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Effect of Mycorrhizal Fungi and Biofertilizers on Vegetative Growth, Flowering Traits and Elemental Composition of *Murraya paniculata* (L.) Jack

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Abstract: Background: A factorial nursery experiment was carried out in spring and autumn of 2023– 2024 at a private nursery within Babylon Province, Iraq, to investigate the influence of biofertilizers combined with Libro organic fertiliser on *Murraya paniculata* (L) Jack. **Objectives:** assess impact of AMF, Bacillus, and Libro organic fertilizer on vegetative growth, flowering, leaf mineral content, and bioactive compounds.Present as concise subsection; align with measured outcomes. biofertilizer treatments were tried with non-inoculation as control (M0), arbuscular mycorrhizal fungus Glomus mosseae (M1), Bacillus circulans (M2) and a combination of both G. mosseaeand *B. circulans* inoculant (M3). These treatments were also mixed with three doses of Libro (0, 5 and 10 ml L^{-1}; F0, F1 and F2) in a completely randomised block design and with three replicates. Observations were taken on vegetative growth, flower character and leaf mineral content (N, P and K), bioactive compounds, as well as mycorrhizal colonisation. Responses varied by trait. The highest mean plant height (96.43 cm) and leaf area (4277.85 mm^2) were obtained in the M1 treatment, while Bacillus inoculation (M2) yielded the highest mean leaf number (80.98 leaves $plant^{-1}$), potassium content (5.5007%), alkaloid content (0.370 mg AE g^{-1}), and total carbohydrates: 20.44%; Only plantation of Musso alone or with phosphorusous were statistically different from the other treatments for all variables. M3 (combined inoculation) recorded the highest means of chlorophyll content (28.62 mg 100 g-1 fresh weight), inflorescence number (17.88 plant-1), Inflorescence diameter (59.05 mm), phosphorus content (0.6429%) and total phenolics concentration (17.14 mg GAE g-1 dry weight). Within Libro types, F1 gave the tallest plant (105.25 cm), and F2 improved many characters, including leaf area, inflorescence diameter, N, P, K and carbohydrate content. Involvement of interaction effects was observed: M1F2 in plant height (117.13 cm) and leaf area (5310.70 mm^2), M2F1 in inflorescences (26.35 $plant^{-1}$), M3F2 in phenolics (19.11 mg GAE g^{-1}), and M2F1 for alkaloids (0.456 mg AE g^{-1}). Table 14. Also, strong AMF structures were recorded from inoculated roots (100% TC and HC in both M1 and M3). In general, the results realised in this study showed that an integration of biofertilizers with organic fertilization positively enhanced several growth and quality characters in the nursery.

Key Words: *Murraya paniculata*, Arbuscular Mycorrhizal Fungi, Bacillus Circulans, Organic Fertiliser, Vegetative Growth, Bioactive Compounds, Phenolics, Alkaloids

INTRODUCTION

Murraya paniculata (L.) Jack, popularly known as orange jasmine or mock orange, is a member of the family Rutaceae. It is an evergreen shrub or small tree growing in the tropics and subtropics as an ornamental plant [1] The plant has thick and shiny, dark-green leaves and strongly scented white flowers with a waxy texture, and the strong fragrance of the flower is why this plant is often planted in gardens or used as hedging [2] Different parts of M. paniculata have long been used in Traditional Asian medicine to treat headaches, toothache, bruising, indigestion, menstrual imbalances and skin inflammation. Phytochemical screening indicated the presence of flavonoids, alkaloids, coumarins and essential oils in the plant, which account for its antioxidant activity, antimicrobial as well as anti-inflammatory [3]. The recent trend in nursery production is the development of sustainable practices that enhance quality with lower reliance on synthetic fertilisers [4]. Arbuscular mycorrhizal fungi (AMF) establish mutualistic relationships with the majority of higher plants, and assist in

nutrient acquisition such as phosphorus (P), water use efficiency, and stress tolerance. Earlier studies on ornamental plants revealed that inoculation with AMF increased growth and flowering, and reduced the need for fertiliser [5]. Plant growth-promoting rhizobacteria (PGPR), especially Bacillus strains, can further benefit the plants by bulk deposition of nitrogen, solubilization of phosphate and production of phytohormones for efficient root growth and nutrient uptake78. Organic fertilisers act in concert with biological inoculants by conditioning soil structure, increasing the level of organic matter, and enhancing microbial activity [6] Broths of liquid organic products featuring humic and fulvic acids, algae extracts, and minerals enhance vegetative and reproductive growth of different crops. In medicinal and aromatic plants, the use of biofertilizers/organisms in addition to organic amendments can modify secondary metabolite production and change phytochemical compositions [7] Although several phytochemical and pharmacological investigations on M. paniculata are available, only a few studies have been conducted on combining arbuscular mycorrhizal fungi (AMF), Bacillus biofertilizers, and organic fertilisers for growth, flowering and bioactive compound accumulation under nursery conditions [8] The present study was aimed to assess the influence of mycorrhizal Fungi (Arbuscular Mycorrhizal fungi) and B. circulans, alone and in combination with Libro organic manure on vegetative growth, flowering, Leaf element composition and some selected bioactive constituents of potted M. paniculata [9].

METHODS

Experimental Site and Plant Material

Two successive trials were carried out in the spring and autumn of 2023–2024 at a private nursery ("Babel for Flower Hobbyists"), Babylon Province, Iraq. Uniform seedlings of M. paniculata from a local nursery were transplanted into poly bag (5 kg) filled with a mixture of loam soil and peat moss (1:3 v/v). Soil sample Before Transplanting took place was collected for chemical analysis by standard methods.

Experimental Design and Treatments

The experiment was conducted in a factorial arrangement based on randomized complete block design (RCBD) with three replications. A total of five plants were included in each experimental unitFirst factor: biofertilizer (M) at four levels

- M0: no biofertilizer (control)
- M1: Glomus mosseae at 5 g pot^{-1}
- M2: Bacillus circulans at 5 g pot^{-1}
- M3: G. mosseae + B. circulans, each at 5 g pot^{-1}

Second factor: Libro organic fertiliser (F) at three levels

- F0: 0 ml L^{-1}
- F1: 5 ml L^{-1}
- F2: 10 ml L^{-1}

Libro was applied as a soil drench 30 days interval from establishment up to flowering. The product comprised humic and fulvic acids (20%), seaweed extract (10%), nitrogen, and calcium as labelled by the manufacturer.

Measured Traits

Vegetative Growth: The height (cm) of plants was recorded at flowering from the soil surface to the plant apex. The total leaves of each plant were counted in five plants of each plot and averaged. Leaf area growth (mm²) was calculated based on scanned images analysed with Digimizer software [10].

Total chlorophyll (mg 100 g^{-1} FW) was extracted with 80% acetone [11]. Absorbance was measured at 645 and 663 nm, with chlorophyll levels calculated using a standard formula.

Flowering Traits

At full flowering, inflorescences per plant were scored on five plants per plot. Inflorescence diameter (mm) was measured using a digital caliper from two opposing furthest points and averaged.

Leaf Mineral Content

Ground leaf samples (dry) were oxidised with H2SO4–salicylic acid–selenium [13]. Total nitrogen (%) was measured by the indophenol blue method (Berthelot reaction) [4] with absorbance at 660 nm. The content of phosphorus (%) was determined colourimetrically by ammonium molybdate–ascorbic acid method at 620 nm. Potassium (phosphorus) (%) was measured using the flame photometer and standard curves.

Bioactive Compounds

Leaf samples were extracted by 80% ethanol. Total phenolic content was measured with the Folin–Ciocalteu reagent and expressed as mg GAE g−1 dry weight. Total flavonoids were analysed according to the aluminium chloride method, and their contents were calculated in mg quercetin equivalent (QE) per gram dry weight. Total alkaloids were quantified by the bromocresol green (BCG) method. and reported as mg of atropine equivalents (AE) per go extract. Total carbohydrates were measured by the phenol–sulfuric acid microplate method [8].

Mycorrhizal Colonisation

Fine roots were sampled, washed in water, cleared with 10% KOH, acidified using 2% HCl and stained with lactoglycerol containing 0.05% trypan blue . The intensity of AMF colonisation was measured according to the magnified intersections method, by quantifying counts of the colonisation points from at least 100 test intersections per sample.

Statistical Analysis

The data were subjected to ANOVA in an appropriate RCBD factorial design. Mean comparisons were conducted with LSD test at 5% probability.

RESULTS AND DISCUSSION

Vegetative Growth

Plant Height: The highest significant variance of the plant height was seen in biofertilizer treatments (Table 1). The highest plants were those achieved in G. mosseae inoculation (M1) with a mean height of 96.43 cm, compared to that obtained from the uninoculated control (M0) of 77.97 cm. This pattern is in line with enhanced nutrient and water acquisition during AMF colonisation. The plant height was also influenced by Libro fertiliser, where F1 (5 ml L^{-1}) had the highest mean height (105.25 cm), followed by F2 (96.27 cm), while the lowest mean was of F0 (60.97 cm).

The interaction of biofertilizer × organic fertiliser was also significant. Tallest plant was observed from M1F2 (117.13 cm) followed by M1F1(115.72cm) and M2F1(114.41cm). M1F0 recorded the lowest value (56.45 cm). These findings suggest that the growth response was not with either inoculation or Libro concentration, but had a combined effect of both.

Number of leaves

The number of leaves differed significantly among the biofertilizer treatments (Table 2). Bacillus circulans (M2) resulted in the highest mean leaf number (80.98 leaves $plant^{-1}$), which was significantly higher compared to the control treatment (M0, 70.75 leaves $plant^{-1}$). In contrast, M1 was also the smallest on average (62.68 leaves per $plant^{-1}$), showing that leaf production responsiveness was not the same for plant height and leaf area.

Among the levels of Libro, F0 led to the highest mean number of leaves (80.10 leaves $plant^{-1}$), whereas lower values were found in F1 and F2 (66.18 and 67.87 leaves $plant^{-1}$). The maximum i value was found in M2F0 (110.25 leaves $plant^{-1}$) and the minimum in M1F1 (49.25 leaves $plant^{-1}$). These measurements indicate strong interaction effects and trait-specific changes in response to microbial inoculation and fertiliser level.

Leaf Area

Leaf area Mycorrhizal inoculation significantly enhanced leaf area as compared to the control (Table 3). M1 recorded the highest average leaf area (4277.85 mm^2), followed by M2 (3823.77mm^2) and in contrast, M3 had the lowest mean of 2412.77 mm^2). The highest mean leaf area among Libro levels was observed in F2(10 mL L^{-1}) (3752.14 mm^2); the means of F0 and F1 did not differ from each other (2960.97 and 2955.98 mm^2, respectively).

Table 1: Effect of Biofertilizers and Libro Organic Fertilizer on Plant Height (Cm) of *Murraya paniculata*

Mean (M)	Libro organic fertilizer (F)			Biofertilizers (M)
	Fertilizer 10 ml L^{-1} F2	Fertilizer 5 ml L^{-1} F1	No fertilizer F0	
77.97	91.73	81.56	60.63	Control (M0)
96.43	117.13	115.72	56.45	Mycorrhiza (M1)
78.67	83.56	114.41	59.92	Bacillus (M2)
89.62	92.67	109.33	66.87	Mycorrhiza + Bacillus (M3)
	96.27	105.25	60.97	Mean (F)

F = 7.0, M = 6.0, MF = 5.0, L.S.D. 0.05

Table 2: Effect of Biofertilizers and Libro Organic Fertilizer on the Number of Leaves (Leaves $Plant^{-1}$) of *Murraya paniculata*

Mean (M)	Libro organic fertilizer (F)			Biofertilizers (M)
	Fertilizer 10 ml L^{-1} F2	Fertilizer 5 ml L^{-1} F1	No fertilizer F0	
70.75	73.6	72.4	66.25	Control (M0)
62.68	67.3	49.25	71.50	Mycorrhiza (M1)
80.98	65.2	67.50	110.25	Bacillus (M2)
71.13	65.4	75.6	72.4	Mycorrhiza + Bacillus (M3)
	67.87	66.18	80.1	Mean (F)

F = 15.00, M = 5.00, MF = 6.00, L.S.D. 0.05

Table 3: Effect of Biofertilizers and Libro Organic Fertilizer on Leaf Area (mm^2) of *Murraya paniculata*

Mean (M)	Libro organic fertilizer (F)			Biofertilizers (M)
	Fertilizer 10 ml L^{-1} F2	Fertilizer 5 ml L^{-1} F1	No fertilizer F0	
3086.93	3650.4	2622.92	2986.48	Control (M0)
4277.85	5310.7	4895.28	2626.56	Mycorrhiza (M1)
3823.77	3981.12	2728.32	4759.87	Bacillus (M2)
2412.77	4067.44	1676.9	1507.96	Mycorrhiza + Bacillus (M3)
	3752.14	2955.98	2960.97	Mean (F)

F = 85.67, M = 90.22, MF = 75.80, L.S.D. 0.05

Table 4: Effect of biofertilizers and Libro Organic Fertiliser on Total Chlorophyll Content (mg 100 g^{-1} Fresh Weight) of *Murraya paniculata*

Mean (M)	Libro organic fertilizer (F)			Biofertilizers (M)
	Fertilizer 10 ml L^{-1} F2	Fertilizer 5 ml L^{-1} F1	No fertilizer F0	
25.42	19.61	32.43	24.21	Control (M0)
26.61	27.39	23.05	29.39	Mycorrhiza (M1)
28.35	27.12	30.79	26.14	Bacillus (M2)
28.62	27.96	27.4	29.5	Mycorrhiza + Bacillus (M3)
26.58	24.77	27.92	27.06	Mean (F)

F = 0.80, M = 0.60, MF = 0.70, L.S.D. 0.05

Table 5: Effect of biofertilizers and Libro Organic fertilizer on number of inflorescences (inflorescences plant⁻¹) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
11.65	10.25	15.5	9.2	Control (M0)
13.77	15.6	14.6	11.13	Mycorrhiza (M1)
17.76	16.7	26.35	10.24	Bacillus (M2)
17.88	24.50	15.6	13.55	Mycorrhiza + Bacillus (M3)
	16.76	18.01	11.3	Mean (F)

F = 4.00, M = 2.75, MF = 3.25

Table 6: Effect of Biofertilizers and Libro Organic Fertilizer on Inflorescence Diameter (Mm) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
45.32	69.15	22.6	45.12	Control (M0)
40.18	56.78	26.78	37.98	Mycorrhiza (M1)
52.17	65.23	34.68	57.6	Bacillus (M2)
59.05	88.4	67.13	22.6	Mycorrhiza + Bacillus (M3)
48.61	69.15	37.57	40.1	Mean (F)

F = 10.45, M = 7.12, MF = 8.50, L.S.D. 0.05

Table 7: Effect of Biofertilizers and Libro Organic Fertilizer on Leaf Nitrogen Content (%) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
2.608	2.537	2.739	2.548	Control (M0)
2.802	2.625	2.869	2.911	Mycorrhiza (M1)
2.69	2.838	2.512	2.82	Bacillus (M2)
2.558	2.903	2.306	2.485	Mycorrhiza + Bacillus (M3)
	2.776	2.606	2.693	Mean (F)

F = 0.10, M = 0.08, MF = 0.09, L.S.D. 0.05

Total chlorophyll content

Both factors had a significant impact on the total chlorophyll content (Table 4). Among the treatments under biofertilizer, plants treated with M3 recorded the highest mean of chlorophyll content (28.62 mg 100 g⁻¹ fw), closely followed by those treated with M2 (28.35), while their counterpart in the control treatment (M0) produced the lowest mean value (25.42). Mean chlorophyll concentration among Libro levels was highest for F1 (27.92), followed by F0, and then F2 (27.06 and 24.77, respectively).

At the interaction level, maximum chlorophyll content was registered in M0F1 (32.43 mg 100 g⁻¹ fresh weight) and the minimum in M0F2 (19.61). This trend shows that chlorophyll response was caused by the composition of the treatment rather than one factor.

Flowering Traits

Number of Inflorescences

No./ (number of inflorescence) Number of inflorescences is an important ornamental trait, and it was significantly influenced by treatments (Table 5). The greatest mean installation number was observed in M3 (17.88 plant⁻¹), followed by M2 (17.76 plant⁻¹), and the control revealed the lowest mean (11.65 plant⁻¹). The application of Libro fertiliser has confirmed an increase in flowering by F1, which reached the highest average of 18.01 inflorescences plant⁻¹ when compared with 11.30 for F0.

The maximum reciprocal interaction value for inflorescence number was obtained with M2F1 (26.35 plant⁻¹) and the minimum in M0F0 (9.20 plant⁻¹). These results support that the biomass, yield, and reproductive performance were significantly affected by the joint application of microbial inoculants and Libro fertiliser.

Inflorescence Diameter

The diameter of the inflorescence was significantly influenced by both factors (Table 6). The largest mean diameter was recorded in M3 (59.05 mm), while M1 had the smallest mean (40.18 mm). Across Libro levels, F2 produced the highest mean diameter (69.15 mm), whereas F1 recorded the lowest mean (37.57 mm). The maximum interaction value (88.40 mm) was observed in M3F2, reflecting a strong positive response of this trait to combined inoculation and the higher Libro rate.

Leaf Mineral Content

Nitrogen: Leaf nitrogen content increased significantly with treatment combinations (Table 7). Among biofertilizer treatments, M1 recorded the highest mean N content (2.802%), followed by M2 (2.690%), while M3 had the lowest mean (2.558%). For Libro levels, F2 produced the highest mean (2.776%), compared with 2.693% for F0 and 2.606% for F1. The highest interaction value was M3F2 (2.903%).

Phosphorus

Leaf phosphorus showed a different pattern (Table 8). The combined inoculation treatment M3 gave the highest mean P content (0.6429%), while the control (M0) had the lowest mean (0.4612%). Libro fertilizer at F2 also produced the

Table 8: Effect of Biofertilizers and Libro Organic Fertilizer on Leaf Phosphorus Content (%) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
0.4612	0.5168	0.5187	0.3480	Control (M0)
0.4646	0.6277	0.3185	0.4477	Mycorrhiza (M1)
0.5594	0.5103	0.6795	0.4884	Bacillus (M2)
0.6429	0.7387	0.4934	0.6966	Mycorrhiza + Bacillus (M3)
	0.5984	0.5025	0.4952	Mean (F)

F = 0.10, M = 0.12, MF = 0.21, L.S.D. 0.05

Table 9: Effect of Biofertilizers and Libro Organic Fertilizer on Leaf Potassium Content (%) Of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
3.1844	5.5597	2.1577	1.8360	Control (M0)
5.4708	6.0210	5.5937	4.7977	Mycorrhiza (M1)
5.5007	6.6207	4.7447	5.1367	Bacillus (M2)
5.0810	6.3070	4.7413	4.1947	Mycorrhiza + Bacillus (M3)
	6.1271	4.3093	3.9913	Mean (F)

F = 1.05, M = 1.21, MF = 2.11, L.S.D. 0.05

Table 10: Effect of Biofertilizers and Libro Organic Fertilizer on Total Phenolic Content (Mg Gae G⁻¹ Dry Weight) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
14.99	16.23	13.17	14.515	Control (M0)
15.72	13.29	14.68	18.165	Mycorrhiza (M1)
15.22	16	14.54	15.17	Bacillus (M2)
17.14	19.11	15.56	18.755	Mycorrhiza + Bacillus (M3)
	16.17	14.14	16.29	Mean (F)

F = 1.90, M = 1.50, MF = 1.65, L.S.D. 0.05

Table 11: Effect of Biofertilizers and Libro Organic Fertilizer on Total Flavonoid Content (Mg Qe G⁻¹ Dry Weight) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
12.43	11.92	13.16	13.22	Control (M0)
11.19	10.55	12.25	11.78	Mycorrhiza (M1)
11.35	9.84	13.32	10.88	Bacillus (M2)
12.24	12.49	11.76	12.46	Mycorrhiza + Bacillus (M3)
	11.2	12.12	11.88	Mean (F)

F = 1.90, M = 1.50, MF = 1.80, L.S.D. 0.05

Table 12: Effect of Biofertilizers and Libro Organic Fertilizer on Total Alkaloid Content (Mg Ae G⁻¹) of *Murraya paniculata*

	Libro organic fertilizer (F)			
Mean (M)	Fertilizer 10 ml L⁻¹ F2	Fertilizer 5 ml L⁻¹ F1	No fertilizer F0	Biofertilizers (M)
0.255	0.178	0.217	0.37	Control (M0)
0.183	0.174	0.193	0.183	Mycorrhiza (M1)
0.37	0.306	0.456	0.348	Bacillus (M2)
0.224	0.23	0.279	0.165	Mycorrhiza + Bacillus (M3)
0.253	0.226	0.276	0.257	Mean (F)

F = 0.05, M = 0.04, MF = 0.03, L.S.D. 0.05

highest mean P content (0.5984%). The maximum interaction value was recorded in M3F2 (0.7387%), indicating a strong positive response of phosphorus accumulation under combined inoculation with the higher Libro rate.

Potassium

Leaf potassium content responded positively to both biofertilizer treatment and Libro level (Table 9). M2 recorded the highest mean K content (5.5007%), closely followed by M1 (5.4708%), whereas the control had the lowest mean (3.1844%). F2 gave the highest mean K content (6.1271%), and the maximum interaction value occurred in M2F2 (6.6207%).

Bioactive compounds

Total Phenolics

Total phenolic content was affected by treatment (Table 10). The highest mean phenolic content was recorded in M3 (17.14 mg GAE g^{-1} dry weight), while the control (M0) had the lowest mean (14.99 mg GAE g^{-1}). Across Libro levels, F0 and F2 (16.29 and 16.17 mg GAE g^{-1}, respectively) were higher than F1 (14.14 mg GAE g^{-1}). The maximum interaction value was M3F2 (19.11 mg GAE g^{-1}).

Total Flavonoids

Total flavonoid content showed a modest but significant variation among treatments (Table 11). The control treatment (M0) recorded the highest mean flavonoid content

Table 13: Effect of Biofertilizers and Libro Organic Fertilizer on Total Carbohydrate Content (%) of *Murraya paniculata*

Mean (M)	Libro organic fertilizer (F) Fertilizer 10 ml L^{-1} F2	Fertilizer 5 ml L^{-1} F1	No fertilizer F0	Biofertilizers (M)
18.99	19.71	14.42	22.85	Control (M0)
15.72	19.93	18.68	8.55	Mycorrhiza (M1)
20.44	20.75	21.67	19.9	Bacillus (M2)
18.26	18.62	20	16.16	Mycorrhiza + Bacillus (M3)
	19	18.69	17.36	Mean (F)

F = 1.00, M = 0.75, MF = 0.85, L.S.D. 0.05

Table 14: Mycorrhizal Colonization Components in Roots of *Murraya paniculata* under Amf-Containing Treatments

Treatment	Total colonization (%)	Hyphal colonization HC (%)	Vesicle colonization VC (%)	Arbuscular colonization AC (%)
M1 (Mycorrhiza)	100	100	90	75
M3 (Mycorrhiza + Bacillus)	100	100	92	78

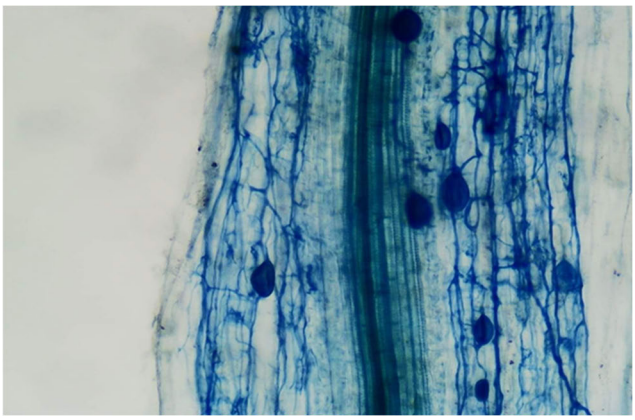

Figure 1: "Microscopic Structure of Plant Tissue (Stained Longitudinal Section)"

(12.43 mg QE g^{-1} dry weight), whereas M1 had the lowest mean (11.19 mg QE g^{-1}). Among Libro levels, F1 produced the highest mean flavonoid content (12.12 mg QE g^{-1}). The highest interaction value was observed in M2F1 (13.32 mg QE g^{-1}), while the lowest was M2F2 (9.84 mg QE g^{-1}) (Figure 1).

Total alkaloids

Total alkaloid content increased most strongly under Bacillus inoculation (Table 12). M2 gave the highest mean alkaloid content (0.370 mg AE g^{-1}), while M1 had the lowest mean (0.183 mg AE g^{-1}). Across Libro levels, F1 produced the highest mean (0.276 mg AE g^{-1}), followed by F0 (0.257 mg AE g^{-1}), whereas F2 was lowest (0.226 mg AE g^{-1}). The highest interaction value was M2F1 (0.456 mg AE g^{-1}).

Total Carbohydrates

The % of total carbohydrate content was profoundly influenced by each factor as well as their interaction (Table 13). Biofertilizers mean comparisons; the highest average carbohydrate concentration (20.44%) was observed by M2 and the lowest average (15.72%) by M1. Regarding Libro levels, F2 had the greatest mean (19.00), followed by F1 (18.69) and F0 (17.36%). The highest single interaction value was however obtained for M0F0 (22.85 %) and the lowest for M1F0 (8.55 %), indicating a clear treatment specific variation.

Mycorrhizal Colonization

Table 14 summarizes mycorrhizal colonization components for the AMF-containing treatments (M1 and M3). Both treatments showed 100% total colonization and 100% hyphal colonization (HC). Vesicle colonization (VC) and arbuscular colonization (AC) were slightly higher in M3 (92% and 78%, respectively) than in M1 (90% and 75%). These values confirm successful AMF establishment in the inoculated treatments.

CONCLUSIONS

This study shows that the response of *Murraya paniculata* to biofertilizers and Libro organic fertilizer was trait-dependent rather than uniform across all measured parameters. G. mosseae alone (M1) was most effective for plant height and leaf area, Bacillus circulans (M2) was superior for leaf number, potassium, alkaloids, and total carbohydrates, and the combined inoculation (M3) gave the best mean values for chlorophyll, inflorescence number, inflorescence diameter, phosphorus, and total phenolics. Libro level F1 favored traits such as plant height, chlorophyll, and inflorescence number, whereas F2 improved leaf area, inflorescence diameter, N, P, K, and carbohydrate content. Several traits showed strong interaction effects (for example, M1F2 for plant height and leaf area, M2F1 for inflorescence number and alkaloids, and M3F2 for phenolics), indicating that the best treatment combination depends on the target production trait. The root colonization data confirmed successful AMF establishment in inoculated treatments. Overall, integrating microbial inoculants with organic fertilization can be a useful strategy for improving growth and selected quality traits of M. paniculata in nursery production.

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