



## Impact of VAMRight (Arbuscular Mycorrhizal Fungi) on Growth, Yield, Tuber Quality, and Nutrient Uptake of Potato in Field Cultivation

Jigar Mistry, Aditi Bijalwan and Yagnesh Thakkar\*

Agrilogy Biosciences Pvt Ltd, Valsad, Gujarat, India

\*Corresponding Author: Yagnesh Thakkar, Agrilogy Biosciences Pvt Ltd, Valsad, Gujarat, India.

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### Abstract

Mycorrhizal inoculation using a commercial arbuscular mycorrhizal biofertilizer (VAMRight) was evaluated under field conditions at Himmatnagar, Gujarat, India, to assess its effect on potato growth, yield, and quality. The experiment was conducted in a randomized complete block design with an uninoculated control and VAMRight applied at 100 g per acre. Application of VAMRight substantially improved root colonization, with treated plants recording  $46.5 \pm 1.8\%$  colonization compared to  $3.4 \pm 0.3\%$  in the control, representing about 1268% increase, indicating successful establishment of mycorrhiza. This was accompanied by improved growth, where plant height reached  $73.8 \pm 1.5$  cm, showing a 27% increase over the control. Yield attributes were also enhanced, with  $8.4 \pm 0.5$  tubers per plant and  $357.2 \pm 4.1$  g tuber weight per plant, corresponding to increases of 40% and 43%, respectively. Consequently, total tuber yield increased to  $21.98 \pm 0.35$  t/ha compared to  $20.85 \pm 0.31$  t/ha in the control, reflecting a 5.4% increase. In addition, quality parameters improved, with starch content reaching  $26.9 \pm 1.1\%$ , showing a 24% increase, along with higher crude protein content. Overall, the results indicate that VAMRight enhances mycorrhizal colonization, growth, yield, and tuber quality, supporting its use as a sustainable alternative in potato cultivation.

**Keywords:** Arbuscular Mycorrhiza; Biofertilizer; Phosphorus Availability; Potato; Tuber Yield

### Introduction

Potato (*Solanum tuberosum* L.) is one of the most important food crops worldwide, ranking fourth after rice, wheat, and maize in terms of global production [1]. Its high yield potential, short growth cycle, and adaptability to a wide range of agro-climatic conditions make potato a key component of global food and nutritional security [2]. The crop is valued primarily for its high carbohydrate content and also contributes essential vitamins, minerals, and dietary fiber to human diets. However, the intensive nature of potato cultivation places considerable demand on soil nutrients, particularly during early vegetative growth, stolon development, and tuber initiation stages, necessitating efficient nutrient management strategies for sustainable production [3].

Among the essential macronutrients, phosphorus plays a crucial role in potato growth and productivity. Phosphorus is a structural component of nucleic acids and phospholipids and is directly involved in energy transfer reactions through adenosine triphosphate (ATP) [4]. It regulates several physiological and biochemical processes including root development, photosynthesis, carbohydrate metabolism, and enzyme activation. In potato, adequate phosphorus availability is particularly important for early root establishment, stolon formation, tuber initiation, and uniform tuber bulking [5]. Phosphorus deficiency during critical growth stages often results in poor root development, delayed tuberization, reduced tuber number, and lower yield [6]. Phosphorus availability remains a major constraint to crop productivity because of its

essential role in plant growth. Although soils contain substantial amounts of total phosphorus, most of it exists in fixed or insoluble forms that cannot be taken up by plants [7]. Phosphorus reacts with calcium in alkaline soils and with iron and aluminum in acidic soils, forming stable, low-mobility complexes. Its limited diffusion in soil causes rapid depletion of phosphorus in the rhizosphere as plant uptake increases, particularly in crops like potato with shallow and less extensive root systems [8].

To compensate for low phosphorus availability, chemical phosphorus fertilizers are widely used in potato production; however, their efficiency is low, as only a small fraction is absorbed by plants while the remainder becomes immobilized in soil [9]. Excessive and repeated application increases production costs, causes nutrient imbalance, reduces soil microbial activity, and degrades soil health. Additionally, phosphorus losses through runoff and leaching contribute to environmental problems such as eutrophication, while the finite nature of phosphate rock raises concerns about the long-term sustainability of chemical fertilizer-based nutrient management [10].

In recent years, increasing attention has been directed toward biologically based nutrient management approaches as sustainable alternatives to chemical fertilizers. Beneficial soil microorganisms such as phosphate-solubilizing bacteria and fungi, including species of *Bacillus*, *Pseudomonas*, *Aspergillus*, *Penicillium*, and *Trichoderma*, have been shown to improve phosphorus availability by solubilizing insoluble phosphate compounds through the secretion of organic acids and phosphatase enzymes [11]. These microorganisms also enhance plant growth through the production of phytohormones, improvement of root architecture, and suppression of soil-borne pathogens [12]. However, the effectiveness of these microorganisms can vary depending on soil conditions, crop type, and environmental factors.

Among biological nutrient acquisition strategies, vesicular arbuscular mycorrhizae (VAM), also known as arbuscular mycorrhizal fungi, represent one of the most widespread and effective symbiotic systems in terrestrial ecosystems [13]. These fungi form mutualistic associations with the roots of the majority of agricultural crops. In this mutualistic association, the host plant provides photosynthetically fixed carbon to the fungus, while the fungus improves the uptake of water and mineral nutrients, particularly phosphorus, from the soil. Vesicular–arbuscular

mycorrhizal (VAM) fungi colonize root cortical cells and form specialized intracellular structures known as arbuscules, which act as the principal sites of nutrient exchange within the plant–fungus association [14].

The most distinctive feature of VAM fungi is their extensive extraradical hyphal network, which extends far beyond the root depletion zone and explores a much larger volume of soil than plant roots alone [15]. As a result of promoting access to stable phosphorus pools and promoting the use of both inorganic and organic phosphorus sources, the hyphal system enhances phosphorus uptake. In addition, vesicular–arbuscular mycorrhizal (VAM) fungi promote the uptake of other essential mineral nutrients, including nitrogen, potassium, calcium, magnesium, zinc, copper, and iron. VAM colonization also improves plant water uptake, enhances photosynthetic performance, modulates hormonal regulation, and increases tolerance to abiotic stresses such as drought and nutrient limitation [16].

Potato is considered a highly mycorrhiza-responsive crop due to its high phosphorus requirement and limited root system. Several studies have reported improved growth, nutrient uptake, and yield in potato following mycorrhizal inoculation [17]. Despite these reported benefits, the adoption of VAM-based biofertilizers in commercial potato production remains limited, and information on the performance of multi-species VAM formulations under field conditions is still insufficient. There is still an absence of extensive study related to the potential benefits for industrial vesicular–arbuscular mycorrhizal (VAM) consortia to improve potato growth and yield as an alternative to conventional chemical phosphorus fertilizer [18].

VAMRight is a mycorrhizal biofertilizer formulated with a consortium of efficient arbuscular mycorrhizal fungi including *Rhizophagus fasciculatus*, *Glomus intraradices*, *Glomus mosseae*, *Glomus aggregatum*, and *Rhizophagus clarus*, selected for their strong root colonization ability and effectiveness in enhancing nutrient uptake [19]. The combined action of multiple mycorrhizal species is expected to improve functional diversity, adaptability across different soil environments, and overall performance in promoting plant growth [20]. However, scientific validation of the effectiveness of such formulations on potato under field conditions is essential to support their practical application and wider adoption [21].

The present study was undertaken to evaluate the effect of VAMRight mycorrhizal inoculation on growth, nutrient uptake, and yield of potato. This research aims to address existing gaps by providing experimental evidence on the role of a VAM-based biofertilizer in improving phosphorus use efficiency and crop performance. The findings of this study are expected to contribute to sustainable nutrient management strategies, reduce dependence on chemical fertilizers, and promote environmentally friendly potato cultivation. By integrating biologically mediated nutrient acquisition with crop productivity, this study contributes to the advancement of sustainable agricultural practices and the improvement of long-term soil health.

## Materials and Methods

### Experimental Site and study location

A field experiment was conducted at Himmatnagar, Gujarat, India, to evaluate the effect of arbuscular mycorrhizal fungi (AMF) on growth, yield, and quality attributes of potato (*Solanum tuberosum* L.) cv. *Lady Rosetta* under open field conditions. The experimental site is characterized by a semi-arid climate with typical agronomic conditions suitable for potato cultivation.

### Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising two treatments with three replications to account for field heterogeneity. The treatments included T<sub>1</sub> – control (without mycorrhizal inoculation) and T<sub>2</sub> – mycorrhiza-treated (inoculated with the commercial arbuscular mycorrhizal biofertilizer VAMRight). Each experimental plot measured 3 m × 3 m (9 m<sup>2</sup>), and a total of six plots (2 treatments × 3 replications) were established.

The crop was planted at a spacing of 60 cm between rows and 20 cm between plants, ensuring an optimum plant population per unit area. A buffer distance of 0.5 m was maintained between adjacent plots, while 1.0 m spacing was maintained between replications to minimize inter-plot interference and ensure treatment independence. Treatments were randomly assigned within each block.

### Mycorrhizal inoculum and composition

The study used a powdered arbuscular mycorrhizal inoculum VAMRight produced by Agrilogy Biosciences Pvt Ltd., with a spore density of 100 spores/g. The arbuscular mycorrhizal fungi that

produced composed the inoculum, 1. *Rhizophagus fasciculatus* (OR563927), 2. *Intraradices Glomus* (OR563925), 3. *Glomus mosseae* (PX844728) 4. *Rhizophagus clarus* (PX900843) and 5. *Glomus aggregatum* (PX844732).

### Measurement of mycorrhizal colonization, growth, yield, and quality parameters

Mycorrhizal colonization in potato roots was assessed to determine the extent of arbuscular mycorrhizal fungi (AMF) association. Root samples were carefully washed to remove soil and cut into 1–2 cm segments. The roots were cleared in 10% KOH at 90°C for 30 minutes, then acidified in 1% HCl, and finally stained with 0.05% Trypan Blue in lactoglycerol following the procedure described by Phillips and Hayman (1970) [22]. Colonization (%) was determined by examining stained root segments under a compound microscope, and the proportion of root length colonized by AMF structures (arbuscules, vesicles, and hyphae) was calculated.

Plant growth was recorded by measuring plant height (cm). Yield and yield-related parameters included tuber size (cm), tubers per plant, tuber weight per plant (g), tubers per m<sup>2</sup>, and total tuber yield (t/ha).

Tuber quality parameters were evaluated by estimating protein and starch contents. Protein content (%) was determined using the Kjeldahl method [23], while starch content (%) was measured following the Enthron reagent method [24]. The starch yield (t/ha) was subsequently calculated by combining the total tuber yield with the measured starch concentration.

### Statistical analysis

The experimental data collected over the two cropping seasons were Statistically analyzed using analysis of variance (ANOVA) corresponding to the RBD structure and treatment means were compared using the LSD test at a probability threshold of  $p \leq 0.05$  [25].

## Result and Discussion

### Influence of VAM formulation on potato growth and tuber development

#### Mycorrhizal colonization

Mycorrhizal colonization in plant roots was markedly enhanced by the application of the VAM formulation, with treated plants

recording  $46.5 \pm 1.8\%$  colonization compared to  $3.4 \pm 0.3\%$  in the control, representing an approximate 1268% increase, which indicates the effective establishment of VAM in the root system (Table 1). This higher colonization suggests improved symbiotic association between plant roots and mycorrhizal fungi, which can enhance nutrient uptake and support better plant growth. In a previous study, arbuscular mycorrhizal inoculation in diseased rice plants resulted in colonization levels ranging from 12.4 to 19.5%, whereas non-inoculated plants recorded only  $2.5 \pm 0.3\%$  colonization [26], demonstrating the beneficial role of mycorrhizal association in increasing root colonization and strengthening plant–microbe interactions.

### Plant height

The application of the VAM formulation led to a marked increase in plant height compared with the control (Table 1). Treated plants obtained  $73.8 \pm 1.5$  cm, while control plants measured  $58.13 \pm 1.2$  cm, representing a 27% increase over the control, indicating enhanced vegetative growth under the treated condition. Under field conditions, tomato plants inoculated with arbuscular mycorrhizal fungi showed a markedly greater plant height compared with non-inoculated plants. The inoculated plants attained a height of 78.93 cm, whereas the non-inoculated plants reached only 48.62 cm, indicating a substantial improvement in vegetative growth due to mycorrhizal inoculation. This enhancement in plant height may be attributed to the symbiotic association between plant roots and arbuscular mycorrhizal fungi, which improves the absorption of essential nutrients, particularly phosphorus, from the soil [27].

In another study, potato plants inoculated with mycorrhizal fungi achieved an average plant height of 72.8 cm, which was higher than that of non-inoculated plants. This increase suggests that mycorrhizal colonization can enhance nutrient absorption and promote vegetative growth, resulting in more vigorous plants under field conditions [28].

### Tuber size

A clear difference in tuber size was observed between the treatments. The treated plants produced larger tubers with an average size of  $6.8 \pm 0.3$  cm, while the control plants produced smaller tubers measuring  $2.8 \pm 0.2$  cm, corresponding to a 143% increase, showing enhanced tuber development (Table 1). Positive influence of arbuscular mycorrhizal fungi (AMF) on tuber development has

been reported in a comparable study. In that study, AMF-inoculated potato microplants produced a higher number of larger, seed-grade tubers (8.5 tubers per plant) compared with non-inoculated plants (3.8 tubers per plant) and seed-tuber controls (1.2 tubers per plant) [29]. The improvement in tuber size may be attributed to enhanced nutrient uptake, particularly phosphorus, through the mycorrhizal hyphal network present in the soil. In addition, AMF colonization improves root efficiency and physiological activity, which promotes better carbohydrate accumulation and supports the development of larger tubers.

### Tubers per plant

The number of tubers per plant was higher in VAM formulation treated plants, which produced  $8.4 \pm 0.5$  tubers per plant compared with  $6.0 \pm 0.4$  tubers per plant in the control, representing a 40% increase over the control (Table 1), demonstrating the positive effect of VAM inoculation on tuber formation. In another study, arbuscular mycorrhizal colonization was reported to enhance tuber initiation in potato plants. The study observed a higher mean tuber number ( $9.0 \pm 1.6$  tubers per plant) in AMF-inoculated plants, whereas non-inoculated plants recorded comparatively lower values [30]. This result indicates that mycorrhizal association positively influences the early stages of tuber formation and contributes to improved reproductive development in potato crops.

### Effect of VAM formulation on tuber yield and productivity in potato

#### Tuber weight

A substantial difference in average tuber weight was observed between the treatments. The treated plants recorded an average tuber weight of  $357.2 \pm 4.1$  g, compared with  $249.2 \pm 3.6$  g in the control (Table 1), representing a 43% increase over the control, indicating improved tuber development in the VAM-treated plants. A previous study demonstrated enhanced tuber biomass in potato plants following inoculation with *Glomus mosseae*. The inoculated plants produced a higher tuber weight, reaching up to 898 g per plant, whereas non-inoculated plants recorded comparatively lower tuber weights under field conditions [31].

#### Tuber yield

Tuber yield increased in the VAM-treated plants, which produced  $21.98 \pm 0.35$  t/ha compared with  $20.85 \pm 0.31$  t/ha in the control,

corresponding to a 5.4% increase, indicating enhanced productivity due to mycorrhizal inoculation (Table 1). A similar result indicated that arbuscular mycorrhizal inoculation improved potato yield under field conditions. AMF-treated potato crops achieved yields of approximately 42.2 t/ha, whereas non-inoculated control plants produced 38.3 t/ha. The higher yield observed in inoculated plants suggests that mycorrhizal association enhances nutrient uptake and plant growth, which ultimately contributes to increased tuber productivity [32].

### Tubers per square meter

The number of tubers per square meter exhibited a substantial increase in the VAM formulation treated plants, reaching  $44.10 \pm 1.85$  tubers  $m^2$ , compared with  $22.75 \pm 1.10$  tubers  $m^2$  in the control, representing a remarkable 94% increase (Table 1). This

considerable enhancement highlights the pronounced effect of mycorrhizal inoculation on tuber proliferation, likely due to improved nutrient uptake, particularly phosphorus, which supports greater vegetative growth and tuber initiation. The increase in tuber density per unit area indicates not only a higher productivity potential but also more efficient utilization of the available soil resources. In comparison, a study assessing different propagation methods reported an average of 15.68 tubers per plant in seedling transplants, which falls within the commonly observed range of 7–14 tubers per plant under favorable growing conditions [33]. This comparison indicates that VAM formulation can substantially enhance tuber production beyond conventional propagation methods, demonstrating its potential for improving field-level potato yield.

Parameter	Control	Treated (VAMRight)	F-value	P-value	CV (%)
Mycorrhizal Colonization (%)	$3.4 \pm 0.3^b$	$46.5 \pm 1.8^a$	412.65	0.001	7.4
Plant Height (cm)	$58.13 \pm 1.2^b$	$73.8 \pm 1.5^a$	18.42	0.004	5.8
Tuber Size (cm)	$2.8 \pm 0.2^b$	$6.8 \pm 0.3^a$	64.75	0.001	6.5
Tubers per Plant	$6.0 \pm 0.4^b$	$8.4 \pm 0.5^a$	12.63	0.014	7.2
Tuber Weight (g)	$249.2 \pm 3.6^b$	$357.2 \pm 4.1^a$	152.88	0.001	4.3
Tuber Yield (t/ha)	$20.85 \pm 0.31^b$	$21.98 \pm 0.35^a$	9.74	0.033	3.9
Tubers per $m^2$	$22.75 \pm 1.10^b$	$44.10 \pm 1.85^a$	98.21	0.001	6.1

**Table 1:** Impact of VAMRight on Growth and Yield Parameters of Potato (*Solanum tuberosum* L.).

### Effect of VAM formulation on protein, starch content, and starch yield in potato tubers

#### Protein content

The application of the VAM formulation considerably enhanced the protein content of potato tubers. VAM-treated plants contained  $11.9 \pm 0.6\%$  protein, compared with  $7.0 \pm 0.4\%$  in the control, corresponding to a 70% increase which indicates the substantial improvement in tuber nutritional quality (Figure 1). This enhancement attributed to the improved nutrient uptake facilitated by the symbiotic association between potato roots and the multi-species arbuscular mycorrhizal fungi present in the VAM formulation, particularly nitrogen and phosphorus, which are essential for protein synthesis. In another study, protein content in fresh potato tubers was reported to be relatively low, typically ranging from 1.7% to 2.3%. However, when expressed

on a dry weight basis, values ranged from 4.5% to 13.6%, placing the 11.9% protein content observed in VAM-treated tubers toward the upper limit of the reported range [34]. These results indicate that VAM formulation application not only increases yield but also substantially improves the nutritional quality of potato tubers, reinforcing its potential as a sustainable biotechnological tool for enhanced crop production.

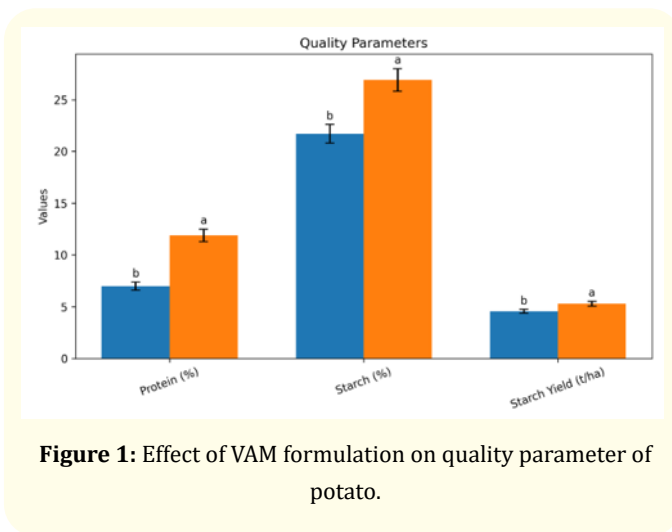
#### Starch concentration

Starch concentration in the tubers was also higher under the treated condition. The treated plants recorded  $26.9 \pm 1.1\%$  starch, while the control plants (Figure 1). This improvement indicates that mycorrhizal inoculation promotes carbohydrate accumulation, enhancing both nutritional value and industrial suitability of the tubers. In another study, potato starch content was reported

to range from 10.8% to 22.1% on a fresh weight basis, whereas high-starch potato varieties were found to contain more than 25% starch, reflecting their suitability for processing and industrial applications [35].

### Starch yield

The increase in tuber yield and starch content together led to a higher starch yield in VAM-treated plants. The treatment produced  $5.29 \pm 0.22$  t/ha, compared with  $4.56 \pm 0.18$  t/ha in the control (Figure 1), representing a 16% increase, indicating the combined impact of enhanced tuber production and starch accumulation. A similar study observed that the application of arbuscular mycorrhizal fungi in potato cultivation resulted in an increase in tuber yield under field conditions. The study reported that mycorrhizal inoculation enhanced overall productivity by approximately 6–8% compared with non-inoculated plants [36].



**Figure 1:** Effect of VAM formulation on quality parameter of potato.

### Conclusion

Field application of the arbuscular mycorrhizal biofertilizer VAMRight substantially enhanced potato result under field conditions. Enhanced root colonization through mycorrhizal association was accompanied by improvements in plant growth, tuber size, tuber number, and tuber weight. Yield-related parameters, including total tuber yield and starch yield, showed consistent improvement under mycorrhizal application. Higher tuber protein and starch contents indicate improved tuber quality and nutrient use efficiency. A sustainable biological technique for enhancing potato yield while reducing usage on synthesized

fertilizer containing phosphorus and promoting ecologically friendly production methods is the application of VAM formulation.

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