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RESEARCH ARTICLE

Study on performance of cabbage (*Brassica oleraceae* var. *capitata* L.) under different production systems

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Abstract

Coimbatore is located in the western part of Tamil Nadu and nestled against the foothills of the Western Ghats. This region's cool climate and favourable terrain make it ideal for cultivating hill vegetables. Cabbage (*Brassica oleracea* var. *capitata* L.) is a significant cole crop known for its high nutritional value. Excessive chemical usage in cabbage cultivation leads to residual effects on soil and produce. This study aimed to identify the best production system for cabbage cultivation in the northwestern parts of Tamil Nadu. An experiment was conducted during the winter season of 2023-2024 at the Tamil Nadu Agricultural University, Coimbatore. The experiment was laid out in a randomized block design (RBD) with four treatments and five replications. The organic farming system exhibited the highest values for plant height (21.47 cm), stalk length (8.49 cm), dry matter accumulation (71.34 g per plant), days to head formation (18.75 days), days to harvest (56.25 days), head diameter (17.70 cm), head compactness (33.91), head weight (945.35 g per plant) and cabbage yield (24.92 t ha^{-1}), surpassing both conventional and natural farming systems. A similar pattern was observed in quality parameters, including TSS (6.54 °Brix), shelf life (12.21 days) and ascorbic acid content (44.26 mg per 100 g). This study highlights an efficient cabbage cultivation system in the Coimbatore region, leading to improved yield, soil health and quality.

Keywords

cabbage; natural farming; nutrition; organic farming; production systems

Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.) is a substantial crop from the Cruciferae family, originated in South and Western Europe and is now cultivated globally in fresh and processed forms (1). Cabbage domestication began in ancient Europe before 1000 BC and it was considered a table luxury in the Roman Empire. By the Middle Ages, cabbage had become a staple in European cuisine (2). Globally, cabbage is grown on 21.5 million hectares, yielding 59.55 million tons with an average productivity of 27.7 t ha^{-1}. In India, cabbage covers 4,23,410 hectares, producing 98,24,990 tons annually, with a productivity of 23.20 t ha^{-1}. Regarding regional distribution, in West Bengal, cabbage is grown on about 86,000 hectares, producing 2.34 million tons annually, making up 24.38% of India's total cabbage production. With cabbage cultivated on 38,000 hectares, Odisha contributes 11.77% of the country's total cabbage output. Regarding productivity, Tamil Nadu holds the highest productivity of cabbage, 68.63 t ha^{-1}(3). Cabbage is widely used in pickles (such as sauerkraut) and salads and it holds medicinal properties, including the treatment of coughs, fever, peptic ulcers and skin conditions. Notably, cabbage also has significant anticancer properties (4). The Food and Agriculture Organization lists cabbage among the top twenty vegetables. Nutritionally, cabbage is low in fat, dietary fibre, and vitamins and minerals. Every 100g of cabbage contains 92.1% moisture,1.7% protein, 0.2g fat, 5.3g carbohydrates, 0.9g fibre, 64mg calcium, 26mg phosphorus, 0.9mg iron, 8mg riboflavin, 0.3mg niacin, 62mg ascorbic acid, and 750 IU of vitamin A. The characteristic flavour of cabbage comes from the sulphur-containing glycoside sinigrin (5).

Conventional farming, which relies heavily on chemical fertilizers, pesticides and monocropping, leads to soil erosion, compaction and depletion of organic matter, gradually reducing soil fertility. In contrast, organic farming improves soil structure, organic carbon and microbial populations (6) through sustainable practices such as crop rotation, composting and reduced chemical inputs (7,8). Organic agriculture is eco-friendly, mitigating environmental degradation and enhancing soil fertility and nutrient management (9,10). Similarly, natural farming promotes soil health regeneration, biodiversity and ecological balance by utilizing natural processes without synthetic inputs. Organic and natural agriculture offer sustainable alternatives to conventional high-input practices by fostering nutrient cycling, implementing effective pest and disease management, and improving soil health while reducing environmental impact (11). These approaches offer long-term ecological benefits, supporting the regeneration of soils and fostering a more resilient agricultural system capable of sustaining both productivity and environmental balance. The present study seeks to evaluate the impacts of various production systems on crop growth, yield and quality, as well as on the physio-chemical and biological properties of the soil.

Materials and Methods

The experiment was conducted in field no. NA3 during (January - April), 2024 at Eastern Block Farms in Tamil Nadu Agricultural University, Coimbatore. The experimental field is geographically located at 11°00'29" N latitude, 76°56'23" E longitude at an altitude of 426.7 m above mean sea level. During the experimentation period, a total rainfall of 78.4 mm was received. Then, the maximum temperature was 33.3 °C, the minimum temperature was 22.7 °C and wind speed was 5.3 km h^{-1} recorded. The study was carried out in Randomized block design (RBD) with four treatments, *viz,* T_1: Absolute Control (no extrernal inputs), T_2: (natural farming practices): *Beejamruth* + *Ghanjeevamruth* @ 250 kg ha^{-1}, *Jeevamruth* @ 500 lit ha^{-1} irrigation twice in a month + dried mango leaves as mulch @ 5t ha^{-1} + whapasa (irrigation in alternate furrows at noon) + *Neemastra* + pheromone trap @ 12 Nos. ha^{-1} (diamond back moth-DBM), Yellow sticky trap @ 12 Nos ha^{-1} (Aphids), T_3 (organic farming practices): FYM@ 25 t ha^{-1}, neem cake@ 250 kg ha^{-1} as basal, Azophos @ 2.5kg ha^{-1}, vermicompost@ 1 t ha^{-1} (30,45,60 DAT), *Panchagavya* @ 3% FS (30,45,60 DAT) + 3G extract @ 5% FS ,Pheromone trap @ 12 Nos. ha^{-1} (DBM), Yellow sticky trap @ 12 Nos ha^{-1} (Aphids), Neem oil @ 3% FS and T_4 (Conventional farming practices) FYM 20 t ha^{-1}, Recommended dose of fertilizers (RDF) N:P:K 50:125:25 kg ha^{-1} and $ZnSo_4$ 50@ kg ha^{-1} along with 2 kg ha^{-1} *Azospirillum* as basal and borax @ 0.25% FS , foliar spray of emamectin benzoate @ 5% SG 200 gm ha^{-1} and it was replicated 5 times. The cabbage var. saint was sown in the nursery, and 35 days -old seedlings were transplanted on 09 January 2024 under 60 cm x 45 cm planting geometry. The soil pH was alkaline, with a value of 8.27. The electrical conductivity (EC) value was 0.45 dSm^{-1}, low salinity. The available soil nitrogen was 203.7 kg ha^{-1}, phosphorus was 21.54 kg ha^{-1} and potassium was 475.72 kg ha^{-1}, low, medium and high, respectively. In addition, the organic carbon content was 0.45%, reflecting a moderate organic matter content, which is critical for soil fertility and structure. The crop was grown as per the recommended practice package.

Growth parameters & head characters

Plant height (cm)

Plant height was recorded from the ground level to the topmost leaf apex of the plants and presented in centimetres. The measurements were recorded at harvest.

Stalk length (cm)

It was taken by cutting the heads and recording the inner stem length in the head.

Dry matter production (g plant $^{-1}$)

Five plants at random were removed per plot each time from the sampling row to estimate dry matter production. Initially, the samples were air-dried and oven-dried at 70°C ± 3°C until constant weight was obtained during harvest.

Head diameter (cm)

It was taken by cutting the head into two halves and measuring the length at the most comprehensive portion of the half-cut head.

Head compactness

The compactness of the head was determined as per the formula given in equation 1(12).

$$Z = \frac{C}{W^3} \times 100 \qquad \text{Eqn 01}$$

Where Z (index of compactness), C (net weight of head) and W (equatorial and polar diameter of head).

Days required to head formation

The number of days from the transplanting date to the observational plant's head initiation was recorded and the average was obtained.

Days required to head harvest

The number of days from the date of transplanting to the date of head harvest of the observational plant was recorded and the average was obtained.

Yield parameters

Net head weight (g plant^{-1})

The weight of heads without leaves and stalks of observational plants were taken and the average was worked out.

Gross head weight (g plant^{-1}):

The weight of observational plants' heads, leaves and stalk were taken and the average was worked out.

Yield per hectare (t ha^{-1})

Based on the yield obtained per plot in kilogram, yield per hectare was calculated in t ha^{-1}.

Physiological parameters

Leaf area index (LAI)

LAI is the projected area of leaves over a unit of land. Maximum leaf length and width of the physiologically active leaf/fully expanded leaf (third leaf) from the top was measured using a metric scale, and the number of leaves per plant was counted at harvest. The leaf area index was calculated using the formula in Equation 2 (13).

$$LAI = \frac{L \times W \times N \times k}{\text{Land area occupied (cm}^2\text{)}} \qquad \text{Eqn 02}$$

Where,

L- leaf length (cm), W- leaf breadth (cm), N- number of leaves per plant and k- conversion factor (0.775)

SPAD value meter (Soil and Plant Analysis Data)

A non-destructive method determined the leaves' chlorophyll content or concentration. SPAD meter was placed on the uppermost third leaf, positioned midway between the base of the leaf and tip, midway between midrib and margin and readings were recorded from five tagged plants at the harvest stage.

Crop growth rate (CGR)

CGR is typically expressed as an increase in crop biomass per unit of time. It was calculated from the period between 60 DAT to harvest and expressed in g m^{-2} day^{-1}. It was given in (equation 3) (13).

$$CGR = \frac{W_2 - W_1}{P\,(t_2 - t_1)} \qquad \text{Eqn 03}$$

Where W_1 and W_2: plant dry weight (g) recorded at time t^1 and t^2, respectively.

t_1 and t_2: time interval between two observations

P: plant spacing (m^2)

Relative growth rate (RGR)

RGR is used to assess crop plants' resource utilization efficiency, overall health and productivity within a specific environmental context. The RGR was calculated for the period of 60 DAT-harvest and expressed in mg g^{-1} day^{-1}. It was given in (equation 4) (14).

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \qquad \text{Eqn 04}$$

Where W_1 and W_2- Plant dry weight (g) recorded at time t_1 and t_2, respectively.

t_1 and t_2 - The time interval between two observations

Soil physio-chemical parameters

The soil sample was collected at 0-15 cm depth from the experimental field and analyzed in a laboratory for physio-chemical parameters like water holding capacity, organic carbon, available nitrogen, available phosphorus and available potassium after harvest of the cabbage. The microbial population was calculated for bacteria, fungi and actinomycetes.

Quality parameters

Total soluble solid (°Brix)

TSS content of the head was worked out by crushing and extracting juice from the mature head through a muslin cloth and the liquid extract obtained was used to record total soluble solids (˚Brix) with the help of a hand refractometer.

Shelf life (days)

The marketable heads were stored at room temperature for 14 days and shelf life was assessed by each treatment individually.

Ascorbic acid (mg 100 g^{-1})

Ascorbic acid (Vitamin C) content was estimated by titrimetric method with 2,6- dichlorophenol-indophenol dye. 2 g of cabbage sample was taken from each treatment for the estimation and ascorbic acid content was expressed in mg 100g^{-1}.

Statistical analysis

The statistical analysis was done using R software version 2.4.2 and the variance analysis technique (ANOVA) for randomized blocked design over the computer. The difference between the treatment means was tested for their statistical significance with the appropriate critical difference (CD) value at a 5% level of significance CD (p=0.05) (15). The Principal Component Analysis (PCA) and correlation analysis were employed to evaluate the experimental data.

Results

Plant growth and head parameters

The application of various inputs through different production systems significantly influenced the plant height, stalk length, dry matter production, head diameter and Head compactness, presented in Tables 1 and 2. The application of organic production practices significantly recorded the highest plant height (21.47 cm), comparable with the conventional production system. However, the lowest plant height, *i.e.*, 18.24 cm, was observed under absolute control treatment. The application of organic production practices significantly showed a higher stalk length (8.49 cm) and the next-best stalk length was recorded using natural farming practices, which was on par with conventional farming practices. And the lowest stalk length (7.37 cm) was observed in absolute control.

Table 1: Effects of various production systems on crop growth and yield.

Treatments	Plant height (cm) (60DAT)	Stalk length (cm) (60DAT)	DMP (g plant^{-1}) (Harvest)	Days for head formation	Days for head harvest	Cabbage yield (t ha^{-1}) (Harvest)
T_1	18.24	6.92	49.53	22.43	72.74	15.13
T_2	19.87	7.94	62.67	19.94	66.70	20.72
T_3	21.47	8.49	71.34	18.75	61.45	24.92
T_4	20.29	7.37	69.76	20.24	63.49	22.12
CD at 5%	**1.68**	**0.77**	**5.50**	**1.81**	**4.57**	**1.72**
SE (d)	**0.77**	**0.35**	**2.52**	**0.83**	**2.10**	**0.79**

Note: T_1- control, T_2- natural farming production system, T_3- organic farming production system and T_4- conventional farming production system

Table 2: Effect of various production systems on head characters.

Treatments	Head diameter (cm)	Head compactness	Head weight (g)	Head color	Head shape
T_1	13.65	37.42	595.23	Blueish green	Round
T_2	15.78	34.78	867.72	Blueish green	Round
T_3	17.70	33.91	945.35	Blueish green	Round
T_4	16.35	35.63	798.62	Blueish green	Round
CD at 5%	**1.49**	**2.32**	**53.59**	**NS**	**NS**
SE (d)	**0.69**	**1.07**	**24.60**	**NS**	**NS**

Note: T_1- control, T_2- natural farming production system, T_3- organic farming production system, T_4- conventional farming production system, NS-Non-Significant

Application of organic production practices significantly showed higher dry matter accumulation (105.79 g) at the harvest stage. The subsequent high dry matter accumulation was recorded with conventional farming practices (99.43 g) at the harvest stage, comparable with natural farming practices-significantly lower dry matter production (83.76 g) at the harvest stage, recorded in absolute control.

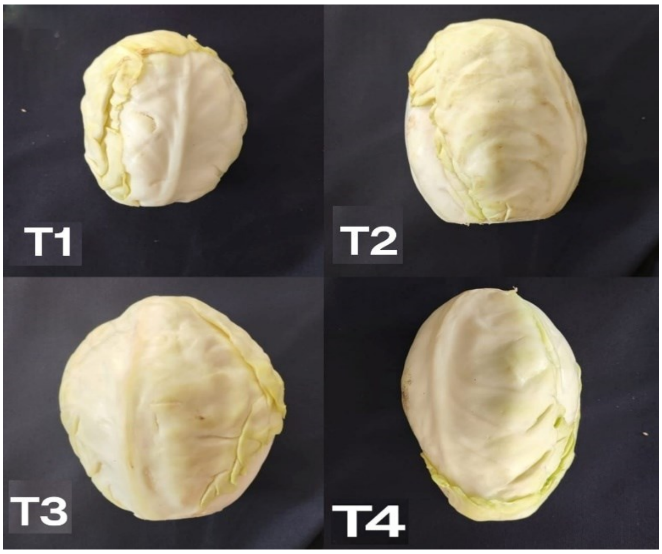
The different production systems significantly impacted the diameter of the cabbage head during the harvesting period, as presented in Fig. 1(a) and 1(b). The highest head diameter (17.60 cm) was observed when applying organic practices, comparable with conventional farming practices. The lowest head diameter was recorded in absolute control. The best head compactness (33.91) was recorded by applying organic farming practices. The next-best head compactness (34.78) was recorded in natural farming practices, comparable with conventional farming practices. Various production systems did not result in noticeable head colour and shape variations.

Physiological parameters

Physiological parameters of plants include LAI, SPAD, CGR and RGR. The influence of various production systems on the physiological parameters of cabbage var saint is presented in Table 3.

Various production systems significantly influenced LAI, SPAD, CGR and RGR during the different growth stages of the crop. Application of organic practices recorded a higher LAI (1.05) at the harvest stage, which was on par with conventional farming practices. The lowest leaf area index was (0.84) observed at the harvest stage in absolute control. The highest chlorophyll content was (59.65) recorded at harvest when applying organic farming practices. The next best reading value was observed with (57.24) conventional farming practices, which is on par with natural farming practices. The significantly lowest chlorophyll content was (45.78) observed in absolute control.

(a) plant at 45 DAT



(b) harvested cabbage

Fig. 1. Images of cabbage under different production systems

The highest crop growth rate observed in various growth stages was (8.49 g m^{-2} day^{-1}) recorded in the organic farming practices, which is on par with conventional farming practices. The lowest crop growth rate (6.92 g m^{-2} day^{-1}) was recorded in absolute control. The highest relative growth rate was observed (0.0147 g m^{-2} day^{-1}) in applying organic practices, which is on par with conventional farming practices (0.0135 gm m^{-2} day^{-1}). The lowest crop growth rate (0.0120 g m^{-2} day^{-1}) was noticed in absolute control.

Yield parameters

The application of various production systems significantly influenced the head weight, gross head weight and total yield of the cabbage (Table 1). Applying organic farming practices recorded the highest head weight (945.35 g). The next highest net head weight (867.72 g) was observed when using conventional farming practices, comparable to natural farming practices. The lowest net head weight (595.23 g) was recorded in absolute control. The various production systems significantly influenced the gross head weight. The highest gross head weight (1765.54 g) was recorded when applying organic practices. The next best gross head weight (1698.42 g) was observed when using conventional practices, comparable to the application of natural farming practices. The lowest gross head weight (1382.97 g) was recorded in absolute control. Among all the treatments, a higher head yield (24.92 t ha^{-1}) was recorded by applying organic practices. The subsequent best yield (22.12 t ha^{-1}) was recorded using conventional farming practices, comparable with natural farming practices. Significantly lowest yield (15.13 t ha^{-1}) was recorded in absolute control.

Quality parameters

The total soluble solids, shelf life and ascorbic content of the cabbage varied due to different production systems, as presented in Table 3. Significantly highest TSS (°Brix) content was (6.54 °Brix) recorded with the organic farming practices. The next highest total soluble solid (°Brix) was (5.82 °Brix) observed in the natural farming practices. Significantly lowest total soluble solids (3.20 °Brix) were recorded with absolute control. The highest shelf life of the cabbage was (12.21 days) recorded with the application of organic practices. The next highest shelf life of the cabbage was (10.25 days) recorded with the application of natural farming practices. The lowest shelf life was (7.31), recorded with absolute control. The ascorbic acid content in cabbage differed significantly due to different production systems. The application of organic farming practices recorded significantly higher ascorbic acid content (44.26 mg 100 g^{-1}), which was on par with natural farming practices (37.10 mg 100 g^{-1}). Significantly less ascorbic acid content (23.47 mg 100 g^{-1}) was observed in absolute control.

Status of the soil

The impact of the various production systems on post-harvest soil is presented in Table 4. The highest levels of soil available nutrients were recorded in plots treated with organic practices, with available nitrogen at (221.7 kg ha^{-1}), available phosphorus at (32.97 kg ha^{-1}) and available potassium at (482.24 kg ha^{-1}). The organic carbon content was (0.53%), and the soil's water-holding capacity reached 66.14%. In contrast, the absolute control plots observed the lowest nutrient levels.

The microbial population (CFU-colony forming units) was high in the plots treated with organic farming practices and recorded the colony-forming units of bacteria (84x10^6 CFU g^{-1}), fungi (46x10^4 CFU g^{-1}), actinomycetes (29x10^3 CFU g^{-1}), which is comparable to the natural farming practices. The lower microbial population was observed under absolute control.

Table 3: Effect of various production systems on physiological and quality parameters of cabbage.

Treatments	Physiological parameters				Quality parameters		
	LAI (Harvest)	SPAD value (harvest)	CGR 60 DAT-Harvest (g m^{-2} day^{-1})	RGR 60 DAT-harvest (g m^{-2} day^{-1})	TSS (°Brix)	Shelf life (days)	Ascorbic acid (mg 100 g^{-1})
T_1	0.84	45.78	6.92	0.0120	3.20	7.31	23.47
T_2	0.95	53.84	7.94	0.0125	5.80	10.25	37.10
T_3	1.05	59.65	8.49	0.0147	6.54	12.21	44.26
T_4	0.97	57.24	7.37	0.0135	4.72	9.84	32.40
CD at 5%	**0.11**	**4.25**	**0.29**	**0.0006**	**0.56**	**0.90**	**3.11**
SE (d)	**0.04**	**1.95**	**0.13**	**0.0029**	**0.26**	**0.41**	**1.43**

Note: T_1- control, T_2- natural farming production system, T_3- organic farming production system and T_4- conventional farming production system

Table 4: Effect of various production systems on post-harvested soil.

Treatments	Soil properties					Microbial population (CFU g^{-1})		
	WHC (%)	Organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorous (kg ha^{-1})	Available potassium (kg ha^{-1})	Bacteria × 10^6 CFUg^{-1}	Fungi ×10^4 CFU g^{-1}	Actinomycetes × 10^3 CFU g^{-1}
T_1	52.75	0.48	106.86	11.54	398.65	34	17	12
T_2	65.32	0.51	184.91	27.32	454.31	76	39	23
T_3	66.14	0.53	221.73	32.97	482.24	84	46	29
T_4	62.35	0.49	217.35	31.64	465.78	38	21	14
CD at 5%	**5.27**	**0.04**	**12.81**	**2.26**	**35.72**	**4.96**	**4.85**	**1.84**
SE (d)	**2.42**	**0.02**	**5.88**	**1.04**	**16.39**	**2.28**	**2.23**	**0.84**

Note: T_1- control, T_2- natural farming production system, T_3- organic farming production system and T_4- conventional farming production system

Correlation analysis

The study reveals several significant correlations among key agronomic traits (Fig. 2). Plant height (PH) demonstrates strong positive correlations with dry matter production ($r = 0.99$, $p < 0.01$), SPAD readings ($r = 0.96$, $p < 0.05$) and gross head weight ($r = 0.99$, $p < 0.01$). This suggests that taller plants are generally associated with higher dry matter production, elevated SPAD values, and heavier gross heads. Similarly, stalk length (SL) is highly correlated with DMP ($r = 1.00$, $p < 0.001$), indicating that longer stalks are linked to greater dry matter production. Dry matter production (DMP) is also closely related to both plant height ($r = 0.99$, $p < 0.05$) and stalk length ($r = 1.00$, $p < 0.001$), further emphasizing the interconnectedness of these traits. The SPAD readings, which reflect chlorophyll content, show strong positive correlations with both plant height ($r = 0.96$, $p < 0.05$) and DMP ($r = 0.98$, $p < 0.05$), suggesting that plants with higher SPAD values tend to be taller and produce more dry matter. The leaf area index positively correlated with crop growth rate ($r = 0.97$, $p<0.05$), indicating that a higher leaf area index is associated with increased growth rates. Similarly, CGR is positively correlated with LAI ($r = 0.97$, $p < 0.05$), reinforcing the idea that growth rate is influenced by leaf area. Relative growth rate also shows positive correlations with SPAD ($r = 0.93$) and plant height ($r = 0.87$), suggesting that higher relative growth rates are linked to greater SPAD values and taller plants.

The gross head weight is positively correlated with plant height ($r = 0.99$, $p < 0.01$) and SPAD ($r = 0.99$, $p < 0.05$), indicating that heavier grain heads are typically found on taller plants with higher SPAD values. Yield biomass also shows positive correlations with plant height ($r = 0.99$) and GHW ($r = 0.99$), suggesting that these factors influence yield biomass. The findings highlight the intricate relationships between these agronomic traits and their collective impact on crop performance.

Principal component analysis

The PCA analysis illustrates the relationships between the treatments and their contributions to cabbage growth and yield characteristics (Fig. 3). It was evident from the score plot and biplot of PCA analysis that among all the treatments applied, T_3, which is an organic farming production system, has the highest impact on the growth and yield parameters of cabbage. Biometric parameters such as dry matter production, LAI, SPAD, gross yield, plant height and Head diameter showed positive values in PCA analysis among the parameters studied, indicating a positive impact by the treatments; however, for head compactness, negative values were observed in PC1indicating negative impact of the treatments. The PCA analysis clearly shows treatment variation in the growth and yield of cabbage as influenced by different crop production systems. The results of PC1 alone were considered as it explains 91% variation and the other two principal components were negligible compared to PC1.

From the scree plot of the PCA analysis, there were three principal components, with PC1 describing 91.7% variation. PC2 explained 6.6% of the variance on top of PC1 and PC3 explained only 1.7%. Since PC1 explained more than 90% variance, we can conclude that T_4, with the highest value, is the most effective for cabbage growth and yield.

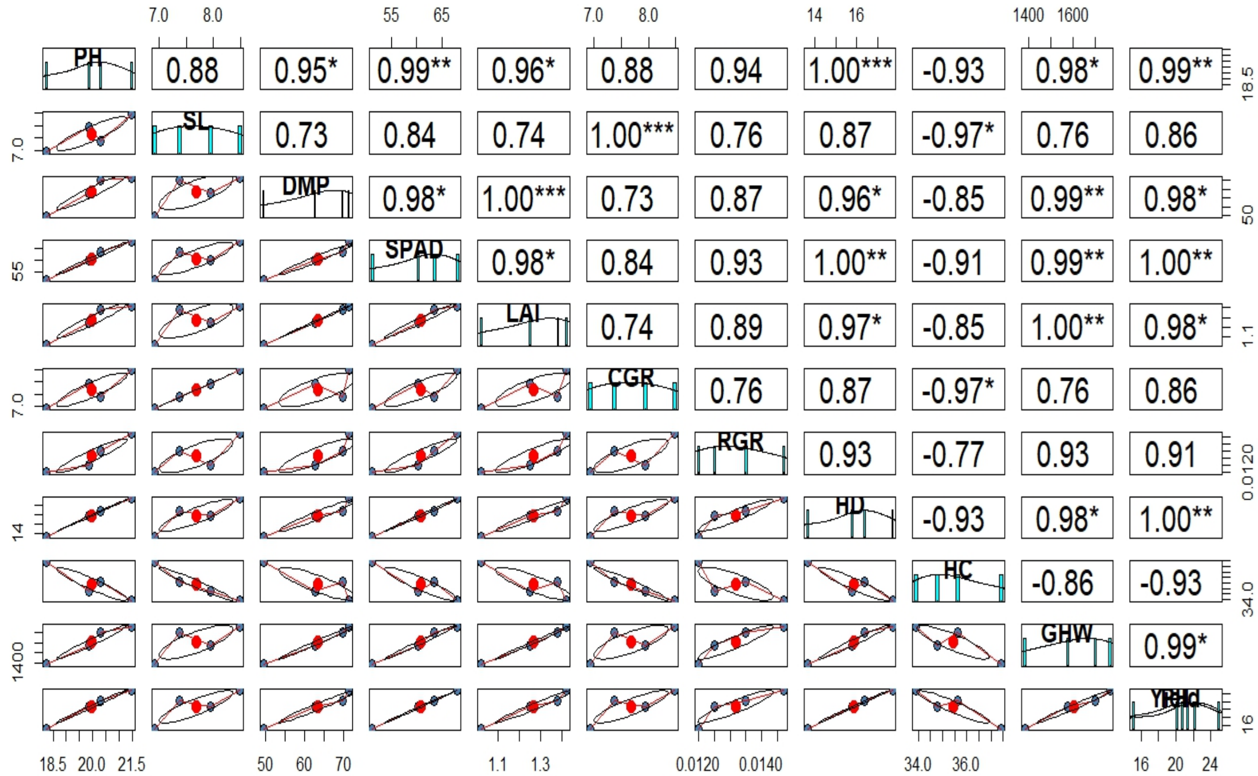
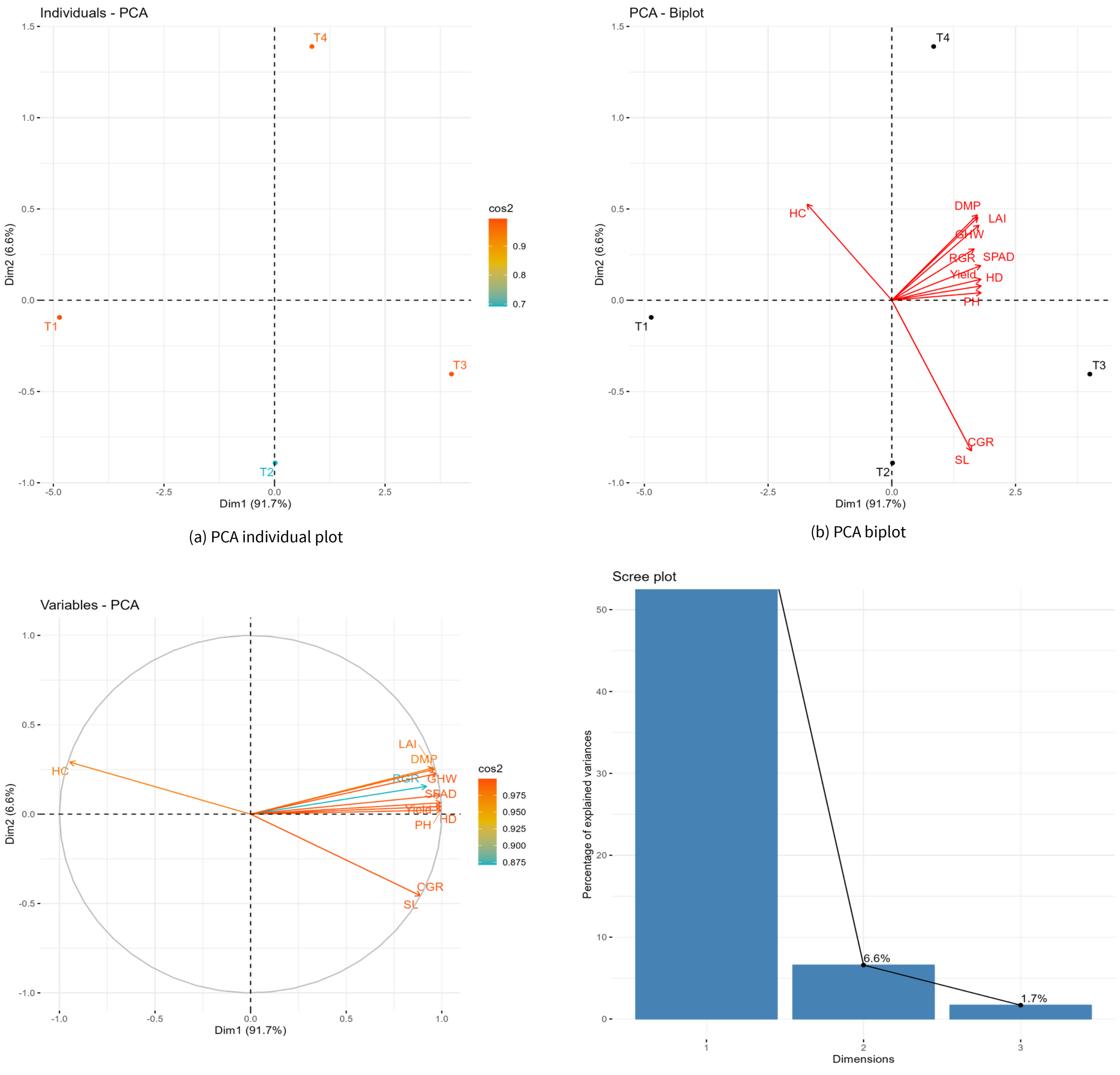


Figure 2. Correlation matrix of growth, physiological, head and yield parameters of cabbage

(Note: PH-plant height, SL-stalk length, DMP– dry matter production, SPAD- chlorophyll content, LAI- leaf area index, CGR-crop growth rate, RGR-relative growth rate, HD- head diameter, HC-head compactness, GHW- gross head weight, yield)



(a) PCA individual plot

(b) PCA biplot

(c) PCA variable plot

(d) Screen plot

Figure 3. Principle component analysis

Discussion

Plant growth and head parameters

The increase in plant height during the early stages of growth affected the uptake of readily available nutrients, especially nitrogen from NPK sources (16). Using organic inputs like FYM, vermicompost, Azospirillum, neem cake, and Panchagavya likely boosted chlorophyll production, which enhanced photosynthesis and promoted greater plant height. Additionally, the essential nutrients such as nitrogen, phosphorus, potassium and beneficial micronutrients found in these organic inputs may have further contributed to increased plant height by enhancing the synthesis of plant metabolites (17). The increased stalk length may be due to faster cell division, elongation and root growth, driven by growth-promoting substances like gibberellic acid and indole-3-acetic acid in organic nutrient sources. These phytohormones likely aided in synthesizing plant metabolites, supporting tissue development and expansion (18). Organic nutrient sources significantly impact dry matter production, likely due to increased nitrogen content, enhanced photosynthesis and improved carbohydrate assimilation (19). Organic amendments improve soil structure and texture, which enhances water and nutrient uptake by roots, leading to a more significant accumulation of photosynthates (20).

Organic nutrients like FYM, neem cake, *Azophos* and vermicompost provide essential macronutrients and beneficial micronutrients, along with growth hormones such as indole acetic acid and gibberellic acid, which are crucial for plant development (17,21). The compactness index is determined by dividing the net head weight by the cube of the mean head depth and diameter. Smaller heads, with lower net weight, depth and diameter, tend to have higher compactness values (21).

Physiological parameters

Applying diverse organic amendments enhances metabolic processes and photosynthetic efficiency, increasing leaf area development (22). Similar findings were reported by (23). Organic nutrient sources significantly boost chlorophyll content by enhancing metabolic activity and chlorophyll pigment biosynthesis (24). Enhanced nutrient uptake substantially contributes to higher CGR and RGR, as organic amendments stimulate biochemical processes, leading to accelerated cell division and expansion (25). These results align with the findings of (26).

Quality parameters

The total soluble solids (TSS) content, a crucial indicator of sweetness and flavour in cabbage, was highest in plots treated with the combination of organic farming practices. This increase in TSS can be attributed to the enhanced physiological processes driven by growth-promoting substances present in the organic amendments (27). The extended shelf life is likely due to reduced respiration and transpiration rates, which decrease moisture loss and delay head loosening, thereby maintaining the cabbage's freshness and prolonged shelf life (27,28). The boost in ascorbic acid is likely due to the enhanced physiological activity induced by the organic nutrients (29). All reports indicate that applying organic amendments significantly elevates ascorbic acid levels and improves the overall quality of the produce.

Yield parameters

The increased yield in cabbage is primarily due to improvements in growth and yield parameters, including net and gross Head weight, better head formation and maturity. Effective nutrient uptake, facilitated by organic inputs like farmyard manure, vermicompost, biofertilizers, neem cake and *Panchagavya*, was vital in maximizing Yield (21). These inputs enhanced photosynthesis and metabolic processes, resulting in higher carbohydrate production and biomass accumulation. These treatments combined the supply of essential nutrients and natural growth regulators, further supporting robust plant growth (30).

Status of the soil

The increased availability of nitrogen, phosphorus, and potassium (NPK) is due to the substantial use of farmyard manure (FYM), vermicompost, neem cake and *Panchagavya* spray. These organic inputs offer a sustained nutrient release, enhancing availability through direct application and soil solubilization. While plants use some nitrogen from FYM via microbial activity, the rest enriches the soil's nutrient reserve (29). Applying organic nutrient sources in the soil significantly increases the soil's available nutrients. This result was comparable with (19). Organic nutrient sources stimulated microbial proliferation through the accelerated decomposition of organic matter. *Panchagavya* exhibited a higher microbial population (29).

Conclusion

Vegetable farming is on the uptrend worldwide. Utilization of high doses of chemicals on the vegetables leads to residual effects and the quality of the produce will be reduced. As well as, the condition of the soil will replenished. Soil health is diminished, fertility status will decrease and the microbial population will be discriminated against due to chemical usage. This study concluded that the best production system for cultivating cabbage in the Coimbatore region is an organic farming system (T3) based on yield, quality and soil health. The judicious application of organic inputs can significantly enhance crop yield, quality and soil health. Excessive use of inorganic inputs could lead to nutrient imbalances and unintended consequences.

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Authors' contributions

ER carried out the studies and drafted the manuscript. SE participated in the conceptualization, design and methodology of the study, as well as supervision. KR, PE, JP, SM, PKP and PP conceived the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

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Declaration of generative AI and AI-assisted technologies in the writing process

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