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Enhancing NPK Fertilizer Efficacy and Ultisol Chemical Characteristics by *Arbuscular Mycorrhiza* in Watermelon Cultivation

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Abstract

Ultisols, characterised by elevated acidity and decreased nutrient availability, restrict watermelon production (*Citrullus lanatus*). This study assesses the impacts of *arbuscular mycorrhiza* (AM) and different NPK fertiliser concentrations on watermelon production at Ultisol. Employing a random block design, the results demonstrated that AM inoculation raised the soil pH to 6.05. The 75% NPK dosage (P3) augmented phosphorus availability (50.56 ppm) and enhanced fruit weight (3.25 kg), circumference (54.19 cm), and length (37.81 cm). Significantly, the combination of AM and 75% NPK (M1P3) optimised soil organic carbon (6.45%) and fruit sweetness (13.90 Brix), surpassing the 100% NPK treatment. In summary, the application of the *Glomus* and *Acaulospora* consortium, with 75% NPK, is ideal for improving ultisol characteristics, increasing watermelon output, and diminishing fertiliser needs.

Keywords: *Acaulospora*; Fertilizer Efficiency; *Glomus*; Suboptimal Land; Watermelon

1. Introduction

Watermelon (*Citrullus lanatus*) is a widely favoured fruit in Indonesia, occupying a pivotal role in the horticulture industry owing to its significant economic significance [1]. Watermelon has a very high water content of around 90-92% and is rich in vitamins and antioxidants [2]. Watermelons are predominantly cultivated in tropical nations such as Indonesia, namely in lowland areas at altitudes of 0–600 meters above sea level, particularly in arid locations with elevated solar intensity [3]. With the increasing population, the annual demand for watermelon in Indonesia escalates. In 2023, national output totalled 408,127 tonnes; yet, variations in yields and a rise in demand suggest a growing public interest. This underscores the necessity for efficient initiatives to enhance production. Nonetheless, augmenting watermelon cultivation on Ultisol is impeded by the soil's inherent low fertility [4].

Arbuscular Mycorrhizal (AM) are mutualistic symbionts that improve the efficiency of nutrient uptake in plants, especially phosphorus, in acidic and low-fertility soils such as Ultisols [5]. The utilisation of mycorrhizal species, including *Acaulospora* and *Glomus*, has demonstrated an impact on soil pH and improved phosphorus availability in Ultisols, with species-dependent variations in response [6]. In acidic soils, *arbuscular mycorrhizal* fungi are recognised for their capacity to solubilise organic phosphorus into orthophosphate forms, which are more readily available to plants [7]. This large hyphal network improves the ability of plant roots to absorb water and vital nutrients, especially phosphorus, which frequently remains unavailable in the soil *Glomus sp*. is known for enhancing phosphorus uptake and facilitating plant growth in nutrient-deficient soil environments [8] .

Arbuscular mycorrhizal markedly elevates the activity of sucrose accumulation enzymes, such as sucrose synthase and sucrose phosphate synthase, therefore augmenting fruit weight and refining the sweetness of watermelon [9]. The application of *arbuscular mycorrhiza* is positively correlated with the dosage of NPK fertiliser; a 50% NPK dose improves plant productivity during the vegetative stage.Inoculation with *arbuscular mycorrhizae* increases leaf chlorophyll

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content and macronutrient absorption, reduces aluminium toxicity in acidic conditions, and regulates proline metabolism, enhancing plant resistance to edaphic stress [10,11]. MA symbiosis enhances watermelon root development and produces phthalate compounds, which change the bacterial community structure in the soil and increase soil enzyme activity, helping plants shed nutrients [12].

Despite extensive research on *mycorrhizae's* ability to reduce the use of chemical fertilisers, little is known about how the combination of *Glomus* and *Acaulospora genera* at different NPK fertiliser dosage levels affects the Ultisol chemistry of watermelon plants. Therefore, this study aims to evaluate how different NPK fertiliser doses impact watermelon plant production by enhancing Ultisol chemical characteristics, such as pH and phosphorus availability, through *Arbuscular Mycorrhizae* inoculation. It is believed that, using this method, a more effective and longer-lasting integrated fertilisation plan will be developed to facilitate the growth of watermelon production across the country, particularly on less-than-ideal land.

2. Material and methods

2.1. Place and Time of Research

Field research was conducted from September to March 2026 in Gelumbang, South Sumatra, Indonesia, located at coordinates 3°14'47.4'' S and 104°26'29.7'' E. This area is part of the dry land region dominated by the Ultisol soil order. The analysis of soil chemical properties will be conducted at the Chemistry, Biology, and Soil Fertility Laboratory, Department of Soil Science, Faculty of Agriculture, Sriwijaya University.

2.2. Research Material

The main materials used include Watermelon seeds (*Citrullus lanatus*), *arbuscular mycorrhizal* (MA) consortium inoculant of the genus *Glomus* and *Acaulospora* , manure. The chemical fertilizers applied consist of NPK 16:16:16, NPK Grower 15-09-20 TE, Nitrabor, MKP, TSP, KCl, and leaf fertilizer. Pure laboratory-grade chemicals are used for soil chemical properties analysis.

2.3. Research Methods

2.3.1. Experimental Design and Field Layout

The field experiment was arranged using a two-factor Randomized Block Design (RBD) with three replications, resulting in 30 experimental units.

Factor I is *Arbuscular Mycorrhizal* Consortium Inoculation (M), consisting of 2 levels: M 0 (without inoculation) and M 1 (with *Glomus* and *Acaulospora* consortium inoculation).

Factor II is the Recommended NPK Fertilizer Dose (P), consisting of 5 levels: P 0 (0%), P 1 (25%), P 2 (50%), P 3 (75%), and P 4 (100% dose of NPK compound fertilizer).

Each experimental plot measured 2 m × 2 m and was planted with 3 watermelon plants in a triangular pattern (planting distance ± 1 m). The total plant population in all experimental plots was 90 plants.

2.4. Research Implementation

2.4.1. Initial Soil Characterization

To assess the initial chemical characteristics of Ultisol soil in Gelumbang, composite soil samples were taken at a depth of 0–30 cm. The parameters tested on the soil samples included pH, cation exchange capacity (CEC), total nitrogen, available phosphate, and base cations (Ca, Mg, and K) [13,14] . The results of this analysis are used as a basis to verify the status of Ultisol and are also used as a reference for developing NPK fertiliser doses [15].

2.4.2. Preparation of Planting Media and Initial Land Management

Weed control and mechanical soil tillage are the first steps in land preparation. After that, the area is divided into experimental plots measuring two by two meters, spaced 70 centimetres apart. Dolomite was evenly applied at a rate of 1.5 kg per plot or equivalent to 3.7 tonnes per hectare to improve the physical and chemical characteristics of the acidic soil [4]. Before planting the seedlings, a biological agent consisting of *Gliocladium sp*. was used to control soil-borne pathogens, also two weeks after liming, manure was applied at a consistent dose of 10 kg/plot (2.5 kg/m^2) as a

soil conditioner and basic nutrient source [16]. Black and silver plastic mulch which has been proven to promote increased fruit weight in watermelon plants, was used to cover the beds to maintain soil moisture by reducing water evaporation and preventing weed growth [18]. Next, the watermelon is planted in planting holes drilled in the mulch with a distance of about one meter.

2.4.3. Seed Sowing

The preparation of watermelon seeds begins with soaking them in warm water for 24 hours to stimulate germination. The seeds that have been soaked are sown into tray pots using a growing medium of a mixture of soil, compost, and burnt rice husks in a volume ratio of 1:1:2. The composition of this media was chosen to optimise aeration and drainage and maintain low levels of available P to stimulate early colonisation of *Arbuscular Mycorrhizal* (AM) [19]. The initial inoculation is carried out during the seedling stage with a minimum dose of 5 g/plant [20] . Maintenance in the nursery includes routine watering twice a day (morning and evening). The seedlings are ready to be transplanted to the field at 14 days after sowing (DAS).

2.4.4. Field Planting and Inoculation

At 14 days after sowing (DAS) or when they have three to four genuine leaves, watermelon seedlings are moved. Planting takes place in 10–15 cm deep planting holes that have been inoculated with a consortium of MA at a maximum concentration of 15 g per plant (20), by making certain that the inoculum comes into direct touch with the seedlings' roots. To reduce transplant stress, the seedlings and their growing material are gently moved. The seedlings are placed upright in the middle of the hole, covered with earth, and gently compacted. Planting is done in the morning (07:00–10:00 WIB) or in the afternoon (15:00–18:00 WIB), and the first watering is done right away to keep the root zone moist and promote plant adaptability.

2.4.5. Plant Maintenance

From the early planting stage through the fruit enlargement phase, watermelon plant maintenance is performed regularly using a preventive strategy based on biological agents. Spreading the biological agent based on the fungus *Gliocladium sp*. is one way to avoid soil pests and diseases like nematodes and cutworms during the early planting stage near the stem's base [17], while surface pests such as snails and slugs are controlled manually. During the active vegetative phase, protection against leaf spot diseases and surface fungi is administered by spraying a bio-fungicide containing the antagonistic fungus *Trichoderma sp*. at a dosage of 30 ml per tank [17] . Subsequently, in the initial generative and blooming stages, rigorous biological control measures are implemented to preserve the vitality of floral organs and fruit buds through a regimen of periodic applications of the biological agent *Gliocladium sp*.(15 g) and the bio-fungicide *Trichoderma sp.* 30 ml [21]. Crop protection prior to harvest during the fruit formation and enlargement phase aims to avert fruit rot and leaf spot diseases induced by fungal or bacterial infections through the alternating application of biological agents, specifically *Gliocladium sp.* (15 g) and *Corynebacterium* 15–30 ml [21] .

2.4.6. Fertilization

Fertilisation management is systematically regulated to address the distinct nutritional requirements of watermelon plants in each physiological stage. The initial fertilisation occurs during the early planting phase, using a blend of NPK 16-16-16 fertiliser and calcium nitrate boron or nitrabor [22]. During the active vegetative phase, functional macrofertilisers are administered through a combination of NPK 16-16-16, Nitrabor, and a high-phosphate foliar fertiliser (Ultradap) to promote the proliferation of the plant's root hair network. The provision of high-concentration phosphate at the initial growth stage is essential for expediting root system development, thereby enhancing the primary nutrient absorption capacity to support vegetative growth, including plant height and stem diameter [23]. The fertilisation formulation is subsequently transitioned to the early generative phase and flowering stage by employing a high concentration of phosphate and potassium through a blend of NPK Grower 15-09-20 TE, Nitrabor, and MKP to stimulate floral primordia initiation [23], and providing calcium-boron, which is essential for improving pollen viability and mitigating the danger of fruit drop [24]. Throughout the fruit development and expansion stage, microfoliar fertilisers (Calcium Boron) are administered incrementally every five days to fortify the fruit cell walls and avert skin cracking caused by humidity variations, with periodic escalations in the dosage of NPK Grower 15-09-20 TE and Nitrabor [23,25]. Furthermore, the mixing of KCl fertiliser has been found to enhance the translocation of photosynthates, increase sugar accumulation (measured in Brix), and improve the weight of watermelon fruit [26].

2.4.7. Harvesting

Watermelon harvesting occurs 60–65 days after sowing (DAS) when the fruit attains peak ripeness. The ripeness indicator is visually signified by the desiccation of the tendril at the fruit's stem node and the alteration of the ground-spot colour to yellowish or cream [27].

2.5. Observation Of Parameters

This study examines soil chemical characteristics and plant responses, categorised into vegetative development and yield components. The chemical properties of the soil were analysed after harvest to assess land fertility, measuring parameters such as soil pH, Cation Exchange Capacity (CEC), Organic Carbon (C-Org), Total Nitrogen (N-Total), Available Phosphorus (P-Available), Available Potassium (K-Available), and the base cations calcium (Ca) and magnesium (Mg).

Observations of plant responses were carried out in two phases. The initial phase encompassed regular assessments of the vegetative development of the plants commencing 10 days after sowing (DAS), incorporating metrics such as plant height and stem diameter. The second stage entailed the observation of yield components of the plants evaluated at harvest (60–65 DAS), encompassing measures such as total fruit weight per plant, fruit flesh thickness, and Total Soluble Solids (TSS) to ascertain the sweetness degree of the fruit.

2.6. Characteristics of Some Initial Soil Chemical Properties

The results of the analysis of several initial soil chemical properties can be seen in Table 1 below:

Table 1 Results of analysis of several initial soil chemical properties

Analysis	**Observation Parameters**	
	Results	Criteria*
pH H_2O	4.52	Very Sour
CEC	17.21 me (100 g) $^{-1}$	Currently
C-Organic	1.90%	Low
N-Total	0.40%	Currently
P-Available	5.78 ppm	Low
K-Available	3.01 me (100 g) $^{-1}$	Very Low
Ca	0.79 me (100 g) $^{-1}$	Currently
Mg	1.70 me (100 g) $^{-1}$	Currently

Note: *) Technical Guidelines for Chemical Analysis of Soil, Plants, Water, and Fertilizer (Center for Standard Testing of Agricultural Land Resources Instruments, BSIP, Ministry of Agriculture)

Initial soil analysis results indicate that Ultisols at the study site acidic, nutrient-poor, and have low base saturation, which are common characteristics of Ultisol soils in tropical wetlands. At low pH, phosphorus is readily bound by Fe and Al, making it less available to plants. Furthermore, high levels of Al-dd can inhibit growth due to their toxicity to roots. This situation indicates that the soil requires improvement through ameliorant materials and biological technologies such as AMF to increase nutrient uptake efficiency [28,29].

2.7. Data Analysis

All data obtained were statistically analyzed using Analysis of Variance (ANOVA) based on a Factorial Randomized Block Design (RAK) at the 5% level to evaluate the independent effects and interactions between treatments. If the ANOVA test results showed a significant effect, the analysis was continued with the Least Significant Difference (LSD) test at the 5% significance level to compare the average values between treatments.

3. Results and discussion

3.1. Characteristics of Some Soil Chemical Properties of Post-Harvest Soil

The analysis results of various initial soil chemical characteristics are presented in Table 2 below as follows:

Table 2 Characteristics of Several Soil Chemical Properties of Post-Harvest Soil

Treatment	pH H_2O	C-Organic (%)	N-Total (%)	P-Available (Ppm)	K-Available (me/100 g)
Factor I: *Mycorrhiza*					
M0 (No *Mycorrhiza*)	5.76 b	5.42 b	0.22 b	38.17 b	0.29
M1 (20 g *Mycorrhiza*)	6.05 a	5.70 a	0.27 a	45.54 a	0.34
LSD 0.05	0.25	0.22	0.03	6.20	ns
Factor II: Various Doses of NPK Fertilizer					
P0 (Fertilizer dose 0%)	5.57 c	5.03 c	0.20 c	35.73 b	0.25 b
P1 (Fertilizer dose 25%)	5.80 bc	5.67 ab	0.24 bc	36.18 b	0.25 b
P2 (Fertilizer dose 50%)	5.91 abc	5.45 b	0.24 bc	41.75 ab	0.27 b
P3 (Fertilizer dose 75%)	6.21 a	5.97 a	0.28 a	50.56 a	0.58 a
P4 (Fertilizer dose 100%)	6.05 ab	5.69 ab	0.26 ab	45.05 ab	0.25 b
LSD 0.05	0.40	0.35	0.04	9.80	0.11
Interaction of Various Doses of *Mycorrhiza* and NPK Fertilizer					
M0P0	5.61 M	5.11 ST cd	0.18 R	24.15 ST e	0.15 R
M0P1	5.76 AM	5.57 ST bc	0.22 S	40.32 ST bcd	0.21 R
M0P2	5.76 AM	5.14 ST cd	0.21 R	34.46 ST cde	0.26 R
M0P3	5.82 AM	5.48 ST bc	0.23 S	44.53 ST abcd	0.62 T
M0P4	5.8 AM	5.78 ST b	0.23 S	47.40 ST abc	0.21 R
M1P0	5:52 AM	4.95 T d	0.21 R	47.32 ST abc	0.34 S
M1P1	5.83 AM	5.77 ST b	0.25 S	32.04 ST de	0.28 R
M1P2	6.06 AM	5.75 ST b	0.26 S	49.05 ST ab	0.28 R
M1P3	6.58 AM	6.45 ST a	0.33 S	56.60 ST a	0.54 T
M1P4	6.25 AM	5.58 ST bc	0.29 S	42.71 ST bcd	0.28 R
LSD 0.05	ns	0.50	ns	13.86	ns

Description: *) AM (Slightly Sour), M (Sour), R (Low), S (Medium), T (High), ST (Very High); LSD 0.05 (Least Significant Difference 5%); ns (not significant).; Source: Criteria for Assessing Soil Chemical Properties Based on the Technical Guidelines for Chemical Analysis of Soil, Plants, Water, and Fertilizers (Center for Standard Testing of Agricultural Land Resources Instruments, BSIP, Ministry of Agriculture).

The analysis of variance results indicate that post-harvest soil pH is strongly affected by the individual factors of *mycorrhiza* and NPK fertiliser dosage, with no interaction seen. *Mycorrhiza* inoculation (M1) markedly elevated the average pH to 6.05 relative to the control (M0 = 5.76), although the 75% NPK dosage (P3) produced the greatest pH of 6.21. The M1P3 combination achieved the greatest numerical value of 6.58, representing a significant increase from the initial highly acidic pH of Ultisol, which was 4.52. The elevation in pH results from the action of *arbuscular mycorrhiza* hyphae, which promote root exudates to chelate the acidity-inducing ions Al^{3+} and Fe^{3+} in the *rhizosphere*. This biological mechanism aligns with findings [11] that *mycorrhiza* successfully alleviate aluminium toxicity and stabilise pH in acidic soils.

The interplay between *mycorrhiza* and NPK fertiliser dosages significantly influences post-harvest organic carbon content. The M1P3 combination yielded the greatest organic carbon content at 6.45%, a significant rise from the baseline soil value of merely 1.90%. Conversely, in the absence of *mycorrhiza* (M0), the organic carbon content was comparatively diminished, fluctuating between 5.11% and 5.78%. The prevalence of organic carbon in M1P3 results from the accumulation of external *mycorrhizal* hyphal biomass abundant in glomalin and the enhancement of

watermelon root exudates. This process aligns which indicate that arbuscular mycorrhiza can promote the production of root organic molecules, thereby enhancing microbial activity and stabilising soil organic matter retention [12].

The individual influence of mycorrhiza and NPK fertiliser dosages considerably impacted post-harvest soil N-Total, although no interaction effects were observed. *Mycorrhizal* inoculation (M1) considerably increased the average total nitrogen (N-Total) to 0.27% compared to the control (M0 = 0.22%). The 75% NPK treatment (P3) yielded the highest soil nitrogen retention at 0.28%, whereas the 100% dose (P4) decreased the N-Total value to 0.26%. The capacity of *mycorrhiza* to sustain nutritional stability suggests that the proliferation of external hyphal networks can sequester and retain functional nitrogen (ammonium and nitrate) in the root zone, thus reducing leaching in Ultisol soil. This indicating that the incorporation of *mycorrhiza* with judicious macro-fertiliser application enhances nutrient retention, since the hyphae function as a biological buffer in the soil. The interplay between mycorrhiza and NPK fertiliser applications significantly influences post-harvest soil phosphorus availability. The amalgamation of M1P3 yielded the greatest phosphorus concentration at 56.60 ppm, significantly above the control (M0P0 = 24.15 ppm) and the initial soil measurement (5.78 ppm). This increase illustrates the efficacy of *arbuscular mycorrhizae* (AM) in dissociating the bonds of insoluble Al-P and Fe-P phosphates in Ultisol soil. AM synthesises organic acids and acid phosphatase enzymes to hydrolyse phosphorus into orthophosphate forms that can be taken by watermelon plants. This biochemical mechanism utilising AM improves nutrient availability by stimulating soil enzyme activity [12]. The presence of mycorrhizae enhances systemic macronutrient efficiency, enabling a reduction in fertiliser use by up to 75% while preserving optimal soil phosphorus availability [9].

The 5% BNT test indicates that the post-harvest K-available content of the soil is considerably affected solely by the dosage of NPK fertiliser, with no interaction or independent effect from mycorrhiza. The administration of 75% NPK (P3) yielded the greatest average K-Available (0.58 me/100 g), notably differing from the 100% dosage (P4), which decreased to 0.25 me/100 g. The reduction in nutrients at the maximum dosage is believed to result from overfertilisation, which saturates Ultisol soil colloids, facilitating the release and leaching of residual potassium. Despite *mycorrhiza*'s negligible impact, the M1P3 combination exhibited a consistently elevated numerical value (0.54 me/100 g), suggesting the involvement of hyphae in the absorption of K^+ cations inside the rhizosphere. This occurrence indicating that the integration of reasonable chemical fertiliser inputs with biofertilisers is essential for preserving soil potassium stability as a plant osmosis regulator [10].

3.2. Watermelon Plant Growth

Table 3 Interaction of *Arbuscular Mycorrhiza* and various levels of NPK fertilizer dosage on the length of plants

Treatment	Plants Length (cm)			
	14 DAS	28 DAS	42 DAS	56 DAS
M0P0	11.6	61.4	265.35 fg	324.97 fg
M0P1	8.4	43.8	240.37 g	302.94 g
M0P2	10.6	63.2	279.63 efg	349.17 fg
M0P3	9.4	63.4	330.94 cde	413.52 de
M0P4	10.2	54.7	340.88 bcd	428.01 cd
M1P0	10.4	62.3	307.61 def	374.72 ef
M1P1	10.1	61.3	377.74 abc	469.76 bc
M1P2	8.8	50	389.69 ab	484.93 ab
M1P3	10.2	77.3	421.06 a	530.68 a
M1P4	9.3	69.8	376.20 abc	467.19 bc
BNT 5%	Mr.	Mr.	*	*
Family Card (%)	20.07	20.29	9.20	7.31

Note: Numbers followed by the same letter indicate that the results are not significantly different in the least significant difference test (LSD 5%); * = Real; tn = Not real; HST = Days After Planting; mm = millimeter; cm = centimeters.

The analysis of variance results indicate that the interaction between arbuscular *mycorrhiza* application and different NPK fertiliser doses did not significantly affect watermelon plant length at 14 and 28 days after sowing (DAS), but it did

have a significant effect at 42 DAS. At 42 DAS, the combined application of arbuscular *mycorrhiza* and NPK fertiliser dosages produced notable variations in plant height. The maximum plant height was recorded in the M1P3 treatment at 421.06 cm, which exhibited a substantial difference from the majority of other treatments, although it was not statistically different from M1P2 (389.69 cm), M1P1 (377.74 cm), and M1P4 (376.20 cm). In contrast, the minimum plant height was recorded in the M0P1 treatment at 240.37 cm. The findings demonstrate that the use of arbuscular *mycorrhiza* in conjunction with NPK fertiliser significantly promotes the vegetative growth of watermelon plants compared to treatments lacking *mycorrhiza*. The findings of the watermelon growth analysis are presented in Table 3.

The enhancement in plant height observed in treatments with *arbuscular mycorrhizae* is attributed to the symbiotic association between *mycorrhizal* fungi and plant roots, which expands the root absorption area, thereby improving the efficiency of nutrient uptake, particularly phosphorus (P), nitrogen (N), and potassium (K). Enhanced food availability facilitates photosynthesis, chlorophyll synthesis, and cellular division and elongation, all of which directly promote stem growth in plants. The integration of *mycorrhiza* with NPK fertiliser at the P3 level yielded the most favourable outcome, as it supplied nutrients in optimal quantities while enhancing plant utilisation efficiency. Nonetheless, elevating the fertiliser dosage to the P4 level did not significantly enhance plant height, suggesting that the plants' nutritional requirements were satisfied at the P3 level, rendering the supplemental fertiliser ineffective in promoting further growth responses. The results suggest that employing arbuscular *mycorrhiza*, in conjunction with the appropriate NPK fertiliser dose, can effectively promote the vegetative growth of watermelon plants.

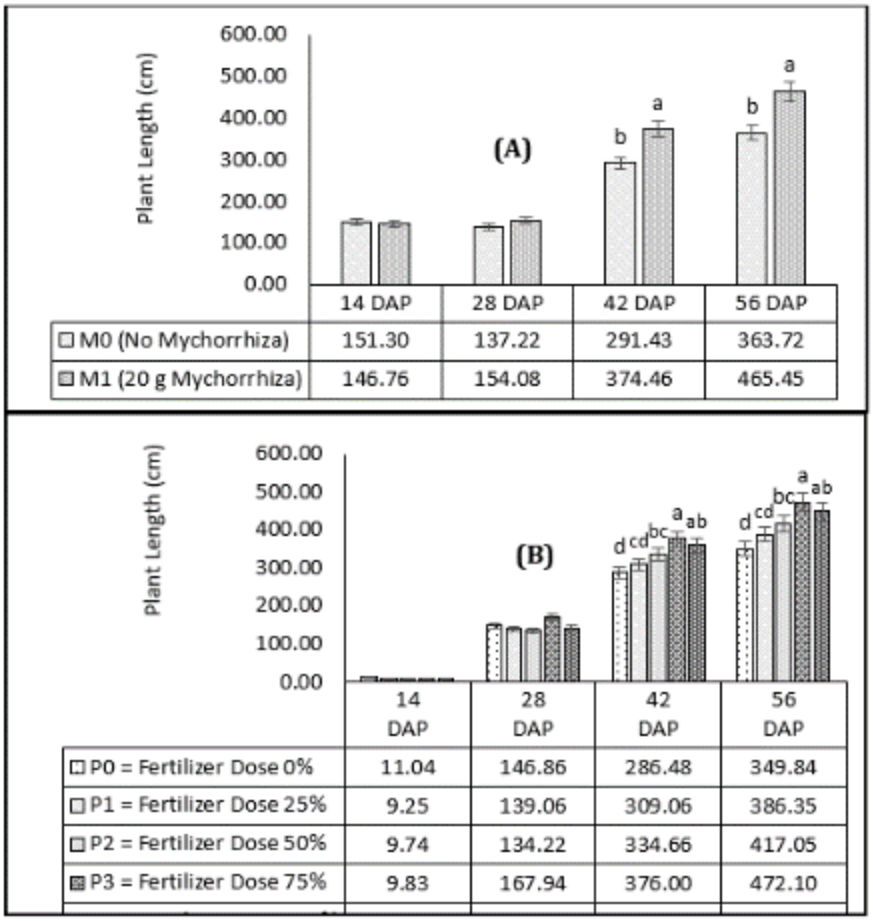
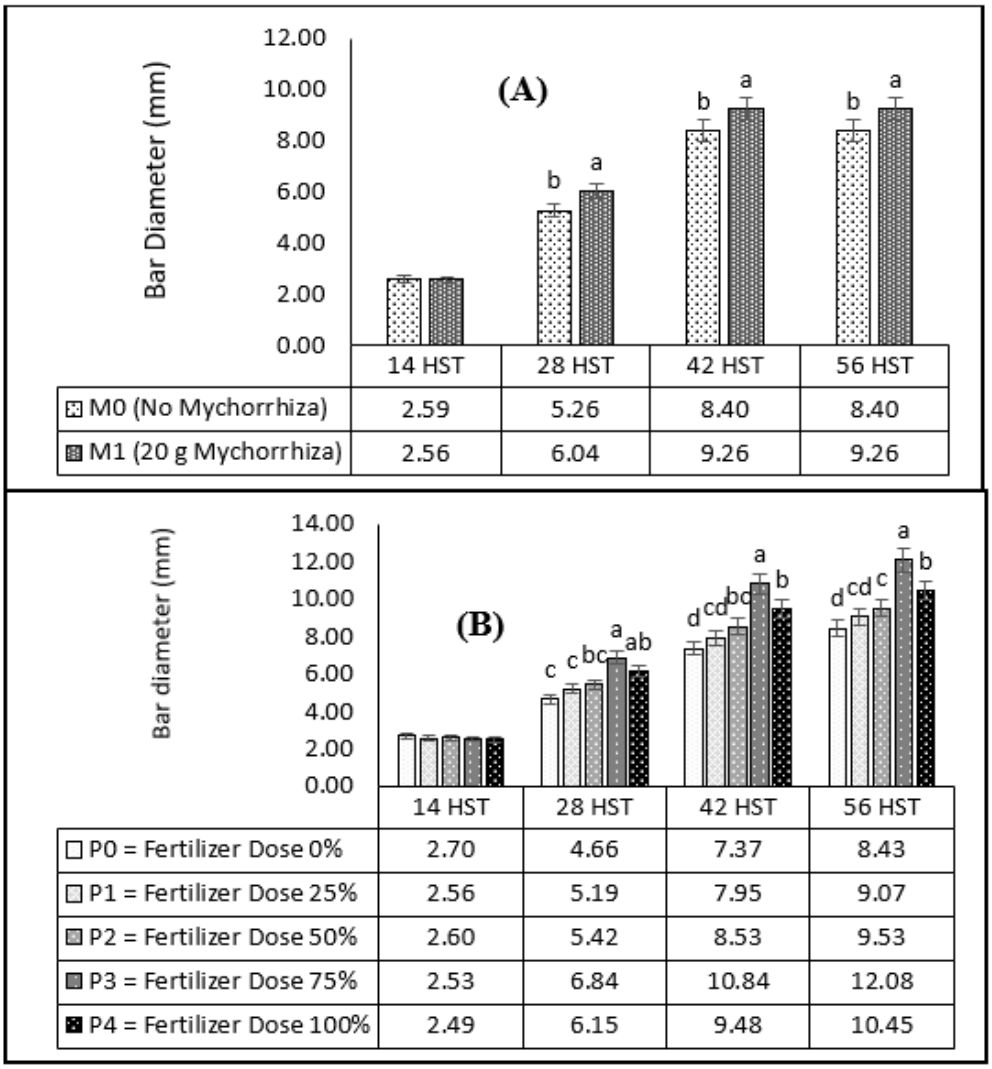


Figure 1 Average graph of treatment on single factor *Arbuscular Mycorrhiza* (A) and various doses of NPK fertilizer (B)

3.3. Stem Diameter

The enhancement in plant height observed in treatments with *arbuscular mycorrhizae* is attributed to the symbiotic association between *mycorrhizal* fungi and plant roots, which expands the root absorption area, thereby improving the efficiency of nutrient uptake, particularly phosphorus (P), nitrogen (N), and potassium (K). Enhanced food availability facilitates photosynthesis, chlorophyll synthesis, and cellular division and elongation, all of which directly promote stem growth in plants. The integration of *mycorrhiza* with NPK fertiliser at the P3 level yielded the most favourable outcome,

as it supplied nutrients in optimal quantities while enhancing plant utilisation efficiency. Nonetheless, elevating the fertiliser dosage to the P4 level did not significantly enhance plant height, suggesting that the plants' nutritional requirements were satisfied at the P3 level, rendering the supplemental fertiliser ineffective in promoting further growth responses. The results suggest that employing arbuscular *mycorrhiza*, in conjunction with the appropriate NPK fertiliser dosage, can effectively promote the vegetative growth of watermelon plants.



	14 HST	28 HST	42 HST	56 HST
M0 (No Mychorrhiza)	2.59	5.26	8.40	8.40
M1 (20 g Mychorrhiza)	2.56	6.04	9.26	9.26

	14 HST	28 HST	42 HST	56 HST
P0 = Fertilizer Dose 0%	2.70	4.66	7.37	8.43
P1 = Fertilizer Dose 25%	2.56	5.19	7.95	9.07
P2 = Fertilizer Dose 50%	2.60	5.42	8.53	9.53
P3 = Fertilizer Dose 75%	2.53	6.84	10.84	12.08
P4 = Fertilizer Dose 100%	2.49	6.15	9.48	10.45

Figure 2 Average graph of treatment on single factor *Arbuscular Mycorrhiza* (A) and various doses of NPK fertilizer (B) against plants stem diameter (mm)

The notable augmentation in stem diameter inside the *mycorrhizal* treatment is attributable to the proliferation of external hyphal networks that promote the uptake of immobile nutrients like phosphorus (P) and improve water absorption efficiency in the root zone. The optimal provision of nutrients and water enhances cell division in the vascular cambium, thereby facilitating an increase in stem diameter to enable assimilation transfer. The superior findings of the 75% fertiliser dose (P3) compared to the 100% dose (P4) suggest the existence of an optimal point for nutrient absorption efficiency. The overuse of chemical fertilisers (P4) is believed to induce micro-salinity stress in the rhizosphere or disrupt nutrient absorption, thereby impeding the vegetative growth of plants. Consequently, the integration of effective nutrient input management with *mycorrhizal* biofertilisers is essential for maintaining the robust canopy structure of watermelon plants during the ensuing reproductive phase.

3.4. Watermelon Production

The study assessed yield components and watermelon fruit quality to determine the efficacy of assimilate distribution from source organs to sink organs. The efficacy of NPK fertiliser is primarily shown by nutrient translocation

performance, facilitated by *Arbuscular Mycorrhiza* (AM) in Ultisol. The assessed parameters encompass physical dimensions (weight, diameter, and length of the fruit) and chemical quality via Total Soluble Solids (Brix). An ANOVA study at a 5% significance level indicates that both independent treatments and the interaction between *mycorrhiza* and NPK fertiliser significantly influence fruit biomass and sweetness. Table 4 and Figure 3 below provide a comprehensive presentation of the average observation data.

Table 4 Watermelon Production Quality

Treatment	Weight Watermelon (Kg)	Watermelon Circumference (cm)	Watermelon Length (cm)	Total Soluble Solids (Brix)
Factor I: Mychorrhiza				
M0 (No Mychorrhiza)	2.40 b	48.27 b	28.86 b	10.99 b
M1 (20 g Mychorrhiza)	2.80 a	51.01 a	34.27 a	12.15 a
LSD 0.05	0.34	2.57	2.73	0.37
Factor II: Various Doses of NPK Fertilizer				
P0 (Fertilizer dose 0%)	1.91c	44.10 c	25.19 c	10.81 c
P1 (Fertilizer dose 25%)	2.52 b	49.22 b	30.24 b	11.36 bc
P2 (Fertilizer dose 50%)	2.75 ab	50.93 ab	32.70 b	11.53 b
P3 (Fertilizer dose 75%)	3.25 a	54.19 a	37.81 a	12.52 a
P4 (Fertilizer dose 100%)	2.60 b	49.76 b	31.88 b	11.63 b
LSD 0.05	0.55	4.08	4.32	0.58

Note: Numbers followed by the same letter indicate that the results are not significantly different in the least significant difference test (LSD 5%); cm = centimeter.

3.4.1. Weight Per Fruit

The results of the 5% LSD test indicated that the application of *mycorrhiza* and NPK fertiliser dosages significantly influenced the weights of individual watermelon fruits. The treatment of 20 g of *mycorrhiza* (M1) considerably increased the average fruit weight to 2.80 kg, in contrast to the 2.40 kg seen without *mycorrhiza* (M0). In terms of fertiliser dosage, treatment P3 (75% dose) yielded a maximum fruit weight of 3.25 kg, which was statistically significantly different from the control (P0) and the full 100% dosage (P4), which recorded weights of 1.91 kg and 2.60 kg, respectively. This indicates that the synergy of *mycorrhizal* hyphal networks and optimal macronutrient availability at a 75% dosage enhances carbohydrate and water accumulation in the fruit during the enlargement phase, supporting the mechanism of improved nutrient efficiency through *mycorrhizal* symbiosis [30].

3.4.2. Fruit Circumference

The measurement of the watermelon fruit circumference reveals a correlation with the fruit weight, attributable to the effect of the applied singular factor. *Mycorrhizal* inoculation (M1) markedly enhanced the fruit circumference to 51.01 cm, a substantial difference compared to the non-inoculated treatment (M0), which yielded an average of 48.27 cm. The administration of 75% NPK dosage (P3) resulted in the largest fruit circumference at 54.19 cm, exceeding all other treatments, including the optimal recommended dosage of 100% (P4), which measured 49.76 cm. This growth stimulation suggests that a well-balanced nutrient supply, coupled with a high-efficiency approach, might enhance cell division and expansion in the pericarp of watermelons, thereby promoting optimal development of the horizontal diameter, or fruit circumference. This aligns with the findings of [31], which indicate that the presence of macronutrients facilitated by biological agents enhances turgor pressure and cell wall production in pericarp tissue, serving as the primary catalyst for fruit morphological expansion.

3.4.3. Fruit Length

The measurement of the watermelon fruit circumference reveals a correlation with the fruit weight, attributable to the effect of the applied singular factor. *Mycorrhizal* inoculation (M1) markedly enhanced the fruit circumference to 51.01

cm, a substantial difference compared to the non-inoculated treatment (M0), which yielded an average of 48.27 cm. The administration of 75% NPK dosage (P3) resulted in the largest fruit circumference at 54.19 cm, exceeding all other treatments, including the optimal recommended dosage of 100% (P4), which measured 49.76 cm. The augmentation in fruit length signifies the efficient transfer of assimilates from leaves to fruit, facilitated by enough phosphorus and nitrogen, which are essential for initial cell elongation following pollination. Recent studies indicate that during this phase, the fruit acts as a crucial sink, requiring elevated quantities of nitrogen and phosphorus to promote cell division and growth [32].

3.4.4. Total Dissolved Solids

In contrast to the earlier physical measures, the sweetness level of watermelon, assessed using Total Dissolved Solids (Brix), exhibits a notable interaction between the *mycorrhizal* treatment and NPK fertiliser dosage (Figure 3). The M1P3 treatment combination (20 g *Mycorrhiza* + 75% Fertiliser Dosage) demonstrated superior efficacy, achieving the maximum sweetness level of 13.90 Brix and statistically ranking first (a), above all other combinations.

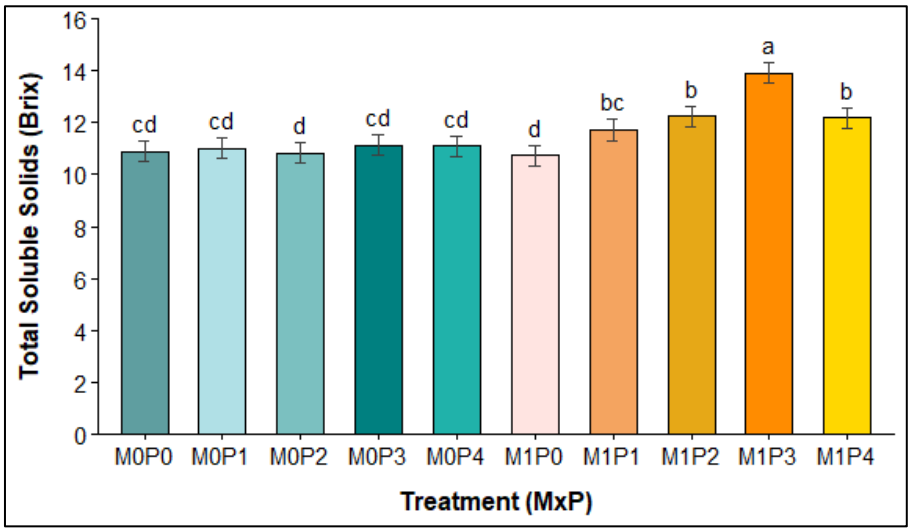


Figure 3 Interaction of *Mycorrhizal* and Fertilizer Treatments on Total Dissolved Solids

In the absence of *mycorrhiza* (M0), elevating the fertiliser dosage from 0% to 100% (M0P0 to M0P4) did not yield a significant rise in Brix, with the average fluctuating between 10.82 and 11.13 Brix. The presence of *mycorrhiza* in the M1P3 treatment markedly expedited the hydrolysis of starch into monosaccharides and augmented the accumulation of sucrose and fructose in the fruit flesh via improved photosynthesis rates and potassium (K) absorption efficiency, recognised as an activator of sugar transport enzymes [33,34].

4. Conclusion

The inoculation of the MA consortium (*Glomus* and *Acaulospora*) significantly enhanced the chemical properties of harvested Ultisol by elevating soil pH and total nitrogen content. Concurrently, the application of NPK fertiliser at 75% (P3) yielded optimal results regarding the availability of soil phosphorus and potassium, while also improving the physical attributes of watermelon, including weight, diameter, and length. An important interaction was attained with the M1P3 treatment (*Mycorrhiza* 20 g + NPK 75%), which effectively enhanced the formation of soil organic matter (C-Organic 6.45%) and yielded the greatest quality of watermelon sweetness at 13.90 Brix. Consequently, the application of biotechnology MA enhances the efficacy of macronutrient fertilisation on Ultisol, allowing for a 25% reduction in chemical fertiliser dosage (to 75% of the original amount) while still preserving the soil's chemical fertility and yielding watermelons of optimal quantity and quality.

Compliance with ethical standards

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Disclosure of Conflict of interest

No conflict of interest to be disclosed.

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