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Effectiveness of Dithane M-45 in Suppressing Fungal Disease Improving The Growth and Yield of Red Bell Pepper (*Capsicum Annuum L.*)

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Abstract

Red bell pepper (*Capsicum annuum L.*) production can be constrained by fungal diseases, making effective disease management important for maintaining plant growth and yield. This study examined the response of red bell pepper to Dithane M-45 under field conditions in Tikala Subdistrict, North Toraja Regency, from July to September 2023. A completely randomized design (CRD) was used to evaluate six concentrations: 0 (control), 2, 4, 6, 8, and 10 g/L, with three replicates per treatment and four plants per experimental unit. The observed variables included the percentage of plants exhibiting fungal disease symptoms, plant height, number of leaves, stem diameter, days to flowering, number of fruits, fruit weight, fruit diameter, and fruit length. Data were analyzed using analysis of variance (ANOVA), followed by the least significant difference (LSD) test at the 5% significance level. Dithane M-45 significantly reduced the proportion of symptomatic plants and improved several growth and yield parameters. The 10 g/L treatment produced the highest recorded values for most vegetative and fruit traits and the lowest recorded disease incidence at 6 weeks after planting (WAP); however, it was not statistically superior to lower concentrations for all disease-related parameters. Accordingly, the findings indicate a concentration-response pattern under the experimental conditions rather than a universally optimal concentration. Practical application should follow the registered product label, safety requirements, and integrated disease management principles. In addition, the unusually high recorded growth values and the absence of confirmed pathogen identification warrant verification and cautious interpretation.

INTRODUCTION

Bell pepper is a high-value vegetable crop widely used for fresh consumption, culinary preparation, and food processing. It is also nutritionally important because the fruit is a rich source of vitamin C and antioxidant compounds. Increasing market demand creates opportunities for producers while also underscoring the need for reliable production practices that maintain crop health and yield.

According to Statistics Indonesia (2023), national bell pepper production reached 19,357 tons in 2019, 17,822 tons in 2020, 12,665 tons in 2021, and 53,620 tons in 2022. These figures indicate substantial year-to-year fluctuations in production. Improving crop management, including disease management, therefore remains important for stabilizing and increasing bell pepper production.

Cultivation practices strongly influence bell pepper productivity, particularly the management of pests and diseases. Plant pests and diseases are major production constraints and can cause substantial yield losses (Directorate of Food Crop Protection, 2018). In bell

pepper cultivation, crop performance may also be affected by environmental variability and disease pressure.

One disease that can reduce bell pepper productivity is Cercospora leaf spot, caused by the fungal pathogen Cercospora capsici Heald et Wolf. C. capsici can infect leaves, petioles, stems, flower stalks, and flowers, whereas fruit infection is uncommon. Leaf infection may lead to defoliation. Typical lesions are circular, with a dark gray center and dark brown margin, and concentric rings may be more apparent on the upper leaf surface. Lesions are generally small but may enlarge as the disease progresses. Therefore, appropriate disease-management measures are necessary to limit disease development and associated crop damage (Gunawan, 2005; Hyder et al., 2023; Isnawan & Mubarok, 2014; Kaisah, 2021; Karoney et al., 2025).

Fungal diseases may be difficult to manage using mechanical practices alone, and fungicide application may be necessary when disease pressure exceeds economically acceptable thresholds. Pesticides should be applied according to the six-right principles: the right target, product, dose or concentration, application method, timing, and quality (Directorate of Food Crop Protection, 2018). Dithane M-45 is a protectant contact fungicide containing the broad-spectrum active ingredient mancozeb, a multisite fungicide that disrupts multiple fungal enzymatic processes (Damayanti et al., 2021). Its application is therefore expected to reduce fungal disease pressure and help maintain bell pepper productivity.

Dithane M-45 is commonly used to manage fungal diseases; however, local evidence is needed to clarify how application concentration relates simultaneously to visible disease symptoms, vegetative growth, and fruit characteristics in red bell pepper. The novelty of this experiment lies in evaluating concentrations ranging from 0 to 10 g/L under field conditions in North Toraja while assessing disease incidence, vegetative growth, flowering, and yield-related traits within the same experimental design (Chen et al., 2024). Accordingly, this study aimed to (1) determine the responses of visible fungal disease incidence, growth, and yield variables to different Dithane M-45 concentrations and (2) identify the concentration associated with the most favorable overall response under the experimental conditions. The findings are intended to provide an empirical basis for disease-management decisions while emphasizing that practical fungicide use should comply with registered label directions and applicable safety requirements.

METHODS

Time and Location

The study was conducted from July to September 2023 in Tikala Subdistrict, Tikala District, North Toraja Regency, at an elevation of 821 m above sea level.

Materials and Equipment

The materials used included red bell pepper seeds, Dithane M-45 fungicide, soil, well-decomposed manure, water, seedling trays, and polybags. The equipment included hoes, tarpaulins, shovels, machetes, buckets, dippers, ropes, bamboo, a mobile-phone camera, calipers, measuring tools, and stationery.

Experimental Design

The study used a completely randomized design (CRD) with six Dithane M-45 concentrations: 0, 2, 4, 6, 8, and 10 g/L.

D0: No Dithane M-45 application
D1: 2 g/L
D2: 4 g/L
D3: 6 g/L
D4: 8 g/L
D5: 10 g/L

Each treatment was replicated three times, resulting in 18 experimental units. Each unit contained four plants, giving 72 plants in total.

Experimental Procedures

Preparation of the Experimental Area

The experimental area was prepared by constructing a growing structure approximately 3 m high.

Preparation of the Growing Medium

The growing medium was prepared by mixing soil and well-decomposed manure at a 1:1 ratio. The manure had been composted for approximately 2-3 months. After thorough mixing, the medium was placed in 40 × 50 cm polybags, with each polybag receiving the same type and amount of growing medium.

Seedling Preparation

Seedlings were raised in trays filled with a thoroughly mixed 1:1 soil-manure medium. Bell pepper seeds were sown evenly and lightly covered with the same medium. The trays were watered until moist and covered with a damp cloth for 24 hours to maintain moisture and facilitate germination. Seedlings were watered in the morning and afternoon. At two weeks of age, they were transferred to 10 × 8 cm polybags; at four weeks, they were transplanted into the larger experimental polybags.

Planting

Seedlings were transplanted at four weeks of age when they had 3-4 leaves. Only healthy and uniform seedlings were selected. One seedling was planted in the center of each polybag, the polybags were arranged at 40 × 40 cm spacing, and the plants were watered immediately after transplanting.

Application of Dithane M-45

Dithane M-45 was sprayed over the entire plant according to the assigned treatment. Each experimental unit received a total of 1 L of treatment solution over four applications at 10, 20, 30, and 40 days after planting, equivalent to 250 mL per application.

Observed Variables

The observed variables were as follows:

a) The disease variable was recorded as the percentage of plants per experimental unit showing visible fungal symptoms, including leaf spot, Fusarium-wilt-like symptoms, and other fungal symptoms. Because the available method describes presence/absence at the plant level rather than a severity scale, this measure is more accurately interpreted as symptomatic-plant incidence.
b) Plant height, measured from the stem base to the highest growing point at 2, 4, and 6 weeks after planting (WAP).
c) Number of leaves, determined by counting fully developed leaves at 2, 4, and 6 WAP.

d) Stem diameter, measured using a caliper at 2, 4, and 6 WAP.
e) Days to flowering, calculated as the number of days from planting until flowering.
f) Number of fruits per plant, determined by counting all fruits produced by each plant.
g) Fruit weight, determined using an analytical balance.
h) Fruit diameter, measured using a caliper.
i) Fruit length, measured using a caliper.

Data Analysis

Data were tabulated and analyzed using analysis of variance (ANOVA). When the treatment effect was significant, means were compared with the Least Significant Difference (LSD) test at the 5% level.

RESULTS AND DISCUSSION

Results

Plant Height

Analysis of variance indicated significant differences in recorded plant height among Dithane M-45 treatments at 2, 4, and 6 WAP. D5 (10 g/L) had the highest recorded means at each observation, including 258.23 cm at 6 WAP, where it was not significantly different from D4. Because the reported 6-WAP height is unusually high for the stated crop stage, the value and its measurement unit should be verified against the raw data before biological interpretation.

Number of Leaves

Analysis of variance showed that Dithane M-45 had a highly significant effect on the number of leaves at 2, 4, and 6 WAP. D5 produced the highest number of leaves at all three observation times - 21.17 (2 WAP), 24.00 (4 WAP), and 23.58 (6 WAP) - differing significantly from the other treatments in each case. Reduced fungal disease may have limited leaf damage and premature leaf loss, allowing plants to retain a larger photosynthetic canopy.

Stem Diameter

Analysis of variance indicated significant differences in recorded stem diameter among treatments. D5 was reported as 3.97 mm at 2 WAP, 4.70 mm at 4 WAP, and 70.8 mm at 6 WAP. The abrupt increase to 70.8 mm strongly suggests that the 6-WAP value or unit requires verification; therefore, no biological explanation should be attached to that value until the raw record is checked.

Vegetative Growth and Flowering at 6 WAP

Mean vegetative growth and flowering responses at 6 WAP are summarized in Table 1 below.

Table 1. Mean Vegetative Growth and Flowering Responses of Red Bell Pepper at 6 WAP

Treatment	Plant Height (cm)	Number of Leaves	Stem Diameter (mm)	Time to Flowering
D0 (Control)	126.8a	7.92a	23.8a	7.00b
D1 (2 g/L)	154.4ab	9.42a	28.3a	7.33b
D2 (4 g/L)	189.63bc	12.75b	38.3b	6.00a
D3 (6 g/L)	204.5cd	15.08c	45.3c	6.00a
D4 (8 g/L)	225.4de	18.67d	56.0d	5.33a
D5 (10 g/L)	258.23e	23.58e	70.8e	6.00a
LSD 5%	41.86	2.06	2.06	0.93

The 5% LSD test showed that D4 (8 g/L) had the lowest recorded time-to-flowering value (5.33), which did not differ significantly from D2, D3, and D5 but differed from D0 and D1. The method defines this variable as days from planting, whereas the table reports values of 5.33–7.33 without an explicit unit.

Fruit Diameter, Fruit Weight, and Fruit Length

Analysis of variance showed that Dithane M-45 significantly affected fruit diameter, fruit weight, and fruit length. Results are summarized in Table 2 below.

Table 2. Mean Fruit Diameter, Fruit Weight, and Fruit Length of Red Bell Pepper

Treatment	Fruit Diameter (mm)	Fruit Weight (g)	Fruit Length (mm)
D0 (Control)	48a	134.87a	68.00a
D1 (2 g/L)	49.95b	139.65ab	69.95ab
D2 (4 g/L)	50.33c	140.04ab	70.33b
D3 (6 g/L)	51.71d	149.95bc	71.71b
D4 (8 g/L)	54.83e	158.29cd	74.83c
D5 (10 g/L)	56.35f	164.82d	76.35c
LSD 5%	1.52	16.67	2.16

D5 produced the largest fruit diameter (56.35 mm), significantly differing from the other treatments, indicating that fruit diameter increased with increasing Dithane M-45 concentration under the conditions of this experiment. D5 also produced the highest fruit weight (164.82 g), not significantly different from D4 but differing significantly from D0, D1, D2, and D3, as well as the greatest fruit length (76.35 mm), following the same significance pattern.

Fungal Symptom Incidence on Red Bell Pepper Leaves and Fruits

Analysis of variance showed significant treatment differences in the recorded percentage of symptomatic plants on leaves at 2, 4, and 6 WAP and on fruits at the final observation. Because the method reports the percentage of affected plants rather than a lesion-severity scale, the results are interpreted here as symptom incidence rather than disease severity. Results are summarized in Table 3.

Table 3. Mean Fungal Symptom Incidence on Red Bell Pepper Leaves and Fruits

Treatment	Leaf Disease Intensity - 2 WAP (%)	Leaf Disease Intensity - 4 WAP (%)	Leaf Disease Intensity - 6 WAP (%)	Fruit Disease Intensity - Final Observation (%)
D0 (Control)	46.36a	45.54a	45.68a	27.45a
D1 (2 g/L)	30.31b	22.89b	31.25b	24.59a
D2 (4 g/L)	25.57c	18.66c	19.64c	20.07b
D3 (6 g/L)	20.49c	19.46c	20.43c	17.70c
D4 (8 g/L)	19.57c	16.10c	13.82c	19.92c
D5 (10 g/L)	20.97c	15.87c	12.08c	18.55c
LSD 5%	10.22	9.22	8.49	3.46

At 2 WAP, the untreated control (D0) had the highest leaf disease intensity (46.36%), differing significantly from the fungicide treatments; the lowest recorded value was 19.57% in D4. Untreated plants showed circular lesions with dark gray centers and dark brown margins. At 4 WAP, D0 again showed the highest disease intensity (45.54%), whereas D5 showed the lowest (15.87%), with the untreated control displaying similar circular leaf spots. At 6 WAP, D0 had the highest fungal disease intensity (45.68%), whereas D5 had the lowest (12.08%), with the control differing significantly from the fungicide treatments throughout.

At the final observation, the highest mean fruit disease intensity occurred in D0 (27.45%) and D1 (24.59%), which did not differ significantly from one another but differed from the higher-concentration treatments. Untreated fruits frequently developed soft brown lesions followed by partial fruit rot. D3, D4, and D5 were not significantly different from one another, indicating that the higher Dithane M-45 concentrations suppressed visible fungal damage on fruits to a comparable degree.

Discussion

Effectiveness of Dithane M-45 in Suppressing Fungal Disease

Dithane M-45 treatments were associated with lower recorded symptom incidence on leaves than the control. At 6 WAP, the recorded value declined from 45.68% in the control to 12.08% at 10 g/L. On fruits, the response was not strictly linear and the higher concentrations did not differ significantly in all comparisons. These patterns support a treatment association under the experimental conditions, but the study did not measure the physiological mechanisms responsible for the growth response; explanations involving photosynthesis, tissue condition, or spray deposition should therefore be regarded as plausible interpretations supported by literature rather than directly observed mechanisms.

Dithane M-45 contains mancozeb, a multisite contact fungicide that acts on plant surfaces by disrupting several pathogen enzyme systems containing sulfhydryl groups. Its multisite activity makes mancozeb useful as a protectant fungicide and generally gives it a lower resistance risk than many single-site fungicides. Because it is not systemic, its effectiveness depends on adequate spray coverage, application timing, wash-off by rain or irrigation, and the emergence of new tissue after spraying. Studies on chilli and bell pepper have also reported that mancozeb, alone or in mixtures, can reduce leaf spot, fruit rot, anthracnose, and

Phytophthora blight when applied appropriately (Fauzi & Widarjo W, 2021; Purnomo & Utami, 2023; Reza et al., 2021; Rianti et al., 2020).

Relationship Between Disease Suppression and Vegetative Growth

The increases in plant height, leaf number, and stem diameter following Dithane M-45 application are more plausibly interpreted as indirect consequences of reduced disease pressure than as a direct growth-promoting effect of mancozeb. Healthier leaves retain a larger photosynthetic area and may sustain carbon assimilation for longer, allowing more assimilates to be allocated to vegetative and reproductive organs. Severe leaf spot can accelerate senescence and defoliation, thereby reducing photosynthesis and assimilate supply. Relationships among canopy health, vegetative growth, and yield in Capsicum have also been reported in studies involving biostimulants, growth-promoting microorganisms, heat stress, and growing media (Kim, 2023; Majkowska-Gadomska et al., 2021; Tuckeldoe et al., 2023; Wilberts et al., 2023; Xhemali et al., 2023; Yang & Wang, 2025). The strong positive response of the recorded vegetative variables to increasing Dithane M-45 concentration should nevertheless be interpreted together with the disease data and the experimental conditions, because fungicide application is expected to affect growth mainly through disease suppression rather than direct growth stimulation.

Reproductive Responses and Yield Components

The 10 g/L concentration produced the greatest fruit diameter, fruit weight, and fruit length, whereas the earliest recorded flowering occurred at 8 g/L. Thus, the concentration producing the maximum response was not identical for every trait. During vegetative growth and fruit enlargement, improved canopy protection may increase assimilate availability, whereas flowering is also influenced by physiological age, temperature, nutrient status, humidity, and source-sink balance. Fruit yield in Capsicum is a complex trait determined by fruit number, fruit size, plant health, genotype, environment, and their interactions (Majkowska-Gadomska et al., 2021; Maleki et al., 2025; Sahmat et al., 2024; Tuckeldoe et al., 2023).

Fruit weight increased from 134.87 g in the control to 164.82 g in D5, an increase of approximately 22.2%. Fruit diameter increased from 48.00 to 56.35 mm (approximately 17.4%), while fruit length increased from 68.00 to 76.35 mm (approximately 12.3%). These responses are agronomically consistent with the possibility that reduced disease intensity helped maintain productive foliage and reduced losses associated with damaged fruits.

Dose-Response Pattern and Determination of an Effective Concentration

Overall, the recorded responses showed a positive concentration-response pattern up to D5 for several vegetative and fruit traits and for leaf disease suppression. However, D3, D4, and D5 did not differ significantly in fruit disease intensity; therefore, 10 g/L was not statistically superior to 6-8 g/L for every variable. Technical recommendations should consider statistical equivalence as well as product-label rates, application cost, phytotoxicity risk, residues, worker safety, and environmental impacts. Under the conditions of this experiment, 10 g/L produced the maximum overall response for most measured growth and yield variables, while 6-8 g/L produced statistically similar fruit-disease suppression in several comparisons.

This interpretation is consistent with integrated disease management principles: use the lowest effective dose, avoid excessive applications, and combine fungicides with sanitation, tolerant varieties, humidity management, rotation of active ingredients, and biological agents.

Recent studies emphasize that sustainable Capsicum disease management should integrate fungicides with Trichoderma, Bacillus, endophytic bacteria, or other biological formulations to suppress pathogens and reduce dependence on synthetic fungicides (Boukaew et al., 2024; Chen et al., 2024; Karoney et al., 2025; Nururrahmani et al., 2025).

Relevance of Pathogen Type and Disease Diagnosis

The observed leaf-spot symptoms were suspected to be associated with Cercospora capsici, but pathogen identity was not confirmed by isolation, morphological characterization, or molecular identification. Bell pepper can be affected by several fungal and oomycete pathogens - including Cercospora, Colletotrichum, Alternaria, Fusarium, Botrytis, Sclerotium, Phytophthora, and Pythium - which differ in epidemiology and response to fungicides. Recent studies have demonstrated variation in Colletotrichum species and virulence on Capsicum, while damping-off, root rot, and Phytophthora blight require management strategies different from those used for leaf spot (Chen et al., 2024; De Silva et al., 2021; Noor & Zakaria, 2024). Consequently, the conclusions of this study should be limited to suppression of the observed fungal disease symptoms rather than effectiveness against all fungal pathogens.

Practical Implications and Sustainability of Mancozeb Use

The results support Dithane M-45 as a protectant fungicide for red bell pepper under the study conditions. However, the 10 g/L treatment must be interpreted in relation to the registered product-label rate and official recommendations for bell pepper; a concentration exceeding the registered label rate should not be recommended on the basis of a single experiment because it may increase residues, costs, operator exposure, and environmental burden. Applications should follow the six-right principles, use appropriate personal protective equipment, comply with application and pre-harvest intervals, and be integrated with other disease-management practices.

Fungicide use should also be placed within a resistance-management framework. Although mancozeb has a multisite mode of action, mixtures or rotations with other fungicides must follow mode-of-action groups and label directions. Repeated applications at excessively short intervals may disrupt non-target microorganisms and increase residue accumulation. Plant extracts, chitosan, antagonistic microorganisms, and nanoformulations have shown potential, but their field consistency, safety, and economic feasibility still require evaluation (Chaurasiya, 2023; Deresa & Diriba, 2023; Sahmat et al., 2024).

Study Limitations and Directions for Future Research

This study has several limitations. First, pathogen identity was not confirmed through isolation, morphological characterization, or molecular methods. Second, several recorded growth values, particularly plant height and stem diameter, are unusually high for the stated crop stage and should be checked against the original measurement units and raw data. Third, the unit used for time to flowering should be verified, as the reported means range from 5.33 to 7.33. Fourth, environmental variables such as rainfall, temperature, relative humidity, and leaf wetness were not reported, although they can strongly influence disease development and the persistence of contact fungicides. Finally, fungicide residues and economic feasibility were not evaluated.

Future studies should confirm pathogen identity, compare Dithane M-45 concentrations with the registered label rate, include a reference fungicide and biological-control treatments, and evaluate residues and economic feasibility. Measurements should also include leaf area,

chlorophyll content, photosynthetic rate, total yield per plant, marketable fruit percentage, and disease-progress curves. Multi-location or multi-season trials would help determine whether the observed concentration response is consistent under different environmental conditions and would strengthen recommendations for integrated bell pepper disease management.

CONCLUSION

Under the conditions of this experiment, Dithane M-45 treatments reduced the recorded incidence of visible fungal disease symptoms and were associated with higher values for several growth and fruit traits. The 10 g/L treatment produced the highest recorded response for most variables and the lowest incidence of leaf symptoms at 6 weeks after planting (WAP); however, it was not statistically superior to the 6–8 g/L treatments for every disease-related parameter. Therefore, the 10 g/L treatment should be interpreted as producing the most favorable overall response under the specific experimental conditions rather than as representing a universally optimal or most effective concentration.

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