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RESEARCH ARTICLE

Nutritional profiling: Prebreeding initiatives for biofortification in tomatoes (*Solanum lycopersicum*)

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Abstract

This research investigates the nutritional composition of 10 tomato (*Solanum lycopersicum* L.) genotypes to identify candidates for biofortification, aiming to address global micronutrient deficiencies. The analysis reveals substantial genetic variability in nutrient content among the genotypes, which can be harnessed in targeted breeding programs for nutritional enhancement. Notably, genotypes G2 and G9 showed superior nutritional profiles, with elevated levels of essential nutrients such as protein, fiber, vitamins A and C and minerals including iron, zinc, magnesium and potassium. These genotypes also demonstrated notable antioxidant activity, particularly in lycopene and β-carotene content, which are associated with reduced risks of chronic illnesses. By examining the proximate composition, antioxidant activity and mineral profiles of each genotype, the study found considerable genetic variability in nutrient contents, which can be leveraged in targeted breeding programs aimed at nutritional enhancement. The high nutrient diversity across the genotypes provides a strong foundation for selecting parent lines in breeding, especially for mineral biofortification and antioxidant enrichment. This study supports the integration of genomic and conventional breeding strategies to develop tomato cultivars that meet the rising demand for nutrient-dense foods, thereby contributing to improved dietary quality and global health outcomes.

Keywords: biofortification; nutritional profiling; prebreeding; tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely consumed vegetables globally, serving as a significant source of essential nutrients including vitamins, minerals and bioactive compounds. In recent years, nutritional breeding has emerged as a crucial strategy to enhance the nutritional quality of tomatoes, addressing global malnutrition challenges and meeting the increasing consumer demand for healthier food options. The nutritional value of tomatoes is primarily attributed to their diverse array of metabolites, including vitamins (particularly A and C), minerals (potassium, iron and zinc), carotenoids (lycopene and β-carotene) and phenolic compounds. Recent studies have demonstrated that genetic improvement through breeding can significantly enhance these nutritional components, making tomatoes an ideal candidate for biofortification programs (1).

Recent estimates indicate that over 2 billion people globally suffer from micronutrient deficiencies (2). Biofortified tomatoes can help address "hidden hunger," particularly in developing countries where tomatoes are a dietary staple (1). Enhanced antioxidant content through breeding has been linked to reduced risks of chronic diseases. Studies show that improved lycopene content can potentially reduce cardiovascular disease risk (3).

• Genomic Approaches includes,

»Development of molecular markers for nutrient-related traits has accelerated breeding programs.

»Application of CRISPR-Cas9 technology for enhancing specific nutrients (4).

The Metabolic Engineering involves,

»Identification of key pathways controlling nutrient accumulation (5).

»Biofortification Strategies includes,

»Success in developing high-iron and high-zinc tomato varieties,

»Enhanced calcium content through targeted breeding approaches (6).

The emergence of new breeding technologies, coupled with an increased understanding of nutrient biosynthesis pathways, has opened new avenues for nutritional enhancement. Recent research has demonstrated that integrated breeding approaches, combining conventional methods with genomic selection, can accelerate the development of nutrient-dense tomato varieties. The following research focuses on the pre-breeding approach for selecting superior parents in terms of nutritional quality for hybridization program in tomatoes, aiming to obtain hybrids that couple high-yielding traits with enhanced nutritional quality.

Materials and Methods

The source of collection of tomato lines were from seed bank of Department of Genetics and Plant Breeding, Annamalai university. Tomatoes thrive in warm temperatures (20 - 30 °C), with ample sunlight and moderate humidity. Optimal growth occurs in well-drained, loamy soil with a pH between 6.0 - 7.0. Standard cultivation process include proper irrigation, mulching, staking, pruning and pest control. Fertilization with nitrogen, phosphorus and potassium, along with crop rotation, enhances productivity.

The tomato genotypes used for nutritional profiling were pre-breeding line sourced from stored germplasm of a private collection. These genotypes are designated as follows: TM22-933-54-22(G1), TM22-934-63-34(G2), TM22-956-32-43(G3), TM22-876-78-01(G4), TS22-933-56-25(G5), TS22-879-34-51(G6), TS22-890-23-09(G7), TS22-767-98-31(G8), TS22 -122-17-13(G9) and TS22-217-40-13(G10). The fruits of all genotypes were washed, cleaned and air dried. The gross chemical composition, including ash, crude protein, fiber, fat and total carbohydrates of tomato genotypes were estimated in plant samples according to the methods of AOAC (7). Mineral nutrient analysis includes the protocol of dissolving the ash samples in 1% hydrochloric acid and the solutions were used for the determination of the following minerals present in the samples namely, iron, zinc, sodium, calcium, manganese, magnesium, potassium and copper by using Atomic Absorption Spectrometry (8). Phosphorus content was determined calorimetrically using the standard method of analysis (9). β-carotene was extracted via column chromatography and estimated calorimetrically according to the standard method of AOAC analysis (7). The content of lycopene was estimated using the procedure outlined in a previous study (10). Datas were analyzed and interpreted using Microsoft Excel.

Results and Discussion

Proximate composition

Proteins are essential for growth, repair and maintenance of body tissues. In tomatoes, higher protein content is valuable for improving nutritional quality, especially for vegetarian diets. The crude protein content among the genotypes was as follows: G2 (12.50 g/100 g) > G9 (11.61 g/100 g) > G8 (11.21 g/100 g) > G1 (11.01 g/100 g) > G10 (10.50 g/100 g) > G5 (10.34 g/100 g) > G4 (10.03 g/100 g) > G6 (9.33 g/100 g) > G3 (9.2 g/100 g 1) > G7 (8.64 g/100 g). The highest crude protein content was observed in G2 (12.50 g/100 g), followed by G9 (11.61 g/100 g) and G8 (11.21 g/100 g), with the lowest in G7 (8.64 g/100 g), indicating a range of 3.86 g. Notably, G2 contains about 45% more protein than G7, demonstrating significant genetic variation that could be exploited in breeding programs. This aligns with findings in an earlier study, which reported protein values ranging between 9.3 and 12.4 g/100 g for newly developed tomato genotypes (11). A similar study observed comparable protein ranges in biofortified tomatoes (12).

The ash content reflects the total mineral content in the fruit, with higher values suggesting better mineral nutrition, making these genotypes valuable for mineral biofortification programs. The value of ash content was observed in order of G9 (16.26 g/100 g) > G2 (15.31 g/100 g) > G8 (14.35 g/100 g) > G3 (13.65 g/100 g) > G10 (13.11 g/100 g) > G4 (12.95 g/100 g) > G7 (12.32 g/100 g) > G1 (12.12 g/100 g) > G6 (11.34 g/100 g) > G5 (11.23 g/100 g). Ash content, indicating total mineral content, varied significantly among genotypes, with G9 (16.26 g/100 g) having the highest content and G5 (11.23 g/100 g) the lowest, showing a range of 5.03 g. G9 contains about 45% more minerals than G5. These findings are comparable to values reported by earlier study, which observed ash content between 11.2 and 16.8 g/100 g in fresh and processed tomatoes (13).

Carbohydrates provide energy and contribute to fruit quality and taste. The total carbohydrates content was: G2 (97.13 g/100 g) > G9 (95.76 g/100 g) > G7 (85.23 g/100 g) > G10 (84.39 g/100 g) > G6 (81.33 g/100 g) > G8 (79.94 g/100 g) > G5 (79.10 g/100 g) > G4 (78.23 g/100 g) > G1 (78.56 g/100 g) > G3 (67.68 g/100 g). The highest carbohydrate content was found in G2 (97.13 g/100 g), followed by G9 (95.76 g/100 g), while G3 (67.68 g/100 g) had the lowest, with a range of 29.45 g. G2 contained about 43% more carbohydrates than G3, consistent with a study, which reported similar carbohydrate ranges in tomatoes processed under varying drying conditions (14).

Dietary fiber aids digestion and gut health. The value of fibers exhibited in order of G2 (10.18 g/100 g) > G9 (10.03 g/100 g) > G7 (9.21 g/100 g) > G4 (9.02 g/100 g) > G1 (8.96 g/100 g) > G6 (8.90 g/100 g) > G8 (8.76 g/100 g) > G5 (8.32 g/100 g) > G10 (9.13 g/100 g) > G3 (7.31 g/100 g). The highest fiber content was observed in G2 (10.18 g/100 g), while the lowest was in G3 (7.31 g/100 g), showing a range of 2.87 g. G2 contained about 39% more fiber than G3, aligning with ranges documented by (15), emphasizing the role of high-fiber genotypes in supporting digestive health. Tomatoes are not significant sources of fat, but some fat content is necessary for the absorption of fat-soluble vitamins and compounds like lycopene. The value of fat content arranged in order of G7 (7.11 g/100 g) > G9 (7.02 g/100 g) > G2 (6.98 g/100 g) > G10 (6.93 g/100 g) > G5 (6.76 g/100 g) > G8 (6.43 g/100 g) > G4 (6.34 g/100 g) > G1 (6.32 g/100 g) > G6 (6.12 g/100 g) > G3 (5.90 g/100 g) The highest fat content was found in G7 (7.11 g/100 g) and the lowest in G3 (5.90 g/100 g), showing minimal variation of 1.21 g (Table 1 and Fig. 1).

Mineral Content

Iron is crucial for hemoglobin formation and oxygen transport. The value of iron content rolls down in order of G2 (1.22 mg/100 g) > G9 (1.21 mg/100 g) > G4 (0.75 mg/100 g) > G8 (0.73 mg/100 g) > G6 (0.67 mg/100 g) > G3 (0.60 mg/100 g) > G1 (0.52 mg/100 g) > G10 (0.51 mg/100 g) > G7 (0.50 mg/100 g) >

Table 1. Proximate composition contents of tomato genotypes

	Proximate composition per 100 g of sample									
Parameters	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**
Crude protein (g)	11.01	12.50	9.21	10.03	10.34	9.33	8.64	11.21	11.61	10.50
Ash (g)	12.12	15.31	13.65	12.95	11.23	11.34	12.32	14.35	16.26	13.11
Total carbohydrates (g)	78.56	97.13	67.68	78.23	79.10	81.33	85.23	79.94	95.76	84.39
Fiber (g)	8.96	10.18	7.31	9.02	8.32	8.90	9.21	8.76	10.03	9.13
Fat (g)	6.32	6.98	5.90	6.34	6.76	6.12	7.11	6.43	7.02	6.93

g-grams

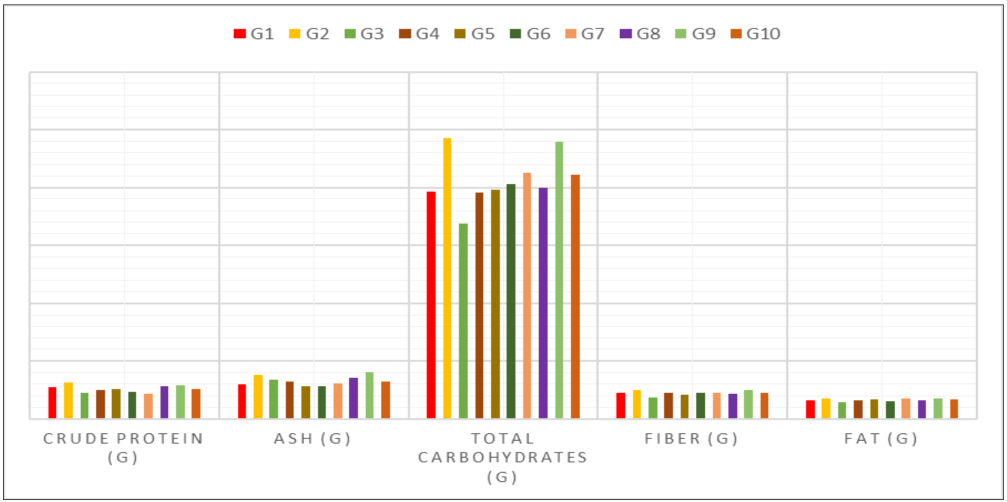

Fig. 1. Proximate composition contents of tomato genotypes.

G5 (0.49 mg/100 g). The highest iron content was recorded in G2 (1.22 mg/100 g) and G9 (1.21 mg/100 g), nearly double those reported in standard tomatoes in a study, where values ranged from 0.6 to 0.9 mg/100 g (13).

Zinc is vital for immune function and protein synthesis. Range across genotypes zinc value is 0.17-3.11 mg/100 g. The value of zinc content was arranged in order of G2 (3.11 mg/100 g) > G9 (2.96 mg/100 g) > G8 (2.32 mg/100 g) > G6 (1.86 mg/100 g) > G4 (1.70 mg/100 g) > G3 (1.34 mg/100 g) > G5 (1.11 mg/100 g) > G1 (0.98 mg/100 g) > G10 (0.95 mg/100 g) > G7 (0.17 mg/100 g) with G2 (3.11 mg/100 g) and G9 (2.96 mg/100 g) demonstrating significantly higher values than the lowest genotype G7 (0.17 mg/100 g), aligning with a study, which noted substantial genetic variability in zinc content (15).

Potassium plays a crucial role in cardiovascular health. G9 exhibited the highest potassium content (35.1 mg/100 g), exceeding levels documented in a report, which observed a maximum of 33 mg/100 g, underscoring its cardiovascular benefits (12).

Calcium is important for bone health. G2 had the highest calcium content (17.2 mg/100 g), supporting its role in bone health and aligning with earlier reports (15).

Magnesium is involved in energy metabolism. The value of magnesium content was observed in order of G2 (30.4 mg/100 g) > G9 (28.8 mg/100 g) > G5 (24.6 mg/100 g) > G10 (23.9 mg/100 g) > G4 (22.1 mg/100 g) > G1 (20.5 mg/100 g) > G8 (17.2 mg/100 g) > G6 (17.4 mg/100 g) > G3 (13.7 mg/100 g) > G7 (11.0 mg/100 g). Magnesium levels in G2 (30.4 mg/100 g) exceeded the previously reported ranges (18 - 26 mg/100 g), demonstrating its role in energy metabolism (16).

Copper is a trace element for various enzymatic processes. G9 had the highest copper content (1.14 mg/100 g), nearly double the greenhouse-grown tomato values (0.6 – 0.7 mg/100 g) reported by a previous study (17).

Sodium content varied among the genotypes: G1 (5.00 mg/100 g) > G4 (4.40 mg/100 g) > G10 (4.29 mg/100 g) > G8 (3.91 mg/100 g) > G6 (3.86 mg/100 g) > G5 (3.77 mg/100 g) > G7 (3.21 mg/100 g) > G9 (3.17 mg/100 g) > G2 (3.10 mg/100 g) > G3 (3.00 mg/100 g). Sodium content was highest in G1 (5.00 mg/100 g), with a range of 2 mg, showing substantial variation across genotypes.

Phosphorus is crucial for structural and metabolic functions. The phosphorus content was as follows: G2 (29.0 mg/100 g) > G9 (27.6 mg/100 g) > G10 (24.1 mg/100 g) > G7 (22.6 mg/100 g) > G3 (21.3 mg/100 g) > G6 (21.1 mg/100 g) > G4 (20.6 mg/100 g) > G1 (19.8 mg/100 g) > G8 (19.2 mg/100 g) > G5 (18.5 mg/100 g). Phosphorus content was highest in G2 (29.0 mg/100 g), supporting structural and metabolic functions, consistent with earlier report (Table 2 and Fig. 2) (6).

Pigment content

Lycopene is a powerful antioxidant linked to reduced risk of cancer and heart disease. The value of lycopene pigment observed in order of G2 (2.76 mg/100 g) > G6 (2.68 mg/100 g) > G4 (2.61 mg/100 g) > G9 (2.57 mg/100 g) > G10 (2.11 mg/100 g) > G7 (1.90 mg/100 g) > G3 (1.86 mg/100 g) > G1 (1.98 mg/100 g) > G5 (1.79 mg/100 g) > G8 (1.73 mg/100 g) (Table 3). The highest lycopene content was observed in G2 (2.76 mg/100 g), surpassing commercial tomato varieties (1.5 – 2.2 mg/100 g) reported by previous study (12). High lycopene levels enhance its appeal for antioxidant-enriched breeding programs.

Antioxidants

β-carotene serves as a precursor to vitamin A and functions as an antioxidant essential for vision and immune health. The β-carotene value exhibited in order of G9 (0.46 mg/100 g) > G3 (0.43 mg/100 g) > G2 (0.36 mg/100 g) > G4 (0.32 mg/100 g) > G7 (0.28 mg/100 g) > G5 (0.26 mg/100 g) > G10 (0.25 mg/100 g) >

Table 2. Various minerals contents analyzed in tomato genotypes

	Minerals per 100 g of sample									
Parameters	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**
Iron (mg)	0.52	1.22	0.60	0.75	0.49	0.67	0.50	0.73	1.21	0.51
Zinc (mg)	0.98	3.11	1.34	1.70	1.11	1.86	0.17	2.32	2.96	0.95
Magnesium (mg)	20.5	30.4	13.7	22.1	24.6	17.4	11.0	17.2	28.8	23.9
Manganese (mg)	0.31	1.40	0.43	0.29	0.21	0.76	0.53	1.01	1.53	0.89
Potassium (mg)	26.3	34.3	25.9	26.1	24.6	24.2	27.0	30.3	35.1	25.3
Calcium (mg)	12.5	17.2	13.0	14.2	13.0	14.6	12.1	15.2	16.8	13.4
Copper (mg)	0.51	1.10	0.13	0.15	0.52	0.44	0.34	0.78	1.14	0.45
Phosphorous (mg)	19.8	29.0	21.3	20.6	18.5	21.1	22.6	19.2	27.6	24.1
Sodium (mg)	5.00	3.10	3.00	4.40	3.77	3.86	3.21	3.91	3.17	4.29

mg-milli gram

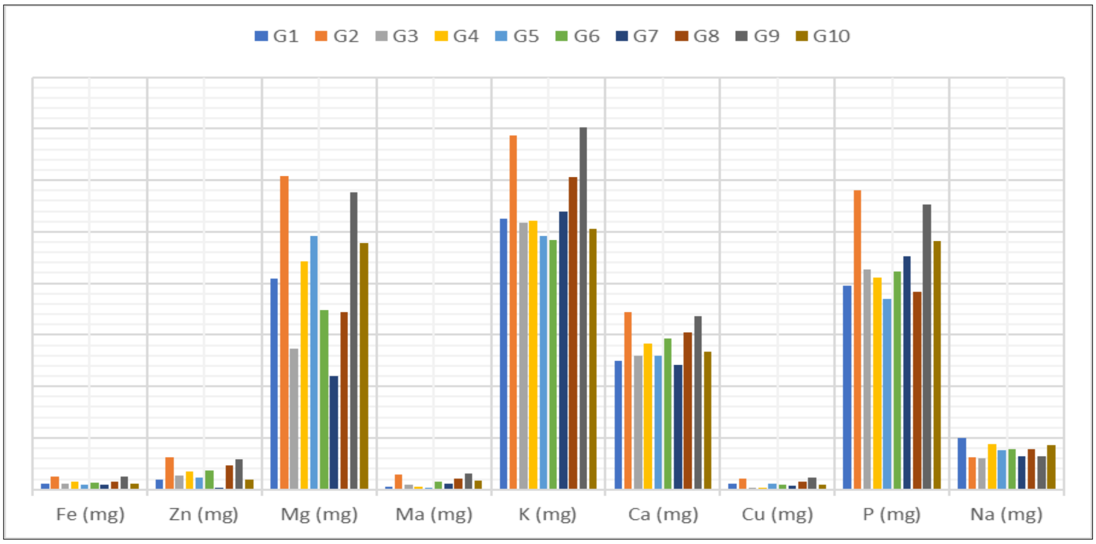

Fig. 2. Various minerals contents analyzed in tomato genotypes.

Table 3. Pigments, antioxidant and vitamin contents of tomato genotypes

Parameters	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**
Pigment content										
Lycopene (mg)	1.98	2.76	1.86	2.61	1.79	2.68	1.90	1.73	2.57	2.11
Antioxidant per 100 g of sample										
β-carotene (mg)	0.23	0.36	0.43	0.32	0.26	0.19	0.28	0.18	0.46	0.25
Vitamins per 100 g of sample										
Ascorbic acid (mg)	13.7	25.8	20.4	19.1	12.9	20.7	14.8	20.1	23.7	15.8
Vitamin A (I.U)	802	1020	900	750	840	780	640	930	1004	832

mg-milli gram, I.U-International Unit

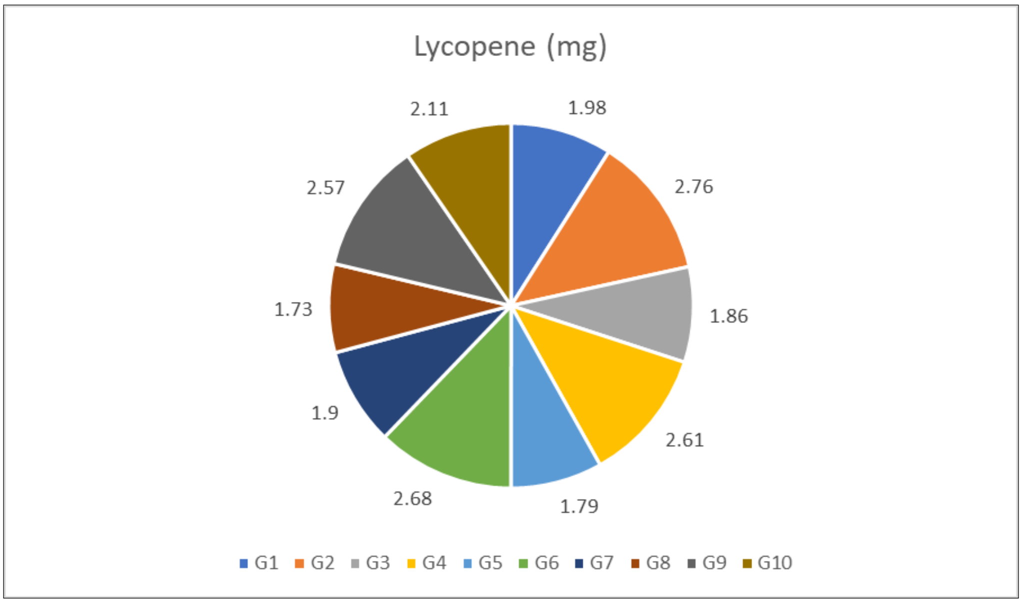

Fig. 3. Lycopene (pigment) content of various tomato genotypes.

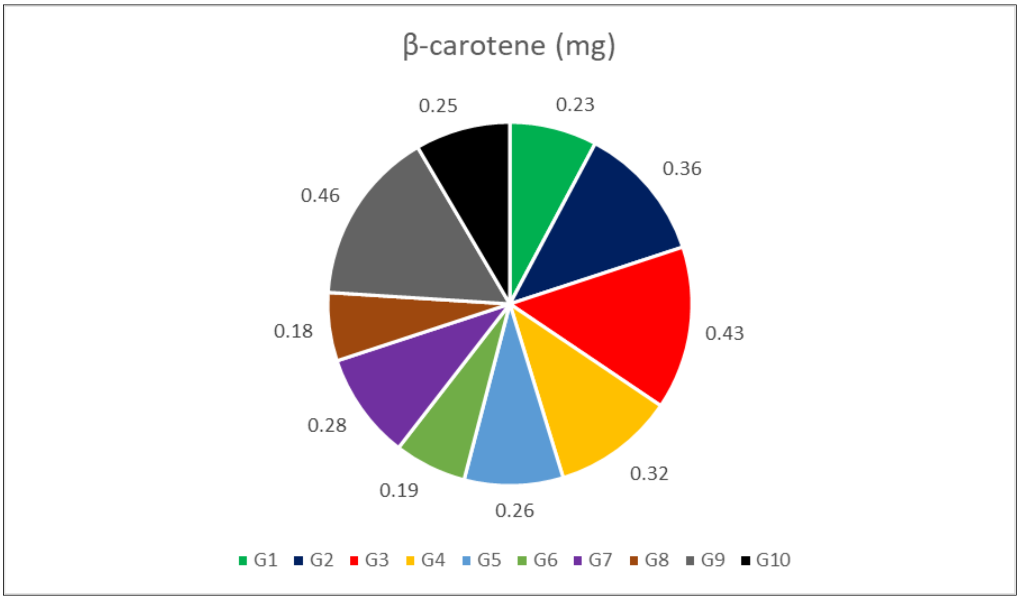

Fig. 4. β-carotene (antioxidant) content of various tomato genotypes.

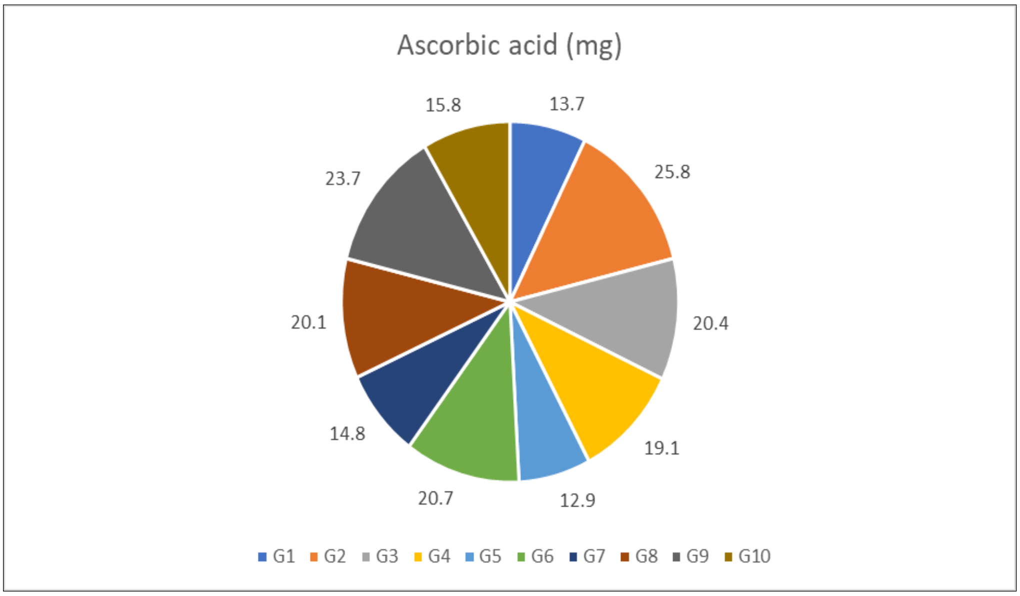

Fig. 5. Ascorbic acid (Vitamin) content of various tomato genotypes.

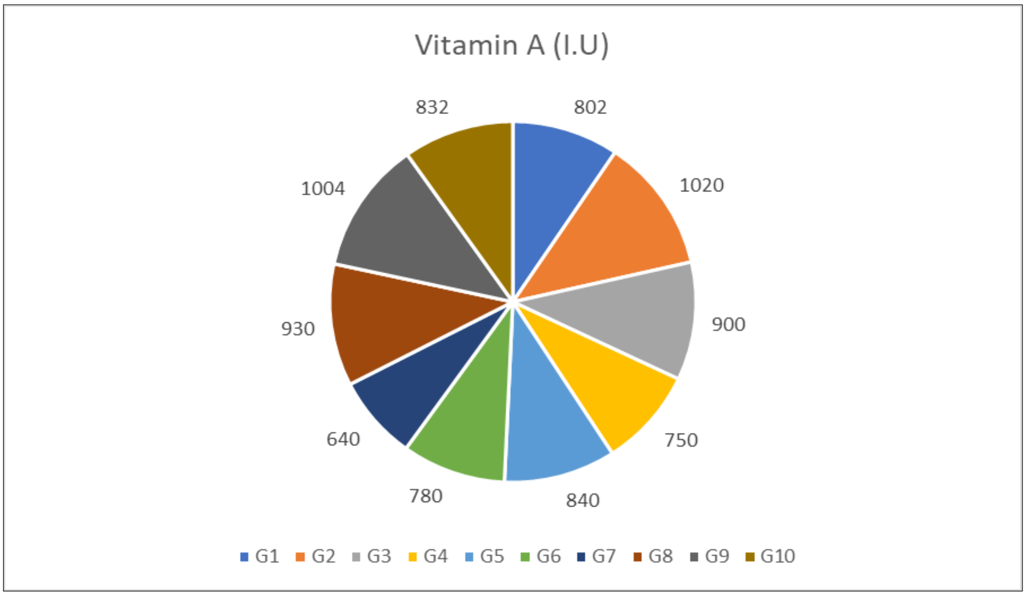

Fig. 6. Vitamin A content of various tomato genotypes.

G1 (0.23 mg/100 g) > G6 (0.19 mg/100 g) > G8 (0.18 mg/100 g) (Table 3). The highest β-carotene levels were found in G9 (0.46 mg/100 g), significantly exceeding the previously reported range of 0.2-0.35 mg/100 g (15).

Vitamins

Vitamin C (ascorbic acid) is a potent antioxidant that supports immune function. The value of ascorbic acid content were observed in order of G2 (25.8 mg/100 g) > G9 (23.7 mg/100 g) > G3 (20.4 mg/100 g) > G6 (20.7 mg/100 g) > G8 (20.1 mg/100 g) > G4 (19.1 mg/100 g) > G10 (15.8 mg/100 g) > G7 (14.8 mg/100 g) > G1 (13.7 mg/100 g) > G5 (12.9 mg/100 g) (Table 3). The highest ascorbic acid content was observed in G2 (25.8 mg/100 g), comparable to the maximum values reported in earlier study (12).

Vitamin A is crucial for vision and cell growth. The value of vit A content rolls down in order of G2 (1020 IU/100 g) > G9 (1004 IU/100 g) > G3 (900 IU/100 g) > G8 (930 IU/100 g) > G5 (840 IU/100 g) > G10 (832 IU/100 g) > G6 (780 IU/100 g) > G4 (750 IU/100 g) > G1 (802 IU/100 g) > G7 (640 IU/100 g). Vit A found highest in G2 (1020 IU/100 g), aligning with previous study, which emphasized the role of high-vitamin-A genotypes in addressing deficiencies (17).

The findings indicate that genotypes G2 and G9 consistently exhibit superior nutritional traits across multiple parameters, making them valuable candidates for biofortification and breeding programs targeting at enhancing tomato nutritional quality.

Conclusion

Genotypes G2 and G9 consistently show superior nutritional profiles across multiple parameters, making them excellent candidates for breeding programs. G8 also shows promise in several nutritional aspects, particularly minerals. These genotypes could be used as parents in breeding programs targeting viz., biofortification for minerals (especially iron and zinc), enhanced vitamin content (particularly vitamins A and C), improved antioxidant profiles (lycopene and β-carotene) and better overall nutritional quality.

Conversely G7 tends to rank lowest in many nutrients, though it shows high values in some traits like fat content. The largest variations are seen in zinc (18-fold difference between highest and lowest), manganese (7-fold difference) and copper (9-fold difference). This comprehensive nutritional profiling provides valuable information for targeted breeding programs aimed at developing more nutritious tomato varieties.

Given the increasing global emphasis on nutritional security and health-promoting foods, nutritional breeding in tomatoes remains a priority area for research and development. Recent advances in breeding technologies, combined with improved understanding of nutrient metabolism, provide promising opportunities for developing more nutritious tomato varieties that can contribute to better global nutrition and health outcomes.

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Authors' contributions

The study was proposed and conceived by GSSP and JLJ, with GSSP conducting the experiments and drafting the manuscript supported by DS and AM. All authors contributed critical feedback, refining the research design, data analysis and manuscript structure to strengthen the overall study.

Compliance with ethical standards

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

Ethical issues: None

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