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Yield components and quality as affected by organic fertilization and molybdenum in broccoli *B. oleracea* var. *italica*

Saif S G M Alramahy and Zainab H Thajeel
Department of Horticulture and Landscape, Faculty of Agriculture, University of Kufa, Najaf, Iraq
E-mail: saifs.alramahy@student.uokufa.edu.iq
E-mail: zainab.alkhuzaie@uokufa.edu.iq

Abstract

Broccoli is one of the most important healthy foods included in healthy eating and weight loss programs. Good broccoli yield for fresh consumption is not only related to the shape or weight of the head but also to its high content of essential nutrients. Therefore, the current study aimed to evaluate the effect of organic fertilization and molybdenum spraying on broccoli yield and its nutrient content. The study was conducted as a two-factor factory experiment using a randomized complete block design (RCBD), comprising 27 experimental units randomly distributed with three replicates. The first factor was organic fertilizer at levels of 0, 1.200, and 1.800 kg/m³, and the second factor was three concentrations of molybdenum (0, 100, and 200 mg/L). The results showed that treatment with organic fertilizer at a level of (1800 kg/m^{3-1}) or spraying molybdenum at a concentration of 200 mg/L^{-1} significantly outperformed the other individual treatments in the studied indicators. Specifically, the treatments showed a significant increase compared to the control group in plant height (20-25%), number of leaves (13-25%), leaf area (18-43%), total chlorophyll content (2-9%), stem diameter (16^{-1}7%), leaf dry weight (30-31%), and flower head weight (33-50%) compared to the control group, which received the recommended organic fertilization. Overall, the best results were achieved with the combined treatment of spraying molybdenum at 200 mg/L^{-1} in the presence of 1800 kg of organic fertilizer. M3 achieved an increase in the study indicators by 30% for plant height, 43% for the number of leaves, 46% for leaf area, 22% for total leaf chlorophyll content, 23% for stem diameter, 48% for vegetative dry weight, and 56% for flower disc weight compared to the control.

Keywords: *Brassicaceae, soil amendment, micronutrients, poultry manure*

1. Introduction

Broccoli (*Brassica oleracea* var. *italica*) is one of the most important crops of the Brassicaceae family. Its original habitat is in the Mediterranean region, especially Italy, from where it spread to most parts of the world (Li et al., 2024). In addition to its importance in fresh consumption and weight loss programs, broccoli contains bioactive compounds, particularly glucosinolates, sulforaphane, and indole-3-carbinol, which have significant health benefits, including antioxidant, anti-inflammatory, and anti-cancer properties (Syed, 2023). Globally, broccoli was cultivated on approximately 1.4 million hectares in 2024, with an average yield of 19 tons/hectare. China and India led the way with 498,862 hectares and 491,000 hectares, respectively, while the cultivated area in the United States reached about 62,605 hectares, and in Iraq only about 804 hectares, reflecting the significant disparity between producing countries (TheWorldRanking, 2024). Organic fertilizers are often rich in macro and micronutrients, with high levels of nitrogen, phosphorus, and potassium, which are essential for plant growth. They also improve the physical and chemical properties of the soil by increasing organic matter content and

activating beneficial microorganisms. This contributes to improved uptake of micronutrients, including molybdenum. Molybdenum plays a direct role in the conversion of nitrates to ammonia by the enzyme nitrate reductase; therefore, an abundance of organic nitrogen from poultry manure enhances molybdenum's activity and increases its nutrient availability to the plant (Mehera, 2022). Foliar feeding is a highly efficient method for supplying broccoli with essential nutrients during its various growth stages, as it improves absorption efficiency and increases nutrient accumulation within the leaves, positively impacting vegetative growth and inflorescence formation. It has been observed that foliar spraying with micronutrients such as molybdenum and boron enhances photosynthesis and increases the efficiency of enzymes involved in this process, thereby improving the qualitative and quantitative yield of broccoli (Sharma et al., 2023). Foliar feeding also contributes to improving head (curd) quality by increasing the head's content of bioactive compounds, vitamins, and sulfur compounds, which are among the most important healthy components of broccoli (Sardar et al., 2022). Molybdenum is one of the factors that may affect the reduction of nitrate accumulation in leafy vegetable crops, as it is involved in plant metabolism. It is the main component of the nitrate reductase enzyme, which converts nitrates into amino acids (Dikareva et al., 2024). Studies confirm that treating plants with molybdenum leads to increased production of this enzyme, enabling the conversion of nitrates into different forms of nitrogen. This prevents nitrate accumulation in lettuce leaves and reduces the harmful effects of these compounds (Shachai et al., 2025). This study, therefore, aimed to evaluate the effect of soil application with organic fertilization (poultry manure compost) and foliar spray with molybdenum on yield components and some qualitative characteristics in broccoli crop.

2. Materials and Methods

Experiment general procedure

The The experiment was conducted in the central agriculture research station at University of Kufa, during the 2025-2025 growing season, to evaluate the effect of soil application with organic fertilization (poultry manure compost) and foliar spray with molybdenum on plant growth and yield components of field grown broccoli plant. The field soil was free of weeds, plowed twice perpendicularly, smoothed and leveled uniformly, and soil sample were subjected to some physical and chemical analysis (Table 1). The land was then divided into three replicates, each containing nine experimental units, for a total of 27 experimental units of 3 meters long and 1 meter wide each as 1 m was left between experimental units, each containing 12 plants of 324 plants in total.

Broccoli seeds were sown in peat moss bed in Styrofoam trays for 35 days, then the seedlings were transplanted to the experimental site at the four-true-leaf stage. Five seedlings were planted per experimental unit at a spacing of 35 cm and drip irrigation was applied. Weeding and hoeing were carried out continuously and crop management continued until full maturity and harvesting. One week post transplanting the treatments were performed using two agents: poultry manure compost at three fertilization levels 0, 1.200 and 1.800 Kg m^3 applied as soil amendment one day before transplanting, three days after, molybdenum at concentrations of 0, 100 and 200 ml L^{-1} applied as foliar spray.

Indicators under study

At the end of the experiment, data were collected for three plants from each experimental unit for yield indicators, including head diameter (cm), head weight (g $plant^{-1}$), Total yield (ton h^{-1}).

$$\boldsymbol{Tot.yield\ (Kg/h)} = \frac{\boldsymbol{yield\ of\ the\ exp.unit\ Kg\ x\ 10000\ sq\ m}}{\boldsymbol{The\ exp.unit\ area\ (sq\ m)}}$$

The studied parameters also included yield content of some bioactive compounds which were: Glutathione (mg Kg^{-1}), Sulforaphane (mg Kg^{-1}) and Glucosinolate (mg Kg^{-1}).

Glutathione was determined in 3 g of the pink disc (mg/kg) using an amino acid analyzer, following the method described by Dahl Lassen et al. (2018).

Sulforaphane was determined in 10 g of the pink disc (mg/kg) using a dichloromethane (CH_2 Cl_2) water bath, followed by HPLC (Celik et al., 2014). The ferric-cyanide reduction method was used to determine glucosinolate (µg/g dry weight) in the pink disc, as described by Jezek et al. (1999). The determination was performed using optical absorption spectroscopy at a wavelength of 420 nm.

Experiment design and data analysis

The experimental treatments were distributed in a two-factorial experiment (Humic acid and SWE) applied using a completely randomized block design (CRBD) with three replications. The data were analyzed using GenStat 12th VSN international (Payne, 2009) software where the ANOVA tables were performed, and the means were compared according to Duncan's multiple range tests at probability level of 0.05 (Hoshmand, 2018).

3. Results and discussion

The results in Table (3) show that the organic fertilization at 1.800 kg/m³ significantly increased crop head diameter to 28.92 cm, compared to the control treatment which yielded only 19.53 cm. Similar results were observed with the application of molybdenum at the higher concentration of 200 mg/L, which led to an increase in head diameter to 25.22 cm, but did not differ from its control. Overall, the largest broccoli heads were recorded in the treatment combining poultry compost at 1.800 kg/m³ and molybdenum application at 200 mg/L, with the highest average recorded among all treatments being 30.25 cm.

Table3. Effect of organic fertilizer and molybdenum on head diameter in field grown broccoli *Brassica oleracea* var. *italica*

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	17.58	19.75	21.25	19.53
1.200	21.92	23.08	24.17	23.06
1.800	27.75	28.75	30.25	28.92
Average	22.42	23.86	25.22	
LSD ($P \leq 0.05$)	Organic fertilizer		Molybdenum	Interaction
	0.540		0.540	0.935

In case treatment effect on head weight, the highest mean value of 827.6 g. $palnt^{-1}$ was recorded due to 1.800 kg/m³ organic fertilizer while molybdenum at 200 mg L^{-1} recorded 731 g. $palnt^{-1}$ which significantly differed from the lower concentration 200 mg L^{-1} and the control treatments which resulted in 658.9 and 589.2 g. $palnt^{-1}$ respectively (Table 4). Generally, the highest head weight was 918.2 g. $palnt^{-1}$ resulted from the interaction treatment of 1.800 kg m³ organic fertilizer and molybdenum at 200 mg L^{-1} recording significant difference from all the treatments.

Table 4. Effect of organic fertilizer and molybdenum on head weight g. $plant^{-1}$ in broccoli *Brassica oleracea* var. *italica* grown under ambient conditions

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	386.4	488.9	576.2	483.8
1.200	629.3	675.3	698.6	667.7
1.800	751.9	812.6	918.2	827.6
Average	589.2	658.9	731.0	
LSD ($P \leq 0.05$)	Organic fertilizer		Molybdenum	Interaction
	40.94		40.94	70.92

The organic fertilizer and molybdenum regardless the application level, significantly affected the total yield (Table 5). The organic fertilizer 1.800 Kg m3 resulted in higher total yield of 33102 Kg h^{-1}, significantly differed from the untreated control (19354 Kg h^{-1}). Similarly, molybdenum treatment, particularly at 200 mg L^{-1}, showed a high increase in total yield, reaching 29239 Kg h^{-1}, that significantly differed from the lower concentration and the untreated control. The interaction of the 1.800 Kg m3 poultry manure compost and 200 mg L^{-1} molybdenum exhibited the highest average of total yield of 36727 Kg h^{-1} which significantly higher than all the other treatments.

Table5. Effect of organic fertilizer and molybdenum on total yield (Kg h^{-1}) in broccoli *Brassica oleracea* var. *italica* grown under field conditions

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	15458	19557	23047	19354
1.200	25172	27011	27942	26709
1.800	30078	32502	36727	33102
Average	23569	26357	29239	

LSD ($P \leq 0.05$)	Organic fertilizer	Molybdenum	Interaction
	1637.7	1637.7	2836.6

It was also observed that head content of Glutathione (mg Kg^{-1}) increased in the 1.800 kg/m³ organic fertilizer to 13.889 mg Kg^{-1}, with a significant difference from the control treatment, which did not exceed 11.264 mg Kg^{-1} (Table 6). Similarly, spraying molybdenum at a concentration of 200 mg/L significantly increased head Glutathione to 12.950 mg Kg^{-1}, compared to the control plants and the lower concentration. The table shows that the interaction between organic fertilization (1.800 kg/m³) and spraying molybdenum at a concentration of 200 mg/L resulted in a significantly higher average of Glutathione content of 14.306 mg Kg^{-1}, showing significant difference ($P \leq 0.05$) from all individual and interaction treatments.

Table 6. Effect of organic fertilizer and molybdenum on head content of Glutathione (mg Kg^{-1}) in field grown broccoli *Brassica oleracea* var. *italica*

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	10.732	11.262	11.798	11.264
1.200	12.205	12.432	12.748	12.462
1.800	13.522	13.839	14.306	13.889
Average	12.153	12.511	12.950	
LSD ($P \leq 0.05$)	Organic fertilizer		Molybdenum	Interaction
	0.5109		0.5109	0.8849

Similarly, results in table (7) indicate a significant effect of the organic compost in the head content of Sulforaphane (mg Kg^{-1}). The 1.800 kg/m³ organic fertilizer resulted in a Sulforaphane of 82.74 mg Kg^{-1} that significantly higher from the lower concentration and the control (57.77 mg Kg^{-1}). Foliar molybdenum at 200 mg L^{-1} significantly increased Sulforaphane to 75.48 mg Kg^{-1}, compared to the control (65.80 mg Kg^{-1}). The highest Sulforaphane (88.44 mg Kg^{-1}) was in the interaction treatment of both factor at the highest application levels.

Table 7. Effect of organic fertilizer and molybdenum on head content of Sulforaphane (mg Kg^{-1}) in field grown broccoli *Brassica oleracea* var. *italica*

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	50.04	57.33	63.95	57.77
1.200	67.62	71.44	74.06	71.04
1.800	77.75	82.04	88.44	82.74
Average	65.80	70.27	75.48	
LSD ($P \leq 0.05$)	Organic fertilizer		Molybdenum	Interaction
	2.927		2.927	5.069

The findings indicated that both studied factors, the organic fertilizer and molybdenum, significantly affected the head content of Glucosinolates mg Kg^{-1} (Table 8). The higher values were always recorded at higher levels and concentrations as the 1.800 kg/m³ organic fertilizer and molybdenum at 200 mg L^{-1} resulted in a head content of Glucosinolates of 81.76 mg Kg^{-1} and 74.67 mg Kg^{-1}, respectively with significant difference from the untreated control. The interaction of the both factors especially at levels formerly mentioned resulted in the highest Glucosinolates value of 87.44 mg Kg^{-1} which was significantly higher than all the other treatments.

Table 8. Effect of organic fertilizer and molybdenum on head content of Glucosinolates (mg Kg^{-1}) in field grown broccoli *Brassica oleracea* var. *italica*

Organic fertilizer Kg m^3	Molybdenum ml L^{-1}			Average
	0	100	200	
0	51.89	57.29	62.44	57.21
1.200	67.14	68.96	74.44	70.08
1.800	77.18	80.66	87.44	81.76
Average	65.40	68.97	74.67	
LSD ($P \leq 0.05$)	Organic fertilizer		Molybdenum	Interaction
	2.812		2.812	4.871

The results show that the organic fertilizer has improved head diameter, head weight and total yield. This is likely due to the fertilizer's content of essential nutrients that effectively support vital plant processes, including carbon metabolism, respiration, and protoplasm formation (Mehera, 2022). The increase in the head diameter in broccoli when treated with organic fertilizer indicates an improvement in the nutritional status of the flower discs as a result of providing essential nutrients within the soil. This contributed to increasing plant hormones, particularly the auxin content (IAA) in the leaves. Upon translocation to the flower discs, IAA enhanced cell division, elongation, and proliferation, and inhibited protein degradation, resulting in a significant increase in disc diameter (Devi et al., 2023). The overall increase in disc weight is attributed to the role of organic

fertilizers, which improve the physical and chemical properties of the soil and raise soil temperature. Furthermore, organic fertilizers contain readily available nutrients for the plant, especially nitrogen, phosphorus, and potassium (N, P, K). This, in turn, contributes to improved vegetative growth and increased nutrient synthesis in the leaves, which is subsequently translocated to the crop head discs, causing a significant increase in head weight (Jha et al., 2025). In addition, organic fertilizers activate beneficial soil microorganisms, which play a crucial role in nutrient mineralization and the production of growth regulators (Sharma et al., 2023). Naturally, this promotes cell division and leads to an increase in the weight of the flower head and the total broccoli yield (Yoldas et al., 2020). Organic fertilizers can always nourish the plants and support their biological activity of microorganisms that break down complex organic compounds into simpler compounds absorbable by plant roots, leading to the gradual release of nutrients in accordance with the plant's needs (Zhang et al., 2023). Moreover, organic fertilizer may also provide the plant with molybdenum (Mo), a cofactor for several key enzymes, particularly those involved in carbon and nitrogen metabolism (Rana et al., 2020). Molybdenum has been observed to enhance the activity of nitrate reductase, thus accelerating the reduction of nitrates and their conversion into nitrogenous compounds used in the formation of amino acids and proteins. This, in turn, increases vegetative growth and yield components (Sun et al., 2024; Oliveira et al., 2022).

The interaction between organic fertilizers and molybdenum shows that combining soil improvement and micronutrient provision enhances vegetative characteristics more effectively than using either alone (Demir et al., 2023). Molybdenum is one of the factors that may influence the reduction of nitrate accumulation in leafy vegetable crops, as it is the main component of the nitrate reductase enzyme, which converts nitrates into amino acids (Dikareva et al., 2024). Treating plants with molybdenum leads to increased production of this enzyme, thus preventing nitrate accumulation in lettuce leaves and reducing the harmful effects of these compounds (Shachai et al., 2025). Molybdenum also enhances the efficiency of nutrient uptake, especially nitrogen and phosphorus, which stimulates cell division and proliferation in leaves and stems, and supports increased stem thickness and leaf size and area. Recent studies on broccoli and cauliflower have confirmed that spraying with molybdenum significantly improves vegetative growth compared to control treatments, with a significant effect on all studied vegetative traits (Hassan et al., 2023; Zhang et al., 2024).

Foliar molybdenum with balanced fertilization can improv the physiological characteristics and bioactive compound content of broccoli. As one study examined the effect of molybdenum spraying on broccoli's secondary compound content, showing a significant increase in the content of bioactive compounds such as vitamin C and carbohydrates, thus improving the plant's nutritional and health value (Sardar et al., 2022).

Glutathione is an antioxidant compound that protects cells from damage caused by free radicals and supports sulfur storage and nitrogen fixation. Studies have shown that organic fertilizers enhance glutathione content by improving plant metabolism, while molybdenum spraying activates nitrogen-binding enzymes, increasing glutathione accumulation in the flower heads (Jasim, 2014).

Sulforaphane is a plant compound derived from glucosinolates that exhibits antioxidant and anticancer properties. Its accumulation in the flower heads depends on the glucosinolate content and the enzymes that break it down. It was also shown that integrated treatment (organic fertilizers + spraying with micronutrients such as molybdenum) increases the activity of these enzymes, thus raising the sulforaphane concentration (Bourak et al., 2023).

The results showed that the treatment of adding organic fertilizers with molybdenum spraying led to an increase in the sulforaphane content in broccoli heads compared to other treatments. Organic fertilizers improve soil fertility and increase microbial activity and the gradual release of nutrients, providing a balanced nutrient

environment that supports the formation of secondary compounds, especially in the presence of molybdenum, which contributes to the activation of vital enzymes associated with nitrogen and sulfur metabolism, thus enhancing the pathway for the formation of sulfur glucosinolates and their conversion to active isothiocyanates such as sulforaphane (Abd El-All et al., 2014). The use of organic fertilizers was found to increase glucosinolate content by improving plant metabolism and balanced growth, while foliar spraying with molybdenum enhances the activity of sulfur and nitrogen synthesis enzymes, leading to increased glucosinolate accumulation in the flower heads (Sharma et al., 2023).

4. Conclusion

In conclusion, the study found that both organic fertilization and foliar spraying with molybdenum play an important role in improving growth, yield components, and the quality characteristics of broccoli (*Brassica oleracea* var. *italica*). The findings clearly indicated that increasing the level of organic fertilizer significantly enhanced head diameter, head weight, and total yield, in addition to improving the concentration of important bioactive compounds such as glutathione, sulforaphane, and glucosinolates. Similarly, foliar application of molybdenum positively affected the studied parameters, particularly at the concentration of 200 mg L^{-1}, which improved both yield components and the nutritional quality of broccoli heads. The interaction between both factors always lead to higher improvements in all measured traits, indicating that integrated nutrient management combining soil organic amendments with micronutrient foliar feeding can effectively enhance plant performance.

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