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RESEARCH ARTICLE

Deciphering nutrient and antioxidants profiling in chilli (*Capsicum annuum* L.) genotypes under sodium carbonate induced sodicity

G Sidhdharth[1], K R Vijayalatha[1*], V Jegadeeswari[2], K Padmadevi[3], K Parameswari[4], T Anitha[5] & J Suresh[6]

[1]Department of Vegetable Science, Horticultural College and Research Institute for Women, Tiruchirappalli 620 027, Tamil Nadu, India
[2]Department of Fruit Science, Horticultural College and Research Institute for Women, Tiruchirappalli 620 027, Tamil Nadu, India
[3]Department of Horticulture, Agricultural College and Research Institute, Karur 639 001, Tamil Nadu, India
[4]Department of Seed Science and Technology, Forestry College and Research Institute, Mettupalayam 641 301, Tamil Nadu, India
[5]Department of Post Harvest Technology, Horticultural College and Research Institute, Periyakulam 625 604, Tamil Nadu, India
[6]Dean, Horticultural College and Research Institute for Women, Tiruchirappalli 620 027, Tamil Nadu, India

*Correspondence email - vijayalatha.kr@tnau.ac.in

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Abstract

Chilli (*Capsicum annuum* L.) is a crop cultivated as both as a vegetable and a spice, valued for its green and red fruits. This study evaluates the nutritional and antioxidant profiles of dry red chilli fruits grown under sodic conditions. The experiment consists of thirty chilli genotypes grown in a Completely Randomized Design with three replications. The results obtained from the dry red fruits indicated that the genotype IC545732 recorded the highest proline content (356.78 µg g^{-1}), total free amino acid content (56.30 mg g^{-1}) and crude fibre content (22.43%), with statistical significance. Similarly, IC545732 exhibited the highest levels of mineral nutrients and antioxidant content. Conversely, the genotype TNAUH00400035 recorded the highest protein content (16.45%) while exhibiting the lowest proline content (228.67 µg g-1), as well as the lowest mineral nutrient and antioxidant content ($p < 0.05$). Furthermore, the study revealed a positive correlation between proline content and total free amino acid levels, as well as key antioxidants viz., vitamin C, total phenol and β-carotene content. Conversely, proline content was negatively correlated with protein content. These findings suggest that the nutritional constituents and antioxidants content respond significantly to variations in proline content. Therefore, superior genotypes with high proline content, antioxidants and mineral nutrients could be used in future crop improvement programs.

Keywords: antioxidant; chilli; proline; sodicity

Introduction

Chilli (*Capsicum annuum*), a member of the Solanaceae family, is an essential vegetable in Indian kitchens, valued for both its unripe green and ripe red fruits. Its characteristic pungency is due to the presence of capsaicin, a compound formed by the condensation of decylenic acid and 3-hydroxy-4 ethoxybenzylamine. In addition to its everyday use for imparting pungency, chillies are also employed in the coloring industry for its red pigment called capsanthin. The essential oil extracted from chilli fruits known as oleoresin is utilized in the food industry for value-added products and in pharmaceuticals.

Dried chilies are widely used in preparing curry powder, curry paste, soups, sauces, pickles and salads. The species was introduced to India by the Portuguese in the 17th century. Presently, chilli cultivation is concentrated in the states of Tamil Nadu, Karnataka, Andhra Pradesh, Odisha, Maharashtra, West Bengal, Madhya Pradesh and Rajasthan, which collectively contributes to more than 80% of India's total chilli production. Chilli thrives in tropical and humid subtropical regions, with optimal temperatures ranging between 15°C and 30°C. It grows best in medium to heavy textured soils such as clay loam, with a pH of 6.5.

Sodicity, an abiotic stress caused by the high presence of sodium ions in the soil, poses a significant challenge to chilli growth and productivity. Chili peppers are not only known for their pungency and bold flavor but also for being a rich source of essential nutrients that promote overall health. The fruits are packed with variety of vitamins, minerals, antioxidants and offers a variety of health benefits. Chillies boost up the immune system with high levels of vitamin C to enhance metabolism and digestive health. Their vibrant

colors and fiery flavors indicate the presence of essential nutrients and bioactive compounds that can enhance overall health. The nutrient profile combined with their culinary versatility makes them a popular choice in cuisines around the world.

Sodicity occurs when sodium ions bind with clay particles, displacing other cations (1). In India, 6.73 million h of land are affected by salinity, with sodic soils covering 2.96 million h (2). Since chilli is highly sensitive to sodic conditions, it is essential to evaluate the performance of different chilli genotypes under sodic soils. This research aims to evaluate the nutrient profile of various chilli genotypes under sodic conditions to identify superior genotypes in terms of nutrient content.

Material and Methods

The experiment was conducted at the Department of Vegetable Science, Horticultural College & Research Institute for Women, Trichy, during 2023-2024 under a Completely Randomized Design with three replications. Thirty chilli genotypes were collected from the National Bureau of Plant Genetic Resources (NBPGR) and the Ramaiah Gene Bank, Tamil Nadu Agricultural University (TNAU), Coimbatore were taken for the experiment. The genotypes were grown in pots, with two plants accommodated per pot. A total number of ten plants per genotype were maintained across five pots.

Before planting, the potting soil was applied with sodium carbonate at a rate of 50 g kg^{-1} of soil (3). The experimental site exhibited predominant sodicity, in with a soil pH of 9.10, an electrical conductivity of 2.21 dSm^{-1} and an Exchangeable Sodium Percentage (ESP) of 18.3%. The plants were irrigated at two days intervals and fertilizers were applied at a rate of 2:2:1 g $plant^{-1}$. Fruits were harvested 90 days after transplanting, at the red fruit stage.

The freshly harvested fruits were washed with clean water and taken for the observation on nutrient profiling and estimation of antioxidants. Observations were recorded for proximate composition, including proline content, protein content, crude fibre content and total free amino acid content. Additionally, mineral nutrient levels *viz.,* phosphorous, potassium, calcium, magnesium and iron and antioxidant contents (vitamin C, total phenol and β-carotene content) were recorded in all the thirty chilli genotypes.

Sample preparation

Freshly harvested red chillies, free from anthracnose and contamination, were selected and washed under running water to remove any external dirt. The fruits were then rinsed with distilled water and dried by placing the fruits in hot air oven at 60°C for about 60 min (4). The obtained sample was used for all estimations, except for the proline content.

Proline content (µg g^{-1})

The proline content (µg/g) in the leaves was determined following the calorimetric method (5). Approximately 0.5 g of leaf tissue was homogenized with 3% sulfosalicylic acid and centrifuged at 1200 rpm for 10 min. The resulting supernatant was mixed with 2 mL of acid ninhydrin and glacial acetic acid and incubated in a water bath for one hour. After incubation, 4 ml of toluene was added and the chromophore-containing toluene layer was carefully transferred. The absorbance was then measured at 520 nm.

$$\text{Proline } (\mu g/g) = \frac{\mu g \text{ of proline/ml} \times 4}{115.50} \times 10 \qquad \text{Eqn. 1}$$

Protein Content (%)

The protein content was estimated using the Biuret method, as it provides more consistent and linear results over a wider protein concentration range. One g of the sample was homogenized in 10 mL of phosphate buffer and then centrifuged to collect the supernatant. The supernatant was diluted to 100 mL with the buffer for further analysis.

A series of test tubes was prepared by pipetting 0, 0.2, 0.4, 0.6, 0.8 and 1.0 mL of a standard protein solution, along with one mL of the plant extract into each tube. Subsequently, 4 mL of Biuret reagent was added to each tube and the mixture was incubated at room temperature for 30 min. The absorbance was then measured at 550 nm against a blank.

$$\text{Protein content} = \frac{\text{Concentration}}{\text{Volume taken}} \times \frac{\text{Total volume}}{\text{Sample weight}} \times 100$$

Eqn. 2

Crude fiber (%)

About two g of sample was boiled in 200 mL of sulfuric acid with bumping chips (substance added to fasten the boiling) for 30 min. After boiling, the mixture was filtered using muslin cloth and the residue was thoroughly washed with boiling water until the washings were no longer acidic.

The washed residue was then boiled in 200 mL of sodium hydroxide solution for 30 min. Again the sample was filtered and again washed with 1.25% sulfuric acid. The residue was then transferred to a pre-weighed ash dish (W1) and dried at 130 ± 2°C for 2 h. After drying, the dish was cooled in a desiccator and weighed again (W2). The residue was then ignited at 600 ± 15°C for 15 min, cooled and weighed (W3). The crude fiber content (%) was calculated using the given formula.

$$\text{Crude fibre } (\%) = \frac{\text{Loss in weight on ignition } (W_2\text{-}W_1)\text{-}(W_3\text{-}W_1)}{\text{Weight of the sample}} \times 100$$

Eqn. 3

Total free amino acid content (mg g^{-1})

A known weight of the sample was homogenized with 80% ethanol. About 0.1 mL of the extract was added with 1 mL of ninhydrin reagent and 5 mL of diluted propanol. The extract was mixed thoroughly and the absorbance was measured at 570 nm using a green filter against a blank, which was prepared by using 0.1 ml of 80% ethanol instead of the extract. The total free amino acids was obtained from the standard curve (6)

Phosphorous (mg $100g^{-1}$)

About one g of the sample was digested using a triple acid mixture (Nitric acid, Sulphuric acid and Perchloric acid in the

ratio of 9:2:1) to ensure optimal oxidizing power, stability and safety during digestion, thereby breaking down organic matter and dissolving minerals.

About 5mL of the extract was transferred into volumetric flask. After adding 5 mL of Barton's reagent, the volume was then brought up to 100 mL using distilled water. The solution was then left for 30 min to develop yellow color and absorbance was measured at 470 nm using a blue filter. The standard curve was then computed from the absorbance value against the concentration.

$$\text{Phosphorus content (\%)} = \frac{A}{106} \times \frac{\text{Volume made up}}{\text{aliquot pipetted out}} \times \frac{\text{Volume made up after digestion}}{\text{weight of sample taken}}$$

Eqn. 4

A - Concentration with reference to the standard curve

Potassium (mg 100g^{-1})

About one g of the samples was digested using 5 mL of a triple acid mixture and the final volume was adjusted to 100 mL with distilled water. A flame photometer was used to determine the potassium (K) concentration in the solution. The potassium present in the sample was computed through the standard curve of potassium using potassium chloride as standard solution.

$$\text{Potassium content (\%)} = \frac{A}{106} \times \frac{25}{5} \times \frac{100}{0.5}$$

Eqn. 5

A - Concentration obtained from the flame photometer

Calcium (mg 100g^{-1})

About 25 mL of the triple acid extract was pipetted into a conical flask. To neutralize the acidity, a 10% sodium hydroxide solution was added dropwise. After neutralization, 50 mg of murexide indicator (ammonium purpurate) was added to the solution. The solution was titrated with 0.02N EDTA until the endpoint was reached, indicated by a violet color change.

$$\text{Calcium content (\%)} = \frac{0.0004 \times b \times 100 \times 100 \times 100}{10 \times w \times (100\text{-}m)}$$

Eqn. 6

W= weight of leaf sample (0.5 g)

B= volume of 0.02 N EDTA

M= moisture per cent

Magnesium (mg 100g^{-1})

A 25 mL portion of the sample was placed in a 250 mL conical flask. The acidity was neutralized by adding an NH_4Cl-NH_4OH buffer solution (pH10). After the pH was stabilized, 2-3 drops of Eriochrome Black-T indicator (azo dye used to detect metal ions) were added to the solution. The solution was then titrated with 0.02N EDTA until the endpoint was reached, indicated by a colour change from red-wine to sky blue.

$$\text{Magnesium content (\%)} = \frac{0.00024 \times (a\text{-}b) \times 100 \times 100 \times 100}{10 \times w \times (100\text{-}m)}$$

Eqn. 7

w-weight of leave sample taken

a-b-volume of 0.02 N EDTA

m-moisture per cent

Iron (mg 100g^{-1})

Iron content was estimated using an Atomic Absorption Spectrophotometer (AAS) based on the triple acid extract obtained from the sample (7).

Vitamin C content (mg 100g^{-1})

About five g of the sample were weighed and macerated with 4% oxalic acid using a pestle and mortar. The resulting mixture was then transferred to a conical flask through Whatman filter paper No.4 and the final volume was adjusted to 100 mL. From the solution, a 10 mL aliquot of this solution was then pipetted and titrated with indophenol dye until the color changed to pale pink.

The vitamin C content of the sample was calculated using the following formula:

$$\text{Vitamin C content of sample} = \frac{1}{V} \times X \times \frac{100}{10} \times \frac{100}{W}$$

Eqn. 8

V= amount of dye consumed, equivalent to the amount of vitamin C in the standard

X= amount of dye consumed, equivalent to the amount of vitamin C present in the sample

W= weight of the sample taken

Phenol content (mg 100g^{-1})

The sample was weighed and ground using a pestle and mortar with 80% ethanol. The homogenate was then centrifuged at 10,000 rpm for 20 min. The supernatant was collected and evaporated to dryness. The residue was dissolved in a known volume of distilled water. Different aliquots (0.2 to 2 mL) were pipetted into test tubes and the volume in each tube was adjusted to 3 mL with distilled water. To each tube, 0.5 mL of Folin-Ciocalteu reagent was added. After 3 min, 2 mL of 20% Na_2CO_3 solution was added and the tubes were mixed thoroughly. The tubes were then placed in boiling water for exactly one min and the absorbance was measured at 650 nm against a reagent blank. The phenol concentration in the sample was calculated using the standard curve.

Vitamin A content (%)

The vitamin A content in leaf samples was estimated using a spectrophotometer. About 250 mg of fresh plant sample was ground with acetone. The extract was then centrifuged at 3000 rpm for 10 min to obtain a clear supernatant, which was subsequently diluted to 10 mL with 80% acetone. The absorbance of the extract was measured at 480 nm and 510 nm using a colorimeter.

$$C=\frac{(7.6\times OD\ @\ 480\ nm)\ -\ (1.49\times OD\ @\ 510\ nm)\times V}{1000\times W}$$

Eqn. 9

C= Total carotenoid content (mg/g), W= Weight of leaf sample (grams)

Statistical Analysis

The observations recorded were statistical analysed at a 5% level of significance using the GRAPES statistical database (8). The pearson correlation plot was constructed using the corrplot package, while the pearson heat map was generated using the pheatmap package in R studio software package.

Results

Proximate composition

The proximate analysis was conducted to evaluate various biochemical parameters *viz.,* proline content (µg g^{-1}), protein content (%), crude fibre (%) and total free amino acid content (mg g^{-1}), were analysed using the standard protocols for thirty chilli genotypes (Table 1).

Among the thirty genotypes, IC545732 exhibited the highest mean proline content (356.78 µg g^{-1}), crude fibre content (22.43%) and total free amino acid content (56.30 mg g^{-1}), while recording the lowest protein content (11.10%). The genotype IC545732 was followed by TNAUH00400088, which showed the second-highest proline content (346.67 µg g^{-1}), protein content (16.34%) and total free amino acid content (54.70 mg g^{-1}). Meanwhile, the genotype TNAUH00400035 recorded the second-highest crude fibre content (21.86%).

Table 1. Performance of genotypes for various biochemical observations

Genotypes	Proline content (µg g^{-1})	Protein (%)	Total free amino acids (mg g^{-1})	Crude fibre (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (%)	Vitamin C (mg/100g)	Phenol (mg/100g)	β carotene (%)
EC599981	300.12	14.11	47.36	20.30	142.34	1342.56	110.54	163.69	5.69	70.01	47.19	13.23
EC599977	321.44	12.89	50.72	20.54	145.65	1461.45	123.78	168.12	5.73	72.90	50.31	12.34
IC255913	275.11	14.73	43.41	19.88	140.78	1510.67	112.93	171.52	5.25	63.17	43.83	10.59
IC255926	238.12	15.91	37.58	20.05	139.35	1373.10	109.72	164.98	5.13	60.03	29.92	9.16
IC255927	248.91	15.11	39.28	20.67	141.85	1456.98	112.78	168.43	5.58	61.18	33.43	10.09
IC255941	325.67	12.56	51.39	21.17	146.42	1367.89	127.56	186.31	5.75	73.90	40.52	13.12
IC255943	312.66	13.13	49.34	20.82	139.12	1534.72	128.49	182.96	5.53	72.49	49.00	12.18
IC255944	260.12	14.87	41.05	19.01	143.11	1359.42	117.83	170.34	5.50	62.49	45.67	10.23
IC208534	246.89	15.2	38.96	20.01	145.63	1389.40	100.63	159.02	5.12	60.98	45.67	10.23
IC208580	325.10	12.86	51.30	18.80	140.57	1434.53	115.39	179.32	5.76	73.04	32.85	12.54
IC208591	301.90	13.78	47.64	20.33	136.54	1498.56	125.93	158.90	5.01	70.68	43.12	11.45
IC545721	267.45	14.78	42.20	18.97	148.43	1520.11	117.90	172.39	5.59	62.57	46.34	10.35
IC545722	237.89	16.34	37.54	19.34	143.73	1343.76	107.97	160.02	4.59	59.95	34.90	9.05
IC545723	330.12	12.54	52.09	18.90	149.10	1299.53	103.95	161.22	4.66	74.26	38.24	11.90
IC545732	356.78	11.1	56.30	22.43	153.12	1734.67	135.23	197.65	5.83	76.78	57.89	14.95
TNAUH00400011	311.82	13.16	49.21	19.01	148.28	1311.85	105.14	156.90	4.58	65.81	55.02	12.05
TNAUH00400012	289.12	14.23	45.62	18.85	150.24	1305.92	128.49	184.85	5.78	65.67	35.89	11.09
TNAUH00400015	240.78	15.42	38.00	19.38	143.29	1410.43	121.62	181.10	5.71	60.23	25.54	9.23
TNAUH00400018	280.11	14.31	44.20	20.71	140.85	1535.45	126.84	185.60	5.67	64.49	34.21	10.78
TNAUH00400028	290.11	14.34	45.78	19.67	135.43	1401.34	107.73	152.85	4.64	72.45	42.89	11.02
TNAUH00400034	312.54	13.02	49.32	21.02	147.35	1590.24	106.49	159.97	4.90	71.36	49.82	12.1
TNAUH00400035	302.83	13.56	47.79	21.86	140.02	1635.78	131.86	194.89	5.78	71.34	43.63	11.63
TNAUH00400037	338.65	12.32	53.44	21.84	141.55	1539.27	129.78	158.63	5.01	74.65	50.21	13.78
TNAUH00400039	304.56	13.21	48.06	19.78	139.69	1328.52	112.67	156.52	4.50	68.12	40.64	11.18
TNAUH00400042	245.78	15.34	38.78	21.02	137.45	1567.83	108.56	165.67	4.72	60.45	30.84	9.46
TNAUH00400048	278.91	14.41	44.01	19.76	134.71	1489.48	100.23	159.10	4.53	66.59	47.01	11.89
TNAUH00400084	295.67	14.22	46.66	20.85	139.89	1585.11	105.67	158.32	4.68	61.34	36.91	11.87
TNAUH00400088	346.67	11.73	54.70	19.11	136.58	1524.55	102.98	154.78	4.49	75.03	54.23	14.21
TNAUH00400103	228.67	16.45	36.08	18.71	132.54	1282.34	98.45	152.76	4.45	57.74	22.10	8.90
TNAUH00400112	257.89	14.92	40.70	20.87	139.10	1610.26	131.67	190.45	5.75	61.28	41.90	10.11
S.Ed	5.81	0.32	0.97	0.40	3.04	36.38	2.53	2.96	0.11	1.33	0.94	0.23
CV(%)	2.46	2.80	2.60	2.43	2.62	3.05	2.67	2.14	2.65	2.44	2.76	2.45

In contrast, the genotype TNAUH00400103 exhibited the highest protein content (16.45%) but recorded the lowest proline content (228.67 µg g^{-1}), crude fibre content (18.71 %) and total free amino acid content (36.08 mg g^{-1}).

Nutrient Profile of chilli genotypes

The genotype IC545732 observed the highest nutrient content across multiple parametrs *viz.,* phosphorous (153.12 mg $100g^{-1}$), potassium (1734.67 mg $100g^{-1}$), calcium (135.23 mg $100g^{-1}$), magnesium (197.65 mg $100g^{-1}$) and iron (5.83 mg $100g^{-1}$) content.

The phosphorous content among the genotype ranged from 132.54 mg $100g^{-1}$ to 153.12 mg $100g^{-1}$ with about 17 out of 30 genotypes ranged between 140 mg $100g^{-1}$ to 150 mg $100g^{-1}$. There existed wide variation for the three following nutrients *viz.,* potassium content (1282.34 mg $100g^{-1}$ to 1635.78 mg $100g^{-1}$), calcium content (98.45 mg $100g^{-1}$ to 131.86 mg $100g^{-1}$), magnesium content (152.76 mg $100g^{-1}$ to 194.89 mg $100g^{-1}$). Further the iron content of the thirty genotypes ranged from 4.45 mg $100g^{-1}$ to 5.83 mg $100g^{-1}$ where about 14 genotypes ranged for the maximum amount of more than 5.50 mg $100g^{-1}$. Comparatively the genotype TNAUH00400103 observed for the poor performance in terms of nutrient content.

Performance of chilli genotypes for various Antioxidants

The antioxidants *viz.,* vitamin C, total phenol and β-carotene content showed significant impact among the thirty chilli genotypes. The genotype IC545732 observed the highest levels of vitamin C content (76.78 mg $100g^{-1}$), total phenol content (57.89 mg $100g^{-1}$) and β-carotene content (14.95 %). Correspondingly, the genotype TNAUH00400103 exhibited the lowest antioxidant content *viz.,* vitamin C content (57.74 mg $100g^{-1}$), total phenol content (22.10 mg $100g^{-1}$) and β-carotene content (8.90 %).

Correlation of biochemical parameters against the sodicity stress

Sodicity stress occurs when there was excessive accumulation of sodium (Na^+) ions in the soil, leading to negative impacts on plant growth, soil structure and water infiltration. Unlike salinity stress, which results from overall salt concentration, sodicity specifically refers to elevated sodium levels relative to calcium and magnesium.

A correlation analysis among the thirty chilli genotypes revealed that proline content exhibited a strong positive correlation with total free amino acid (r=1.00). On the other hand, protein content was negatively correlated with both proline content and free amino acids (r=-0.98). Additionally, proline content exhibited close relation with antioxidants *viz.,* vitamin C content (r=0.93), phenol content (r=0.67) and β-carotene content (r=0.94).

The strong relationship between proline content and antioxidants suggests that proline plays a dual role as an osmoprotectant and a reactive oxygen species (ROS) scavenger, which is crucial for plant stress responses. Chilli genotypes with higher proline and antioxidant levels exhibited greater stress resistance, making them promising candidates for the development of sodicity-resistant lines.

Correspondingly, the mineral nutrients *viz.,* phosphorous, potassium, calcium, magnesium and iron observed no significant correlation with the proline content and protein content. Similarly, mineral nutrient parameters also exhibited no significant correlation with antioxidant content. The correlation within the mineral nutrients suggested that the calcium content, magnesium content and iron content were positively associated to each other.

The crude fibre content was positively correlated with the mineral nutrients *viz.,* potassium and calcium while no significant correlation with the phosphorous, magnesium and iron content (Fig. 1).

Discussion

Chillies are a powerhouse of essential nutrients, serving as an excellent source of vitamin C, which supports immune function and skin health, as well as vitamin A (9,10). Additionally, they provide small amounts of fiber, iron and potassium, all of which support overall health.

Proline, a non-essential amino acid, plays a crucial role in regulating cellular responses to stress and contributes to proper immune function. It plays a crucial role in the synthesis of collagen, a key structural protein found in connective tissues, skin, tendons and bones (11). In response to the sodic stress, many plants accumulate proline as an osmoprotectant, that helps stabilize proteins and cell membranes. In the current study, proline content ranged between 228.67 µg $g^{-1}$to 356.78 µg g^{-1}, with the highest level observed in genotype IC545732, indicating its potential tolerance to sodicity stress (12). On the other hand, the genotype with the lowest proline content was observed in TNAUH00400103 indicated that genotype could be more or less susceptible to sodicity compared to other genotypes.

The protein content in the present study negatively correlated with the proline content. The genotype IC545732, that recorded highest proline content recorded for the lowest protein content (11.1%). As proline levels rise in response to stress, the total protein content may decrease because energy is diverted from growth to survival mechanisms on stress-induced metabolic changes (13). Previous study conducted on purslane supports this findings, showing that protein content continuously decreased with the increasing stress level and proline content (14).

Meanwhile, genotype IC545732 that recorded the highest proline content and lowest protein content, also exhibited the highest total free amino acid (56.30 mg g^{-1}). The proline concentration under stress rises with the increased levels of total free amino acid content. The same was also supported with the previous findings in ber (15).

The correlation plot from the present study also depicts that the proline content is positively correlated to the total free amino acid content, while the protein content is negatively correlated with both. This inverse relationship suggests that plants may reallocate resources to prioritize proline synthesis over the production of other amino acids. Stress-induced protein breakdown may contribute to an

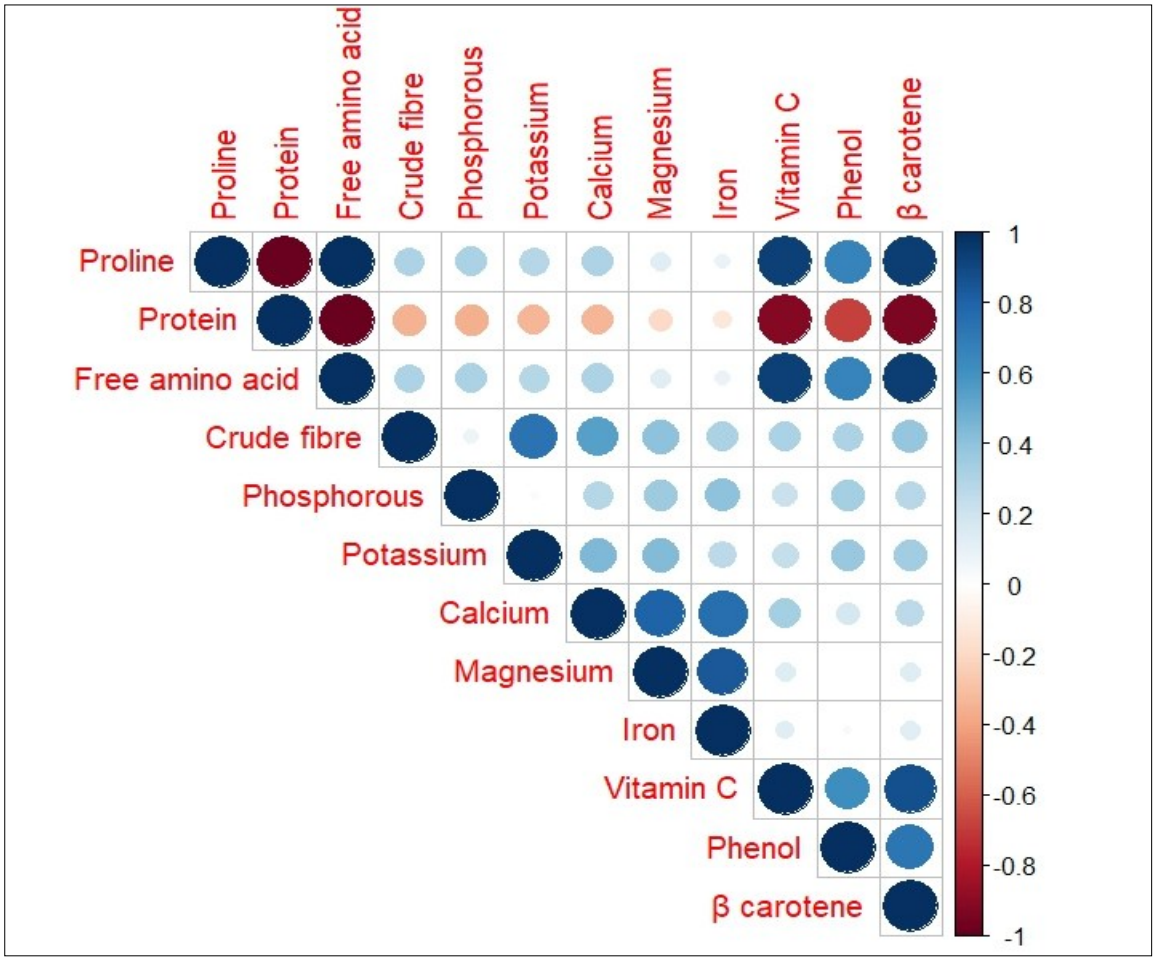

Fig. 1. Correlation plot among different genotypes for biochemical observations.

increase in free amino acid levels, which helps plants cope by providing energy and enhancing osmoprotection (16,17).

The crude fibre content, showed no significant relation with the proline content or the protein content under stress conditions. This is expected, as crude fiber primarily consists of cellulose, hemicellulose and lignin, which contribute to structural rigidity rather than immediate biochemical stress responses (18).

Among the chilli genotypes, IC545732 was identified as the best-performing genotype in terms of mineral nutrition. Interestingly, while this genotype exhibited the highest proline content, the study found no significant correlation between proline levels and any of the mineral nutrients (19). However, calcium, magnesium and iron content displayed a significant positive correlation with each other (20).

The antioxidant-rich profile in chilli aids in combating free radicals, supporting long-term health and well-being. The findings of present study exhibited diverse range of antioxidants *viz.,* vitamin C content ranging 57.74 mg $100g^{-1}$ to 76.78 mg $100g^{-1}$; phenol content ranging 22.10 mg $100g^{-1}$ to 57.89 mg $100g^{-1}$; β-carotene ranging 8.90 mg $100g^{-1}$to 14.95 mg $100g^{-1}$.

The finding suggests a direct relationship between proline and antioxidants under stress (21).

Proline not only functions as an antioxidant itself but also enhances the activity of other antioxidants by stabilizing cells and maintaining redox balance. This relationship is vital for plant survival under environmental stress, as it helps limit oxidative damage and protect cellular integrity (22). Additionally, proline enhances the plant's overall antioxidant capacity by supporting the regeneration of other antioxidants and maintaining an optimal cellular environment for their function (23).

A heat map was generated to visualize the nutritional variations across genotypes (Fig. 2). Based on the observed data, the thirty genotypes were classified into two primary groups, with each group further divided into two secondary groups, reflecting variations in different nutritional constituents among the chilli genotypes.

Conclusion

The proximate composition analysis of different genotypes of chilli revealed that the proline content, total free amino acid content and crude fibre content observed highest in the genotype IC545732 while the protein content observed highest in the genotype TNAUH00400103 with lowest proline content.

The genotype IC545732 also observed for the highest mineral nutrition and antioxidant contents compared to other genotypes. The proline content exhibited positive correlation with the total free amino acid and antioxidant content. The superior genotypes might be forwarded to the subsequent generations in the various crop improvement programs.

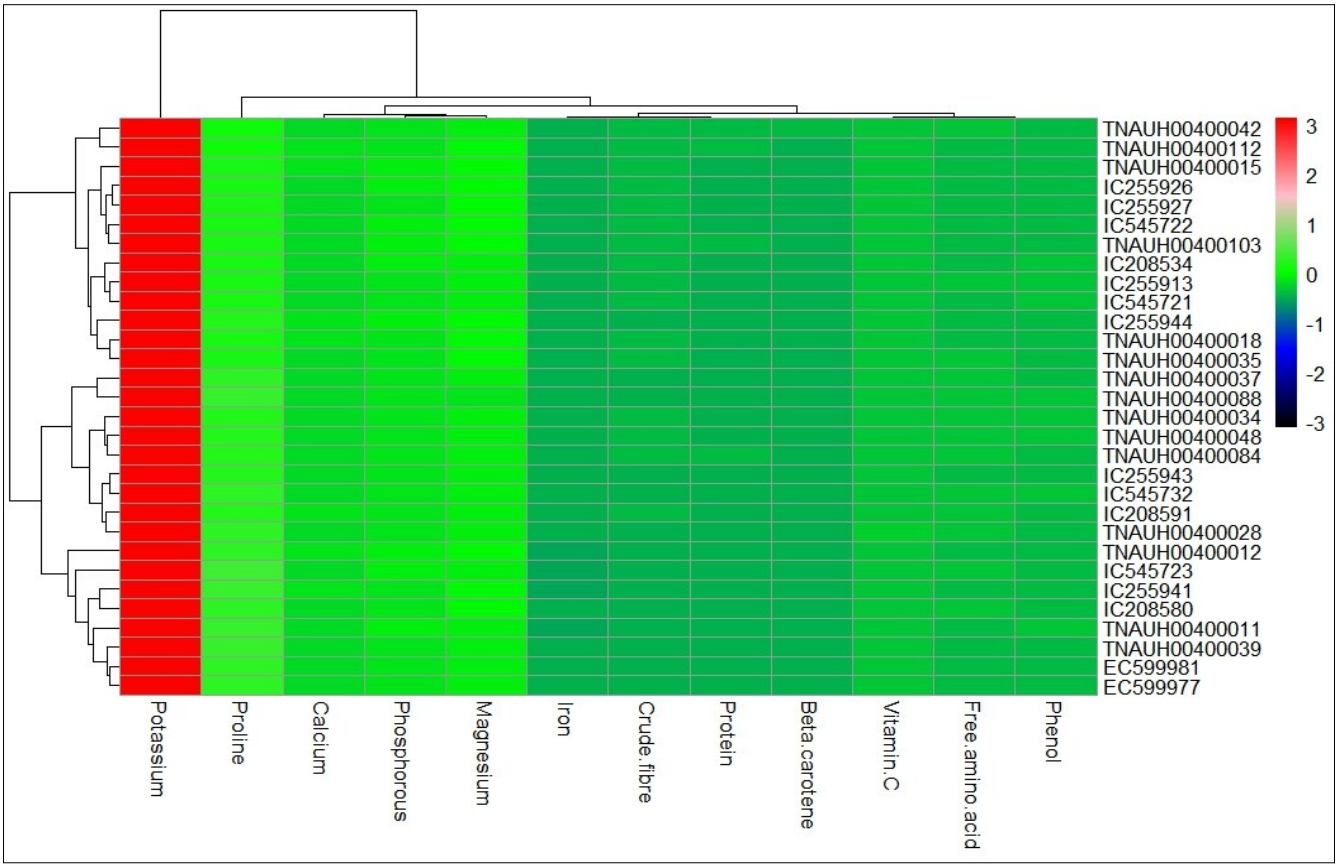

Fig. 2. Heat map visualizing the various observations for 30 different genotype.

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Authors' contributions

GS carried out the experimental work and performed the statistical analysis. KRV drafted the manuscript. VJ performed the laboratory experiments; KPD performed critical revision of manuscript; TA and KPM carried out the laboratory experiments and performed the statistical analysis; JS given final approval of the version to be published.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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