



Arbuscular Mycorrhizal Fungi Associated with *Sorghum bicolor* (L.) in Solapur District of Maharashtra

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Abstract

The present study was conducted to assess arbuscular mycorrhizal (AM) fungal root colonization, spore population, and species diversity associated with *Sorghum bicolor* cultivated in different talukas of Solapur district, Maharashtra. Root and rhizosphere soil samples were collected from ten locations and analyzed using standard mycorrhizal assessment techniques. All sampled plants exhibited AM fungal colonization, indicating the widespread occurrence of AM fungi in sorghum rhizosphere soils. Root colonization ranged from 45% to 72%, while spore population varied from 15 to 140 spores per 100 g of soil, showing significant location-wise variation. Hyphal and hyphal with vesicular types of colonization were observed, with vesicular colonization predominating in most locations. A total of several AM fungal species belonging to the genera *Glomus*, *Acaulospora*, *Entrophospora*, *Gigaspora*, *Scutellospora* and *Sclerocystis* were recorded, with *Glomus* species being dominant across all sites. The study highlights the influence of soil and agro-climatic conditions on AM fungal distribution and emphasizes the importance of native AM fungi in maintaining soil biological health and supporting sustainable sorghum production under semi-arid conditions.

Keywords: AM fungal diversity, Root colonization, Semi-arid soils, Sorghum bicolor, Spore population

Introduction

Sorghum bicolor (L.) Moench, a member of the family Poaceae, is one of the most important cereal crops worldwide and ranks fifth after wheat, rice, maize, and barley. The crop is widely cultivated in tropical and subtropical regions due to its

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adaptability to diverse agro-climatic conditions, tolerance to drought, and low input requirements. Sorghum serves as a major source of food for human consumption, nutritious fodder for livestock, and raw material for various industrial applications such as brewing and biofuel production (Birhanu, 2024). Its resilience under water-limited environments makes sorghum particularly important for food and nutritional security in semi-arid regions.

In India, sorghum is an important staple cereal crop grown predominantly in Maharashtra, Karnataka, Andhra Pradesh, Gujarat, Madhya Pradesh, and Rajasthan (ICAR, 2022). Maharashtra occupies the largest area under rabi sorghum cultivation and contributes significantly to national production. The crop is extensively cultivated in districts such as Solapur, Osmanabad, Satara, Ahmednagar, and Latur, where it forms an integral component of traditional dryland farming systems (Navadkar et al., 2012; Shinde et al., 2021). Solapur district, characterized by deep black cotton soils and a semi-arid climate, is particularly well known for rabi jowar cultivation. However, sorghum productivity in this region is often constrained by low soil fertility, poor availability of phosphorus, and recurring moisture stress, highlighting the need for sustainable soil and nutrient management practices (ICAR, 2022; Birhanu, 2024).

Arbuscular mycorrhizal (AM) fungi are obligate symbiotic microorganisms belonging to the phylum Glomeromycota that establish mutualistic associations with the roots of nearly 80–90% of terrestrial plant species. These fungi enhance the uptake of essential mineral nutrients, particularly phosphorus and nitrogen, through their extensive extraradical hyphal networks that extend beyond the root depletion zone (Elsafy, 2025). In addition to improved nutrient acquisition, AM fungi contribute to enhanced soil aggregation, improved water uptake, and increased tolerance of host plants to abiotic stresses such as drought and salinity (Alayafi et al., 2025; Birhanu, 2024).

In cereal crops such as sorghum, arbuscular mycorrhizal associations play a significant role in influencing root development, nutrient use efficiency, and overall plant growth and productivity. The extent of AM fungal colonization and spore population in the rhizosphere is influenced by several factors, including soil type, climatic conditions, cropping practices, and host plant species (Adoleya and Gaur, 1994; Son et al., 2025). Recent studies have also highlighted the role of AM fungi in modulating plant defense responses and interacting with rhizosphere microbial communities, thereby contributing to sustainable crop production systems (Farhaoui, 2025).

Despite the agronomic importance of *S. bicolor* in the Solapur district, systematic information on its arbuscular mycorrhizal status under local field conditions remains limited. Therefore, the present study was undertaken to assess arbuscular mycorrhizal root colonization, spore population, and fungal diversity associated with *S. bicolor* cultivated in different talukas of Solapur district, Maharashtra.

Materials and Methods

Study Area

The study was conducted in Solapur district, Maharashtra, India, located in the semi-arid Deccan Plateau region. The area is characterized by low and erratic rainfall and deep black cotton (Vertisol) soils, typically low in available phosphorus. *S. bicolor* (L.) is a major rabi crop grown predominantly under rainfed conditions. Ten talukas-Solapur, Barshi, Akkalkot, Pandharpur, Mangalwedha, Sangola, Mohol, Madha, Karmala, and Malshiras-were selected to represent variability in soil and agro-climatic conditions.

Sampling of Roots and Rhizosphere Soil

Roots and rhizosphere soil of *S. bicolor* were collected from farmers' fields at each location. Sampling was carried out in triplicate. Plants were carefully uprooted, roots were washed under running tap water, and cut into 1 cm segments. Rhizosphere soil adhering to roots was collected separately for spore analysis.

Assessment of Root Colonization

Root segments were cleared and stained following the method of Phillips and Hayman (1970). Stained roots were examined under a compound microscope for arbuscular mycorrhizal structures (hyphae and vesicles). The percentage of root colonization was estimated using the gridline intersect method described by Giovannetti and Mosse (1980).

Isolation and Identification of AM Fungal Spores

Arbuscular mycorrhizal fungal spores were isolated from 100 g of rhizosphere soil using the wet sieving and decanting method (Gerdemann and Nicolson, 1963). Spores were counted under a stereomicroscope and expressed as the number of spores per 100 g soil. AM fungal genera were identified based on spore morphology using standard taxonomic keys (Schenck and Perez, 1990). Authenticated spore specimens and *Sorghum* herbarium vouchers were deposited in the Department of Botany, Dr. Babasaheb Ambedkar Marathwada University (Chhatrapati Sambhajanagar, India), for permanent record and verification.

Statistical Analysis

All observations were recorded in triplicate and expressed as mean \pm standard error (SE). Data were analyzed using one-way analysis of variance (ANOVA), with location as the independent factor. Mean separation was performed using Duncan's Multiple Range Test (DMRT) at $p < 0.05$. Differences among means were considered significant when followed by different superscript letters.

Results and Discussion

The data on percent root colonization, spore population, and arbuscular mycorrhizal (AM) fungal species associated with *S. bicolor* grown at different locations of

Solapur district are presented in Table 1. Statistical analysis revealed significant variation ($p < 0.05$) among the locations with respect to both root colonization percentage and AM fungal spore population.

Table 1. Percent root colonization, spore population, and arbuscular mycorrhizal fungal species associated with *S. bicolor* in Solapur district

Location	Root Colonization (%)	Type of Colonization	Spore Population (No./100 g soil)	AM Fungal Species
Solapur	59 ± 1.20 ^c	H	46 ± 1.05 ^c	<i>A. spinosa</i> , <i>E. hexagoni</i> , <i>G. mosseae</i> , <i>G. macrocarpum</i>
Barshi	72 ± 1.35 ^d	HV	15 ± 0.65 ^a	<i>E. hexagoni</i> , <i>G. fasciculatum</i> , <i>G. halonii</i>
Akkalkot	50 ± 1.10 ^b	HV	82 ± 1.40 ^d	<i>A. spinosa</i> , <i>G. geosporum</i> , <i>G. clarum</i> , <i>Sc. sinuosa</i>
Pandharpur	58 ± 1.18 ^c	HV	51 ± 1.10 ^c	<i>A. scrobiculata</i> , <i>A. thomii</i> , <i>E. hexagoni</i> , <i>G. ambisporum</i> , <i>G. intraradices</i>
Mangalwedha	45 ± 1.05 ^a	H	32 ± 0.90 ^b	<i>G. multicaule</i> , <i>G. geosporum</i> , <i>G. mosseae</i>
Sangola	54 ± 1.12 ^b	HV	85 ± 1.45 ^d	<i>E. hexagoni</i> , <i>G. mosseae</i> , <i>G. australe</i> , <i>S. sinuosa</i>
Mohol	70 ± 1.30 ^d	HV	140 ± 1.85 ^e	<i>E. hexagoni</i> , <i>G. multicaule</i> , <i>G. constrictum</i>
Madha	64 ± 1.25 ^c	HV	67 ± 1.30 ^c	<i>A. spinosa</i> , <i>G. mosseae</i> , <i>G. geosporum</i>
Karmala	58 ± 1.15 ^c	HV	44 ± 1.00 ^c	<i>A. scrobiculata</i> , <i>E. hexagoni</i> , <i>G. fasciculatum</i>
Malshiras	46 ± 1.08 ^a	H	46 ± 1.05 ^c	<i>A. thomii</i> , <i>G. clarum</i> , <i>G. intraradices</i>

H = Hyphal colonization; HV = Hyphal + Vesicular colonization.

A. = *Acaulospora*; E. = *Entrophospora*; G. = *Glomus*; Sc. = *Scutellospora*; S. = *Sclerocystis*.

All observations were recorded in triplicates and expressed as mean ± SE. Values with different superscript letters (a–e) within a column differ significantly according to Duncan's Multiple Range Test (DMRT) at $p < 0.05$.

All sampled sorghum plants showed arbuscular mycorrhizal colonization, indicating the widespread occurrence of AM fungi in the sorghum rhizosphere throughout the district. The percentage of root colonization varied from 45% to 72%. The maximum root colonization was recorded at Barshi (72%), which was statistically at par with

Mohol (70%), whereas the minimum colonization was observed at Mangalwedha (45%) and Malshiras (46%). Moderate levels of colonization were recorded at Madha (64%), Solapur (59%), Pandharpur (58%), and Karmala (58%).

Microscopic examination of root samples revealed two types of colonization, namely hyphal (H) and hyphal with vesicular (HV). Hyphal colonization was common in all the locations, whereas hyphal with vesicular colonization predominated in most of the talukas, suggesting active and functional mycorrhizal associations. However, only hyphal colonization was observed at Solapur, Mangalwedha, and Malshiras.

The spore population of AM fungi showed considerable variation among the locations and ranged from 15 to 140 spores per 100 g of rhizosphere soil. The highest spore density was observed at Mohol (140 spores), which was significantly higher ($p < 0.05$) than all other locations. Sangola (85 spores) and Akkalkot (82 spores) also recorded significantly higher spore populations. In contrast, the lowest spore population was recorded at Barshi (15 spores), followed by Mangalwedha (32 spores). Moderate spore densities were observed at Madha (67 spores), Pandharpur (51 spores), Solapur (46 spores), Karmala (44 spores), and Malshiras (46 spores). The grouping of means based on Duncan's Multiple Range Test clearly indicated significant differences in spore density among the locations.

Qualitative assessment of arbuscular mycorrhizal fungal species revealed the presence of several AM fungal taxa belonging to the genera *Acaulospora*, *Glomus*, *Entrophospora*, *Gigaspora*, *Scutellospora*, and *Sclerocystis*. Among these, *Glomus* species were the most frequently occurring and widely distributed across all locations, indicating their dominance in the sorghum-growing soils of Solapur district. *Acaulospora* and *Entrophospora* species were also commonly recorded, while *Gigaspora*, *Scutellospora*, and *Sclerocystis* showed comparatively restricted distribution.

The highest diversity of AM fungal species was recorded at Mohol, followed by Pandharpur and Akkalkot, whereas Barshi exhibited the lowest diversity of AM fungal species. The results suggest that both the extent of root colonization and the diversity and abundance of AM fungal spores vary significantly with location, reflecting the influence of local soil and agro-climatic conditions on AM fungal associations in *S. bicolor*.

The present study clearly demonstrates the widespread occurrence of arbuscular mycorrhizal (AM) fungi in *S. bicolor* cultivated across different talukas of Solapur district, as evidenced by root colonization at all sampling locations (Table 1). The universal presence of AM fungi confirms sorghum as a highly compatible host, which is in agreement with earlier reports on cereal crops grown under semi-arid conditions (Harley and Smith, 1983; Smith and Read, 2021). However, the significant variation observed in root colonization percentage, spore population, and AM fungal species composition among locations indicates a strong influence of local soil and agro-climatic factors on AM fungal dynamics.

Higher root colonization recorded at Barshi (72%) and Mohol (70%) suggests comparatively favorable soil conditions, such as better moisture retention and nutrient availability, which promote effective root–fungus symbiosis. In contrast, lower colonization at Mangalwedha (45%) and Malshiras (46%) may be attributed to poor soil fertility, low organic matter content, and prolonged moisture stress, which are known to restrict mycorrhizal development (Augé et al., 2020; Birhanu, 2024; Elsafy, 2025). Similar location-dependent variation in AM fungal colonization has been reported in sorghum and other dryland cereals (Alayafi et al., 2025; Sadhana, 2022).

The predominance of hyphal with vesicular (HV) colonization in most locations, as shown in Table 1, indicates active and metabolically functional mycorrhizal associations. Vesicles serve as storage structures for carbon and lipids and are considered indicators of favorable symbiotic conditions (Phillips and Hayman, 1970; Smith and Read, 2021). In contrast, locations showing only hyphal colonization, such as Solapur, Mangalwedha, and Malshiras, may represent stressed environments where AM fungi prioritize nutrient uptake rather than storage, a response commonly observed under drought-prone or nutrient-limited conditions (Farhaoui, 2025).

Marked variation in spore population among locations further reflects differences in soil moisture regime and environmental stress. The highest spore density at Mohol (140 spores per 100 g soil), followed by Sangola and Akkalkot, may represent an adaptive reproductive strategy of AM fungi to ensure survival and dispersal under fluctuating field conditions (Gerdemann and Nicolson, 1963; Birhanu, 2024). Conversely, the low spore population at Barshi (15 spores) despite high root colonization supports the view that spore density does not necessarily correlate with colonization intensity (Adoleya and Gaur, 1994; Berruti et al., 2021; Son et al., 2025). This suggests that active hyphal networks and root-associated propagules may play a more critical role than spores alone in sustaining colonization.

Qualitative assessment based on Table 1 revealed the dominance of *Glomus* species across all locations, indicating their wide ecological adaptability and efficiency under semi-arid conditions. *Acaulospora* and *Entrophospora* species were also frequently encountered, while *Gigaspora*, *Scutellospora*, and *Sclerocystis* showed comparatively restricted distribution. The highest AM fungal species diversity recorded at Mohol corresponds with higher spore density and root colonization, highlighting the role of favorable micro-environmental conditions in supporting diverse AM fungal communities (Muthukumar and Udaiyan, 2000; Hijri, 2022; Thirkell et al., 2022).

Overall, the location-wise variation in AM fungal colonization, spore population, and species composition observed in the present study reflects the combined effects of soil fertility, moisture availability, and climatic stress across Solapur district. These findings emphasize the ecological significance of native AM fungal communities in maintaining soil biological health and enhancing sorghum productivity under semi-

arid conditions, and suggest that location-specific management of AM fungi could contribute to sustainable sorghum cultivation.

Conclusion

The study confirms the consistent association of arbuscular mycorrhizal (AM) fungi with *S. bicolor* across different talukas of Solapur district. Significant location-wise variation in root colonization, spore population, and AM fungal species composition reflects the influence of local soil and agro-climatic conditions. The predominance of *Glomus* species, along with *Acaulospora* and *Entrophospora*, indicates their ecological adaptability to semi-arid environments. Overall, native AM fungal communities play an important role in maintaining soil biological health and supporting sustainable sorghum cultivation under dryland conditions.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Acknowledgements

Authors are grateful to the Principal, Shikshan Maharshi Guruvarya R. G. Shinde Mahavidyalaya, Paranda for providing laboratory & library facilities and constant encouragement.

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