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Evaluation of Vermicompost and Vermiwash as Organic Amendments for Enhancing Growth and Yield of Mung Bean (*Vigna radiata* L.)

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This study examined the effects of vermicompost (VC) and vermiwash (VW) on the growth and yield of three mung bean varieties (*MI5, MI6* and *MIMB7*) recommended by the Department of Agriculture, Sri Lanka. Treatments included VC and VW applied at 25 – 100%, alongside chemical fertiliser and an untreated control. Treatments with higher nutrient inputs, particularly 75% VC and 100% VC, were consistently associated with superior vegetative growth and pod production, identifying them as the most promising for improving mung bean performance. Among these, VC-based treatments showed the strongest and most consistent positive associations with yield-related traits, confirming the greater effectiveness of VC over VW and chemical fertiliser. At the varietal level, *MIMB7* emerged as the best-performing variety, exhibiting superior growth and yield characteristics, particularly under 75% and 100% VC treatments. In contrast, *MI6* and *MI5* showed intermediate and lower performance, respectively, suggesting that *MI6* is moderately responsive and may benefit from balanced nutrient treatments; however, neither variety matched the productivity of *MIMB7*. The 75% VC treatment demonstrated significantly higher responses in most measured parameters compared with both chemical fertiliser and the control across all varieties, and its performance was comparable to 100% VC; therefore, 75% VC was identified as the most appropriate level for practical field application to enhance vegetative growth and yield. These results suggest that VC provides a sustainable and efficient organic fertilisation strategy; however, further field-based studies are required to validate its long-term effects on crop productivity and soil health.

Keywords: vermicompost, vermiwash, organic farming, mung bean, sustainable agriculture

Mung bean (*Vigna radiata* L.) is a short-duration grain legume of great importance, widely cultivated in Asia for its nutritional and soil fertility benefits. It is a rich source of protein, essential amino acids, vitamins, and minerals, making it a valuable dietary component in addressing protein-energy malnutrition (Mishra *et al.* 2020). Moreover, mung beans enhance soil health by fixing nitrogen symbiotically and are frequently included in crop rotations to improve the productivity of integrated farming systems (Mahmood *et al.* 2021). In Sri Lanka, mung bean is a minor yet economically important legume, with varieties such as *MI5, MI6* and *MIMB7* recommended by the Department of Agriculture, Sri Lanka, for their early maturity and adaptability (DOA 2024). According to the Central Bank of Sri Lanka‘s Annual Report (2023), the country‘s total mung bean production reached approximately 15,800

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metric tons from 24,300 hectares of cultivated land, reflecting a modest yield of 0.65 tons per hectare. Despite its significant domestic production will only meet 42% of national demand, which requires imports of about 21,000 metric tons annually at LKR 4.2 billion, which is a significant foreign exchange liability (DOA 2024). These are statistics that highlight the necessity of sustainable strategies to improve the productivity of domestic mung beans. The issues related to high use of synthetic fertilisers, such as price fluctuations, reduced soil health, and environmental effects, highlight why farmers should explore the possibility of using precision application methods, organic amendments, and integrated nutrient cycling systems that have the potential to support agriculture at high levels with better long-term sustainability (Krasilnikov *et al.* 2022). Vermicompost (VC) and vermiwash (VW) are organic amendments which can serve two purposes: as a waste valorisation strategy and as a soil fertility enhancement tool, since they are environmentally friendly alternatives to synthetic inputs. Vermicompost is a nutrient-rich and biologically active earthworm-produced bio-degradation product that contains plant growth regulators, beneficial microbes, and humic compounds (Sharma *et al.* 2019). VC application improves soil structure, water-holding capacity (Xu & Mou 2016), and nutrient uptake, with demonstrated benefits for legume crops such as cowpea, mung bean, and soybean (Mathenge *et al.* 2019; Al-Tawarah *et al.* 2024; Amaya-Gómez *et al.* 2025). The potassium and phosphorous of VW were remarkably stable over time, but if the initial ammonium content was high, the content changed with temperature (Jaikishun *et al.* 2018).). Nahar *et al.* (2024) reported that foliar or soil applications of VW enhance photosynthesis, nodulation, and reproductive parameters in legumes. Despite these global findings, there is limited research on VC and VW used in the production of mung beans in Sri Lanka. Research on fertilisers in the country has mainly focused on inorganic nutrient inputs rather than on integrated or organic nutrient input methods. Moreover, the comparative impacts of VC and VW across chemical fertilisers on the various mung bean varieties in Sri Lanka have not been tested. This gap is critical for devising environmentally friendly solutions tailored to local production systems. The study aimed to evaluate the impact of different ratios of VC and VW, along with chemical fertilisers, on the growth and yield components of mung bean varieties; *MI5, MI6* and *MIMB7* recommended by the Department of Agriculture (DOA), Sri Lanka. The ultimate goal is to support farmers in adopting eco-friendly soil management strategies that enhance mung bean production while maintaining long-term soil health.

MATERIAL AND METHODS

Experimental site: This study was conducted as a pot experiment in an open agricultural field in Bulathsinghala, Kaluthara District, Sri Lanka (6.58° N and 79.96° E). The experiment ran from December 2024 to April 2025. The area has an average annual temperature of 26.3°C, annual rainfall of 2,931 mm, and humidity of 80%.

Planting materials: Three mung bean varieties (*Vigna radiata* L.), namely *MI5, MI6* and *MIMB7,* recommended by the DOA, Sri Lanka, were selected for this experiment. Seeds were collected from the Grain Legume and Oil Crops Research and Development Centre, Sri Lanka.

Vermicompost unit: The composting process was carried out over 45 days using approximately 500 g of earthworms of the species *Eisenia fetida,* following the method described by Wani *et al.* (2013). A plastic barrel (60 cm × 45 cm × 30 cm) with bottom holes was used as the compost unit, and decayed leaves of *Gliricidia sepium* and *Helianthus annuus* L. were layered. The mixture contained cow dung and kitchen waste in a 1:1 ratio, which accelerated decomposition and increased worm activity. The contents were regularly moistened and covered with gunny bags to retain moisture and ensure aeration. The compost matured within 45 – 50 days (Masri *et al.* 2022). A similar composting unit was established for VW production using a separate plastic barrel, and water was sprayed at regular intervals to maintain optimal moisture levels. VW was collected as a liquid extract after two weeks (Nahar *et al.* 2024).

Treatment application: The study included 10 treatments (Table 1), with five replicates applied across three varieties (*MI5, MI6* and *MIMB7*), resulting in 150 experimental units (10 treatments × 5 replicates × 3 varieties). Treatments were conducted under uniform environmental conditions in a single experimental area. Healthy, uniform seeds of mung bean varieties (*MI5, MI6* and *MIMB7*) were directly sown in polythene pots (30 cm × 20 cm) and later thinned to three uniform seedlings after establishment. All pots were maintained under uniform environmental conditions and arranged randomly. Irrigation was applied regularly to maintain adequate soil moisture, and all pots received equal amounts of water throughout the experimental period. Weeding and other intercultural operations were carried out manually as required. No plant-protection chemicals were applied during the experiment. VC was added to pots according to the treatment plan. For VW, only topsoil was used in the pots, and VW was applied one week after planting and continued until 8 weeks at weekly intervals. The application volume was adjusted according to plant growth stage to ensure adequate foliar coverage: 50 mL per plant during weeks 1 – 2, 100 mL per plant during weeks 3 – 4, and 150 mL per plant during weeks 5 – 8. VW was applied using a hand sprayer to achieve uniform wetting of the leaf surface. All applications were carried out in the morning to minimise evaporation and ensure efficient absorption. The chemical fertiliser treatment included a basal application of Urea (35 kg/ha), Triple Superphosphate (TSP) (100 kg/ha), and Muriate of Potash (MOP) (75 kg/ha), followed by a Urea (30 kg/ha) application at the onset of flowering.

The nutrient composition of VC and VW was analysed before application. Total nitrogen (N) was determined using the Kjeldahl digestion and distillation method (Bremner & Mulvaney 1982). Available phosphorus (P) was estimated by the vanadium molybdate yellow colour method (Jackson 1973). Potassium (K) content was measured using a flame photometer following wet digestion (Jackson 1973). Soil organic matter content was determined using the Walkley and Black wet oxidation method (Walkley and Black 1934; Nelson & Sommers 1982).

Data collection: Plant height, number of leaves, and number of branches were recorded weekly up to eight weeks after planting. Days to flowering, number of pods/plant, pod length [cm], pod width [cm], seeds per pod, and hundred-seed weight were recorded according to the descriptor developed by IBPGR (1985).

Data analysis: All collected data were analysed using analysis of variance (ANOVA) in Minitab 17. Residual normality was assessed with the Anderson–Darling test, and homogeneity of variances was tested with Levene's test. A significance level of $p < 0.05$ was used to determine statistically significant differences among treatment means. Where significant differences were observed, mean separation was performed using Tukey's honestly significant

Table 1

Treatment structure of the pot experiment

Treatment	Nutrient Source	Concentration / Description
T1	VC	25% VC + 75% soil
T2	VC	50% VC + 50% soil
T3	VC	75% VC + 25% soil
T4	VC	100% VC
T5	VW	25% VW
T6	VW	50% VW
T7	VW	75% VW
T8	VW	100% VW
T9	Chemical control	Recommended chemical fertiliser (DOA)
T10	Negative control	No fertiliser

Note: VC − vermicompost; VW − vermiwash; DOA − Department of Agriculture, Sri Lanka.

difference (HSD) test. To evaluate the combined influence of treatment type and variety, a two-factor factorial design was employed. Multivariate analysis was performed to assess overall relationships among treatments and measured traits. Principal component analysis (PCA) was conducted in R (version 4.5.0) to reduce data dimensionality and identify the major variables contributing to variation among treatments. A biplot was generated from the first two principal components (PC1 and PC2) to visualise associations between treatments and growth and yield parameters.

RESULTS

Nutrient Composition of Vermiwash, Vermicompost and Soil

The nutrient composition of VC, VW and the experimental soil is presented in Table 2. The pH values of all materials were within a slightly acidic to near-neutral range, with VW (6.08), vermicompost (6.62), and soil (6.38), indicating suitable conditions for plant growth. Electrical conductivity (EC) varied among the materials, with VC recording the highest value (1.54 dS/m), followed by soil (1.02 dS/m), while VW showed a comparatively low EC (0.02 dS/m).

Total nitrogen content was highest in VW (3.00%), followed by VC (1.12%), while the soil contained a relatively low nitrogen level (0.05%). Available phosphorus in VW was recorded as 0.78 mg/L, whereas VC contained only trace amounts, and soil had a low available phosphorus content of 3.3 mg/kg. Similarly, available potassium in VW was 0.75 mg/L, while VC and soil recorded higher values of 58.98 mg/kg and 48.8 mg/kg, respectively.

Organic matter content was markedly higher in VC (32.98%) compared to soil (7.58%). The VC exhibited superior organic matter and moderate nutrient availability, whereas VW contained higher nitrogen but comparatively lower available phosphorus and potassium. The experimental soil showed relatively low nutrient status, particularly for nitrogen and phosphorus, indicating the need for nutrient supplementation.

Effects of Organic Fertilisers on Growth and Yield of Three Mung Bean Varieties

The application of different concentrations of VC and VW significantly influenced the growth and yield parameters of the three mung bean varieties of *MI5, MI6* and *MIMB7* ($p < 0.05$) (Table 3).

For the *MI5* variety, plant growth and yield parameters showed significant responses to VC and VW treatments. Plants receiving 100% VC (T4) achieved the greatest plant height (38.14 ± 1.5 cm), significantly different from the T10 (25.46 ± 0.42 cm) ($p < 0.001$). The T2 and T3 also showed comparatively higher plant height (35.34 cm and 36.84 cm, indicating a positive effect of increasing VC levels. In contrast, the lowest plant height was ob-

T a b l e 2

Nutrient characteristics of vermiwash, vermicompost, and experimental soil

Parameter	Unit	Vermiwash (VW)	Vermicompost (VC)	Soil
pH	–	6.08	6.62	6.38
EC	dS/m	0.02	1.54	1.02
Total N	%	3.00	1.12	0.05
Available P	mg/L	0.78	–	–
	mg/kg	–	Trace	3.3
Available K	mg/L	0.75	–	–
	mg/kg	–	58.98	48.8
Organic Matter	%	–	32.98	7.58

Note: Available phosphorus and potassium are expressed in mg/L for vermiwash and mg/kg for vermicompost and soil.

T a b l e 3

Effects of vermicompost on growth and yield of three mung bean varieties

Variety	Treat-ments	Plant height	Number of leaves	Number of main branches	Days to flowering	Number of pods/plant	Pod length [cm]	Pod width [cm]	Seeds per pod	100 seed weight [g]
MI5	T1	34.46 ± 0.70^{c}	15.00 ± 0.00^{a}	5.00 ± 0.00^{a}	40.60 ± 0.55^{b}	5.80 ± 1.30^{bc}	6.56 ± 0.57^{ab}	0.52 ± 0.04^{a}	7.00 ± 0.00^{ab}	4.21 ± 0.12^{c}
	T2	35.34 ± 1.20^{bc}	15.00 ± 0.00^{a}	5.00 ± 0.00^{a}	36.00 ± 0.00^{c}	5.60 ± 1.51^{bc}	4.60 ± 0.89^{d}	0.54 ± 0.55^{a}	7.40 ± 1.37^{ab}	4.21 ± 0.21^{c}
	T3	36.84 ± 1.60^{ab}	16.20 ± 1.64^{a}	5.00 ± 0.00^{a}	34.40 ± 0.55^{d}	6.60 ± 0.89^{b}	6.44 ± 1.45^{ab}	0.52 ± 0.04^{a}	7.60 ± 1.24^{a}	5.32 ± 0.23^{b}
	T4	38.14 ± 1.50^{a}	16.80 ± 1.64^{a}	4.80 ± 0.45^{a}	32.60 ± 0.55^{e}	10.12 ± 0.89^{a}	7.12 ± 0.71^{a}	0.54 ± 0.05^{a}	8.40 ± 1.84^{a}	6.82 ± 0.32^{a}
	T5	24.60 ± 0.89^{f}	12.60 ± 1.34^{b}	4.00 ± 0.00^{a}	40.60 ± 0.55^{b}	3.00 ± 0.71^{d}	6.00 ± 0.70^{bc}	0.50 ± 0.00^{a}	6.20 ± 0.45^{bc}	5.80 ± 0.45^{abc}
	T6	25.20 ± 0.45^{ef}	12.00 ± 0.00^{b}	4.00 ± 0.00^{a}	38.40 ± 0.55^{bc}	3.60 ± 0.55^{d}	7.00 ± 0.68^{a}	0.48 ± 0.04^{a}	6.20 ± 0.45^{bc}	6.20 ± 0.45^{ab}
	T7	26.58 ± 0.16^{e}	12.60 ± 1.34^{b}	4.00 ± 0.00^{a}	36.60 ± 0.55^{c}	3.40 ± 1.14^{d}	5.58 ± 0.97^{cd}	0.52 ± 0.04^{a}	6.20 ± 0.45^{bc}	5.80 ± 0.49^{abc}
	T8	28.78 ± 0.60^{d}	14.00 ± 0.00^{a}	4.00 ± 0.00^{a}	35.20 ± 0.45^{cd}	4.60 ± 0.89^{cd}	7.54 ± 0.44^{a}	0.50 ± 0.00^{a}	6.20 ± 0.45^{bc}	6.80 ± 0.40^{a}
	T9	26.60 ± 0.16^{e}	12.60 ± 1.34^{b}	4.00 ± 0.00^{a}	38.20 ± 1.30^{bc}	3.00 ± 0.70^{d}	6.44 ± 0.43^{ab}	0.50 ± 0.00^{a}	5.60 ± 0.55^{cd}	5.60 ± 0.35^{bc}
	T10	25.46 ± 0.42^{ef}	9.00 ± 0.00^{c}	3.00 ± 0.00^{b}	42.40 ± 0.55^{a}	2.60 ± 0.55^{e}	5.58 ± 0.42^{cd}	0.50 ± 0.00^{a}	5.20 ± 0.45^{d}	5.20 ± 0.45^{cd}
MI6	T1	35.82 ± 0.22^{d}	15.00 ± 0.00^{a}	5.00 ± 0.00^{b}	38.00 ± 0.70^{c}	4.80 ± 0.84^{cd}	7.06 ± 0.66^{ab}	0.52 ± 0.04^{a}	6.20 ± 1.64^{ab}	5.80 ± 0.90^{bc}
	T2	39.18 ± 0.23^{c}	15.60 ± 1.34^{a}	4.80 ± 0.45^{b}	36.40 ± 0.55^{d}	6.60 ± 0.55^{bc}	7.42 ± 0.42^{a}	0.48 ± 0.04^{a}	6.40 ± 1.34^{ab}	5.80 ± 0.41^{bc}
	T3	43.38 ± 1.09^{b}	15.00 ± 0.00^{a}	5.00 ± 0.00^{b}	34.40 ± 1.14^{e}	7.80 ± 1.09^{b}	7.46 ± 0.45^{a}	0.52 ± 0.04^{a}	7.40 ± 1.34^{a}	6.40 ± 0.12^{ab}
	T4	52.34 ± 0.43^{a}	16.20 ± 1.64^{a}	6.58 ± 0.45^{a}	31.60 ± 1.14^{f}	10.80 ± 1.10^{a}	7.42 ± 0.55^{a}	0.48 ± 0.04^{a}	7.00 ± 0.00^{a}	6.14 ± 0.23^{ab}
	T5	27.52 ± 0.29^{e}	12.00 ± 0.00^{b}	4.00 ± 0.00^{c}	41.40 ± 0.55^{b}	3.40 ± 0.55^{de}	5.94 ± 0.84^{bc}	0.48 ± 0.05^{a}	6.00 ± 0.00^{ab}	5.80 ± 0.00^{bc}
	T6	27.52 ± 1.02^{e}	12.00 ± 0.00^{b}	4.00 ± 0.00^{c}	39.60 ± 1.82^{c}	3.80 ± 0.45^{de}	6.64 ± 0.64^{abc}	0.48 ± 0.05^{a}	5.60 ± 0.89^{b}	5.60 ± 0.50^{c}
	T7	27.58 ± 0.13^{e}	12.00 ± 0.00^{b}	4.00 ± 0.00^{c}	36.80 ± 0.84^{d}	4.80 ± 1.09^{cd}	7.40 ± 0.46^{ab}	0.48 ± 0.05^{a}	5.80 ± 0.45^{b}	6.20 ± 0.45^{ab}
	T8	29.18 ± 0.89^{e}	13.60 ± 1.34^{b}	4.00 ± 0.00^{c}	34.40 ± 0.55^{e}	6.00 ± 1.23^{bc}	7.78 ± 0.22^{a}	0.48 ± 0.05^{a}	6.00 ± 0.00^{ab}	7.00 ± 0.00^{a}
	T9	28.32 ± 0.22^{e}	11.00 ± 0.00^{c}	4.00 ± 0.00^{c}	38.40 ± 0.55^{c}	3.00 ± 0.71^{e}	5.58 ± 0.61^{c}	0.48 ± 0.05^{a}	6.00 ± 0.00^{ab}	5.60 ± 0.00^{c}
	T10	25.64 ± 0.15^{f}	9.00 ± 0.00^{d}	3.00 ± 0.00^{d}	43.40 ± 0.55^{a}	2.00 ± 0.71^{f}	4.90 ± 1.78^{d}	0.50 ± 0.00^{a}	5.20 ± 1.09^{b}	4.80 ± 0.80^{d}
MIMB7	T1	37.28 ± 1.85^{c}	14.40 ± 1.34^{c}	5.00 ± 0.00^{a}	41.00 ± 1.00^{a}	4.00 ± 0.70^{cd}	6.86 ± 0.80^{ab}	0.50 ± 0.00^{a}	6.60 ± 1.52^{ab}	6.90 ± 0.24^{bc}
	T2	40.84 ± 2.57^{c}	16.80 ± 1.64^{b}	4.40 ± 1.34^{ab}	38.40 ± 0.55^{c}	4.40 ± 0.55^{cd}	7.34 ± 0.46^{a}	0.50 ± 0.07^{a}	6.40 ± 1.34^{ab}	7.14 ± 0.11^{b}
	T3	46.88 ± 4.89^{b}	18.00 ± 0.00^{ab}	4.80 ± 0.45^{a}	35.00 ± 0.71^{d}	7.00 ± 0.70^{b}	7.18 ± 0.36^{ab}	0.52 ± 0.04^{a}	7.00 ± 0.00^{a}	7.16 ± 0.14^{ab}
	T4	52.70 ± 0.57^{a}	19.80 ± 1.64^{a}	5.00 ± 0.00^{a}	32.60 ± 0.89^{e}	11.00 ± 1.40^{a}	7.74 ± 0.27^{a}	0.54 ± 0.05^{a}	7.40 ± 1.34^{a}	8.12 ± 0.23^{a}
	T5	27.68 ± 0.16^{d}	12.00 ± 0.00^{d}	4.20 ± 0.45^{ab}	38.60 ± 0.89^{c}	4.60 ± 0.55^{cd}	3.98 ± 0.93^{d}	0.48 ± 0.05^{a}	5.60 ± 0.69^{b}	5.00 ± 0.60^{d}
	T6	28.06 ± 0.38^{d}	12.60 ± 1.34^{cd}	4.00 ± 0.00^{b}	37.00 ± 1.23^{c}	4.80 ± 0.84^{c}	6.04 ± 0.57^{bc}	0.48 ± 0.05^{a}	5.60 ± 0.59^{b}	5.60 ± 0.55^{cd}
	T7	27.42 ± 0.59^{d}	12.00 ± 0.00^{d}	4.00 ± 0.00^{b}	35.60 ± 1.34^{d}	4.60 ± 0.89^{cd}	6.38 ± 1.16^{bc}	0.52 ± 0.04^{a}	5.60 ± 0.81^{b}	5.80 ± 0.60^{c}
	T8	28.50 ± 0.12^{d}	12.60 ± 1.34^{cd}	4.00 ± 0.55^{b}	35.40 ± 0.89^{d}	6.20 ± 0.84^{bc}	7.88 ± 0.84^{a}	0.48 ± 0.05^{a}	5.60 ± 0.97^{b}	6.80 ± 0.65^{b}
	T9	25.66 ± 0.19^{e}	9.00 ± 0.00^{e}	4.00 ± 0.00^{b}	38.20 ± 0.84^{c}	3.20 ± 0.84^{de}	4.36 ± 0.77^{d}	0.48 ± 0.05^{a}	6.00 ± 0.00^{ab}	5.00 ± 0.50^{d}
	T10	27.56 ± 0.33^{d}	8.00 ± 0.00^{f}	3.00 ± 0.00^{c}	41.80 ± 0.45^{a}	2.60 ± 0.55^{e}	4.48 ± 1.15^{cd}	0.50 ± 0.00^{a}	4.00 ± 1.87^{c}	4.00 ± 1.00^{e}

Note: Means were separated within each variety; treatment means were compared at the 5% significance level ($p < 0.05$), Means followed by different letters indicate significant differences among treatments, while means sharing the same letters are not significantly different.

served in the negative control (T10). Similarly, the number of leaves was significantly influenced by the tested VC and VW treatments ($p<0.001$), with the highest value recorded in the T4 (16.80 ± 1.64), compared to only 9.00 leaves in the negative control (T10). The T1, T2, T3, and T8 also showed significantly higher leaf numbers than the negative control (T10). However, VC treatments consistently produced significantly greater leaf numbers compared to VW treatments (Table 3). Branch development differed significantly among treatments ($p<0.001$). Treatments T1 − T9 were statistically similar with T1, T2 and T3 recording the highest number of branches (5.00 ± 0.00), followed by T4 (4.80 ± 0.45) and T5 − T9 (4.00 ± 0.00). In contrast, T10 produced the lowest main branches (3.00 ± 0.00). Days to flowering differed significantly among treatments ($p<0.001$). The longest time to flowering was recorded in T10 (42.40 ± 0.55 days), which was significantly higher than all other treatments. T1 and T5 (40.60 ± 0.55 days) were statistically identical. The shortest time to flowering was recorded in T4 (32.60 ± 0.55 days), followed by T3 (34.40 ± 0.55 days). The number of pods per plant differed significantly among treatments ($p<0.001$). The highest number of pods per plant was recorded in T4 (10.12 ± 0.89), which was significantly superior to all other treatments. T3 (6.60 ± 0.89) produced the next highest number of pods. The lowest number of pods per plant was observed in T10 (2.60 ± 0.55), which was significantly lower than all other treatments. The pod length was significantly affected by the treatments ($p<0.05$). The longest pods were recorded in T8 (7.54 ± 0.44 cm), T4 (7.12 ± 0.71 cm), and T6 (7.00 ± 0.68 cm), with overlapping responses among these treatments. Intermediate pod lengths were observed in T1, T3 and T9 (6.56 − 6.44 cm), while T5 (6.00 ± 0.70 cm) showed slightly lower values. The shortest pods were recorded in T2 (4.60 ± 0.89 cm), followed by T7 (5.58 ± 0.97) and T10 (5.58 ± 0.42) indicating a clear reduction compared to higher-performing treatments. Seeds per pod were significantly affected by the treatments ($p<0.05$). The highest values were recorded in T4 (8.40 ± 1.84) and T3 (7.60 ± 1.24), with T1 and T2 (7.00 − 7.40) showing overlapping intermediate responses. Treatments T5 − T8 (6.20 ± 0.45) produced lower values with no clear differences among them. The minimum number of seeds per pod was observed in T10 (5.20 ± 0.45), followed by T9 (5.60 ± 0.55), indicating a clear reduction compared to higher-performing treatments. The 100-seed weight of the *MI5* variety varied significantly among treatments. The highest seed weight was recorded in T4 (6.82 ± 0.32 g), which was statistically similar to T8 (6.80 ± 0.40 g), and both were significantly higher than T1 and T2. Treatments T6 (6.20 ± 0.45 g), T5 (5.80 ± 0.45 g), and T7 (5.80 ± 0.49 g) showed intermediate values and did not differ significantly from either the highest or some of the lower-performing treatments. T3 (5.32 ± 0.23 g) exhibited moderate seed weight, while T9 (5.60 ± 0.35 g) and T10 (5.20 ± 0.45 g) were not significantly different from several other treatments in the intermediate range. The lowest seed weights were recorded in T1 (4.21 ± 0.12 g) and T2 (4.21 ± 0.21 g), which were significantly lower than the top-performing treatments.

In the *MI6* variety, all parameters except pod width were significantly affected by the treatments. Plant height showed a strong response to treatments ($p<0.001$), with the tallest plants observed under 100% VC (T4) (52.34 ± 0.43 cm), while the shortest plants were recorded in the control (T10) (25.64 ± 0.15 cm). The 75% VC treatment (T3) produced the second-highest plant height and was significantly different from both the chemical fertiliser (T9) and control treatments. In contrast, treatments T5, T6, T7, and T8 did not differ significantly from the chemical fertiliser treatment (T9). Leaf number varied significantly among treatments ($p<0.001$). Treatments T1 − T4 recorded higher leaf numbers (15.00 − 16.20), with no significant differences among them. T8 (13.60 ± 1.34) showed intermediate values and was significantly lower than T1 − T4 but higher (not significantly) than T5 − T7 (12.00 ± 0.00). The lowest leaf numbers were observed in T10 (9.00 ± 0.00), which were significantly different from all other treatments. The number of main branches varied significantly among treatments ($p<0.001$). T4 (6.58 ± 0.45) recorded the highest number of branches and was significantly different from all other treatments. Treatments T1, T2 and T3 (4.80 − 5.00) showed similar values and were not significantly different from each other. Treatments T5 − T9 (4.00 ± 0.00) recorded lower values with no significant differences among them, while T10 (3.00 ± 0.00) showed the lowest number of branches and was significantly different from all other treatments. Days to flowering differed significantly among treatments ($p < 0.001$), indicating a strong treatment effect. The earliest flowering was observed in T4 (31.60 ± 1.14 days), which was statistically different from all other treatments. Treatments T3 (34.40 ± 1.14 days) and T8 (34.40 ± 0.55 days) also recorded relatively earlier flowering but were not significantly different from each other. Intermediate flowering durations were observed in T2 (36.40 ± 0.55 days), T7 (36.80 ± 0.84 days), T1 (38.00 ± 0.71 days), T9 (38.40 ± 0.55 days), and T6 (39.6 ± 1.82 days), with overlapping values indicating no clear statistical separation among these treatments. Treatment 5 (41.40 ± 0.55 days) showed delayed flowering compared to most treatments. The latest flowering was recorded in T10 (43.40 ± 0.55 days), which was significantly different from all other treatments. The number of pods per plant varied significantly among treatments ($p < 0.001$), indicating a strong treatment effect. The maximum number of pods was recorded in T4 (10.80 ± 1.10), which was statistically different from all other treatments. T3 (7.80 ± 1.09) also produced a relatively higher number of pods but remained significantly lower than T4. Lower pod numbers were observed in T6 (3.80 ± 0.45) and T5 (3.40 ± 0.55), which were not significantly different from each other. The minimum number of pods was recorded in T10 (2.00 ± 0.71), which was significantly different from most other treatments. Pod length varied significantly among treatments ($p < 0.001$). The longest pods were observed in T8 (7.78 ± 0.22 cm), followed by T3 (7.46 ± 0.45 cm), T2 (7.42 ± 0.42 cm), and T4 (7.42 ± 0.55 cm); however, these treatments were not significantly different from each other, indicating overlapping responses. The shortest pods were observed in T9 (5.58 ± 0.61 cm) and T10 (4.90 ± 1.78 cm), with T10 showing the minimum value and being significantly lower than other treatments. Seeds per pod showed limited variation among treatments, with T3 (7.40 ± 1.34) and T4 (7.00 ± 0.00) recording relatively higher values, although several treatments (T1, T2, T5, T8, and T9) exhibited overlapping responses, indicating no clear statistical separation. Lower values were observed in T6 (5.60 ± 0.89), T7 (5.80 ± 0.45), and T10 (5.20 ± 1.09), with T10 representing the minimum. The T3 and T4 reported significantly higher seeds per pot compared to the negative control (T10). In contrast, 100 seed weight showed clearer differentiation among treatments. T8 (7.00 ± 0.00 g) recorded the highest seed weight, followed by T3 (6.40 ± 0.12 g), T4 (6.14 ± 0.23 g), and T7 (6.20 ± 0.45 g). The lowest value was recorded in T10 (4.80 ± 0.80 g), indicating a clear reduction compared to other treatments.

For the *MIMB7* variety, the response to vermicompost application was most pronounced. Plant height differed significantly among treatments ($p < 0.001$), with the tallest plants in 100% VC (52.70 ± 0.57 cm) and the shortest in the chemical control (25.66 ± 0.19). The T3 reported the second -highest plant height (46.88 ± 4.89cm) that significantly different from T9 and T10. The number of leaves also differed significantly among treatments. T4 (19.80 ± 1.64) recorded the highest leaf number, followed by T3 (18.00 ± 0.00) and T2 (16.80 ± 1.64). The T1 (14.40 ± 1.34) showed intermediate values, while treatments T5 – T8 (12.00 – 12.60) recorded lower leaf numbers with no clear separation among them. The lowest values were observed in T9 (9.00 ± 0.00) and T10 (8.00 ± 0.00), indicating a distinct reduction. In contrast, the number of main branches showed relatively limited variation among treatments. T1 (5.00), T3 (4.8), and T4 (5.00) recorded higher values and were similar to T2 (4.4) and T5 (4.2), indicating partial overlap among these treatments. However, treatments T6 – T9 (4.00) formed a lower group and were distinct from T1, T3 and T4. The lowest number of branches was observed in T10 (3.00 ± 0.00), which was clearly separated from all other treatments. Days to flowering were significantly influenced by treatments, with earlier flowering observed in T4 (32.60 ± 0.89 days), while T10 (41.80 ± 0.45 days) and T1 (41.00 ± 1.00 days) recorded the longest duration. Intermediate flowering times were observed in T3 (35.00 ± 0.71), T7 (35.60 ± 1.34), and T8 (35.40 ± 0.89), whereas T2, T5, T6, and T9 showed relatively delayed flowering with overlapping values. The number of pods per plant also varied significantly among treatments. T4 (11.00 ± 1.40) produced the highest number of pods and was clearly separated from all other treatments.

T3 (7.00 ± 0.70) and T8 (6.20 ± 0.84) showed moderate pod numbers, while T1, T2, T5, T6, and T7 recorded lower values with no clear differences among them. The lowest pod number was observed in T10 (2.60 ± 0.55). Pod length showed less distinct separation among several treatments ($p < 0.05$). Longer pods were observed in T8 (7.88 ± 0.84 cm), T4 (7.74 ± 0.27 cm) and T2 (7.34 ± 0.46 cm), although these treatments were not significantly different from each other. The minimum pod lengths were recorded in T5 (3.98 ± 0.93 cm), T9 (4.36 ± 0.77 cm), and T10 (4.48 ± 1.15 cm). Pod width did not show any significant variation among treatments, with all values ranging between 0.48 and 0.54 cm, indicating that this trait was not influenced by treatment differences. Seeds per pod were significantly affected by the tested treatments ($p < 0.05$). The highest number of seeds per pod was recorded in T4 (7.40 ± 1.34) and T3 (7.00 ± 0.00), whereas the lowest value was observed in T10 (4.00 ± 1.87), indicating a clear reduction. Lower seed numbers were recorded in T5 − 8 (5.60), while T1, T2 and T9 (6.00 − 6.60) showed intermediate values with overlapping responses. In contrast, 100 seed weight showed clearer differentiation among treatments ($p < 0.05$). T4 (8.12 ± 0.23 g) recorded the highest seed weight, followed by T3 (7.16 ± 0.14 g) and T2 (7.14 ± 0.11 g), although some overlap was present among these treatments. Intermediate values were observed in T8 (6.80 ± 0.65 g) and T1 (6.90 ± 0.24 g), while lower values were recorded in T5 (5.00 ± 0.60 g) and T9 (5.00 ± 0.50 g). he lowest seed weight was observed in T10 (4.00 ± 1.00 g), indicating a clear reduction compared to VC and VW treatments.

Interaction Effects of Treatment Type and Mung Bean Variety on Growth and Yield Parameters

The interaction effects of treatment type and mung bean variety on growth and yield parameters were analysed using ANOVA, and the results are summarised in Table 4. Treatment type significantly influenced all measured traits, including plant height, number of leaves, number of main branches, days to flowering, number of pods per plant, pod length, pod width, and seeds per pod ($p < 0.01$). Varietal differences were also significant for plant height, number of leaves, number of main branches, and seeds per pod, whereas effects on days to flowering, number of pods per plant, pod length, and pod width were not significant. Importantly, significant interaction effects between treatment type and variety were observed for plant height, number of leaves, number of main branches, days to flowering, number of pods per plant, and seeds per pod, indicating that mung bean varieties responded differently to the applied treatments. The adjusted R^2 values ranged from 1.13% for pod width to 97.34% for plant height, indicating that the model explained most of the variability for key growth and yield traits. Overall, these findings suggest that both the choice of treatment and the specific variety are critical determinants of mung bean performance, with certain varieties exhibiting superior responses under higher concentrations of VC and VW applications.

Multivariate Assessment VC and VW Treatments

The PCA biplot (Figure 1) shows the multivariate relationships among mung bean treatments based on measured vegetative and yield traits. The first two principal components (Dim1 and Dim2) together accounted for 69.2% of the total variation (Dim1: 56.2%; Dim2: 13%), capturing most of the variability among treatments.

Dim1 (56.2%) separates treatments primarily according to yield-related traits, including plant height, number of leaves, number of main branches, pod length, and number of pods per plant. Treatments positioned positively along Dim1 exhibited higher values of these traits. Dim2 (13%) captures variation related to phenology (days to flowering) and pod width, distinguishing early- versus late-flowering treatments.

Positive correlations were observed among plant height, pod number, and main branch number, indicating that treatments promoting vegetative vigour also enhanced pod production. Days to flowering showed weak or negative correlations with yield traits, as reflected by its near-orthogonal orientation to most vectors. Pod width was moderately associated with Dim2 but weakly correlated with other traits. Ellipses represent 95% confidence intervals for treatment groups. Treatments T3 (75% VC), T4 (100% VC), and T8 (100% VW) clustered on the positive side of Dim1, demonstrating superior performance in plant height, leaf number, and pod production, highlighting them as the most promising high-yielding treatments. Treatments T2 (50% VC) and T6 (50% VW) exhibited intermediate performance, whereas T10 (Control) and T9 (Chemical fertiliser) were associated with lower vegetative growth and yield. T1 (25% VC) and T5 (25% VW) showed moderate vegetative growth but fewer pods, whereas T7 (75% WV) was intermediate.

The *MI5* variety was predominantly positioned on the negative side of Dim1, indicating relatively poor performance in vegetative growth and pod production. This variety showed lower plant height, fewer leaves, and fewer pods per plant, suggesting limited growth potential under most treatments. Furthermore, MI5 was associated with late flowering across several treatments, including T1 (25% VC), T5 (25% VW), and T9 (Chemical fertiliser).

T a b l e 4

The interaction effects of treatment type and variety on growth and yield parameters

Factor	Plant height (Adj ss)	Number of leaves (Adj ss)	Number of main branches (Adj ss)	Days to flowering (Adj ss)	Number of pods per plant (Adj ss)	Pod length (Adj ss)	Pod width (Adj ss)	Seeds per pod (Adj ss)
Treatment type	7,823.5++	901.74++	95.207++	1,292.46++	779.340++	93.521++	0.018400++	80.37++
Variety	299.5++	18.20++	2.013++	0.49	2.520	4.098	0.001733	13.48
Treatment type × variety	783.5++	57.48++	9.053++	78.04++	50.280++	33.832	0.011600	40.79++
Model summary R-Sq(adj)	97.34%	78.45%	78.07%	95.60%	85.97%	56.16%	1.13%	50.79%

Note: Adj ss − adjusted sum of squares; R-Sq(adj) − adjusted coefficient of determination; ++statistically significant at $p < 0.01$.

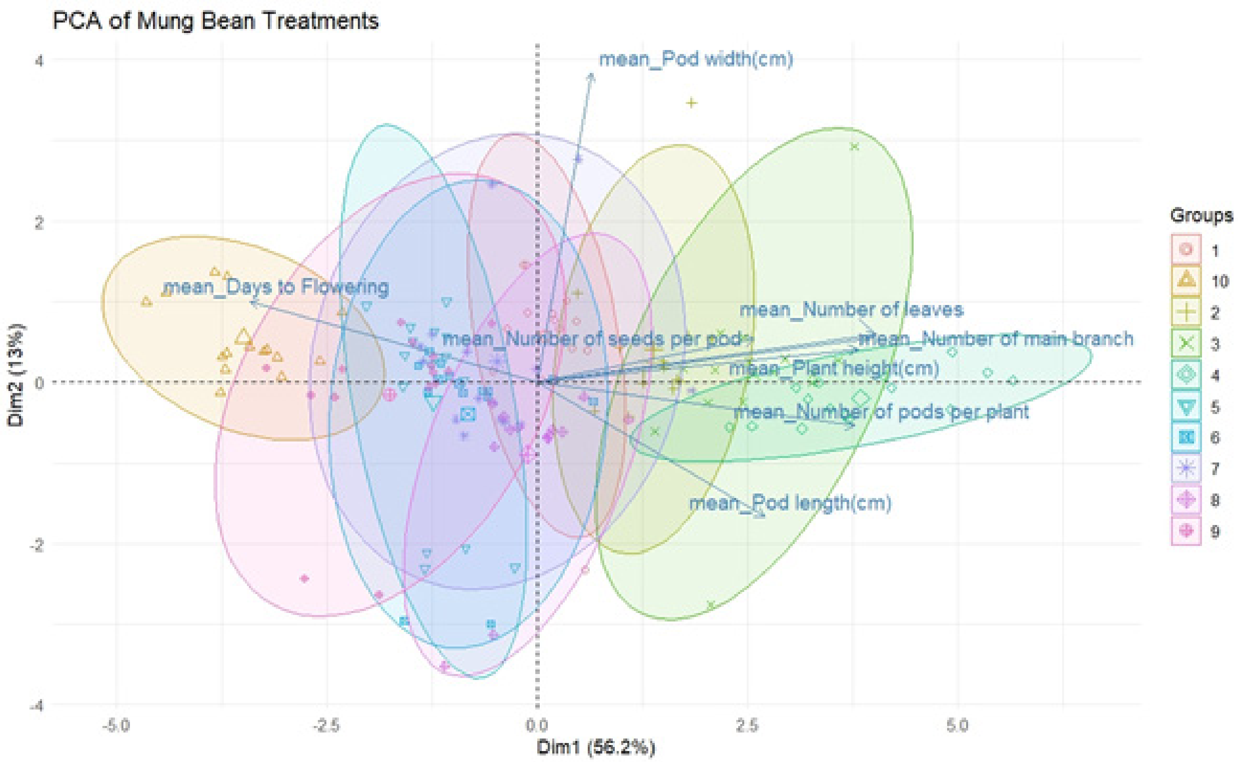

Figure 1. Principal component analysis (PCA) biplot showing the multivariate relationships among mung bean (*Vigna radiata* L.) treatments based on vegetative and yield traits. The first two principal components (Dim1 and Dim2) explain 69.2% of the total variation (Dim1 = 56.2%, Dim2 = 13%), capturing the major differences among the 10 treatments, including varying levels of vermicompost, vermiwash, chemical fertiliser, and control.

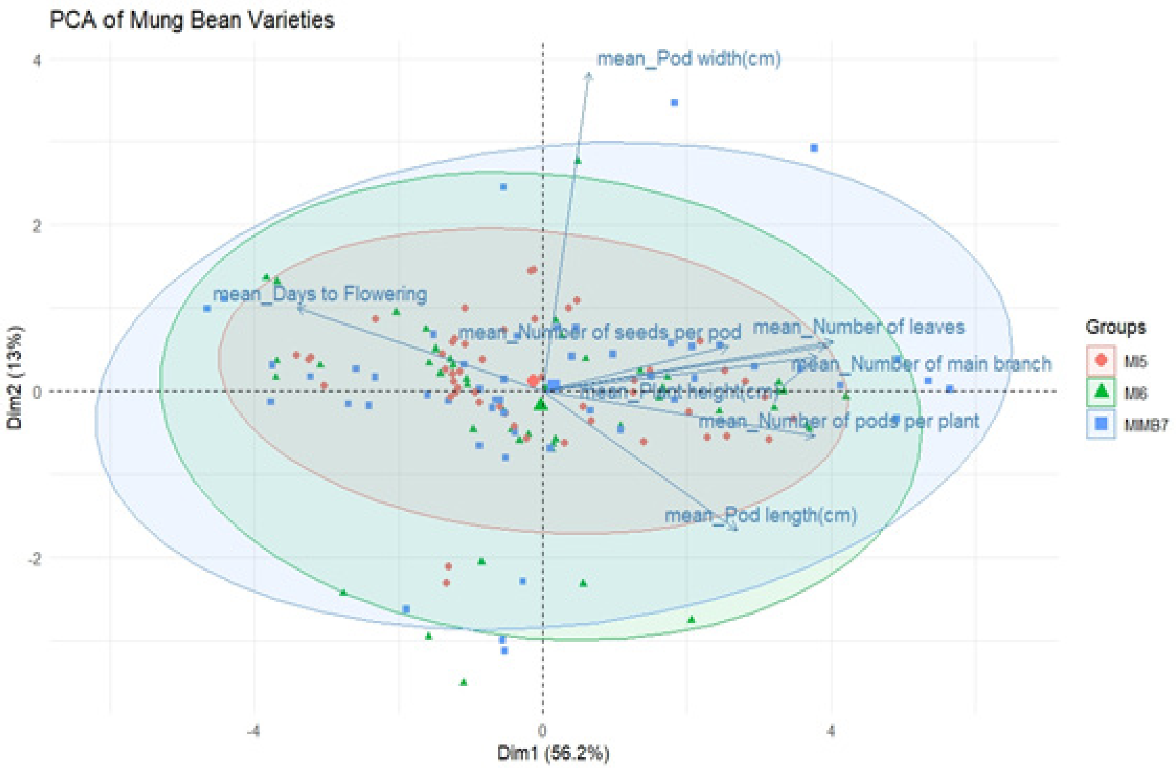

Figure 2. PCA-based clustering of mung bean varieties (MI5, MI6 and MIMB7) showing their distribution and grouping patterns based on vegetative and yield traits, with 95% confidence ellipses representing variability within each variety.
Note: PCA – see Figure 1.

These treatments likely contributed to the subdued vegetative growth and lower yield observed for *MI5*. The poor performance of *MI5* under these conditions underscores its limited suitability for high-yield environments and highlights the need to improve growth-promoting treatments. The *MI6* variety occupied an intermediate position along Dim1, suggesting moderate performance relative to both vegetative growth and pod production. This variety demonstrated balanced growth under treatments such as T2 (50% VC) and T6 (50% VW), where it exhibited moderate values for plant height, number of leaves, and number of pods per plant. *MI6* was positioned in the middle of the PCA biplot, indicating that it has the potential for improvement in terms of yield, particularly under treatments that provide a balanced supply of nutrients. Although *MI6* did not outperform *MIMB7,* its intermediate performance suggests that it could be a suitable option for environments where a balance between vegetative growth and flowering time is desired. *MIMB7* demonstrated exceptional performance, clustering predominantly towards the positive side of Dim1. This positioning indicates that *MIMB7* exhibited superior vegetative growth and yield characteristics compared to the other varieties. Under treatments with higher concentrations of VC and VW, specifically T3 (75% VC) and T4 (100% VC), *MIMB7* showed the highest plant height, number of leaves, and number of pods per plant, making it the most high-yielding variety among the tested treatments. These treatments enhanced its growth and yield performance, highlighting *MIMB7*'s suitability for environments where high yield is a priority. Its early flowering and robust pod production suggest that *MIMB7* is well-suited for regions requiring both vigorous vegetative growth and efficient pod development.

The PCA analysis identified distinct performance patterns across the three mung bean varieties under the different treatment conditions (Figure 2). While *MI5* showed poor vegetative growth and low yields, *MI6* displayed moderate growth with potential for improvement under balanced treatments. In contrast, *MIMB7* exhibited the best overall performance, particularly under higher concentrations of VC and VW, making it the most suitable variety for high-yield environments. These findings emphasise the importance of selecting appropriate treatments, such as higher levels of VC and VW, to optimise mung bean production, especially for varieties like *MIMB7*, which excel under such conditions.

DISCUSSION

The results of this study support the finding that both VC and VW increase the growth and yield of the mung bean varieties. The nutrient analysis showed that these organic amendments provide the necessary macronutrients and organic matter and help maintain optimum soil pH. These findings align with those of Zarei *et al.* (2017), who reported that VC improves nutrient availability and microbial activity in the soil. Similarly, crops are known to benefit from physiological processes, as evidenced by Suthar (2009), who reported that VW, which contains significant levels of plant growth regulators, i.e., auxin and cytokinin, has positive effects on crop-related actions.

One of the most notable observations was the very high phosphorus level in VW, consistent with studies by Makkar *et al.* (2017), who reported high phosphorus levels in VW produced from mixed organic waste. The high organic matter content in vermicompost aligns with findings from Joshi *et al.* (2014), who highlighted its role in improving soil structure, water retention, and microbial biomass, all important factors in plant development. Recent studies have demonstrated growing interest in naturally derived organic inputs for sustainable crop production. For instance, Kasthurirathna *et al.* (2025) reported that foliar application of an aqueous extract of *Moringa oleifera* enhanced germination and vegetative growth in Sri Lankan traditional rice accessions, highlighting the potential of organic biostimulants to improve plant performance across different crop species. Application of organically derived fish waste extract significantly induced vegetative growth in cucumber, underscoring the potential of organic inputs to promote plant development (Wijesundara *et al.* 2025; Wijesundara *et al.* 2026). In the present study, although the 100% VC treatment provided useful information on crop response under high organic input conditions, its sole application may not be economically or practically feasible under field conditions. The 75% VC treatment also demonstrated significantly higher responses in most measured parameters compared with both the chemical fertiliser and the control across all varieties, and therefore 75% VC was identified as the most appropriate level for practical field application to enhance vegetative growth and yield of Cowpea varieties. Future studies should focus on integrated nutrient management strategies that combine VC with recommended chemical fertiliser rates to optimise productivity and nutrient use efficiency.

Plant height increased uniformly across all types of mung beans *(MI5, MI6* and *MIMB7*) with increasing concentrations of VC. This result corroborates the work of Gutiérrez-Miceli *et al.* (2007), who demonstrated that organic inputs increase root elongation and shoot development in legumes. Plant growth regulators in VW, including indole acetic acid and humic substances, act similarly to synthetic hormones by improving photosynthetic efficiency and root development, resulting in taller shoots and denser foliage. Studies on crops such as okra (*Abelmoschus esculentus*) and black gram (*Vigna mungo*) show that 15% VW applications increased plant height by up to 108% and root length by 64% over controls after five weeks (Elumalai *et al.* 2013). Similarly, Pushpakumari *et al.* (2023) reported that VW enhanced the vegetative growth of cowpea varieties, further supporting the positive role of organic amendments in promoting legume growth. Likewise, Belmeskine *et al.* (2020) reported that vermicompost application significantly increased shoot biomass in common bean plants. The increased number of leaves and branches observed at higher vermicompost levels also supports findings by Pant *et al.* (2009), who reported increased vegetative growth of spinach. Dilshan *et al.* (2023) reported that applications of 30% and 40% VW improved lettuce growth and yield compared with the control, enhancing plant height, leaf number, leaf area, biomass, and root length. Such enhancements can be linked to the slow, gradual release of nutrients together with useful microbial metabolites, as reported by Lazcano and Domínguez *et al.* (2011).

Also, the timing of flowering was affected by VC. Early flowering in high-VC treatments is consistent with Rehman *et al.* (2023), who report that compost promotes flowering through enhanced nitrogen availability and hormonal effects. This finding is further supported by Aslam *et al.* (2024), who earlier found that mung beans under organic regimes flowered sooner than those under chemical regimes. VC induces earlier flowering and higher flower counts in plants such as tomatoes and petunias, often advancing stages by weeks with 40 − 50% soil substitution. Foliar VW with potassium nitrate further improves floret length and yield in crops such as tuberose (Steffen *et al.* 2019). Based on the reported yield, an increase in the number of pods, pod length and the number of seeds per pod was observed with vermicompost. These results align with Pooja *et al.* (2022), who demonstrated that vermicompost enhances the reproductive growth of legumes. Zuo *et al.* (2018) also reported improved fruiting in strawberries grown in vermicompost-enriched soils.

However, pod width did not show significant treatment effects, consistent with Khan *et al.* (2015), who proposed that these traits are more genetically determined. The significant increase in seed number at higher VC levels is also consistent with the results of Hosseinzadeh *et al.* (2016) on chickpeas under organic fertilisation.

Similar favourable effects on mung bean performance were observed with VW. The increased plant height, leaf number, and shorter duration to flowering in VW treatments align with Akazawa *et al.* (2023) and Jaybhaye and Bhalerao (2015), who attributed these improvements to plant growth substances in VW. Greater pod numbers and pod lengths were also noted, consistent with Rajasooriya and Karunarathna (2020) in cowpea. With increased flowering, outcomes reported by Awadhpersad *et al.* (2021) were observed. The strong interaction between yield response to fertiliser concentration and mung bean variety indicates that genotypic differences moderate how plants respond to organic inputs. This confirms the conclusions of Islam *et al.* (2024), who emphasised genotype-mediated nutrient utilisation efficiency. According to Mathenge *et al.* (2019), legume responses to soil amendments also differed depending on genotype. The enhanced model observed in this study (Adjusted R^2 >85% for many traits) further underscores the efficiency of organic inputs when properly paired with appropriate varieties under controlled conditions. Reproduction is faster in legumes treated with VW, and yield parameters are improved.

CONCLUSIONS

The study demonstrated that a comparative evaluation of vermicompost, vermiwash, chemical fertiliser, and control treatments revealed distinct variety-specific responses in mung bean. Across all three varieties (*MI5, MI6* and *MIMB7*), VC treatments consistently improved growth and yield parameters compared with chemical fertiliser and control, while VW treatments produced moderate responses generally comparable to chemical fertiliser. Although 100% VC recorded the highest values for most traits, 75% VC achieved statistically comparable performance for key parameters such as plant height, pod number, and seed weight. Among the varieties, *MIMB7* showed the strongest response to VC application, followed by *MI6,* while *MI5* exhibited relatively moderate responses. While the 100% vermicompost treatment was beneficial in the analysis, it is recognised that such high concentrations may not always be practical for large-scale agricultural systems. Therefore, 75% vermicompost is a more practical and sustainable alternative, offering significant improvements in plant vigour and yield. Future research should focus on further optimising 75% vermicompost and vermiwash combinations and on investigating their long-term effects on soil health and productivity. Such studies will help refine practical guidelines for incorporating organic amendments into mung bean farming while ensuring economic feasibility and environmental sustainability.

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