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Effect of different organic manures and bio-fertilizers on growth & quality of red cabbage (*Brassica oleracea* L. var. *capitata* f. *rubra*)

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Abstract
Red cabbage (*Brassica oleracea* L. var. *capitata* f. *rubra*) is an exotic vegetable that is high in antioxidants, anthocyanin pigments, vitamins and medicinal properties. This study was conducted to assess the impact of bio-fertilizers and organic manures on the growth, quality and nutritional characteristics of red cabbage in Punjab's agro-climatic conditions. The experiment took place at the Experimental Research Farm, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib and used the hybrid cultivar "Ruby Ball F_1. The experiment was designed as a factorial randomised block design with sixteen treatment combinations that included bio-fertilizers (Azotobacter, phosphate solubilising bacteria, potash solubilising bacteria and control) and organic manures (farmyard manure, poultry manure, vermicompost and control). Each treatment was repeated three times. We kept track of growth parameters like plant height, spread, number of leaves, leaf area, leaf length and width, stalk length and diameter, phenological traits like days to head initiation and maturity, head characters and quality and biochemical attributes like total soluble solids, shelf life, titratable acidity, moisture content, dry matter, vitamin A, ascorbic acid, anthocyanin content and physiological loss in weight. The findings indicated that the applications of bio-fertilizer and organic manure had a substantial impact on all measured parameters. Azotobacter applied at 5.0 kg ha^{-1} consistently produced better growth, earlier head initiation and better quality and nutritional attributes than other bio-fertilizers. It led to higher total soluble solids, a longer shelf life, better moisture retention and more vitamin A, ascorbic acid and anthocyanins, while lowering titratable acidity, dry matter percentage and physiological weight loss. Vermicompost applied at 5 t ha^{-1} was the best of the organic manures. It made vegetative growth, head characteristics and biochemical quality much better. The combined use of Azotobacter and vermicompost turned out to be the best and most long-lasting way to manage nutrients for growing red cabbage. This method not only improved growth, quality and nutritional value, but it also provided an environmentally friendly and cost-effective alternative to relying solely on inorganic fertilisers, which helps make vegetable production systems more sustainable.

Keywords: Red cabbage, bio-fertilizers organic manures, vermicompost, azotobacter

Introduction
A beautiful and nutritious exotic vegetable is red cabbage (*Brassica oleracea* L. var. *capitata* f. *rubra*). It has 2x=2n=18 chromosomes and is Brassicaceae. *Rubra* is a cabbage subgroup (Manasa *et al*., 2017) [25]. This herbaceous plant has a short stem and a red-leafed crown. This vegetable is used in salads, curries, pickles and dehydration. Red cabbage has therapeutic benefits. The anticancer activity comes from indole-3-carbinol. It contains 0.35 percent proteins, 0.25 percent lipids, minerals such calcium (3.56 percent), phosphorus (19.90 percent), potassium, sulphur and vitamins A, B1, B2 and C. Recently, red cabbage, known for its health benefits and sensory qualities, has grown in popularity. Despite its low cultivation in India, farmers have been embracing it owing to its excellent nutritional value and rising tourism (Manivannan M I *et al*., 2004) [26]. Because red cabbage is eaten raw, it preserves vitamins sensitive to heat processing and certain polyphenolic components (Ismail *et al*., 2004) [19]. Anthocyanin pigment gives red cabbage its deep purplish-red colour and antioxidant and anticancer properties (Varul *et al*., 2000) [45]. It lowers blood cholesterol. Indian cabbage, including red cabbage, is grown on 400 thousand hectares and produces 8972 thousand MT (Anonymous, 2018) [2]. Andhra Pradesh produces 81.45 thousand tonnes of crops on 5.43 thousand acres.

Besides India, red cabbage is grown in Northern Europe, America and China (Manasa *et al*., 2017) [25].
Organic nutrients including vermicompost, farmyard manure and bio-fertilizer improve soil physic-chemical and biological characteristics and nutrient absorption (Lal and Kanaujia, 2013) [22]. Vermicompost includes plant-available nutrients such nitrates, exchangeable phosphorus, soluble potassium, calcium and magnesium. Water-soluble vermicompost components such humic acid, growth regulators, vitamins, minerals and beneficial microorganism boost plant nutrient availability, growth and yield (Chaterjee *et al*., 2010) [7]. P_2O_5, K_2O and N are in vermicompost (Rao *et al*., 2015) [32]. Growth regulators, vitamins and micronutrients in vermicompost improve plant nutrient availability, boosting growth, yield and quality (Atiyeh *et al*., 2002) [3]. Farmyard manure (FYM) provides macro and micronutrients to boost crop output. Inorganic fertilizer costs have risen, making FYM preparation and application easy for Indian farmers. Manure provides all crop nutrients, including trace elements. Manure utilization efficiency by a crop depends on its application technique, time to assimilate and soil microorganism decomposition rate (Herbert, 1998) [17]. Azotobacter, a free-living aerobic, fixes atmospheric nitrogen in the plant's root zone, whereas PSB dissolves insoluble soil phosphates (Devi *et al*., 2017) [23].

Materials and Methods

The experiment was carried out at Experimental Research Farm of Department of Agriculture, Mata Gujri College, Fatehgarh Sahib. Fatehgarh Sahib town is located on Ambala-Ludhiana national highway no. 1 and this is well connected through road linkage to other important town cities of Punjab as well Union Territories Chandigarh which is capital of Punjab. Fatehgarh Sahib is 50 km away from Chandigarh and 35 km from Patiala. The town lies between at 76°-22'E to 76°-46'E latitude and 30° - 36'N to 30° - 39'N longitude and at a mean height of 279 m above sea level. Red Cabbage (*Brassica oleracea* L. var. *capitata* f. *rubra)* cv. Ruby Ball F_1 hybrid of Takii seeds was used for study. The important characteristic of the variety are mature in 78-100 days in north India during winter season. It is outstanding variety producing compact, standard red heads with little core. It is mid-season cultivar. Ideal for closely spaced succession sowing in cabbage. The experiment was laid out in factorial randomized block design with three replications. The Total number of treatments is sixteen with three replications. The details of layout plan and treatments are presented in table 1 treatment's detail is given below:

Table 1: Different treatments combination

Treatment	Symbol	Treatment Combination (Bio-fertilizer and Organic manure)
T_1	B_0M_0	Control
T_2	B_0M_1	No Bio-fertilizer + FYM @ 20.0 t ha^{-1}
T_3	B_0M_2	No Bio-fertilizer + Poultry Manure @ 10 t ha^{-1}
T_4	B_0M_3	No Bio-fertilizer + Vermicompost @ 5 t ha^{-1}
T_5	B_1M_0	*Azotobacter* @ 5.0 kg ha^{-1} + No Manure
T_6	B_1M_1	*Azotobacter* @ 5.0 kg ha^{-1} + FYM @ 20.0 t ha^{-1}
T_7	B_1M_2	*Azotobacter* @ 5.0 kg ha^{-1} + Poultry Manure @ 10 t ha^{-1}
T_8	B_1M_3	*Azotobacter* @ 5.0 kg ha^{-1} + Vermicompost @ 5 t ha^{-1}
T_9	B_2M_0	PSB @ 5.0 kg ha^{-1} + No Manure
T_{10}	B_2M_1	PSB @ 5.0 kg ha^{-1} + FYM @ 20.0 t ha^{-1}
T_{11}	B_2M_2	PSB @ 5.0 kg ha^{-1} + Poultry Manure @ 10 t ha^{-1}
T_{12}	B_2M_3	PSB @ 5.0 kg ha^{-1} + Vermicompost @ 5 t ha^{-1}
T_{13}	B_3M_0	KSB @ 5.0 kg ha^{-1} + No Manure
T_{14}	B_3M_1	KSB @ 5.0 kg ha^{-1} + FYM @ 20.0 t ha^{-1}
T_{15}	B_3M_2	KSB @ 5.0 kg ha^{-1} + Poultry Manure @ 10 t ha^{-1}
T_{16}	B_3M_3	KSB @ 5.0 kg ha^{-1} + Vermicompost @ 5 t ha^{-1}

*PSB = Phoshphate solubilizing bacteria
*KSB = Potash solubilizing bacteria

Plant height (cm): The height of the five randomly selected plants was measured at the interval of 30, 45, 60 days. It was measured from ground to the tip of longest leaf with the help of scale and the average plant height was calculated. It is expressed in centimeters.

Plant spread (cm): Plant spread was measured as the maximum growth of the plant in either directions (North-South or East-West). It was measured in centimeters at 30, 45, 60 days after transplanting with the help of scale and the average was worked out.

Number of leaves plant^{-1} = In red cabbage, only well-developed leaves were counted from five randomly selected plants at the interval of 30, 45 and 60 days and added to get the average of total number of leaves. The number of leaves was divided with the number of plants to get the average number of leaves per plant.

Leaf area plant^{-1} (cm^2) = Leaf area plant^{-1} has been measured from the randomly selected five leaves from each five plants from each plot. Leaf area of each leaf measured with "Leaf Area Meter". Mean leaf area of five leaves of particular plant considered as leaf area of single leaf and then it multiply with the total number of leaves per plant to calculate the leaf area per plant.

Leaf length (cm) = Longest leaf of randomly selected plants were selected and length was measured at the interval of 30, 45 and 60 days. It measured from the base of the leaf petiole to the tip of the leaf lamina with the help of scale and average was worked out and expressed in centimeter.

Leaf width (cm) = Longest leaf of randomly selected plants were selected and width was measured at the interval of 30, 45 and 60 days. It was measured with the help of scale and average was worked out and expressed in centimeter.

Stalk length (cm) = Stalk length were measured from the five randomly selected plants. It was measured at the time of harvesting with the help of scale. It is measured from ground level to head base and the average value was worked out.

Stalk diameter (cm) = Stalk length were measured from the five randomly selected plants. It is measured in centimeters. It was measured at the time of harvesting with the help of scale and the average value was worked out.

Days taken to head initiation (days) = Number of days taken to head initiation was recorded from transplanting to when the plants in a plot showed emergence of head. The value was expressed in days.

Head height (cm) = The height was recorded from the five randomly selected head from each plot was measured with the help of scale and mean value was worked out. It was expressed in centimeters.

Head Polar diameter (cm) = Ultimate length of the head in vertical position wasmeasured in centimeter and average was calculated treatment wise.

Head Equatorial diameter (cm) = The diameter of the head in horizontal position position wasmeasured in centimeter and average was calculated treatment wise.

Days taken to head maturity (days) = The number of days on which head attained marketable maturity was recorded and days to marketable maturity of head were worked out from the date of transplanting.

Total soluble solids (^{0}Brix) = Five heads with appropriate maturity were randomly selected from each plot, crushed it and then the juice was extracted from the head. The drop of juice put on the hand refractometer of 0-32 ^{0}brix is used to determine the total soluble solids of red cabbage by using "Erma Hand Refractometer". The reading was recorded is expressed as degree Brix (^{0}Brix).

Shelf life (days) = It refer to the number of days, from the red cabbage head harvested till its quality will starting to deteriorate of randomly selected five heads from each plot. Shelf life should be considered in the number of days.

Titratable acidity (%) = Take 5-10 g sample. To this add a little amount of water and mix thoroughly then make dilutions. Now titrate the sample against 0.1 N NaOH using phenolphthalein as an indicator. Appearance of light pink colour denotes the end point. The value was expressed in percentage of titratable acidity in juice.

$$\text{Titratable acidity (\%)} = \frac{1 \times \text{Eq. wt. of acid} \times \text{Normality of NaOH} \times \text{titer} \times 100}{1. \quad \text{Wt. of sample}} \times 100$$

Moisture content (%) = A sample of 20 g chopped head from 5 selected plants was dried in a hot air oven at 65°C for 72 hours, until constant weight was achieved. Then the moisture content percentage in head was calculated by using the following formula-

$$\text{Moisture content \%} = \frac{\text{Fresh weight - Dry weight}}{\text{Fresh weight of chopped head}} \text{ X } 100$$

Head dry matter content (%) = A random sample of 20g of fresh weight head of red cabbage from each replication was taken and chopped it. Then dried freshly in the direct sun light for 2 days and then it was dried in an oven at 65°C for 72 hours, until constant weight was achieved. The dry weight recorded in grams and the mean value calculated. Then the dry matter percentage in head was calculated by using the following formula-

$$\text{Dry matter content (\%)} = \frac{\text{Dry weight of sample (g)}}{\text{Fresh weight of sample (g)}} \times 100$$

Vitamin A (mg 100 g^{-1}) = Crush the sample with the acetone and anhydrous sodium sulphate. Then filter the sample with the help of whatman filter paper. After that volume make up with petroleum ether. Then put the sample in spirit flask and shake well. Then upper layer made up of Vitamin A. After that note the reading on 452 wavelength by spectrophotometer.

Ascorbic acid (mg 100g^{-1}) = Vitamin C or ascorbic acid was extracted from the sample with 0.14 percent oxalic acid and determined by titrimetric method using 2, 6-dichloroindophenol dye solution (0.04%) which was standardized against standard L-ascorbic acid (0.1 mg ml^{-1}) of 0.4 percent oxalic acid solution and volume was made to 100 litre by it. It was filtered through whatman filter paper number 4.10ml of aliquot was titrated with standardized dye. The result was expressed as ascorbic acid 100 g of sample (Ranganna 1997).

$$\text{Vitamin C} = \frac{\text{Dye factor} \times \text{Titre reading} \times \text{Volume made}}{\text{Aliquot taken} \times \text{weight sample}} \times 100$$

Anthocyanin (mg 100 g^{-1}) = Crush the sample with the acetone and anhydrous sodium sulphate. Then filter the sample with the help of whatman filter paper. After that volume make up with petroleum ether. Then put the sample in spirit flask and shake well. Then Lower layer made up of Anthocyanin. After that note the reading on 452 wavelength by spectrophotometer.

Statistical Analysis = The statistical analysis was done as per design of the experiment as suggested by Panse and Sukhatme (1987). The interpretation of results is based on 'F' test. The critical difference (C.D) was worked out for significant treatments.

Results and Discussion

Plant height (cm)

When it comes to determining the production and harvesting stage of red cabbage, the plant height is the most crucial thing to consider. In the current experiments, it was found that the use of organic manures and bio-fertilizers led to a large rise in the amount. The highest plant height of 20.53 centimetres at 30 days after transplantation, 25.80 centimetres at 45 days after transplantation and 29.43 centimetres at 60 days after transplantation was achieved from B1 (Azotobacter at 5.0 kg ha 1). According to Sharma *et al.* (2002) [37], one of the possible explanations for the maximisation of plant height that occurs as a result of the application of Azotobacter could be due to the enhancement of biological nitrogen fixation, which ultimately results in an increase in plant height. The findings of Singh *et al.* (2015) [41], who discovered that inoculation of Azotobacter led to rapid growth in plant height in comparison to PSB, are comparable to their findings. When it comes to organic manures, the maximum plant height of 19.97 centimetres at 30 days after transplanting, 24.95 centimetres at 45 days after transplanting and 29.01 centimetres at 60 days after transplanting was obtained from M3 (Vermicompost at 5 tonnes per hectare). Vermicompost manure promotes a growth and development of plants due to the presence of humic acid as well as micro and macronutrients (Atiyeh *et al.*, 2002) [3]. This may be one of the possible reasons for the maximum plant height that can be achieved through the application of vermicompost. According to Chatterjee *et al.*'s (2005) [6] research, the application of vermicompost at a rate of 6 tonnes per hectare resulted in the greatest rise in the height of the cauliflower plants that were sprouting.

Plant spread (cm)

The spread of the plant is another significant characteristic that has a role in determining the yield of the crop. The greater the plant's spread, the greater the number of hypocotyl branches that will ultimately result in an increase in crop output. When Azotobacter was sprayed at a rate of 5.0 kg ha 1, the largest plant spread was attained in this experimental study. The plant spread was 29.70 cm at 30 DAT, 43.58 cm at 45 DAT and 60.97 cm at 60 DAT. Azotobacter is capable of producing plant hormones such as indole acetic acid, gibberellins, siderophores and cytokinins, as well as vitamins such as thiamine and riboflavin with their ability to manufacture these substances. Azotobacter is responsible for the exogenous release of these substances that promote plant growth, which ultimately results in an increase in the plant's productive capacity and growth. According to Pandey and Kumar (1989) [29], several strains of Azotobacter are also known to promote the uptake and utilisation of important nutrients by the plants that are directly connected with them. The highest plant spread of 29.22 centimetres at 30 days after transplanting, 43.25 centimetres at 45 days after transplanting and 60.01 centimetres at 60 days after transplanting was achieved by applying vermicompost at a rate of 5 tonnes per hectare. According to Chatterjee *et al.* (2005) [6], vermicompost has the ability to enhance the physical, chemical and biological aspects of soil since it releases nutrients into the soil, which eventually helps to stimulate the growth of crops. Both the experimental study conducted by Kumar *et al.* (2013) [21] on cauliflower and the one conducted by Mal *et al.* (2014) [23] on sprouting broccoli are consistent with this conclusion.

Number of leaves plant^{-1}

An increase in the number of leaves leads to an increase in the photosynthetic rate, which in turn leads to an accumulation of carbohydrates in the leaves. According to the findings of the current investigation, the highest number of leaves plant 1 was obtained from B1 (Azotobacter at a rate of 5.0 kg ha 1) at 30 DAT, 14.96 at 45 DAT and 17.35 at 60 DAT. There is a possibility that the reason for the largest plant spread with Azotobacter treatment is due to the accelerated biological nitrogen fixation, which ultimately demonstrates a good effect on the vegetative growth of plant spread (Singh *et al.*, 2015) [41]. The highest number of leaves, 12.59 at 30 days after transplanting, 14.86 at 45 days after transplanting and 17.23 at 60 days after transplanting, were obtained from M3 (Vermicompost at 5 tonnes per hectare). The timely delivery of nutrients, particularly nitrogen, phosphorus and potassium, which are essential for the vegetative growth of the plant, may be one of the possible causes for the maximum number of leaves that plant 1 has when vermicompost is applied. According to Rai *et al.* (2008) [9], the use of vermicompost as a source of organic manure may have contributed to the development of the geophysical characteristics of the soil, including its porosity, aeration and capacity to store water. In cabbage, Zango *et al.* (2009) [47] obtained findings that were comparable to those described above.

Leaf Area (cm^2)

In terms of the growth characteristics of the crops, the area of the leaves has a significant impact. In the current research, the highest leaf area of 297.37 cm2 was achieved by applying Azotobacter at a rate of 5.0 kg per hectare. It is possible that the increase in leaf area is related to the fixation of nitrogen that is not readily available to the plants and the production of organic molecules that are rich in energy in plants that have been inoculated with Azotobacter (Vassilev *et al.*, 2006) [46]. According to the findings of Kashyap *et al.* (2005) [20] in broccoli and Verma and Yadav (2011) in cauliflower, our findings are consistent with the findings of those studies. There is a possibility that the leaf area has increased as a consequence of an increase in the photosynthetic rate, which has led to an increased buildup of carbohydrates in the leaves. Vermicompost was applied at a rate of 5 tonnes per hectare, which resulted in the greatest leaf area of 295.18 square centimetres being obtained in the case of organic manures. The application of vermicompost, either on its own or in combination with other substances, has a greater impact on the vegetative growth of plant leaves. According to Zango *et al.* (2009) [47], these findings are consistent with their findings. They discovered that the vermicompost manure brought about an increase in the leaf area of the cabbage plant. In broccoli, Mollah *et al.* (2009) [27] reported findings that were comparable to those described above.

Leaf Length (cm)

The length of the leaves is a significant factor in determining the growth characteristics of the crop. As a result of the application of Azotobacter at a rate of 5.0 kg ha 1, the maximum leaf length was measured to be 28.44 cm at 30 DAT, 32.06 cm at 45 DAT and 33.95 cm at 60 DAT. These results were obtained in the current investigations. In his study from 1965, Paleg came to the conclusion that the mechanism of action of gibberellins in the apex of the responsive plant results in increased protein synthesis, cell division, auxin production and cell expansion. Taking all of these factors into consideration has resulted in an increase in a variety of growth characteristics of broccoli. The findings shown here are very similar to those presented by Davis *et al.* (2000) [10] and Rahman *et al.* (2015) [30]. When organic manures were treated at a rate of 5 tonnes per hectare, the maximum leaf length was 28.03 centimetres at 30 days after transplanting, 31.83 centimetres at 45 days after transplanting and 33.71 centimetres at 60 days after transplanting. According to Chaudhary *et al.* (2012) [8], the use of vermicompost may enhance the availability of water, micronutrients and key nutrients in the soil, which may be the explanation for the maximum leaf length that occurs as a result of the application of vermicompost.

Leaf width (cm)

The width of the leaves is a significant factor in determining the growth characteristics of the crop. As a result of the application of Azotobacter at a rate of 5.0 kg ha 1, the maximum leaf width was measured to be 20.28 cm at 30 DAT, 24.73 cm at 45 DAT and 27.61 cm at 60 DAT. These measurements were acquired in the current investigations. According to Sarkar *et al*. (2010) [34], the application of Azotobacter results in an increase in leaf width. This development is attributed to the manufacture of auxin, vitamins and growth chemicals within the plant. When organic manures were treated at a rate of 5 tonnes per hectare, the maximum leaf width was 20.14 centimetres at 30 days after transplanting, 24.30 centimetres at 45 days after transplanting and 27.32 centimetres at 60 days after transplanting. Vermicomposting has been shown to enhance the budget of key soil micronutrients and to promote the population of microorganisms, which ultimately leads to an increase in leaf width and output on a sustainable basis.

Stalk Length (cm)

It was determined that the maximum stalk length was achieved by applying Azotobacter at a rate of 5.0 kg ha 1, which is equivalent to 8.79 cm. According to Siddique *et al*. (2014) [39], the activity of microorganisms in the soil is responsible for the maximum stalk length of the red cabbage plant. These microorganisms fix nitrogen in the soil, which in turn increases the vegetative growth of the plant since it contributes to the plant's overall growth. These findings are consistent with the findings of Sharma *et al*. (2002) [37] and Singh and Singh (2005) [40], who discovered that the administration of Azotobacter resulted in an increase in the vegetative growth components. A maximum stalk length of 8.37 centimetres was achieved in organic manures with the application of vermicompost at a rate of 5 tonnes per hectare on average. The vermicompost raises the level of moisture and nutritional content in the soil, which in turn leads to a greater uptake of nutrients by the plants. This, in turn, causes the plants to grow more quickly, as evidenced by the increased stalk length in comparison to the control. According to Deshpande *et al*. (2007) [11], the reason for the maximum stalk length could be that the soil conditions were more favourable, which resulted in rapid growth during a relatively shorter period of time. Additionally, Sajib (2015) [33] and Devi *et al*. (2012) [12] also reported findings that were comparable in the case of cabbage.

Stalk diameter (cm)

When Azotobacter was sprayed at a rate of 5.0 kg ha 1, which is equivalent to 7.80 cm, the maximum stalk diameter was achieved. The largest possible diameter of the stalk of the red cabbage plant. A maximum stalk diameter of 7.46 centimetres was achieved in organic manures with the application of vermicompost at a rate of 5 tonnes per hectare on average.

Days taken to head initiation (Days)

Through the process of early head initiation in red cabbage, early formation occurs, which ultimately contributes to the timely maturation of the crop. When Azotobacter was treated at a rate of 5.0 kg ha 1 (which is equivalent to 50.03 days), the minimum number of days required for the commencement of the head was obtained. It is possible that the early initiation of the head is caused by the stimulating impact of Azotobacter, which fixes nitrogen into the soil and makes it easily accessible to plants, as well as growth hormones, which induce the early initiation of the head (Chaurasia *et al*., 2008) [9]. According to Singh and Ram (2005) [40], nutrients are essential components of nucleotides, proteins, chlorophyll and enzymes that are involved in a variety of metabolic processes. These processes have a direct influence on the vegetative and reproductive phases of the plant life cycle. In the case of organic manures, the shortest amount of time needed for head initiation was achieved by applying vermicompost at a rate of 5 tonnes per hectare, which is equivalent to 50.93 business days. There is a possibility that the early head start was caused by improved availability, solubility and utilisation of plant nutrients, which led to increased plant growth and head formation (Selvaraj 2003) [35]. It is possible that this is due to the prolonged retention of moisture, which causes the plants to take in a greater quantity of nutrients, which in turn causes the plants to grow more quickly in comparison to the control group, as stated by Grewal and Singh in 1994 [16]. There is a possibility that the reason could be beneficial soil moisture and favorable conditions, which resulted in rapid growth in a relatively shorter amount of time.

Total soluble solids (^{0}Brix)

The amount of total soluble solids found in the head of the red cabbage is one of the most important quality parameters. As a result of the current research, the highest total soluble solids (TSS) of 7.71 ^{0}Brix was achieved from B1 (Azotobacter at 5.0 kg ha 1). It was suggested by Thilakavathy and Ramaswamy in 1999 [43] that the improvement in total soluble solids (TSS) that occurred as a result of the application of bio-fertilizers rather than control might be ascribed to improved nutrient uptake and improved photosynthesis, in addition to biochemical and physiological activities. In addition to enhancing physiological and biochemical processes, azotobacter may have been responsible for the fixation of a greater quantity of nitrogen by plants. Both Bahadur *et al*. (2006) [4] and Shukla *et al*. (2006) [38] obtained results that were comparable when they studied cauliflower and tomato, respectively. M3 (Vermicompost at 5 tonnes per hectare) was found to have the highest total soluble solids (7.55 billion brix) in organic manure. The total soluble solids (TSS) content of vermicompost was found to be higher than that of poultry manure and no manure (Surindra, 2007) [42]. This is due to the fact that vermicompost contains beneficial elements of nutrients.

Shelf life (days)

One of the most important quality parameters of red cabbage is the length of time that the head can be stored. In the current research, the compound B1 (Azotobacter at a concentration of 5.0 kg ha 1) was found to have the longest shelf life (17.39 days). It is likely that the application of bio-fertilizers lowered the rate of respiration, which led to an increase in the food's storage life and a decrease in the amount of weight that was lost through physiological processes. In the case of cucumbers (Mali, 2004) [24], bitter gourds (Umlong, 2010) [44] and carrots (Umlong, 2010) [44], researchers have reported findings that are comparable to our own. Azotobacter may have fixed a greater quantity of nitrogen in the soil and made it available to plants, which led to improved nitrogen uptake by plants and enhanced biophysical and biochemical activities. This is still another possible explanation for the longer shelf life of the product. In the case of garden pea, Bahadur *et al*. (2006) [4] found results that were virtually identical. When it comes to organic manure, the maximum shelf life of 16.61 days was found to be in M3 (Vermicompost at 5 tonnes per hectare). Vermicompost has been shown to have a longer shelf life than poultry manure and no manure (Surindra, 2007) [42]. This is due to the fact that vermicompost contains a higher concentration of nutrients than poultry manure.

Titratable acidity (%)
Within the application of Azotobacter at a rate of 5.0 kg ha 1, the titratable acidity content was found to be at its lowest point, which was 0.23 percent. According to Esitken *et al*. (2010) [14], the drop in titratable acidity may be related to the conversion of organic acids and photosynthates into sugar during the ripening process of the fruit, which is facilitated by the application of bio-fertilizers. In a similar manner, the decrease in titratable acidity may also be attributed to the utilization of acids as a substrate for respiration during the ripening process and the neutralization of organic acids due to the presence of potassium in tissues. Acharya *et al*. (2017) [1] verified a similar conclusion. In the case of organic manure, the lowest titratable acidity of 0.24 percent was calculated for M3 (Vermicompost at a rate of 5 tonnes per hectare).

Moisture content (%)
It was noted that the treatment of Azotobacter at a rate of 5.0 kg ha 1 resulted in the highest moisture content (90.41%) in red cabbage. Among the organic manure samples, the M3 (Vermicompost at 5 tonnes per hectare) sample had the highest moisture content, which was measured at 89.63 percent.

Dry matter (%)
It was determined that B1 (Azotobacter at 5.0 kg ha 1) was responsible for the lowest amount of dry matter (9.67%) in red cabbage. As a result of the lower nitrogen supply that occurs under organic management, plants have a tendency to increase the synthesis of nitrogen-poor molecules (polyphenols, cellulose and starch) rather than the synthesis of nitrogen-rich compounds like amino acids, proteins or alkaloids, which leads to an increase in the dry matter content of the product. This can be explained by the fact that the low nitrogen supply causes plants to produce more of these molecules. When it comes to organic manure, the M3 (Vermicompost at 5 tonnes per hectare) was found to have the lowest dry matter content (9.82 percent). Vermicompost was an excellent source of nitrogen for both crop plants and animals. Nitrogen, which is a component of amino acids, nucleotides, nucleic acids, co-enzymes, auxins, cytokinins and alkaloids, has the ability to drive cell elongation, cell enlargement and cell division, which resulted in a larger dry matter content in the head of sprouting broccoli (Bhardwaj *et al*., 2007) [5]. When sprouting broccoli under vermicompost, Sharma (2002) [37] obtained results that were comparable to those described above.

Vitamin A (mg 100 g^{-1})
Vitamin A is a significant component when it comes to taking into consideration nutritional aspects. The highest amount of vitamin A, 267.68 milligrammes per one hundred grammes, was found in B1 (Azotobacter at a rate of 5.0 kilogrammes per hectare). In organic manure, the highest vitamin A concentration (265.39 mg 100 g 1) was found in M3 (Vermicompost at 5 t ha 1), which was the most abundant source of vitamin A. According to Firoz *et al*. (2009) [15], the ability of vermicompost to produce phytohormones, such as gibberellins, cytokines-like compounds and auxin, results from tryptophan, ethylene and vitamins. Additionally, this ability is largely attributed to nitrogen fixation and phosphate solubilisation.

Ascorbic acid (mg 100 g^{-1})
Vitamin C is a significant component when it comes to taking into consideration nutritional aspects. A total of 52.44 milligrammes per one hundred grammes of ascorbic acid was collected from B1 (Azotobacter at a rate of 5.0 kilogrammes per hectare). This is because Azotobacter has a beneficial influence on the enzyme reaction and the creation of metabolites for the synthesis of carbohydrates and proteins, which ultimately results in an increase in the amount of ascorbic acid that is present. M3 (Vermicompost at a rate of 5 tonnes per hectare) was the organic manure that had the highest ascorbic acid content, which was 50.40 milligrammes per one hundred grammes. According to Firoz *et al*. (2009) [15], the ability of vermicompost to produce phytohormones, such as gibberellins, cytokines-like compounds and auxin, results from tryptophan, ethylene and vitamins. Additionally, this ability is largely attributed to nitrogen fixation and phosphate solubilisation.

Table 2: Effect of different organic manures and biofertilizers on growth parameters of red cabbage

Treatment	TSS (^{0}brix)	Shelf life (days)	Titratable acidity (%)	Moisture content (%)	Dry matter (%)	Vitamin A (mg 100 g^{-1})	Ascorbic acid (mg 100 g^{-1})	Anthocyanin content (mg 100 g^{-1})	Physiological loss in weight (g)
Biofertilizers (B)									
B_0	6.42	12.46	0.32	81.68	11.88	235.20	41.47	22.68	14.16
B_1	7.71	17.39	0.23	90.41	9.67	267.68	52.44	32.04	11.25
B_2	7.62	16.93	0.24	89.81	9.78	266.36	51.42	31.15	11.40
B_3	7.28	16.10	0.27	88.00	10.11	259.24	47.78	28.58	12.67
SE(m)±	0.15	0.35	0.01	1.15	0.24	3.90	0.93	0.77	0.25
$CD_{0.05}$	0.31	0.72	0.01	2.35	0.49	7.97	1.90	1.57	0.52
Organic Manures (M)									
M_0	6.82	14.05	0.30	84.74	10.91	246.84	44.36	25.01	13.48
M_1	7.22	15.88	0.27	86.35	10.68	254.63	48.49	28.74	12.41
M_2	7.44	16.33	0.25	89.18	10.03	261.61	49.84	29.95	11.89

M_3	7.55	16.61	0.24	89.63	9.82	265.39	50.40	30.74	11.70
SE(m)±	0.15	0.35	0.01	1.15	0.24	3.90	0.93	0.77	0.25
$CD_{0.05}$	0.31	0.72	0.01	2.35	0.49	7.97	1.90	1.57	0.52
Interaction (BxM)									
B_0M_0	6.18	12.36	0.34	75.98	13.02	211.77	41.23	22.30	14.35
B_0M_1	6.23	12.38	0.33	77.05	12.95	225.43	41.33	22.67	14.30
B_0M_2	6.55	12.43	0.32	86.70	10.86	248.58	41.53	22.76	14.12
B_0M_3	6.71	12.65	0.31	86.98	10.68	255.00	41.77	23.00	13.87
B_1M_0	7.20	15.57	0.28	88.23	10.17	260.00	46.82	27.22	12.98
B_1M_1	7.70	17.36	0.23	90.33	9.67	267.00	52.83	32.03	11.24
B_1M_2	7.93	18.12	0.21	91.31	9.59	269.33	54.89	34.29	10.42
B_1M_3	8.00	18.50	0.19	91.77	9.23	274.40	55.20	34.60	10.37
B_2M_0	7.02	14.48	0.29	87.72	10.22	259.87	44.79	25.52	13.06
B_2M_1	7.64	17.10	0.24	89.78	9.97	266.00	51.59	31.66	11.60
B_2M_2	7.86	17.84	0.22	90.38	9.62	268.40	54.30	33.03	10.54
B_2M_3	7.97	18.29	0.20	91.38	9.29	271.17	54.99	34.39	10.39
B_3M_0	6.86	13.78	0.30	87.01	10.23	255.71	44.60	25.00	13.53
B_3M_1	7.33	16.68	0.27	88.24	10.12	260.10	48.22	28.62	12.52
B_3M_2	7.43	16.91	0.26	88.33	10.04	260.14	48.65	29.72	12.48
B_3M_3	7.50	17.01	0.25	88.40	10.06	261.00	49.63	30.96	12.16
SE(m)±	0.30	0.70	0.01	2.30	0.47	7.80	1.86	1.54	0.50
$CD_{0.05}$	0.62	1.44	0.02	4.70	0.97	15.93	3.80	3.14	1.03

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

After reviewing the results, it was discovered that the individual influence of bio-fertilizer on anthocyanin content shows that the highest value is (32.04 mg 100 g 1) in B1 (Azotobacter at 5.0 kg ha 1). In M3 (Vermicompost at a rate of 5 tonnes per hectare), the individual effect of organic manure on anthocyanin content reveals that the highest value is 30.74 milligrammes per one hundred grammes. Based on the findings of Tyagi *et al*. (2003), the utilisation of vermicompost, which contains a substantial quantity of humic, has the potential to induce the production of phenolic compounds, including flavonoids and anthocyanins.

Physiological loss in weight (g)

The data showed that treatment B1 (Azotobacter at 5.0 kg ha 1) had the lowest physiological loss in weight (11.25 g) among the bio-fertilizers. This was the case in the individual effect of bio-fertilizers. The use of bio-fertilizers most likely resulted in a decrease in the rate of respiration, which in turn led to an increase in storage life and a decrease in PLW. The results that were reported in cucumber (Mali, 2004) [24] and carrot (Umlong, 2010) [44] are comparable to the findings that we obtained. When considering the individual effects of organic manures, the treatment M3 (Vermicompost at a rate of 5 tonnes per hectare) was shown to have the least amount of physiological weight loss (11.70 grammes).

Conclusion

The current study unequivocally established that the combined application of bio-fertilizers and organic manures substantially affected the growth, yield characteristics, quality and nutritional profile of red cabbage. Azotobacter applied at 5.0 kg ha^{-1} was the best of the bio-fertilizer treatments. It consistently produced the tallest plants, the widest plants, the most leaves, the largest leaves, the longest and widest stalks and the earliest head initiation and maturity. This treatment also improved quality measures like total soluble solids, shelf life, moisture content, vitamin A, ascorbic acid and anthocyanin content. It also lowered titratable acidity, dry matter percentage and physiological weight loss. Also, vermicompost applied at 5 t ha^{-1} had the most noticeable positive effects on vegetative growth, head characteristics and biochemical quality attributes among organic manures. The improvements seen can be linked to vermicompost's ability to make nutrients more available, boost microbial activity, improve the physical and chemical properties of the soil and contain substances that help plants grow. The best way to manage nutrients for red cabbage was to use both Azotobacter and vermicompost together. This made the plants grow better, taste better, have more nutrients and last longer. This combined method is a long-term, environmentally friendly and cost-effective way to grow red cabbage instead of only using inorganic fertilizers.

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