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RESEARCH ARTICLE

Impact of organic inputs on quality traits and nutrient content of Bottle gourd (*Lagenaria siceraria* L.): Heat map, PCA, correlation and path analysis

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Abstract

Nutrient deficiency in vegetables is a significant challenge for meeting the dietary needs of a growing population and improving the nutritional quality of bottle gourd (*Lagenaria siceraria* L.) through organic inputs can address this issue. An experiment was conducted at the Department of Vegetable Science, Tamil Nadu Agricultural University (2023-2024) aimed to enhance the nutritional quality of bottle gourd through organic methods. The research was conducted using a Randomized Block Design (RBD) with 11 treatment combinations and control, the study focused on improving its nutrient content, avoiding pesticide residues and supporting eco-friendly cultivation. Statistical analyses such as ANOVA, Principal Component Analysis (PCA), path analysis, phenotypic correlation and heat map analysis were used to evaluate the effects of organic inputs on the nutritional quality and market value of bottle gourd, ensuring better health benefits. Results from Season I and Season II revealed that treatment T9, which incorporated (Farmyard manure, Vermicompost, Neem cake, 3G extract, five-leaf extract, Panchagavya, Fish fermented extract, Egg fermented extract, *Bacillus substilis*), treatment T_9 yielded the highest nutritional quality in bottle gourd, including protein (0.0275%), ascorbic acid (8.61%) and total ash (6.27%). It also had the highest macro and micronutrient levels, such as phosphorus (19.1 mg/g), potassium (1.74 mg/g), calcium (30.2 mg/g), copper (0.066 mg/g), iron (0.038 mg/g) and selenium (0.318 mg/g), showcasing its superior nutritional profile. These findings suggest that organic inputs, particularly in treatment T_9, significantly enhance the nutritional quality of bottle gourd, offering a viable eco-friendly alternative to conventional cultivation methods.

Keywords

bottle gourd; heat map; nutritional quality; organic inputs; path analysis; PCA

Introduction

As the most populous country in the world, India faces increasing pressure on its arable land and food systems to meet the growing demand for nutritious food (1). This problem can be mitigated by increasing the number of vegetables consumed by urban and rural residents (2). Vegetables, often called protective food, are inexpensive sources of essential vitamins and minerals, playing a crucial role in human nutrition. Beyond their nutritional value, vegetables are increasingly recognized for their functional and medicinal properties. In addition to their nutritional worth, vegetables are becoming highly popular for their functional and medicinal properties (3). Although synthetic fertilizers and agrochemicals have helped meet food demands, their indiscriminate use has negatively affected soil productivity, environmental health and food quality (4).

This can be prevented by significantly decreasing fertilizer consumption without sacrificing vegetable quality if the nutrients are incorporated in the form of organic inputs. Organic manures provide essential macro and micro components for plants. They preserve the nutritional balance necessary for plant growth by releasing nutrients gradually into the soil solution. Organic manures enrich the soil with essential macro and micro-nutrients, slowly releasing them into the soil and improving water infiltration, moisture retention and soil structure (5). Nowadays, liquid organic manures are utilized as topdressing during crop growth, are easy to make and are effective for most vegetables. This increases the production of organic crops. Unlike conventional organic manures, liquid organic manures are particularly effective for certain vegetables because they provide readily available nutrients, improving plant uptake and growth, especially in fast-growing crops like leafy greens (6). Additionally, their rapid absorption supports better root development and yield in nutrient-demanding vegetables (7).

Bottle gourd (*Lagenaria siceraria*) is a fast-growing annual climber (8) and a vital vegetable crop that is rich in nutrients. 100 g edible portion contains approximately 0.2% protein, 2.9% carbohydrate, 0.5% fat and 11 mg per 100 g fresh weight vitamin C (9). Its high nutritional content, medicinal properties and importance in traditional ayurvedic medicine make it an ideal candidate for organic input studies to improve its nutritional quality. In addition to its nutritional benefits, bottle gourd is used in Ayurvedic medicine to treat conditions such as high blood pressure, gastrointestinal issues and diabetes. Its therapeutic qualities further highlight the importance of enhancing its nutritional value through organic methods (10). This study aimed to assess the impact of organic inputs on the nutritional quality of bottle gourd, focusing on evaluating different organic treatments.

Materials and Methods

The experiment was conducted at Ramanadhapuram village, Thadagam (PO), Coimbatore North (TK), Coimbatore 76.93°E longitude and 11.01°N latitude at an altitude of 427m above mean sea level. Coimbatore from October 2023 to January 2024 (Season I), February 2024 to May 2024 (Season II) using bottle gourd (*Lagenaria siceraria* L. var. TNAU Hybrid CO1). The data on rainfall was 149.700mm, the mean maximum temperature ranges from 29.2°C (84.6°F) to 35.9°C (96.6°F) and the mean minimum temperature ranges from 9.8°C (49.6°F) to 24.5°C (76.1°F). Relative humidity, on an average of 73.0%, was recorded during the cropping seasons (2023-2024). The experimental field utilized alluvial soil, known for its fertility and well-drained structure, providing an ideal environment for crop growth. The experiment used a Randomized Block Design (RBD) with 11 treatments and three replications. Treatment details are given in Table. 1.

To experiment over two seasons, the experimental field was thoroughly ploughed to achieve a fine tilth in both Season I and Season II. Pits of 60 cm^3 were prepared with a spacing of 2 × 1.25 m. The seeds were soaked in water overnight and treated with *Bacillus subtilis* at a dosage of 10 g/kg before sowing. *Bacillus subtilis* is commonly used as a seed treatment because it promotes plant growth by suppressing soil-borne pathogens and enhancing nutrient availability. It also stimulates plant immune responses, improving seed germination and vigour. FYM (farmyard manure), neem cake and vermicompost were applied as a basal dose according to the treatment plan for each season. During both seasons, liquid organic manures were used as foliar sprays in specific treatment combinations: Panchagavya (3% spray), fish-fermented extract (10% spray) and egg-fermented extract (10% spray) were applied in specific treatment combinations, with each treatment receiving a total of three foliar sprays at 15-day intervals after initial application. Botanical extracts were used as foliar sprays in both seasons to manage pest populations. Botanical extracts were chosen over chemical alternatives because they are environmentally friendly, biodegradable and pose less risk to non-target organisms, including beneficial insects. They also reduce the chance of pest resistance developing over time. The 3G extract of 3% (garlic, ginger and green chilli) and the 5-leaf extract of 3% (neem leaves, chaste tree leaves, amaranth leaves, barbados nut leaves and crown flower leaves) were applied accordingly. This approach ensured consistent treatment across both seasons, allowing for the assessment of nutritional quality and other parameters.

Table 1. Treatment details of the experiment

T_1	FYM 10t/ha+ Vermicompost 3.5t/ha+ Panchagavya 3% spray + Egg fermented extract + *Bacillus subtilis* + 3G extract.
T_2	FYM 10t/ha+ Vermicompost 3.5t/ha+ Panchagavya 3% spray + egg fermented extract + *Bacillus subtilis* + 5 leaf extract.
T_3	FYM 10t/ha+ Vermicompost 3.5t/ha+ Panchagavya 3% spray+ Fish fermented extract + *Bacillus subtilis* + 3G extract
T_4	FYM 10t/ha+ Vermicompost 3.5t/ha+ Panchagavya 3% spray + Fish fermented extract + *Bacillus subtilis* + 5 leaf extract
T_5	FYM 10t/ha+ Neem cake 100kg/ha+ Panchagavya 3% spray + Egg fermented extract + *Bacillus subtilis* + 3G extract
T_6	FYM 10t/ha+ Neem cake 100kg/ha+ Panchagavya 3% spray + Egg fermented extract + *Bacillus subtilis* + 5 leaf extract
T_7	FYM 10t/ha+ Neem cake 100kg/ha+ Panchagavya 3% spray+ Fish fermented extract + *Bacillus subtilis* + 3G extract
T_8	FYM 10t/ha+ Neem cake 100kg/ha+ Panchagavya 3% spray + Fish fermented extract + *Bacillus subtilis* + 5 leaf extract
T_9	FYM 10t/ha+ Vermicompost 1.75t/ha+ Neem cake 50kg/ha + Panchagavya 3% spray + Egg fermented extract + Fish fermented extract + *Bacillus subtilis* + 3G extract + 5 leaf Extract
T_{10}	FYM 25t/ha + *Bacillus subtilis* + 3G extract + 5 leaf extract.
T_{11}	FYM 25t/ha alone (control).

Fruits were harvested at the vegetable maturity, determined by visual inspection of fruit size and firmness. A nutritional analysis of ascorbic acid content was estimated using the titrimetric method with 2, 6-dichlorophenol indophenol dye, expressed in mg per 100g of fruit pulp as per the standard method(11). Total soluble protein was estimated at the vegetable maturity stage using the standard process and expressed as a percentage (12). Ash content was determined gravimetrically by heating fruit samples in a muffle furnace until a constant mass (13). Crude fibre content was estimated using the standard method and expressed as a percentage (14). Carbohydrate content was assessed using the technique at the vegetable maturity stage and expressed as a percentage (15). Calcium and magnesium content were calculated using EDTA titration with Eriochrome black T as an indicator. Phosphorus was measured colourimetrically at 470 nm using ammonium molybdate and ammonium metavanadate, compared to a standard curve. Potassium content was determined by flame photometry after neutralization with ammonium hydroxide. Iron content was measured colourimetrically at 490 nm after reaction with ortho phenanthroline and hydroxylamine hydrochloride. Recorded data were statistically analyzed using Heat map, PCA, Two-way ANOVA and Pathway analysis packages in R (version 4.2.3). A two-way analysis of variance (ANOVA) was carried out using stats software to determine the significant differences among the organic inputs. A heat map visualizes data patterns through colour gradients, often highlighting relationships between quality attributes. Principal component analysis (PCA) is employed to reduce data dimensionality while preserving variance, helping to identify key contributing factors. Two-way ANOVA determines the significance of differences among groups, particularly for analyzing interactions between factors. Pathway analysis identifies biological pathways affected by treatments, linking them to functional outcomes.

Results and Discussion

Heat map analysis

A cluster heat map is a type of data visualization that combines a heat map with clustering to reveal patterns and relationships in the data. A heat map displays data values in a matrix format where colors represent individual values. The findings are presented in a heat map, where the horizontal axis represents the quality parameters and the vertical axis represents the eleven different organic treatments. The red color represents higher values, while the blue color represents lower values (Fig.1). The color intensity in each cell of the heat map above represents the values of quality parameters. The organic input combinations in the treatment T_9(FYM 10t/ha + vermicompost 1.75t/ha + neem cake 50kg/ha + panchagavya 3% spray + egg fermented extract + fish fermented extract + *Bacillus subtilis* + 3G extract + 5-leaf extract) facilitated for the high values of fruit yield, carbohydrate content, crude fiber content, total ash content, ascorbic acid content, TSS, protein content, sodium content, potassium content, zinc content, calcium content, selenium content, iron content, phosphorous content, manganese content, copper content and magnesium content followed by the treatment T_6 (FYM 10t/ha + neem cake

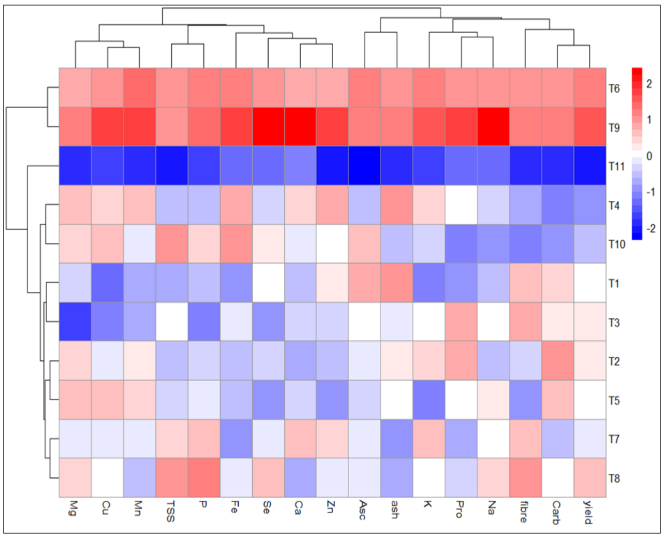

Fig. 1. Heat map for nutritional quality parameters with respect to different organic treatments.

100kg/ha + panchagavya 3% spray + egg fermented extract + *Bacillus subtilis* + 5-leaf extract). The treatment T_{11}(control) showed the minimum values in all quality parameters among the various organic treatments. The combination of FYM (Farmyard Manure), vermicompost, neem cake and other organic inputs in treatment T_9 contributed significantly to the enhanced bottle gourd nutrient content by improving soil fertility, microbial activity and nutrient availability. FYM and vermicompost are rich in organic matter, enhancing soil structure and water retention and providing essential nutrients such as nitrogen, phosphorus and potassium. Neem cake contributes to pest suppression and nutrient cycling, while Panchagavya and egg and fish fermented extract stimulate microbial populations, enhancing nutrient mineralization and plant growth. The inclusion of *Bacillus subtilis* further promotes disease resistance and nutrient uptake. This comprehensive input combination leads to better plant health, nutrient accumulation (such as carbohydrates, fibre, proteins and essential minerals) and higher productivity. The consistent performance of T9 across two seasons indicates its reliability in enhancing the nutritional quality of bottle gourd through the combined effects of organic manures and bio-fertilizers.

This might be due to the application of vermicompost containing high levels of humic substances, which influences nitrogen uptake, assimilation and metabolism. It improves the nitrate reductase activity (16). Nitrate reductase catalyzes the conversion of nitrate into nitrite. The nitrite will be converted to ammonia, producing amino acids. The different amino acids combine to form proteins, which might increase the protein content (17). The increase in crude fibre content could be due to their essential role in the biosynthesis of chlorophyll molecules, affecting the total carbohydrate content, increasing the photosynthates translocation from source to sink and increasing the different growth substances (18,19). The increase in ascorbic acid content in bottle gourd might be due to the application of organic fertilizers and biofertilizers, which might have helped improve the uptake of significant nutrients, including micronutrients, leading to increased biosynthesis of vitamins. This is following the findings of various researchers (20-22). The increasing TSS content might be due to organic manures' significant role in improving TSS, particularly FYM.

Principal component analysis

PCA is essential for analyzing multivariate data reduction strategies and determining which basic components best capture variation. One can expect the first component to account for a considerable portion of the total variation. Variation in the subsequent principal components (PC) decreases. When analyzing different organic treatments, PCA can help uncover relationships between organic treatments and their effects on various quality parameters. Each eigenvalue corresponds to the variance captured by its associated principal component. A higher eigenvalue means that the principal component captures more of the variance in the data. From Table. 2, PC_1, with an eigenvalue of 10.898, captures a significant amount of variance, indicating that it is the most crucial component in explaining the variability in the quality parameters, followed by PC2 (1.455) and PC3 (1.112). PC1 has a very high eigenvalue compared to the others, which means PC1 captures the majority of the variance in the dataset.

A scree plot is a useful graphical tool in Principal Component Analysis (PCA) that helps to determine the number of principal components to retain. The Scree plot of the variables in this study, reveals that the first three Eigenvector had eigenvalues more significant than the one (Table. 2), explaining PCA1 68.1% variance, PCA2 9.1% variance and PCA3 6.9% collectively explained about 84.1% of the total variation among the quality parameters in 11 different organic treatment combinations which shown (Fig. 2). PC1 has a significant contribution to its variation by the parameters such as protein (0.734), ascorbic acid (0.828), carbohydrate (0.686), TSS (0.818), total ash (0.737), crude Fiber (0.628), Ca (0.872), Cu (0.868), Fe (0.819), Mg (0.799), Mn (0.92), P (0.845), Se (0.887), Na (0.881), Zn (0.907), K (0.869) as indicated by the factor loadings of principal components (Table 3). The scree plot shows a sharp decline from PC1 to PC3 and then, it levels off, so we might retain the first three principal components.

From the above loading plot (Fig. 3), PC1 accounted for 68.1 percent of the variances. This is the equivalent of six different quality parameters, namely carbohydrate, crude fiber, protein, Cu, Mg and Fe and it shows that these were significant contributing factors to the variance across factors. As a result, organic treatments with high PC1 scores would show considerable variation in these quality parameters. The PC2 has 1.455 eigenvalues and contributes 9.1% variations, respectively. PC2 is associated with TSS, Zn and Mn.

The correlation strength in a PCA biplot was indicated by the proximity (closeness) of parameters in the plot. Firmly correlated variables will be close to each other or have arrows pointing in similar directions. Among carbohydrate and crude fiber quality traits, Ca and Cu show the strongest positive correlation. The strong positive correlation between traits like carbohydrate, crude fiber, Ca and Cu in a PCA biplot suggests that enhancing one may improve the others. This can be practically important in organic farming as selecting or breeding bottle gourd varieties with higher nutrient content may simultaneously increase Fiber and mineral content, promoting better crop quality and nutritional benefits without relying on synthetic inputs. Carbohydrates, crude Fiber, Ca and Cu show considerably longer dispersion. Total ash content shows lesser dispersion.

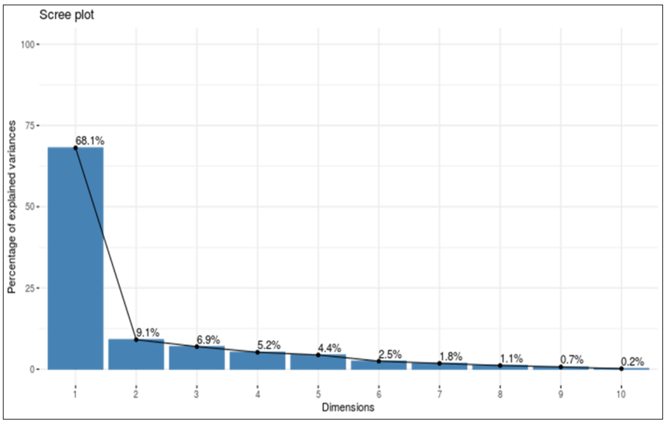

Fig. 2. Scree plot for PCs' in quality parameters of bottle gourd.

Table 2. Contribution of quality parameters of bottle gourd to different PCs

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigen Value	10.898	1.455	1.112	0.834	0.702	0.395	0.286	0.182	0.11	0.026
Variance %	68.114	9.091	6.948	5.212	4.388	2.471	1.789	1.137	0.686	0.164
Cumulative Variance %	68.114	77.204	84.153	89.365	93.753	96.224	98.013	99.15	99.836	100.00

Table 3. % contribution of variables on PCs

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Protein	0.734	0.395	0.391	-0.273	0.207	0.169	0.033	0.077
Ascorbic acid	0.828	0.187	-0.184	0.353	-0.253	0.115	0.164	-0.072
Carbohydrate	0.686	0.563	0.058	0.306	0.313	0.006	0.063	-0.018
TSS	0.818	-0.108	-0.477	0.044	0.035	0.277	0.034	-0.087
Total ash	0.737	0.235	0.428	0.314	-0.313	-0.077	-0.021	0.055
Crude Fiber	0.682	0.579	-0.386	-0.106	-0.076	-0.04	-0.104	0.003
Ca	0.872	-0.145	0.093	-0.306	-0.165	-0.195	0.027	-0.193
Cu	0.868	-0.407	0.106	0.063	0.227	0.031	0.017	-0.1
Fe	0.819	-0.355	0.165	-0.124	-0.153	0.25	0.242	0.107
Mg	0.799	-0.366	0.129	0.363	0.16	-0.075	-0.175	0.107
Mn	0.92	-0.114	0.309	0.052	0.098	0.016	-0.094	-0.131
P	0.845	-0.221	-0.39	0.091	0.234	-0.1	-0.06	0.036
Se	0.887	-0.112	-0.218	-0.09	-0.049	-0.235	0.138	0.243
Na	0.881	0.149	0.037	-0.268	0.218	-0.213	0.151	-0.05
Zn	0.907	-0.026	-0.034	-0.019	-0.383	-0.09	-0.12	-0.037
K	0.869	0.041	-0.013	-0.306	-0.055	0.208	-0.288	0.091

(Ca-Calcium, Cu-Copper, Fe- Iron, Mg-Magnesium, Mn-Manganese, P-Phosphorous, Se-Selenium, Na-Sodium, Zn-Zinc, K-Potassium)

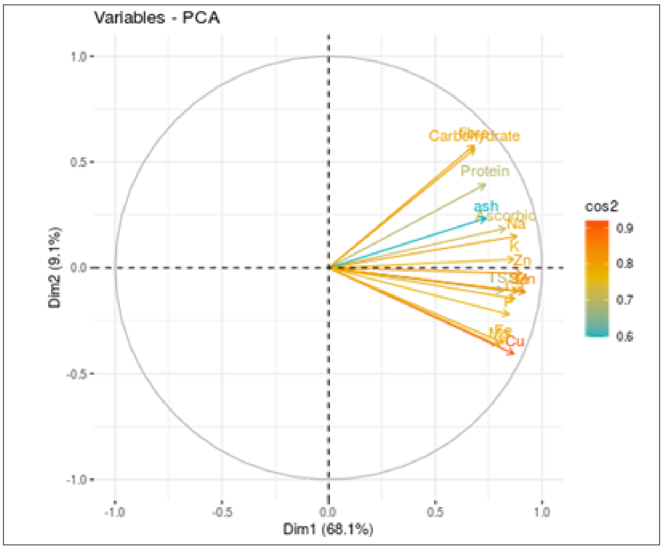

Fig. 3. Contribution of each quality parameter of bottle gourd in a factor loadings plot.

ANOVA

ANOVA was used to examine the mean values of the observed traits on nutritional quality parameters to determine the significant differences between them. The source of variation within the parameters and statistical significance are presented in Table. 3

Table 4-5 showed that the treatment T_9 had the highest carbohydrate content (0.122%) and the lowest carbohydrate content was observed in T_0(0.105%), the highest protein content was observed in T_9(0.0275%) and the lowest protein content was observed in T_0 (0.0218%), highest ascorbic acid content was observed in T_9(8.61%) and the lowest ascorbic acid content was observed inT_0(5.49%), highest TSS content was observed in T_9 (2.31) and the lowest TSS content was observed in T_0 (1.57). Treatment T_9also recorded high total ash content (6.27%), followed by treatment T_6(8.44). The treatment T_9also recorded high crude fibre content (1.139%), followed by the treatment T_6(1.135%). Micronutrient contents such as highest calcium content (30.2 mg/g), highest copper content (0.066 mg/g), highest iron content (0.038 mg/g), highest magnesium content (16.1 mg/g), highest manganese content (0.099 mg/g), highest phosphorous content (19.1 mg/g), highest selenium content (0.318 mg/g), highest potassium content (1.74 mg/g), highest sodium content (3.18 mg/g), highest zinc content (1.12 mg/g). The treatment T_0 (control) had the lowest mean values in nutritional quality parameters. The increasing total ash content might be due to organic manures increasing the total ash content in bottle gourd by enriching the soil with essential minerals like calcium, magnesium, potassium and phosphorus when applied with FYM and vermicompost. The increased total ash content and higher levels of carbohydrates, proteins and essential micronutrients (calcium, magnesium, potassium and phosphorus) from organic manure applications like FYM and vermicompost enhance the nutritional value of produce. These nutrients support energy metabolism, muscle function, bone health, heart function and cellular processes, offering significant health benefits and helping to prevent nutrient deficiencies in consumers. The highest phosphorous content in the treatment T_9 might be due to the application of vermicompost, which had a considerable amount of humic acid, which improves the phosphorus availability by chelation, acidifying mechanisms or microbial-induced mineralization. The results are confirmatory

Table 4. Effects of different organic inputs on the major nutrient content of bottle gourd across two seasons

Treatment	Calcium (mg/g)	Copper (mg/g)	Iron (mg/g)	Magnesium (mg/g)	Manganese (mg/g)	Phosphorous (mg/g)	Selenium (mg/g)	Sodium (mg/g)	Zinc (mg/g)	Potassium (mg/g)
T1	22.2	0.033	0.018	13.3	0.077	15.3	0.272	2.64	0.96	1.22
T2	21.7	0.044	0.021	14.7	0.085	15.7	0.265	2.67	0.87	1.51
T3	22.5	0.035	0.024	11.2	0.078	14.1	0.254	2.74	0.89	1.45
T4	24.8	0.051	0.031	15.1	0.089	15.3	0.267	2.69	1.01	1.52
T5	22.5	0.054	0.022	14.9	0.088	16.2	0.255	2.78	0.84	1.19
T6	26.1	0.058	0.033	15.3	0.096	18.7	0.292	2.92	1.02	1.67
T7	25.3	0.046	0.019	13.6	0.083	17.4	0.271	2.74	0.97	1.53
T8	21.8	0.048	0.024	14.6	0.079	18.5	0.285	2.81	0.91	1.44
T9	30.2	0.066	0.038	16.1	0.099	19.1	0.318	3.18	1.12	1.74
T10	23.2	0.053	0.032	14.8	0.082	17.1	0.276	2.58	0.93	1.37
T11	20.4	0.028	0.016	10.8	0.067	13.2	0.249	2.53	0.71	1.08
F test	S	S	S	S	S	S	S	S	S	S
Cd @ 5%	1.07	0.13	0.15	0.63	0.37	0.84	0.64	0.06	0.06	0.08
S. Ed	0.51	0.06	0.07	0.3	0.18	0.4	0.31	0.13	0.13	0.04

Table 5. Effects of different organic inputs on the minor nutrient content of bottle gourd across two seasons

Treatment	Protein (%)	Ascorbic acid (%)	Carbohydrate (%)	Total ash (%)	TSS (^{0}Bx)	Crude Fiber (%)
T1	0.0225	8.27	0.118	6.11	1.91	1.124
T2	0.0256	7.33	0.121	5.54	1.92	1.098
T3	0.0258	7.58	0.117	5.26	2.07	1.131
T4	0.0243	7.07	0.109	6.09	1.93	1.086
T5	0.0241	7.23	0.119	5.47	1.96	1.082
T6	0.0262	8.47	0.121	6.17	2.31	1.135
T7	0.0228	7.34	0.113	4.77	2.17	1.123
T8	0.0236	7.38	0.116	4.89	2.27	1.134
T9	0.0275	8.61	0.122	6.27	2.31	1.139
T10	0.0219	8.12	0.111	5.02	2.28	1.074
T11	0.0218	5.49	0.105	4.07	1.57	1.053
F test	S	S	S	S	S	S
Cd @ 5%	0.6	0.3	1.07	0.27	0.07	1.18
S. Ed	0.29	0.14	0.51	0.13	0.03	0.57

with (23). The application of vermicompost reduces the uptake of NaCl and increases the potassium and calcium content (24). The application of vermicompost increased the iron content by chelating with iron and made them available to the plants (25-27). The increasing manganese content might be due to better micronutrient uptake of the plant by organic fertilizers, which results in increased accumulation in the plant (28).

Path analysis

Path analysis is a methodology that holds strength because it enables researchers to investigate both direct and indirect effects while using a variety of independent and dependent variables. Here, path analysis was used to determine the direct and indirect effects of the quality parameters on fruit yield in bottle gourd, with 11 treatments of various organic combinations. It's employed to investigate the causal connections between variables.

The path diagram is presented in Fig. 4, phosphorus (0.549) and manganese (0.409) have the highest positive direct effects on fruit yield, while calcium (-0.480) and magnesium (-0.363) have the highest negative direct effects. The direct adverse impact of calcium and magnesium on fruit yield in the path analysis suggests that excessive nutrient levels may interfere with nutrient uptake or physiological processes essential for fruit production. It indicates the importance of balanced soil nutrient management, as over-supplying calcium and magnesium could inhibit phosphorus and manganese efficiency, ultimately reducing yield. Adjusting fertilization practices to avoid over-application of these minerals could improve productivity. These findings suggest that phosphorous and manganese significantly impact bottle-gourd fruit yield. Calcium and magnesium do not significantly influence fruit yield. The highest positive indirect effect is in phosphorous and copper (0.427), followed by phosphorous and magnesium (0.389). The highest negative indirect effect is observed in copper and magnesium (-0.299), followed by calcium and ascorbic acid (-0.251), which indicates that phosphorous and copper indirectly influence the fruit yield. Copper and magnesium have no indirect effect on the fruit yield of bottle gourd.

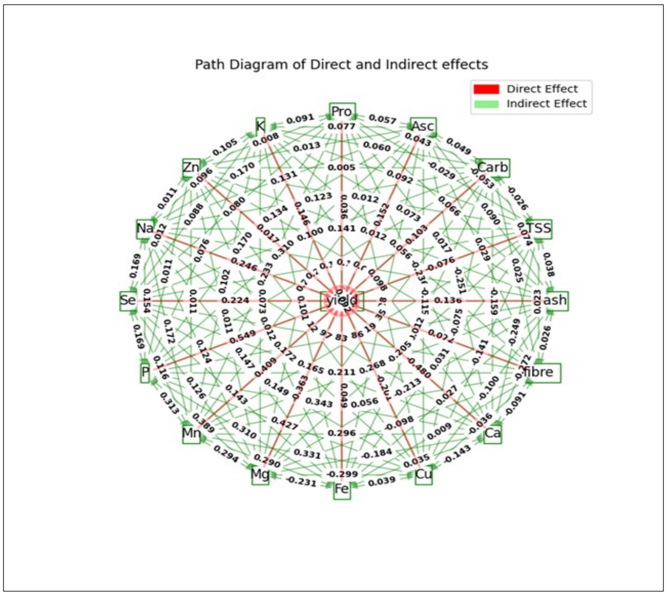

Fig. 4. Path analysis for different quality parameters.

(Pro-Protein, ASC-Ascorbic acid, Carb-Carbohydrate, TSS-Total soluble solids, Ash-Total Ash, Fiber-Crude Fiber, FY-Fruit yield).

Phenotypic correlation matrix

The diagonal elements reflect the correlation of each process with itself, which is always perfect because every process is perfectly associated with itself. A positive correlation coefficient (closer to 1) indicates that two processes will likely occur together or follow a similar pattern. A negative correlation coefficient (closer to -1) suggests that one process happens more frequently. From the Table. 6 "Magnesium" and "Copper" have a correlation coefficient of approximately 0.825, which suggests a positive correlation between these two stages. A positive correlation coefficient (closer to 1) indicates that two processes tend to occur together or have a similar pattern of occurrence, which means that if magnesium content increases, copper content also increases. In contrast, a negative correlation coefficient (closer to -1) indicates that when one process happens more frequently, the other happens less frequently. Manganese: These had a significant positive correlation with several stages, including calcium, copper, iron and magnesium. Sodium: These have a relatively high positive correlation with

Table 6. Phenotypic correlations for different quality parameters of bottle gourd

	Yield	Pro	ASC	Carb	TSS	Ash	Fiber	Ca	Cu	Fe	Mg	Mn	P	Se	Na	Zn	K
Yield	1.000																
Pro	0.504**	1.000															
ASC	0.645**	0.373*	1.000														
Carb	0.646**	0.418*	0.471**	1.000													
TSS	0.603**	0.381*	0.702**	0.344*	1.000												
Ash	0.541**	0.485**	0.664**	0.543**	0.282	1.000											
Fiber	0.463**	0.243	0.406*	0.347*	0.323	0.366*	1.000										
Ca	0.522**	0.492**	0.524**	0.331	0.520**	0.566**	0.190	1.000									
Cu	0.552**	0.504**	0.573**	0.373*	0.704**	0.499**	0.180	0.713**	1.000								
Fe	0.487**	0.494**	0.581**	0.241	0.637**	0.564**	0.189	0.717**	0.806**	1.000							
Mg	0.468**	0.344	0.572**	0.372*	0.565**	0.587**	0.270	0.508**	0.825**	0.638**	1.000						
Mn	0.614**	0.569**	0.599**	0.529**	0.534**	0.655**	0.137	0.723**	0.808**	0.708**	0.718**	1.000					
P	0.663**	0.310	0.565**	0.430*	0.791**	0.339	0.383*	0.624**	0.778**	0.565**	0.708**	0.570**	1.000				
Se	0.662**	0.357*	0.599**	0.446**	0.582**	0.512**	0.370*	0.737**	0.668**	0.640**	0.562**	0.520**	0.755**	1.000			
Na	0.665**	0.691**	0.535**	0.502**	0.573**	0.522**	0.256	0.800**	0.701**	0.597**	0.504**	0.702**	0.629**	0.687**	1.000		
Zn	0.587**	0.454**	0.745**	0.305	0.667**	0.696**	0.386*	0.762**	0.669**	0.698**	0.607**	0.649**	0.612**	0.699**	0.649**	1.000	
K	0.625**	0.622**	0.530**	0.410*	0.628**	0.501**	0.385*	0.670**	0.633**	0.690**	0.498**	0.702**	0.520**	0.602**	0.657**	0.723**	1.000

** = Significant at 1% and * = Significant at 5 % level of significance (Pro-Protein, ASC-Ascorbic acid, Carb-Carbohydrate, TSS-Total soluble solids, Ash-Total Ash, Fiber-Crude Fiber, FY-Fruit yield, Ca-Calcium, Cu-Copper, Fe-Iron, Mg-Magnesium, Mn-Manganese, P-Phosphorous, Se-Selenium, Na-Sodium, Zn-Zinc, K-Potassium) several stages, including calcium, copper and manganese. Selenium, zinc, potassium, phosphorous, iron and magnesium: This stage has a positive correlation with most other stages, but the correlation is moderate.

Conclusion

This study demonstrated that the use of organic inputs can significantly enhance the nutritional quality of bottle gourd, with treatment T_9 showing the most substantial improvement across key parameters such as protein, ascorbic acid, carbohydrate and essential micronutrients including calcium, magnesium and zinc. By enhancing the nutritional profile of bottle gourd, organic inputs offer a sustainable farming solution and contribute to healthier diets, particularly in regions where micronutrient deficiencies are prevalent. Applying organic inputs such as vermicompost and bio-fertilizers reduces the reliance on chemical fertilizers and pesticides, promoting soil health and minimizing environmental pollution, making this approach a key component of sustainable agriculture. The improved nutritional quality of bottle gourd from organic treatments can increase its market value, offering farmers higher economic returns while meeting consumer demand for healthier, pesticide-free produce. Further research is recommended to evaluate the long-term effects of these organic inputs across different environmental conditions and crop varieties. Scaling up these practices could provide a practical and sustainable solution for improving crop quality and farm profitability.

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Authors' contributions

SP contributed to conceptualizing and supervising the research design and experimental planning. PK carried out the experiment, data collection and analysis. MA contributed by imposing the experiment and PS helped with statistical analysis.

Compliance with ethical standards

Conflict of interest : According to the writers, they have no conflicts of interest. This attests to the fact that the text has not been submitted for publication elsewhere and is an original work. Furthermore, we attest that all references have been appropriately cited and that no information, including tables and figures, has been taken verbatim from other publications. All authors consent to submit this manuscript to the Plant Science Today journal.

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