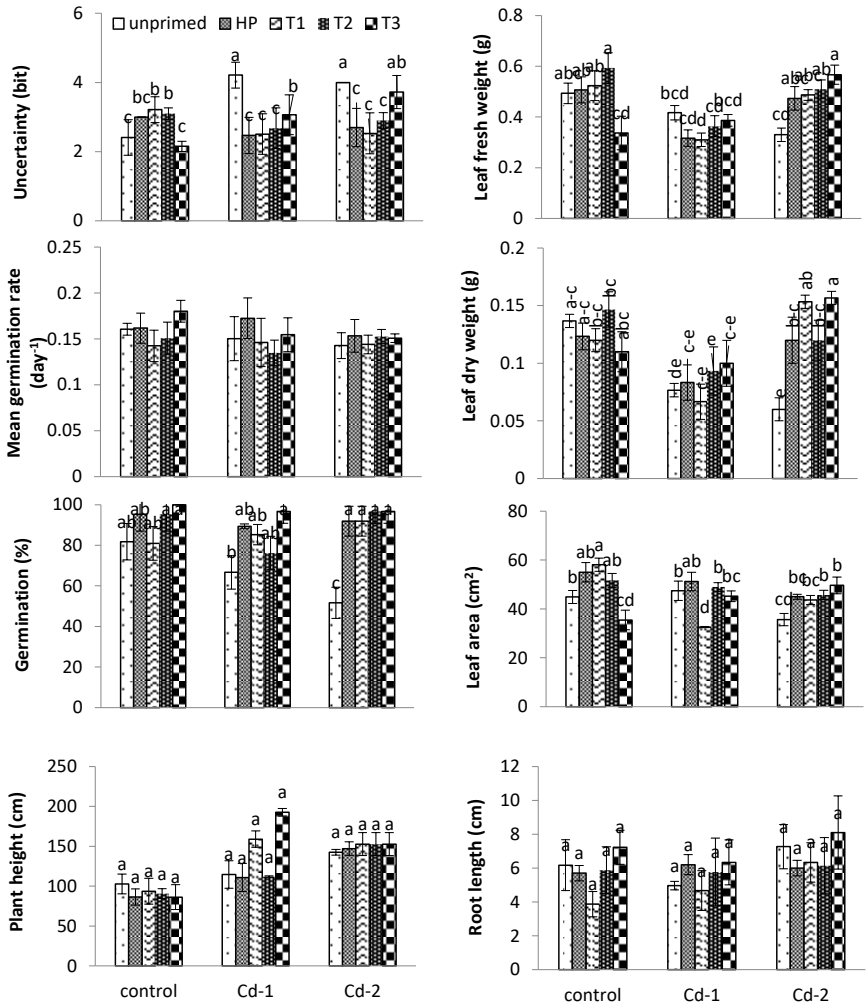

Fig. 1: Morphological comparison of unprimed, hydroprimed (HP), and lysine-primed (0.01, 0.1 and 1 mM, labeled as T1, T2, and T3, respectively) *M. charantia* grown under control (CD-0), 2 and 5 mg $CdCl_2$/kg soil (CD-1 and 2). Error bars indicate standard deviation, and letters on each column represent LSD at the 0.01 significance level

growth stage and the extraction solvent. Bitter melon leaves showed MIC against both species across all extraction methods. The best results were achieved with acetone and methanol extracts. Against *S. aureus*, bitter melon inhibited growth up to the second dilution, which was further enhanced by lysine treatment and Cd stress. Against *P. aeruginosa*, bitter melon inhibited growth up to the third dilution, with no additional benefit from stress or priming observed in water and methanol extracts. In the acetone extract, results were poor in untreated samples but improved with Cd stress and priming treatments (Table 1). MIC of extract against *S. aureus* was positively correlated with nutritive parameters, peroxidase, flavonoids, p-coumaric acid (p-CA), gallic acid (GA), chlorogenic acid, quercetin (Que), kaempferol (KMF), hydroxybenzoic acid (HBA) and negatively with phytate, H_2O_2, coumarins, syringic acid (SA) and m-coumaric acid (m-CA) (Table 1 and 2).

Phenolic profile

Phenolic profile of the whole fruit varied between untreated and treated plants. Leaf and fruit samples contained different amounts of p-CA, GA, Butylated hydroxyanisole (BHA), HBA, sinapic acid (SiA), cinnamic acid (CA), Que, KMF, HBA, BA, SA and m-CA. The highest percentage was that of GA, which was comparatively higher in leaves than in fruits. Except for p-CA and BHA and benzoic acid (BA), all phenolics showed a positive correlation with lysine priming (Figs. 5–6). There was a positive correlation between lysine priming and all biochemicals, but a negative one with phytate, H_2O_2, MDA, p-CA, BHA and BA. Cd treatment showed a negative correlation with nutritive components but a positive one with antinutritive phytate and MIC against *S. aureus.*

Table 1: Antibacterial activities (MIC) against *S. aureus* and *P. aeruginosa* of leaf extracts (water, acetone and methanol) of primed (unprimed, hydro primed, 0.01, 0.1 and 1 m*M* lysine) *M. charantia* growing under Cd stress conditions

Solvent	Seedling stage		Vegetative Stage	
	Control	Lysine	Control	Lysine
		MIC against *S. aureus*		
Water	0	0	2	3
Methanol	2	5	2	4
Acetone	3	3	2	2
	Cd stress	Lysine	Cd stress	Lysine
Water	1	1	3	4
Methanol	3	3	3	5
Acetone	4	4	3	3
		MIC against *P. aeruginosa*		
	Control	Lysine	Control	Lysine
Water	1	1	3	3
Methanol	1	2	3	3
Acetone	3	3	1	2
	Cd stress	Lysine	Cd stress	Lysine
Water	2	2	3	3
Methanol	2	3	3	3
Acetone	4	4	2	3

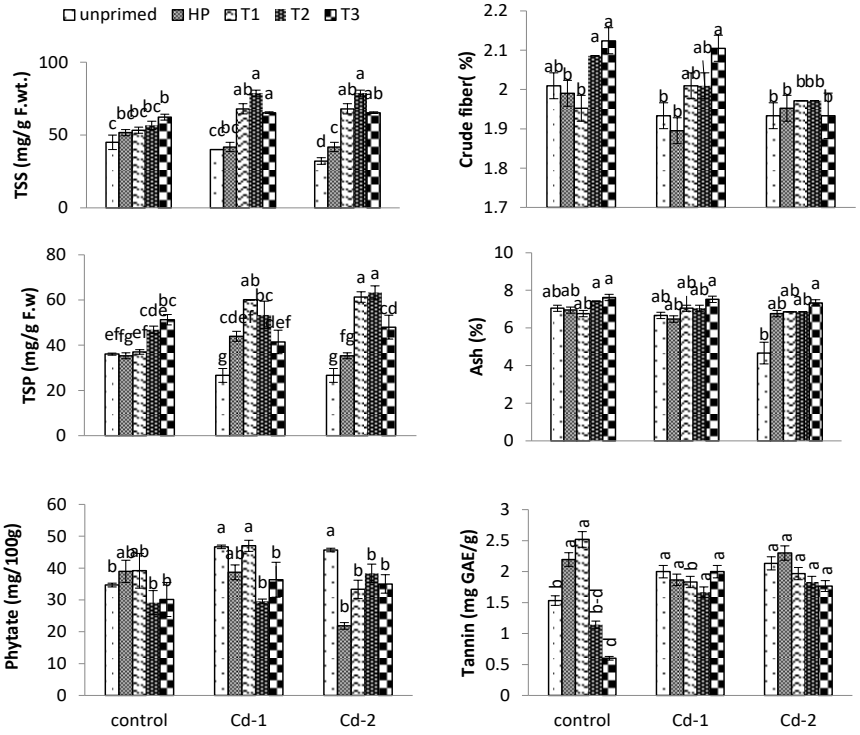

Fig. 2: Nutritive and antinutritive attributes of unprimed, hydroprimed (HP), and lysine-primed (0.01, 0.1 and 1 mM, labeled as T1, T2, and T3, respectively) *M. charantia* grown under control (CD-0), 2 and 5 mg $CdCl_2$/kg soil (CD-1 and 2). Error bars indicate standard deviation, and letters on each column represent LSD at the 0.01 significance level

Discussion

Amino acid metabolism interacts with other metabolic pathways, including energy, carbohydrate, other amino acids, carbon, nitrogen, hormones and secondary metabolism. Lysine is one of the amino acids that positively influence plant growth by causing endogenous and exogenous changes (Yang *et al.* 2020). In the current study, lysine priming affected the growth and metabolism of bitter melon, altering its tolerance to Cd. Safeena variety of bitter melon under mild Cd stress maintained its morphological features, indicating moderate Cd tolerance. However, at higher stress levels, the plants experienced a significant reduction in growth. Lysine-primed plants exhibited better growth and yield (Fig. 1 and 4), which is consistent with the literature (Yang *et al.* 2020; Mfarrej and Al-Huqail, 2025; Rathore *et al.* 2025).

Table 2: Correlation of Cd stress, lysine priming and MIC with all biochemical attributes

Variables	Cd stress	Lysine	MIC against *P. aeruginosa*	MIC against *S. aureus*
Lysine	0.000	1	------	0.905
S. aureus	0.369	0.905	------	1
P. aeruginosa	------	------	------	-----
Crude fiber	-0.433	0.707	------	0.533
Ash	-0.433	0.707	------	0.426
Total soluble Phenolics	0.913	0.149	------	0.539
Total soluble sugars	0.366	0.533	------	0.569
Total chlorophyll	-0.048	0.533	------	0.569
Total soluble Proteins	0.212	0.972	------	0.848
Phytate	0.433	-0.938	------	-0.745
MDA	0.433	-0.707	------	-0.426
H_2O_2	-0.518	-0.707	------	-0.426
POD	0.780	0.676	------	0.408
Flavonoids	0.000	0.557	------	0.784
p-CA	0.961	-0.038	------	0.374
Gallic acid	0.174	0.641	------	0.644
Salycilic acid	-0.548	-0.447	------	-0.674
Chlorogenic acid	0.305	0.249	------	0.476
Coumarins	0.287	-0.888	------	-0.665
Quercetin	0.472	0.664	------	0.812
Kaempferol	0.469	0.703	------	0.848
Hydroxy benzoic acid	-0.548	0.447	------	0.135
Benzoic acid	-0.628	-0.427	------	-0.567
Cinnamic acid	-----	-------	------	-------
Syringic acid	-0.311	-0.676	------	-0.637
m-coumaric acid	-0.311	-0.676	------	-0.637
Sinapic acid		------	------	-------

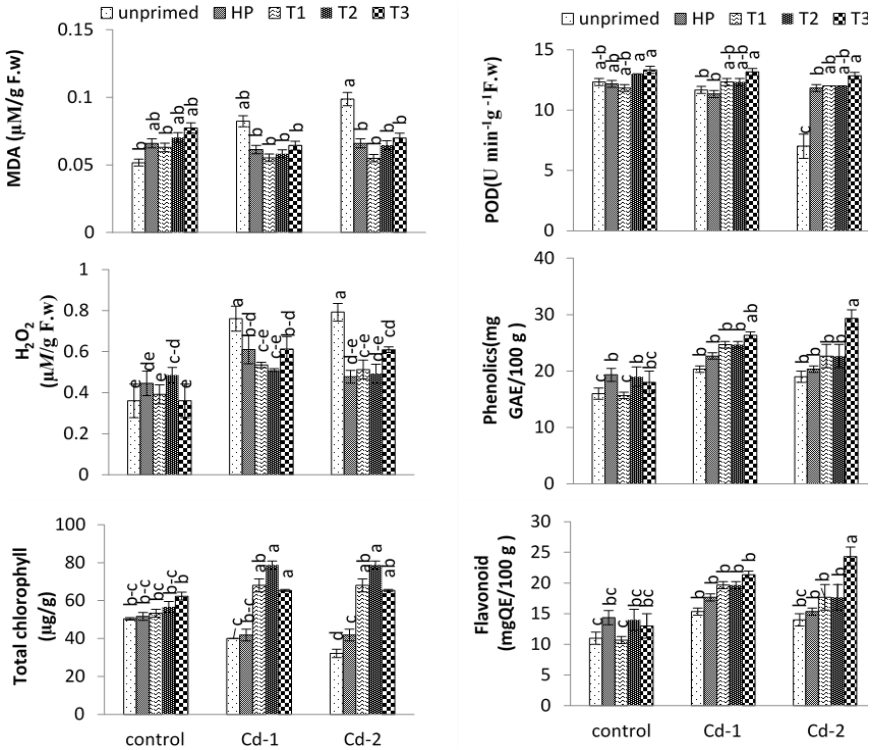

Fig. 3: Oxidants and antioxidants of unprimed, hydroprimed (HP), and lysine-primed (0.01, 0.1 and 1 mM, labeled as T1, T2, and T3, respectively) *M. charantia* grown under control (CD-0), 2 and 5 mg $CdCl_2$/ kg soil (CD-1 and 2). Error bars indicate standard deviation, and letters on each column represent LSD at the 0.01 significance level

Chlorophylls play a vital role in plant growth and stress tolerance. Additional reports also highlight their function as anticancer and antioxidant agents in medicinal plants. Some derivatives of chlorophyll, particularly poly-L-lysine derivatives, showed antimicrobial activity (Gerola *et al.* 2011). Total chlorophyll content of bitter melon showed a

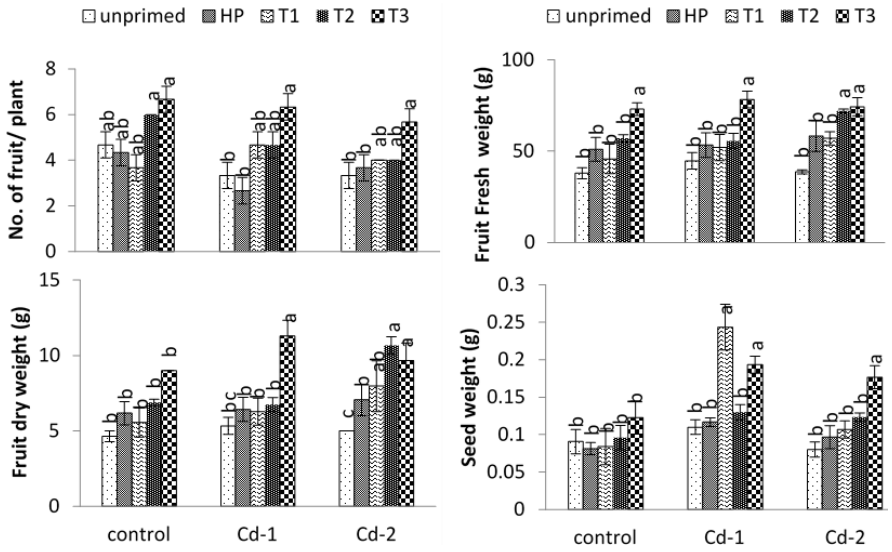

Fig. 4: Yield of unprimed, hydroprimed (HP), and lysine-primed (0.01, 0.1 and 1 mM, labeled as T1, T2, and T3, respectively) *M. charantia* grown under control (CD-0), 2 and 5 mg $CdCl_2$/kg soil (CD-1 and 2). Error bars indicate standard deviation, and letters on each column represent LSD at the 0.01 significance level

positive correlation with lysine treatment and MIC against *S. aureus* (Table 2). Mirtaleb *et al.* (2021) reported a similar increase in photosynthetic activity in plants treated with other amino acids, supporting our findings (Fig. 2).

Nutritive and antinutritive components, including carbohydrates, proteins, crude fiber, fats, phytate and tannins, determine nutritional quality. In the current study, Cd stress reduced nutritional parameters and increased the antinutritional phytate content. Lysine priming enhanced the nutritional status of fruit by increasing total soluble sugars and proteins, while reducing phytate content. Moreover, priming maintained levels of crude fiber and tannins (Fig. 2). Increased ash percentage was another indicator of better mineral composition in primed plants.

Excessive MDA and H_2O_2 production in plants is a marker of stress-induced damage from peroxidation. When consumed as food, these compounds can weaken the human immune system and contribute to chronic ailments including cancer, diabetes, kidney problems, neurodegenerative disorders, cardiovascular issues (Liguori *et al.* 2018) and antibiotic resistance (Ahmed *et al.* 2019). Stressed bitter melon showed higher accumulation of MDA and H_2O_2 (Masood et al. 2025). Lysine priming reduced both markers, demonstrating its potential to confer Cd tolerance and enhance food quality (Mfarrej and Al-Huqail 2025).

Stress-related excessive ROS synthesis can be countered by naturally produced antioxidants or through strategic solutions. Korfi *et al.* (2021) noted a correlation between the anticancer effects of drugs and inhibition of ROS. Bitter melon demonstrates good antioxidant properties (Khalid *et al.* 2021). In the present study, Lysine treatments increased the antioxidant potential of bitter melon, particularly in terms of POD, phenolics and flavonoids (Fig. 3).

The phenolic profiles of bitter melons changed in response to Cd stress and lysine priming. Major components were GA, known for its broad therapeutic applications and its use as a food additive. GA also exhibits antimicrobial, antioxidant, anticancer and anti-inflammatory properties (Hadidi *et al*. 2024). In leaves, the GA content was higher than in fruit (Fig. 4). Overall, Cd stress reduced this compound, whereas lysine priming increased it in both parts. Lysine priming also increased the levels of anticancer compounds, including chlorogenic acid and quercetin, in bitter melon (Fig. 5 and 6). To date, there is no evidence for direct lysine entry into the phenolic pathway. However, lysine via the saccharopine pathway produces a precursor to the phenolic pathway, which could be a possible justification for its effect on the phenolic profile (Kiyota *et al.* 2015; Mahmood *et al.* 2022).

The antibacterial potential of untreated leaf extracts against *S. aureus* and *P. aeruginosa* showed the inhibitory power of their nutraceutical metabolites (Table 1). Previously, GA has been reported to have antimicrobial effects against both species (Khoshi *et al.* 2024). Being a major component of bitter melon, the presence of these phenolics could be a justification for this antimicrobial potential. In stressed leaves, GA was reduced, but other medicinally known phenols, the coumarins and p-CA were increased. These findings support previous reports that higher phenolic content and stress enhanced the therapeutic potential of various plants (Falcão *et al.* 2025; Alum 2025). Lysine priming exclusively improved MIC against *S. aureus*, possibly related to high quercetin levels in primed leaves (Table 1), supporting the findings of Veiko *et al.* (2023). Previously, quercetin (Chittasupho *et al.* 2021), sinapic acid, chlorogenic acid, syringic acid and ferulic acid (Shi *et al.* 2016) and GA (Hadidi *et al.* 2024) have been reported to possess antimicrobial potential. The presence of

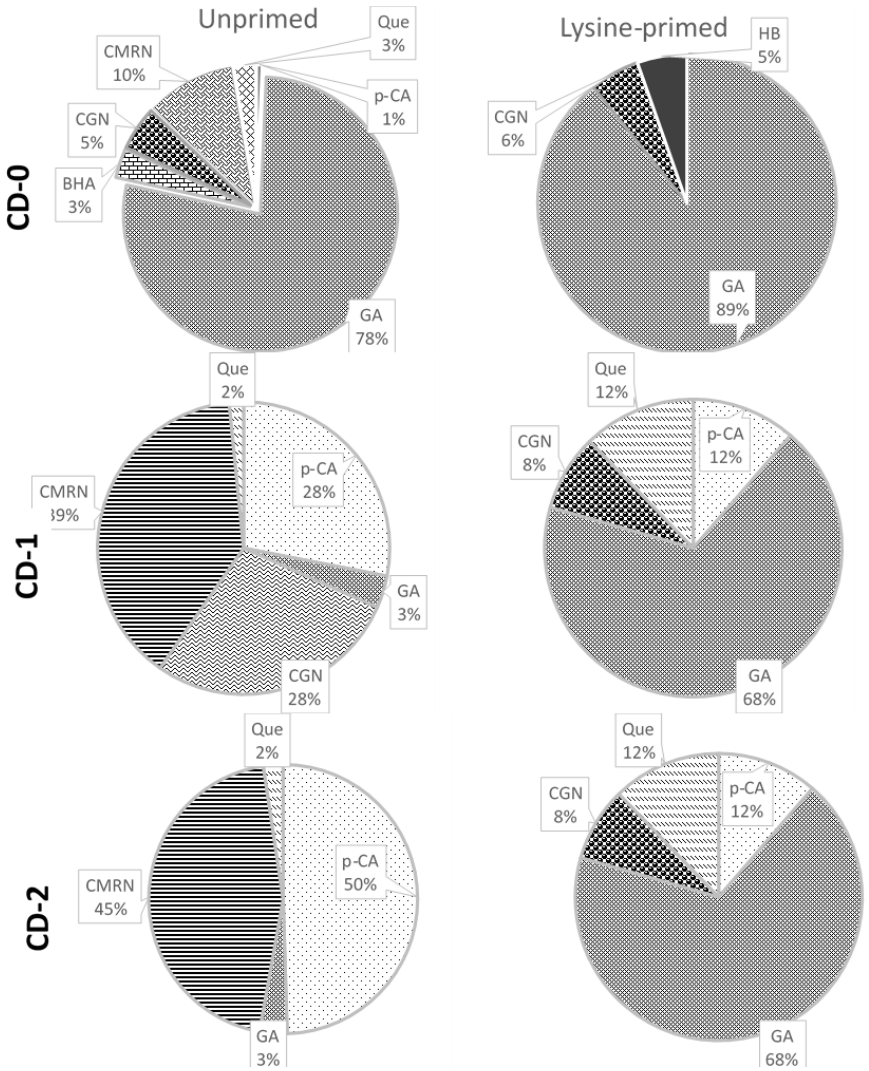

Fig. 5: Phenolic profile (HPLC) of leaves from primed (unprimed, hydroprimed, 0.01, 0.1 and 1 m*M* lysine) *M. charantia* growing under control (CD-0), 2 and 5 mg $CdCl_2$/kg soil (CD-1 and 2) stress. Where p-CA, GA, SA, CGN, CMRN, Que, KMF, HB and BA are present: p-CA, gallic acid, salicylic acid, chlorogenic acid, coumarin, quercetin, kaempferol, HB acid and benzoic acid respectively

these phenolics in bitter melon (Figs. 5–6) supports the medicinal importance of bitter melon, particularly in terms of its antimicrobial activity and other associated therapeutic potentials.

Conclusion

Before recommending any treatment for a food crop, it is wise to evaluate the nutritional and antinutritional values that may be affected. Nearly all nutritional parameters were improved or maintained in lysine-primed plants. Additionally, better antioxidants against ROS suggest benefits for Cd stress tolerance. The variation in the phenolic profile of lysine-primed plants shows potential for future manipulation of phenolic metabolism for specific goals (stress tolerance/medicinal).

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Author Contributions

For research articles, all authors contributed equally.

Data Availability

The data will made available on a fair request to the authors

Ethics Approval

Nor applicable.

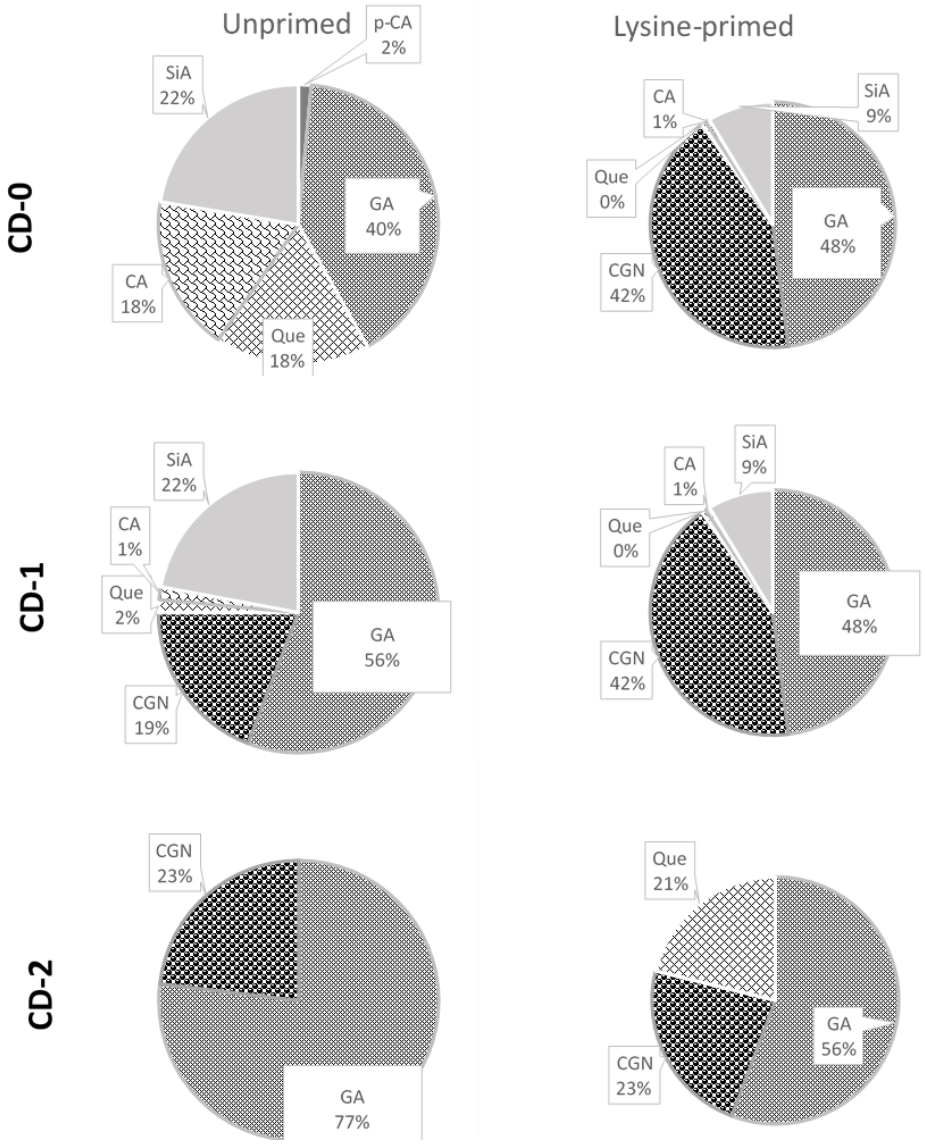

Fig. 6: Phenolic profile (HPLC) of fruit from primed (unprimed, hydroprimed, 0.01, 0.1 and 1 m*M* lysine) *M. charantia* growing under control and Cd stress. Where p-CA, GA, SA, CGN, CMRN, Que, KMF, HB and BA are present: p-CA, gallic acid, salicylic acid, chlorogenic acid, coumarin, quercetin, kaempferol, HB acid and benzoic acid, respectively

Conflicts of Interest

No conflict of interest.

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