RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (2) 752-760, 2025
http://doi.org/10.54910/sabrao2025.57.2.31
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

ARBUSCULAR MYCORRHIZA FUNGI AND MINERAL FERTILIZER EFFECTS ON GROWTH AND PRODUCTION TRAITS OF THE POTATO (*SOLANUM TUBEROSUM* L.)

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SUMMARY

This study investigated the combined effects of arbuscular mycorrhiza fungi (AM) and foliar fertilizer (Growmore) application on potato tuber growth and yield to improve nutrient efficiency, crop productivity, and agricultural sustainability, conducted in May-September 2023 in Bantaeng, Indonesia. The two-factor factorial field experiment involved four doses of AM (control, 7.5, 15, and 22.5 g plant^{-1}) and three concentrations of foliar fertilizer application (2, 4, and 6 g L^{-1}), repeated three times. The results showed a significant interaction effect on the combination of AM application (15 g plant^{-1}) and foliar fertilizer (6 g L^{-1}), increasing stem diameter, number of leaves, tuber weight, and yield. The foliar fertilizer (4 g L^{-1}) affected the number of leaves, while AM (15 g plant^{-1}) increased tuber weight and yield. Phosphorus content analysis was highest when adding AM (15 g plant^{-1}) and foliar fertilizer (6 g L^{-1}). The highest protein appeared with AM (7.5 g plant^{-1}) and foliar fertilizer (6 g L^{-1}), and the maximum vitamin C emerged with AM (15 g plant^{-1}) and foliar fertilizer (4 g L^{-1}) applications. An integrated approach using AM (15 g plant^{-1}) and foliar fertilizer (4-6 g L^{-1}) proved effective in increasing potato productivity.

Keywords: Potato (*S. tuberosum* L.), mycorrhiza, mineral fertilizer, growth traits, potato tubers

Key findings: In potato (*S. tuberosum* L.) production, a significant increase occurred by using mycorrhiza and foliar application of mineral fertilizers.

Communicating Editor: Dr. Anita Restu Puji Raharjeng

Manuscript received: May 15, 2024; Accepted: November 06, 2024.

Citation: Carong NFR, Rafiuddin, Mantja K (2025). Arbuscular mycorrhiza fungi and mineral fertilizer effects on growth and production traits of the potato (*Solanum tuberosum* L.). *SABRAO J. Breed. Genet.* 57(2): 752-760. http://doi.org/10.54910/sabrao2025.57.2.31.

INTRODUCTION

The need for agricultural products is increasing in line with the rising population; the available food must meet the needs of the community. Potatoes are tuber crops that replace staple foods because they are high in carbohydrates (Sultana et al., 2016). This crop has a good market opportunity; hence, its serious cultivation can increase farmers' income. Potatoes are the third most consumed crop worldwide after rice and wheat (Rahaman and Shehab, 2019). Potato is also an essential source of vitamin C (ascorbic acid), vitamins B (thiamine, niacin, and vitamin B6), and minerals P, Mg, and K (Fernando et al., 2020; Koch et al., 2020; Raigond et al., 2020).

In Indonesia, the current potato production is only 1,314,650 tons obtained from a crop area of 68,223 hectares, and the average productivity is 19.27 t ha^{-1} (Andayani and Rusnadiatman, 2013; Mandala and Putri, 2020; Prabawardani et al., 2022). Indonesia's population reaches 270.02 million, and the potato consumption has increased to 2.82 kg/capita/year, with a total requirement of 6,160,560 tons $year^{-1}$ (Yulianti and Yefriwati, 2020). This rise in potato consumption compels potato production to improve in quantity and quality to keep its sustained availability. Therefore, efforts can focus on enhancing potato production by using fertilizer like arbuscular mycorrhiza fungi and a foliar fertilizer, such as Growmore.

Arbuscular mycorrhiza can increase the absorption of nutrients from the soil and stimulate plant growth, enhancing the absorption of metals, such as P, K, Ca, Mg, Fe, and Cu (Tuheteru et al., 2022). Mycorrhiza can support plants in obtaining easy access to nutrients, even with nutrient deficiency and environmental stress conditions in the soil (Fard et al., 2020). Naturally, a plant with a proper association in the root grows healthier than a plant without a symbion in its root (Dobo, 2022). One promising avenue to enhance both the yield and nutritional quality of potatoes is the use of arbuscular mycorrhiza fungi (AMF) as biofertilizers (Sadhana, 2014; Berruti et al., 2016; Igiehon and Babalola, 2017). AMF grow in symbiosis with over 80% of land plants and exchange water and nutrients with their hosts for photosynthetically derived carbon (C) (Smith and Read, 2010, Keymer et al., 2017, Brundrett and Tedersoo, 2018). In fact, inoculation with on-farm produced mixed-species AMF communities has appeared to enhance the yield of potatoes (Douds et al., 2007) and several other crops, including eggplants, peppers, strawberries, and sweet potatoes, up to 15% (Douds and Reider, 2003; Douds et al., 2007, 2015, 2017).

The addition of Growmore fertilizer causes the faster absorption of harvest elements in plants because of their availability in ionic forms (Purnama et al., 2023). Foliar fertilizer has the N and K content of 32% and 0.88%, respectively (Mahardika et al., 2015). Foliar fertilization through leaves has become more successful than through roots because the leaves have the leaf mouth (stomata), which directly absorbs water and nutrients necessary for growth and development of crop plants (Gani et al., 2023). Consequently, plants can grow faster, and one can conclude that giving arbuscular mycorrhizal and foliar fertilizers can boost potato plants' growth and production.

Arbuscular mycorrhiza and foliar fertilizers have significant nutrient contents for plant growth and development (Mahardika et al., 2015). Moreover, fertilization through leaves seemed more effective because the stomata on the leaves can absorb water and nutrients needed by plants for faster growth and production (Sharanappa and Nabooji, 2020). Therefore, the use of arbuscular mycorrhizal and foliar fertilizers can boost the growth and production of crop plants, including potato plants.

For instance, applying foliar fertilizer and arbuscular mycorrhiza to a potato farm could considerably enhance the growth and tuber yield of potatoes (Fall et al., 2023). Foliar fertilizers deliver essential nutrients, such as nitrogen and potassium, directly to the leaves, promoting potato growth and yield, as the arbuscular mycorrhiza enhances the plant's capacity to absorb nutrients (Wu et al., 2023). Therefore, the presented research aimed to explain or describe arbuscular mycorrhiza (AM) and foliar fertilizers on potato plant growth and

production, which could contribute to efforts to raise the potato productivity in Indonesia.

MATERIALS AND METHODS

Experimental location and procedure

This research on potato (*Solanum tuberosum* L.) crop transpired from May to September 2023 in Bantaeng Regency, South Sulawesi, Indonesia (GPS coordinates or research map). The latest study arrangement had a factorial design with two factors. The first factor was the mycorrhiza (M) with four levels, i.e., control, 7.5, 15, and 22.5 g plant^{-1}, while the second factor was the Growmore leaf fertilizer (G), with three levels, i.e., 2, 4, and 6 g L^{-1} water. Based on these two factors, 12 treatment combinations existed, repeated three times, and the total experimental units were 36.

Crop husbandry

The initial clearing from dirt and weeds prepared the research area for use. Subsequently, pre-planting herbicide spraying used Golma 240 EC. By hoeing as deep as 30 cm, researchers created the plots with a size of 2.0 m × 1.8 m, the height of 30 cm, the distance between plots at 30 cm, and the distance between the groups at 50 cm.

Fertilization and mulching

Fertilization continued for three days before planting using the mycorrhiza with various doses according to the assorted treatments: m0 (control), m1 (7.5 g plant^{-1}), m2 (15 g plant^{-1}), and m3 (22.5 g plant^{-1}). Mycorrhiza application happened in the morning or evening. The next stage involves the installation of plastic mulch, which was then hollowed out based on predetermined planting spacing and the placement of treatment pegs on each bed.

Planting

Potato tuber planting commenced with a prescribed planting configuration of 60 cm × 40 cm, wherein individual potato tubers' placing in the planting holes had a depth of 10 cm, yielding one tuber per hole. This configuration establishes 15 populations within each experimental plot. The planting holes, augmented with bulbs, subsequently bore backfilling with loose soil. Before the planting process, each plot underwent labeling corresponding to its designated treatment, streamlining both the planting procedure and the subsequent field observations.

Foliar fertilizer application

The application of Growmore leaf fertilizer proceeded three times, i.e., 20 days after plant (DAP), 40 DAP, and 60 DAP, made by spraying Growmore fertilizer on potato plant leaves evenly. The doses of Growmore attained preparation in accordance with the treatments.

Parameters recorded and analysis

In potato plants, the data recorded comprised various parameters, including stem diameter (mm), number of leaves (strands), fresh tuber weight (g), tuber yield (t ha^{-1}), phosphorus (%), crude protein (%), and vitamin C (%). All the observed data subsequently incurred analysis using various statistical methods, including analysis of variance (ANOVA). In the presence of statistically significant differences among the treatments, additional tests took place to discern the mean differences among the treatments. The Tukey's test employed showed comparison of the treatment means with a significance level of 5%.

RESULTS AND DISCUSSION

The observations on stem diameter revealed the highest average stem diameter (12.87 mm) appeared with the combined application

Table 1. Effect of mycorrhiza and Growmore foliar fertilizer on the stem diameter of potato (*S. tuberosum* L.) at 58 days.

Treatments	g1	g2	g3
m0	10.70b	12.53ab	11.90ab
m1	12.20ab	11.96ab	11.53ab
m2	12.10ab	11.63ab	12.87a
m3	11.27ab	11.36ab	12.33ab
NP BNJ	1.38		

Remarks: The numbers followed by the same letters (a,b) were not significantly different in the BNJ follow-up test α 0.05.

of mycorrhiza (15 g plant^{-1}) and foliar fertilizer (6 g L^{-1}) in potato (*S. tuberosum* L.) (Table 1). The said value was significantly different from the lowest stem diameter (10.70 mm) obtained with the combination of mycorrhiza control (0 g plant^{-1}) and foliar fertilizer (2 g L^{-1}), but not significantly different from other treatments, except for the combination of treatment without mycorrhiza and foliar fertilizer (2 g L^{-1}). Mycorrhiza plays an effective role in boosting the uptake of nutrients, both micro and macro. The use of mycorrhiza can also increase the water availability for potato plants. Past studies revealed the provision of mycorrhiza can produce a significantly larger stem diameter than plants without mycorrhiza treatment (Putri et al., 2016). The increase in stem diameter by mycorrhiza treatment seemed closely related to the root system formed due to root infection by mycorrhiza.

Mycorrhiza infection will form a good root system, which makes plants more capable of absorbing nutrients and water from the soil optimally, and the plants grow and develop well (Daras et al., 2013). As for the application of foliar fertilizer, assumably, the higher the concentration, the more able to provide nutrients, causing plant cell metabolism to run better, and the plant growth does not experience hindrances in the vegetative phase. The abundant N content better accelerates the process of photosynthesis, which helps in creating larger, dark green stems, and eventually, helps in the vegetative process (Rahmah et al., 2014).

The observed results on the number of leaves did not have a significant interaction effect between mycorrhiza and foliar fertilizer treatments, but affected the number of leaves per stalk on potato plants. Although, the single-foliar fertilizer treatment gave a notable effect on the number of leaves per stalk (Table 2). The highest average number of leaves per stalk resulted in the treatment of foliar fertilizer (4 g L^{-1}), with an average of 57.36 strands. The said treatment was not substantially different from the foliar fertilizer (6 g L^{-1}); however, it differed remarkably from the Growmore leaf fertilizer (2 g L^{-1}), displaying the least number of leaves per stalk (53.85 strands). Foliar fertilizer is capable of producing massive leaves because a leaf fertilizer has a high content of macronutrients, as well as micronutrients functioning to enhance plant growth. Nurmas and Fitriah (2011) reported fertilization through leaves tends to succeed and be more effective on broad and wide leaf surfaces.

Foliar fertilizer affects the number of leaves, assuming its nitrogen content is sufficient for potato needs, especially in the formation of chlorophyll in leaf organs. Fertilization directly through plant leaves with sufficient concentration can provide significant results on plant vegetative growth. Aritonang and Surtinah's (2018) findings revealed chlorophyll content in potato leaves was higher than in leaves with sufficient light intensity. The role of chlorophyll in absorbing light will increase the photolysis process that will produce materials for use in dark reactions to produce carbohydrates, as a food source for plants.

Observations on potato fresh tuber weight disclosed no interaction between mycorrhiza and foliar fertilizer treatments on the average tuber weight; however, mycorrhiza alone provided a remarkable effect on the tuber weight (Table 3). The maximum average tuber weight (70.45 g) was evident in

Table 2. Effect of mycorrhiza and Growmore foliar fertilizer on the number of leaves per stalk of potato (*S. tuberosum* L.).

Treatments	Leaves Stalk^{-1} (strands)
Mycorrhiza	
Control	55.06
7.5 g plant^{-1}	54.51
15 g plant^{-1}	55.31
22 g plant^{-1}	57.95
Growmore	
2 g L^{-1} water	53.85q
4 g L^{-1} water	57.36p
6 g L^{-1} water	55.91pq
NP BNJ	3.17

Remarks: The numbers followed by the same letters (p,q) were not significantly different in the BNJ follow-up test α 0.05.

Table 3. Effect of mycorrhiza and Growmore foliar fertilizer on the fresh tuber weight and tuber yield of potato (*S. tuberosum* L.).

Treatments	Fresh tuber weight (g)	Tuber yield (t ha^{-1})
Mycorrhiza		
Control	60.01	8.94
7.5 g plant^{-1}	70.18	9.58
15 g plant^{-1}	70.46	11.82
22 g plant^{-1}	62.77	9.02a
NP BNJ	11.87	2.98
Growmore		
2 g L^{-1} water	60.06	10.04
4 g L^{-1}water	55.91	9.42
6 g L^{-1} water	68.50	10.05

Remarks: The numbers followed by the same letters (a,b) and (p,q) were not significantly different in the BNJ follow-up test α 0.05.

the mycorrhiza treatment (15 g plant^{-1}). Though, it did not significantly differ from mycorrhiza's other treatments. The lowest average tuber weight (60.01 g) appeared in the control treatment of mycorrhiza. Apparently, the increase in tuber weight was due to the positive role of mycorrhiza in increasing the absorption of water and nutrients for plants. Plants inoculated with mycorrhiza will have better growth and biomass because they can facilitate the improvement of plant nutrients, and the plants could grow better than plants without mycorrhiza. Higher doses of mycorrhiza will increase the number of hyphae around the roots, thus, tubers can grow well (Berruti et al., 2016). The photosynthates related to increased plant growth sustained translocation to plant tubers. Better plant growth produces optimal photosynthesis, and the number of tubers and the tuber weight produced were higher in potato (Sánchez-Rojo et al., 2011). Such finding aligns with the previous research, which exhibited mycorrhiza (15 g plant^{-1}) showed best results in potato fresh weight (Veriani et al., 2019).

For the average tuber yield per hectare, no interaction emerged between mycorrhiza and foliar fertilizer, nor the single factor (Table 3). The highest average tuber production per hectare occurred in the mycorrhiza treatment (15 g plant^{-1}), with an average of 11.82 t ha^{-1}, which was not significantly different from other treatments. The lowest average tuber production per hectare appeared in the treatment without

mycorrhiza (8.94 t ha^{-1}) (Table 3). The topmost average tuber production per hectare manifested in the mycorrhiza treatment (15 g $plant^{-1}$), with an average of 11.82 t ha^{-1}, which was nonsignificantly different from other treatments. The least average tuber production per hectare was prominent in the treatment without mycorrhiza (8.94 t ha^{-1}). The results enunciated different doses of mycorrhiza considerably modified the tuber weight and its yield per hectare.

Rhizobacteria can synthesize and release auxins as secondary metabolites, contributing to increased tuber weight and yield in potato plants. Auxins can stimulate root growth and lateral root formation, thereby increasing the plant's ability to absorb more water and nutrients, eventually positively influencing a rise in biomass production and crop yields (Ahemad and Kibret, 2014). Veriani et al. (2019) mentioned potato plants with CMA (15 g $plant^{-1}$) have a higher fresh tuber weight and yield per hectare than CMA doses of 5 and 10 g $plant^{-1}$.

Observed data on phosphorus content parameters showed the highest average phosphorus content (0.15%) was with the interaction of arbuscular mycorrhiza (15 g $plant^{-1}$) and Growmore leaf fertilizer (6 g L^{-1}) (Table 4). However, the lowest average phosphorus (0.11%) appeared in all other interaction treatments. This is probably because the best phosphorus content with mycorrhiza dose (15 g $plant^{-1}$) was in accordance with past findings, which stated the application of mycorrhiza (15 g $plant^{-1}$) displayed the best dose to enhance phosphorus uptake (Lubis et al., 2020; Yusubakhmedov et al., 2024). As for the application of Growmore leaf fertilizer, one can suspect the higher the concentration, the higher the phosphorus content. Foliar fertilizer (6 g L^{-1}) has proven to fulfill the nutrients of potato plants. Surtinah (2013) also reported that at low concentrations, the nutrients did not show a real effect, while at high concentrations, it could result in considerable growth.

Data on crude protein content revealed the supreme crude protein content (2.96%) was evident in the combination of mycorrhiza (7.5 g $plant^{-1}$) and Growmore leaf fertilizer (6 g L^{-1}) (Table 4). However, the least protein content (1.90%) came from the interaction of mycorrhiza control treatment (m0) and foliar fertilizer (4 g L^{-1}). Giving mycorrhiza at a dose of 7.5 g $plant^{-1}$ was able to produce the highest average protein content. The presented results agreed with the past research revealing the mycorrhiza performance can be noticeable through research to determine the right dose and the right way (Rokhminarsi et al., 2022). As for the application of foliar fertilizer, assumingly, the higher the concentration, the higher protein content can surface, and foliar

Table 4. Effect of mycorrhiza and Growmore foliar fertilizer on the phosphorus, crude protein, and vitamin C content of potato (*S. tuberosum* L.).

Sample Codes	Nutrients composition		
	Phosphorus (%)	Crude protein (%)	Vitamin C (%)
m0g1	0.11	2.76	648.46
m1g1	0.11	2.73	650.37
m2g1	0.11	2.89	655.87
m3g1	0.11	2.85	654.57
m0g2	0.13	1.90	656.46
m1g2	0.12	2.76	656.13
m2g2	0.14	2.77	657.11
m3g2	0.11	2.80	652.11
m0g3	0.13	2.95	655.87
m1g3	0.11	2.96	652.30
m2g3	0.15	2.49	655.54
m3g3	0.13	2.84	655.28

Source: Feed Chemistry Laboratory, Department of Nutrition and Animal Feed, Faculty of Animal Husbandry, Hasanuddin University, Makassar, Indonesia

fertilizer (6 g L^{-1}) was able to fulfill the nutrient demand of potato plants. The nutrients with higher concentrations showed remarkable effects and better plant growth (Surtinah, 2013; Haq et al., 2021; Nurul-Afza et al., 2023).

For vitamin C content, results showed the maximum average vitamin C content (657.11%) emerged with the combined application of arbuscular mycorrhiza (15 g $plant^{-1}$) and foliar fertilizer (4 g L^{-1}) (Table 4). However, the minimum average of vitamin C content (648.46%) resulted in the interaction of arbuscular mycorrhiza control and foliar fertilizer (2 g L^{-1}). This is probably because the mycorrhiza at the rate of 15 g $plant^{-1}$ was the best dose, in accordance with past findings (Sari et al., 2021). Provision of mycorrhiza can increase the size of the fruit and the number of seeds, affecting the quality of fruits (Agustin et al., 2017; Kumar et al., 2017). Foliar fertilizer application at a concentration of 4 g L^{-1} was the superior dose for obtaining a higher vitamin C content. The results revealed the application of foliar fertilizer at a concentration of 4 g L^{-1} ably enhanced the vitamin C content in potato tubers.

CONCLUSIONS

In potato, the mycorrhiza (15 g $plant^{-1}$) and foliar fertilizer (6 g L^{-1}) were distinctly the best combination for stem diameter and phosphorus (%), foliar fertilizer (4 g L^{-1}) produced the highest number of stalk leaves, and mycorrhiza (15 g $plant^{-1}$) was superior for highest tuber weight and production. The maximum protein content (%) came from the combination of mycorrhiza (7.5 g $plant^{-1}$) and foliar fertilizer (6 g L^{-1}), and the higher vitamin C content (%) emerged by the combination of mycorrhiza (15 g $plant^{-1}$) and foliar fertilizer (4 g L^{-1}).

ACKNOWLEDGMENTS

The authors thank the campus of Hasanuddin University Makassar, the Feed Chemistry Laboratory of the Department of Animal Nutrition and Food, Faculty of Animal Husbandry, Hasanuddin University Makassar, and the Bantaeng Horticultural Research Center, South Sulawesi, Indonesia.

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