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Research Article

Arbuscular Mycorrhizal Fungi as a Sustainable Biofertilizer for Enhancing Sesame Production in Semi-Arid Agroecosystems

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Abstract

Sesame (*Sesamum indicum* L.) is an economically important oilseed crop widely cultivated in semi-arid regions; however, its productivity is frequently constrained by poor soil fertility and low nutrient availability. Arbuscular mycorrhizal fungi (AMF) are known to enhance nutrient uptake, plant growth, and stress tolerance through beneficial symbiotic interactions with plant roots. Nevertheless, limited information exists regarding the influence of AMF inoculation on sesame cultivated under the semi-arid conditions of Northern Nigeria. Therefore, this study evaluated the effects of AMF inoculation on the growth and yield performance of sesame. Soil samples were collected from three sesame farms located in Yusufari and Machina Local Government Areas of Yobe State, Nigeria. AMF inoculum obtained from the Microbiology Laboratory of Yobe State University, Damaturu, was applied to treatment soils, while non-inoculated soils served as controls. Vegetative growth parameters and yield components were assessed, and the data were analyzed using descriptive statistics and multivariate cluster analysis. The results demonstrated significant improvements ($P < 0.05$) in vegetative growth parameters of AMF-treated plants compared with the control, including petiole leaf length (8.14 ± 0.15 to 8.82 ± 0.13 cm), base leaf length (8.10 ± 0.12 to 8.50 ± 0.07 cm), petiole length of top leaf (0.98 ± 0.05 to 1.08 ± 0.08 cm), basal leaf width (1.88 ± 0.08 to 2.08 ± 0.08 cm), middle leaf length (7.70 ± 0.19 to 8.22 ± 0.11 cm), and middle leaf width (1.98 ± 0.05 to 2.16 ± 0.06 cm). Similarly, significant increases were observed in yield-related traits, including number of capsules per plant (41.20 ± 1.48 to 46.00 ± 2.00), capsule length (2.22 ± 0.05 to 2.36 ± 0.11 cm), capsule thickness (1.96 ± 0.05 to 2.12 ± 0.08 cm), capsule width (1.16 ± 0.05 to 1.46 ± 0.05 cm), and number of seeds per capsule (72.20 ± 3.70 to 87.80 ± 4.21). These findings indicate that AMF inoculation significantly enhances sesame growth and yield under semi-arid soil conditions and may represent a sustainable strategy for improving sesame productivity in Northern Nigeria..

Keywords: Arbuscular mycorrhizal fungi, Growth and yield, Inoculation, Northern Nigeria, Sesame plant.

1. Introduction

Sesame plant (*Sesamum indicum* L.) is typically found in tropical and subtropical locations. This plant is renowned for requiring less manure and water [1, 2]. Sesame plant seeds' economic significance is mostly attributable to the fact that it contains 25% of the protein in meat and is 50% rich in high-quality oil [3]. Sesame plant seeds are used as decorations in baking and the sugar business. The oil derived from the Sesame plant seeds is biochemically stable [4] and utilized in producing margarine, soap, perfume, cosmetics, and confectionery, in addition to being consumed by humans. Sesame oil is used in medicine for its anti-inflammatory, analgesic, and antioxidant effects [5].

The review revealed that the sesame seed production and area harvested generally increased from 1996 to 2007 but significantly decreased between 2008 and 2018. The review also revealed that while the export quantities and values were low, they gradually increased from 2009 to 2016. The decreased production between 2008 and 2016 could have been due to challenges such as pests and diseases, loss of soil fertility, prolonged drought, poor agronomic practices, poor-yielding varieties, and lack of access to credit. According to Wacal [6], the top 5 world sesame seed producers were Sudan (981 000 tons), Myanmar (768 858 tons), India (746 000 tons), Nigeria (572 761 tons) and the United Republic of Tanzania (561 103 tons).

The total production value of Nigeria's sesame seed between 2014 and 2022 reached about $4,722,467,000 billion, ranking it the second largest exporter of sesame globally in

2022, with an annual export quantity of 297,000 metric tons [7]. Mycorrhizae are consequently an essential component of tropical ecosystems, particularly in soils that are particularly deficient in some nutrients, such as nitrogen and phosphorus [8, 9], as well as trace metals like copper and especially given that the majority of cultivated plants engage with Inoculating arbuscular mycorrhizal fungi (AMF) in this environment while still producing. AMF into the soil has been demonstrated to be one of the biological methods by which the crop may tolerate stress and boost productivity. AMFs are particularly effective at stimulating plant growth [10].

Mycorrhiza fungi, one of the most significant soil microorganisms, enhance host plants' ability to absorb water and nutrients by coexisting with various plant species [11,12]. Mycorrhizal fungi are now understood to improve plant nutrition and, as a result, the growth of host plants by improving nutrient and water absorption [13]. The primary benefit of the symbiotic connection with mycorrhizal fungus is an increase in the host plant's ability to absorb minerals, particularly immobile elements like phosphorus [13]. By converting rock phosphate into more readily available forms, the mycorrhiza inoculation may aid in the efficient consumption of this mineral, which the sesamum plant will absorb for improved growth and development [14].

Mycorrhizal injection greatly boosted the colonization of sesame roots. Compared to the control, mycorrhizal inoculation greatly boosted the colonization of sesame roots in both sterile and nonsterile soil. Compared to adding mineral phosphorus, inoculation with mycorrhiza was more effective and positively expressed in growth parameters (plant height, leaf number, dry weight, tissue phosphorus, and nitrogen) [15-17].

High seed yield in sesame is correlated with long, thick capsules [18]. Askander et al. [19] highlighted the significance of enhancing sesame's strong antioxidant capacity. Due to sesame's impact on the photosynthetic system, prolonged irrigation intervals cause a reduction in sesame growth and seed yield [20]. According to Konovalova et al [21], ideal irrigation conditions result in the highest sesame seed output.

However, the utilization of mycorrhiza, particularly in poor soils, is crucial in sustainable agricultural systems for increasing crop productivity and maintaining soil quality [22]. Studies on ecology and physiology have demonstrated that AMF symbiosis frequently results in greater absorption of water and phosphorus from soil [13, 23]. Mycorrhizal inoculation dramatically increased the uptake of nutrients, particularly phosphorus, in sesame [24]. Mycorrhizal fungi use numerous mechanisms to dissolve and break mineral and organic phosphorus, including promoting plant root length growth, spreading hyphae, and releasing phosphatase enzymes or organic acids [13]. In this regard, Gholinezhad and Darvishzadeh [25] demonstrated that the treatment combination of "inoculation with Azospirillum and complete irrigation" resulted in the highest amounts of oleic acid (69.24%) and linolenic acid (11.54%) contents in canola.

In contrast, the treatment combination of "non-inoculated plants and cutting irrigation at the seed formation stage" resulted in the highest amounts of erosic acid. Mycorrhizal fungi have been found to considerably enhance the amounts of palmitic fatty acids (160%), oleic (23%), linoleic (30%), and linolenic acid (15%) in sunflower seeds [25]. Mycorrhizal fungi injection improved the host plants' nutritional, physiological, and morphological state, enhancing their qualitative and quantitative performance under both normal and abiotic stress conditions in various plant species [26]. However, fewer studies have considered the importance of mycorrhiza. In terms of physiology and oilseed composition, the interactions between drought stress and mycorrhizal fungus inoculation of sesame have not yet been studied, especially in northern Nigeria. Hence, this study focuses on the effect of inoculating AMF on the growth performance of the Sesame plant, and also, on the effect of inoculating AMF on yield and yield components of the Sesame plant using Yusufari and Machina local government area of Yobe State, Nigeria as a case study.

2. Materials and Methods

2.1. Study area description and soil sampling

The experiment was condcted at tt the he northern part of Yobe State, in the Sudan–Sahel ecological zone of northeastern Nigeria is home to Yusufari and Machina Local Government Areas. The estimated location of Yusufari is around latitude 13°04′06″N and longitude 11°10′33″E with a height of 338 m above sea level, while Machina is located around 13°08′11″N and 10°02′57″E with a height of 350–360 m above sea level. They are hot, semi-arid regions with a long dry season and a short rainy season (June to September). The rainfall varies from 300 to 600 mm per year with high temperature throughout the year. The maximum temperature is often above 40°C in the dry season while the minimum temperature is between 18-22°C in the Harmattan season.

The soils are mainly sandy loam to loamy sand and are low in nutrients and organic matter. The pH of soils is primarily in the range of 5.5-7.0. The concentrations of total nitrogen (TN) and total phosphorus (TP) are generally low, ranging from 0.224–0.504 g kg^{-1} and 4.864–11.76 mg kg^{-1}, respectively. Soil samples were collected from three sesame farms located in Yusufari and Machina Local Government Areas of Yobe State, Nigeria. The collected soils were homogenized and used for both the AMF-treated and non-treated sesame plants under pot experimental conditions.

2.2. Preparation of the inoculation of mycorrhiza

Arbuscular mycorrhizal fungi inoculum was obtained from the Microbiology Laboratory, Yobe State University, Damaturu, Nigeria. The inoculum was incorporated into the soil designated for the treatment pots prior to planting.

2.3. Experimental design and plant growth conditions

The experiment was conducted as a pot study to evaluate the effects of AMF inoculation on the growth performance, yield, and yield components of sesame (*Sesamum indicum* L.) in Yobe State, Nigeria. The study was arranged in a completely randomized design (CRD) consisting of two treatments: (i) AMF-inoculated sesame plants and (ii) non-inoculated sesame plants serving as the control. Each treatment was replicated adequately to ensure statistical reliability.

Homogenized soil was placed into uniform pots, which were randomly arranged to minimize positional effects. The AMF inoculum was applied at planting by placing it in direct contact with the seeds or root zone. Control pots received the same quantity of soil without AMF inoculum. All pots were maintained under similar environmental conditions, and standard agronomic practices, including watering and weeding, were uniformly applied throughout the experimental period to minimize confounding effects [23].

2.4. Quantitative trait measurements

Quantitative growth and developmental traits were assessed according to standard sesame descriptor guidelines. Plant height at physiological maturity was measured from the ground surface to the apex of the main shoot and expressed in centimeters (cm). Internode length was determined as the average distance between successive nodes on the main stem.

Petiole length of basal, middle, and upper leaves was measured in centimeters using five representative leaves sampled from each position along the main stem. Similarly, leaf length and width of basal, middle, and upper leaves were measured, with leaf width recorded at the widest portion of the leaf blade. Measurements of the upper leaves were taken approximately 5 cm below the shoot apex.

Yield-related traits were evaluated at physiological maturity. The number of capsules per plant was determined by counting all capsules produced on each plant. Capsule size parameters, including length (cm), width (cm), and thickness (mm), were measured from five randomly selected capsules collected from the main stem. Seed number per capsule was determined from five randomly selected capsules collected from the middle portion of the main stem, and the average value was calculated.

2.5. Plant growth and morphological measurements

At harvest, the number of primary branches per plant was recorded along with the previously described growth parameters. Plant height was measured using a 100 cm wooden ruler, while leaf length, width, and thickness were measured using a 30 cm ruler. For leaves with lobed blades, leaf width was determined as the maximum diameter of an imaginary circle that could fit within the leaf blade, following the method described by Ma et al. [27]. In addition, qualitative traits including the colour characteristics of stems, flowers, leaves, capsules, and seeds were evaluated, as plant colour is considered an important descriptor for accurate plant characterization according to Yang et al. [28].

2.6. Qualitative traits

Qualitative traits were evaluated in the field following the standard sesame descriptor guidelines. Plant growth type was classified as indeterminate (1) or determinate (2). Growth habit was recorded as prostrate, semi-erect, or upright, while the branching pattern of upright stems was categorized as opposite (1), alternate (2), ternary (3), or mixed (4).
Stem colour on the lower half of the main stem was scored as green (1), yellow (2), purplish-green (3), purple (4), or other (99). The shape of the middle leaves was classified as linear (1), lanceolate (2), elliptic (3), ovate (4), narrowly cordate (5), or other (99). Leaf colour of fully expanded middle leaves was recorded as green, green with yellowish tint, blue-grey, purple cast, or other (99).

Capsule arrangement was categorized as monocapsular (1) or multicapsular (2). Corolla exterior and interior colours were evaluated as white (1), white with pink shading (2), white with deep pink shading (3), pink (4), light violet (5), dark violet (6), purple (7), red (8), maroon/light maroon (9), or other (99). Capsule colour was assessed on sun-dried capsules and classified as green (1), straw/yellow (2), brown/tan (3), or purple (4). Seed coat colour was scored as white (1), cream (2), beige (3), light brown (4), medium brown (5), dark brown (6), brick red (7), tan (8), olive (9), grey (10), or other (99) [29,30, 31].

2.7. Data analysis

SPSS Software (IBM Corp., released in 2013) was used, and descriptive data analysis was performed on the farmer survey's data. Armonk, NY: IBM Corp., IBM SPSS Statistics for Windows, Version 22.0. In order to examine the variation within a distribution as described by Frankfort-Nachmias et al. [32], the Index of Qualitative Variation (IQV) was calculated. Using SAS software, Version 9.3 (SAS Institute, Cary, North Carolina, U.S.), Multivariate Cluster Analysis was performed on the data from the morphometric investigation.

3. Results

3.1. Effect of inoculating AMF on the growth performance of the Sesame plant

Figures 1 and 2 present the mean growth performance indicators of Sesamum under control and AMF treatments. Petiole leaf length increased from 8.140 ± 0.1517 cm in the control to 8.816 ± 0.1276 cm following AMF inoculation (Figure 1a), showing a significant improvement ($p < 0.0001$). Similarly, base leaf length increased from 8.10 ± 0.12 cm to 8.50 ± 0.071 cm under AMF treatment ($p < 0.0002$) (Figure 1b).

The petiole length of the top leaf increased from 0.98 ± 0.045 cm in the control to 1.08 ± 0.084 cm in AMF-treated plants ($p = 0.0462$) (Figure 1c). Basal leaf length also increased from 1.88 ± 0.084 cm to 2.08 ± 0.084 cm following AMF inoculation ($p = 0.0054$) (Figure 1d).

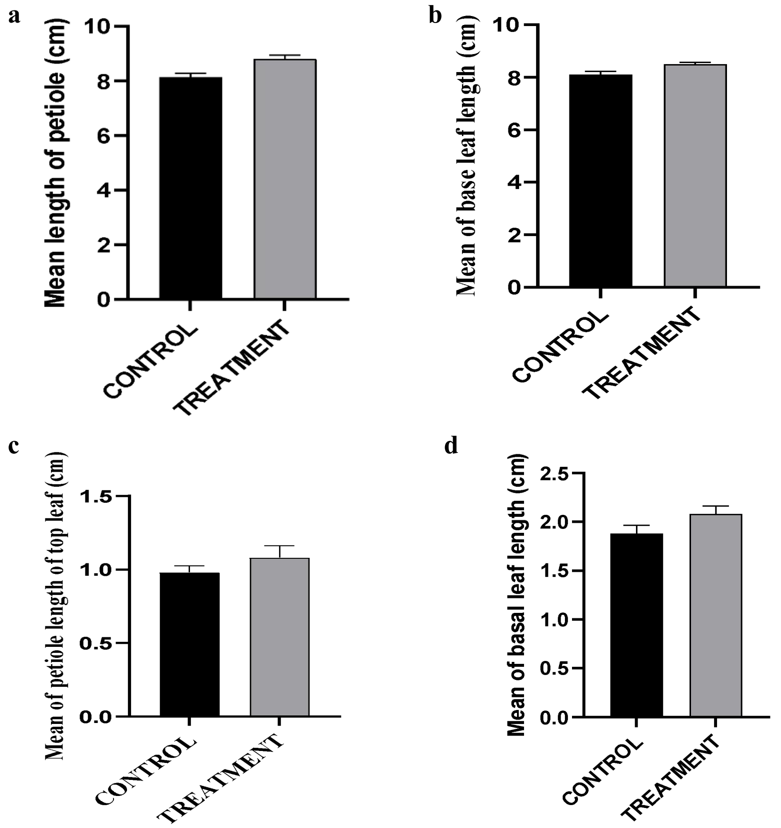

Figure 1. Effects of arbuscular mycorrhizal fungi (AMF) inoculation and non-inoculated control treatments on the growth and morphological traits of Sesamum indicum plants: (a) petiole length, (b) base leaf length, (c) petiole length of top leaf and (d) basal leaf length.

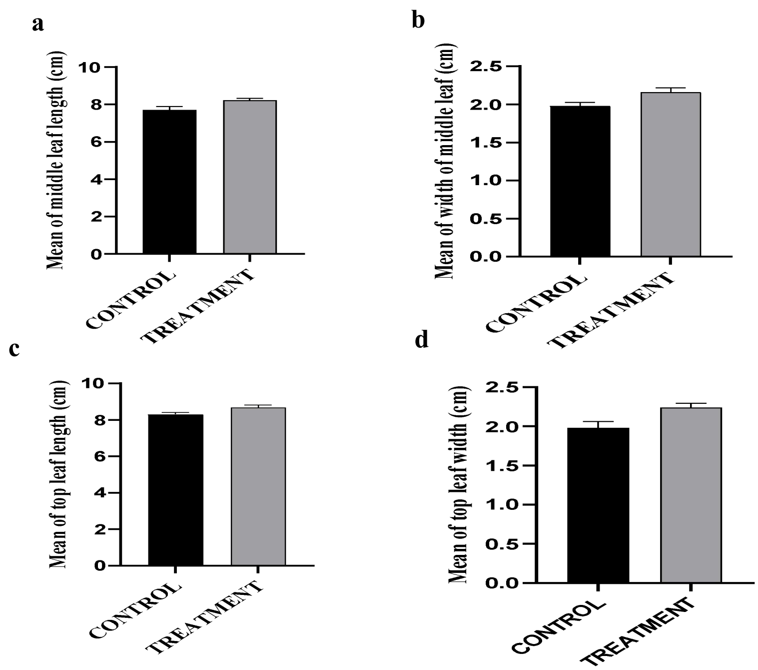

Figure 2. Effects of arbuscular mycorrhizal fungi (AMF) inoculation and non-inoculated control treatments on the growth and morphological traits of Sesamum indicum plants (a) basal leaf length, (b) middle leaf length, (c) middle leaf width, (d) top leaf length and (3) top leaf width.

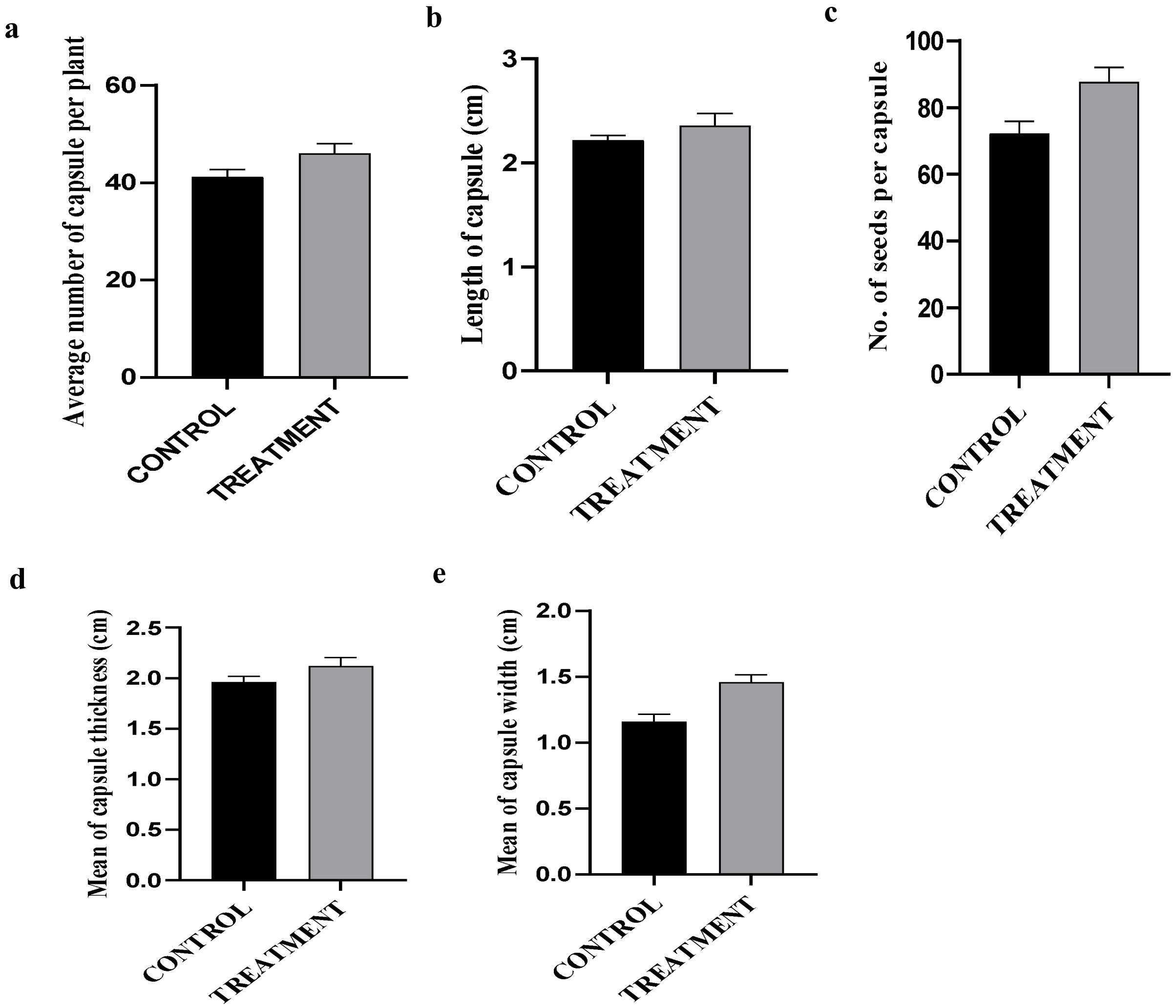

Figure 3. Effects of arbuscular mycorrhizal fungi (AMF) inoculation and non-inoculated control treatments on the growth and morphological traits of Sesamum indicum plants: (a) capsule per plant, (b) capsule length, (c) number of seed per capsule, (d) capsule thickness and (e) capsule width.

Leaf morphological traits of the middle leaf were significantly enhanced by AMF treatment. Middle leaf length increased from 7.70 ± 0.19 cm in the control to 8.22 ± 0.11 cm in inoculated plants (p = 0.0007) (Figure 2a), while leaf width increased from 1.98 ± 0.045 cm to 2.16 ± 0.06 cm (p = 0.0005) (Figure 2b). Top leaf traits showed a similar pattern, with leaf length increasing from 8.30 ± 0.10 cm to 8.68 ± 0.13 cm (*p = 0.0009*) (Figure 2c) and leaf width increasing from 1.98 ± 0.084 cm to 2.24 ± 0.055 cm under AMF treatment (*p = 0.0004*) (Figure 2d).

3.2. Effect of inoculated AMF on the yield and yield components of the Sesame plant

Figure 3 (a–e) illustrates the effects of AMF inoculation on the yield and yield-related components of Sesamum plants. Significant improvements were observed in all measured yield parameters following AMF treatment compared with the control group.

The mean number of capsules per plant increased from 41.20 ± 1.48 in the control plants to 46.00 ± 2.00 in AMF-inoculated plants, indicating a significant enhancement in capsule production (*p = 0.0026*). Likewise, capsule length increased from 2.22 ± 0.047 cm in the control group to 2.36 ± 0.11 cm following AMF inoculation, with the difference being statistically significant (*p = 0.0339*).

AMF treatment also positively influenced capsule morphology. Capsule thickness increased from 1.96 ± 0.054 cm in the control plants to 2.12 ± 0.083 cm in inoculated plants. Similarly, capsule width showed a marked increase from 1.16 ± 0.054 cm in the control to 1.46 ± 0.054 cm under AMF treatment, representing the highest level of significance among the measured yield traits.

Overall, these findings demonstrate that AMF inoculation significantly improved both the yield and capsule characteristics of Sesamum plants, suggesting a beneficial role of AMF in enhancing sesame productivity and reproductive performance.

4. Discussion

4.1. Effect of inoculating AMF on the growth performance of the Sesame plant

The present experiment showed that AMF inoculation had a positive effect on the growth of *Sesamum indicum*, as all leaf growth parameters were significantly higher than in non-inoculated controls. The data reflecting changes in petiole length, leaf length, and leaf width demonstrated that AMF enhances morphological growth in sesame plants, consistent with Yakasai and Rabiu [33], who provided a review of AMF and plant growth and nutrient uptake. These are some biologically significant changes where the size of leaves and length of the petiole is directly proportional to the efficiency of photosynthesis and the overall biomass production.

In addition to this, the AMF also establish mutualistic interactions with the roots of most of the earth plants, and distribute the hyphe networks throughout the ground, enhancing nutrient and water uptake, particularly phosphorus, nitrogen and micronutrients [34]. This extensive hypar absorption system can be the explanation why the parameters of the growth of leaves were enhanced in this experiment, since the more the nutrient is available, the more likely the possibility of initiating the process of cell division and growth of tissues. The same has been replicated with other crops like sesame and others whose crops inoculated with AMF have better biomass, nutrient composition, and physiological functions compared to controls in the absence of the mycorrhizal plant [24]. Specifically, it has been noted that biomass and nutrient uptake were remarkably elevated by the AMF-inoculated sesame plant, which favours the trend in vegetative growth which was observed in this study.

Furthermore, Also, AMF can increase the physiological processes (due to chlorophyll production, stomatal conductance, and water use efficiency) that support the greater photosynthetic activity and growth at both favourable and unfavourable conditions [35, 36]. This experiment was not directly taken of physiological parameters, but morphological gains were observed and are highly suggestive of the occurrence of improved nutrient processes and photosynthetic capacity within AMF-treated sesame plants. Morphologically, the large-scale shift in the structure of the leaves emphasizes the possibility of AMF being used as a sustainable biofertilizer in the agriculture of the sesame plant. The introduction of AMF inoculants in the harvesting systems can reduce the application of artificial fertilizers, improve the well-being of the soil and enhance the resistance of crops to nutrient deficiencies that are prone to occur in tropical agroecosystems [37]. In general, these findings support the strategic application of AMF in sustainable agricultural practice that is able to achieve maximum crop performance and efficiency of resource utilization.

4.2. Effect of inoculated AMF on yield and yield components of the Sesame Plant

This paper revealed that inoculation of *Sesamum indicum* with AMF was of significant effect as shown in increased yield and yield parameters, which are the number of capsules, the size of the capsule (length, thickness and width) and the number of seeds per capsule. The heightened amount of the count of the number of capsules per plant in AMF-treated sesame signified enhanced reproductive expansion that is generally clarified by enhanced nutrient uptake and enhanced physiological functionality of mycorrhizal plants [38, 39]. AMF fungi are known to increase phosphorus and nitrogen uptake, which are some of the nutrients considered to be vital in flowering, capsule and seed development [40]. The increased size of inoculated plant capsules might be linked with an increase in assimilates in the period of reproductive growth since AMF boost the photosynthetic capacity and translocation of carbon to the growing sinks [26, 41]. Similar increases in the size of the capsule and the number of seeds following the inoculation with AMF in Sesamum plant and other oil crops have also been reported, whereby mycorrhizal symbiosis enhanced the stability of the yield and seed filling [42].

The apparent increase in seed number per capsule also indicated that AMF is able to enhance the pollen viability, ovule fertilization or post fertilization seed development through improved mineral nutrition and hormonal homeostasis. These results are consistent with recent research, which found that AMF inoculation positively influences yield components by increasing nutrient utilization and reducing reproductive abortion during the field test [43-45]. Pragmatically, these findings expose the potential of AMF to be a sustainable bio-feed in the manufacture of the sesame plant. The application of mycorrhizal inoculation of the sesame agro system can probably lead to an increase in the yield without the use of chemical fertilizers, which additionally helps to create ecologically and resource-saving agriculture, particularly in tropical soils that are often nutrient-limited.

This study was conducted at a single experimental site during one growing season. Therefore, the results may not fully represent the variability of soil, climatic, and management conditions across tea-growing regions in Tanzania and East Africa. In addition, the study focused primarily on nutrient uptake and did not evaluate changes in soil microbial activity, post-harvest soil fertility, or long-term soil organic matter dynamics. Further multi-site and long-term studies are therefore recommended to validate the performance of FOMI Chai fertilizers under different agroecological conditions and to assess their long-term effects on soil health and tea productivity.

4.3. Conclusion

This study is a good indication that AMF inoculation is a strong indicator that can be applied to boost the vegetation growth and yield performance of *Sesamum indicum*. The plants that were inoculated with AMF according to this study had always shown better growth based on all the measured parameters, which include petiole length, basal, middle and top leaf dimensions and the width of the leaf as opposed to the non-inoculated control. The statistical significance and consistency of these positive effects prove that AMF had a strong and positive influence on the vegetation development of sesame. Notably, the positive effects of AMF were transferred to reproductive qualities and yield attributes. The number of capsules per plant, size of capsules (length, thickness and width) and seeds per capsule were significantly enhanced in inoculated plants, and this showed that AMF not only stimulates vegetative growth, but it also increases reproductive success and final yield formation. These results are an indication of a more effective assimilate partitioning and the overall plant performance over the growth cycle.

The most important finding made in this study is that AMF inoculation does not have stage-specific activity that positively affects growth and yield components, but enhances them simultaneously. This is a two-fold advantage that highlights the practical significance of AMF in ensuring plant productivity between the vegetative and reproductive programs. The practical importance of this result is that it could offer a sustainable, low-impeding strategy to improve the performance of the Sesamum plant, especially in soils that are low in nutrients; therefore, this could provide a practical alternative to the use of synthetic fertilizers.

Author contributions

Conceptualization, Formal analysis, Methodology, Visualization, Validation, Project administration, and Writing – review & editing: Adebowale David Dada , Abubakar A. Kachallah and Jeremiah Oluwagbenga Oroboade; Data curation and Resources; Abubakar Alhaji Kachallah and Segun Gbolagade. Jonathan; Investigation and Supervision: Segun G. Jonathan and Tolulope Deboral Ojewole. All authors read and approved the final manuscript.

Ethical approval

Not applicable.

Conflicts of Interest

The authors report no conflicts of interest.

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Data availability statement

The data presented in this study are available on request from the corresponding author.

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References

1. Pusadkar, P. P., Kokiladevi, E., Bonde, S. V., & Mohite, N. R. (2016). Sesame (Sesamum indicum L.) importance and its high-quality seed oil: a review. Trends in Biosciences, 8(15), 3900-3906.
2. Teklu, D. H., Abbas, A. A., You, J., & Wang, L. (2025). Genes and QTLs Discovery for Sesame (Sesamum indicum L.) Breeding Traits: A Review. Oil Crop Science. https://doi.org/10.1016/j.ocsci.2025.03.003
3. Rauf, S., Basharat, T., Gebeyehu, A., Elsafy, M., Rahmatov, M., Ortiz, R., & Kaya, Y. (2024). Sesame, an underutilized oil seed crop: Breeding achievements and future challenges. Plants, 13(18), 2662. https://doi.org/10.3390/plants13182662
4. Anilakumar, K. R., Pal, A., Khanum, F., & Bawa, A. S. (2010). Nutritional, medicinal and industrial uses of sesame (Sesamum indicum L.) seeds: an overview. Agriculturae Conspectus Scientificus, 75(4), 159-168.
5. Hsu, E., & Parthasarathy, S. (2017). Anti-inflammatory and antioxidant effects of sesame oil on atherosclerosis: a descriptive literature review. Cureus, 9(7). https://doi.org/10.7759/cureus.1438
6. Wacal, C., Basalirwa, D., Okello-Anyanga, W., Murongo, M. F., Namirembe, C., & Malingumu, R. (2021). Analysis of sesame seed production and export trends; challenges and strategies towards increasing production in Uganda. OCL 28: 4. https://doi.org/10.1051/ocl/2020073
7. Afolabi, A. A., Boluwaji, O. R., Ajewole, O. C., & James, A. A. (2025). Trends and growth rates in Nigeria's sesame seed production and exports: implications for agricultural policy. fudma journal of sciences, 9(12), 120-125.
8. Cardoso, E. J., Nogueira, M. A., & Zangaro, W. (2017). Importance of mycorrhizae in tropical soils. In Diversity and Benefits of Microorganisms from the Tropics (pp. 245-267). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-55804-2_11
9. Rigobelo, E. C. (2024). Introductory Chapter: The Importance of Mycorrhiza Fungi to Sustainable Food Production. In Unveiling the Mycorrhizal World. IntechOpen. https://doi.org/10.5772/intechopen.115286
10. Burak, K., Yanardağ, İ. H., Gómez-López, M. D., Faz, Á., Yalçin, H., Sakin, E., & Yanardağ, A. (2024). The effect of arbuscular mycorrhizal fungi on biological activity and biochemical properties of soil under vetch growing conditions in calcareous soils. Heliyon, 10(3). https://doi.org/10.1016/j.heliyon.2024.e24820
11. Owiny, A. A., & Dusengemungu, L. (2024). Mycorrhizae in mine wasteland reclamation. Heliyon, 10(13). https://doi.org/10.1016/j.heliyon.2024.e33141
12. Huey, C. J., Gopinath, S. C., Uda, M. N. A., Zulhaimi, H. I., Jaafar, M. N., Kasim, F. H., & Yaakub, A. R. W. (2020). Mycorrhiza: a natural resource assists plant growth under varied soil conditions. 3 Biotech, 10(5), 204. https://doi.org/10.1007/s13205-020-02188-3
13. Wahab, A., Muhammad, M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., & Reddy, S. P. P. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. Plants, 12(17), 3102. https://doi.org/10.3390/plants12173102
14. Abou-el-Seoud, I. I., & Abdel-Megeed, A. (2012). Impact of rock materials and biofertilizations on P and K availability for maize (Zea mays) under calcareous soil conditions. Saudi Journal of Biological Sciences, 19(1), 55-63. https://doi.org/10.1016/j.sjbs.2011.09.001
15. El-Sherbeny, T. M. S., Mousa, A. M., & El-Sayed, E. S. R. (2022). Use of mycorrhizal fungi and phosphorus fertilization to improve the yield of onion (Allium cepa L.) plant. Saudi Journal of Biological Sciences, 29(1), 331-338. https://doi.org/10.1016/j.sjbs.2021.08.094
16. Paravar, A., Maleki Farahani, S., & Rezazadeh, A. (2022). Lallemantia iberica and Lallemantia royleana: The effect of mycorrhizal fungal inoculation on growth and mycorrhizal dependency under sterile and non-sterile soils.

Communications in Soil Science and Plant Analysis, 53(7), 880-891. https://doi.org/10.1080/00103624.2022.2034844
17. Hazrati, S., Mohammadi, M., Mollaei, S., Ebadi, M., Pignata, G., & Nicola, S. (2025). Nitrogen Fertilization and Glomus Mycorrhizal Inoculation Enhance Growth and Secondary Metabolite Accumulation in Hyssop (Hyssopus officinalis L.). Nitrogen, 6(3), 60. https://doi.org/10.3390/nitrogen6030060
18. Zhou, R., Dossa, K., Li, D., Yu, J., You, J., Wei, X., & Zhang, X. (2018). Genome-wide association studies of 39 seed yield-related traits in sesame (Sesamum indicum L.). International journal of molecular sciences, 19(9), 2794. https://doi.org/10.3390/ijms19092794
19. Askander, N. Z., Mohamed, H. M. A., Kenawi, M. A., & Abdelsalam, R. R. (2023). Phytochemical profile and antioxidant activity of sesame seed (Sesamum indicum) by-products for improving cupcake shelf life. Minia J. of Agric. Res. & Develop, 4(43), 873-886.
20. Yousefzadeh-Najafabadi, M., & Ehsanzadeh, P. (2021). Correlative associations of photosynthetic and rooting attributes of sesame: Drought-induced reversed associations are corrected upon salicylic acid exposure. South African Journal of Botany, 142, 266-273. https://doi.org/10.1016/j.sajb.2021.06.044
21. Konovalova, V., Konovalov, V., Tyshchenko, A., Tyshchenko, O., Sharii, V., Fundirat, K., & Reznychenko, N. (2024). Influence Of Irrigation Methods And Regimes On Sesame Seed Yield. Scientific Papers. Series A. Agronomy, 67(1).
22. Kuila, D., & Ghosh, S. (2022). Aspects, problems and utilization of Arbuscular Mycorrhizal (AM) application as bio-fertilizer in sustainable agriculture. Current Research in Microbial Sciences, 3, 100107. https://doi.org/10.1016/j.crmicr.2022.100107
23. Auge, R. M. (2001). Water relations, drought and vesicular-arbuscular mycorrhizal symbiosis. Mycorrhiza, 11(1), 3-42. https://doi.org/10.1007/s005720100097
24. Zhou, R., Raza, A., Song, J., Janiad, S., Li, Q., Huang, M., & Hassan, M. A. (2025). Growth-promoting effects of arbuscular mycorrhizal fungus Funneliformis mosseae in rice, sesame, sorghum, Egyptian pea and Mexican hat plant. Frontiers in Microbiology, 16, 1549006. https://doi.org/10.3389/fmicb.2025.1549006
25. Gholinezhad, E., & Darvishzadeh, R. (2021). Influence of arbuscular mycorrhiza fungi and drought stress on fatty acids profile of sesame (Sesamum indicum L.). Field Crops Research, 262, 108035. https://doi.org/10.1016/j.fcr.2020.108035
26. Begum, N., Qin, C., Ahanger, M. A., Raza, S., Khan, M. I., Ashraf, M., & Zhang, L. (2019). Role of arbuscular mycorrhizal fungi in plant growth regulation: implications in abiotic stress tolerance. Frontiers in Plant Science, 10, 1068. https://doi.org/10.3389/fpls.2019.01068
27. Ma, J., Niklas, K. J., Liu, L., Fang, Z., Li, Y., & Shi, P. (2022). Tree size influences leaf shape but does not affect the proportional relationship between leaf area and the product of length and width. Frontiers in Plant Science, 13, 850203. https://doi.org/10.3389/fpls.2022.850203
28. Yang, J., Wang, X. R., & Zhao, Y. (2022). Leaf color attributes of urban colored-leaf plants. Open Geosciences, 14(1), 1591-1605. https://doi.org/10.1515/geo-2022-0433
29. FAO (1985). Descriptors for Sesame. Food and Agriculture Organization of the United Nations, Rome, Italy.
30. IPGRI, N. (2004). Descriptors for sesame (Sesamum spp.). International Plant Genetic Resources Institute, Rome, Italy, 28-46.
31. Smith, S. E., & Read, D. J. (2010). Mycorrhizal symbiosis. Academic Press. https://doi.org/10.1016/B978-0-12-370526-6.X5001-6
32. Frankfort-Nachmias, C., Leon-Guerrero, A., & Davis, G. (2020). Social statistics for a diverse society. Sage Publications.
33. Yakasai, U. A., & Rabiu, S. 2025. The impact of arbuscular mycorrhizal fungal inoculants on growth, nutrients, and yield of vegetable plants: A review. Fudma Journal Of Sciences. 9(3), 215-223. https://doi.org/10.33003/fjs-2025-0903-3353
34. Shah, S., Nawaz, T., & Fahad, S. (2025). Arbuscular mycorrhizal fungi role in plant beneficial elements uptake and nutrient acquisition. Rhizosphere, 101141. https://doi.org/10.1016/j.rhisph.2025.101141
35. Yooyongwech, S., Samphumphuang, T., Tisarum, R., Theerawitaya, C., & Cha-Um, S. (2016). Arbuscular mycorrhizal fungi (AMF) improved water deficit tolerance in two different sweet potato genotypes involves osmotic adjustments via soluble sugar and free proline. Scientia Horticulturae, 198, 107-117. https://doi.org/10.1016/j.scienta.2015.11.002
36. Hamedani, N. G., Gholamhoseini, M., Bazrafshan, F., Habibzadeh, F., & Amiri, B. (2022). Yield, irrigation water productivity and nutrient uptake of arbuscular mycorrhiza inoculated sesame under drought stress conditions. Agricultural Water Management, 266, 107569. https://doi.org/10.1016/j.agwat.2022.107569
37. Fall, A. F., Nakabonge, G., Ssekandi, J., Founoune-Mboup, H., Badji, A., Ndiaye, A., & Ekwangu, J. (2023). Combined effects of indigenous arbuscular mycorrhizal fungi (AMF) and NPK fertilizer on growth and yields of maize and soil nutrient availability. Sustainability, 15(3), 2243. https://doi.org/10.3390/su15032243
38. Wahab, A., Muhammad, M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., & Reddy, S. P. P. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. Plants, 12(17), 3102. https://doi.org/10.3390/plants12173102
39. Farhaoui, A., Taoussi, M., Laasli, S. E., Legrifi, I., El Mazouni, N., Meddich, A., & Lahlali, R. (2025). Arbuscular Mycorrhizal Fungi and Their Role in Plant Disease Control: A State-of-the-Art. The Microbe, 100438. https://doi.org/10.1016/j.microb.2025.100438
40. Chinnathambi, S., Peeran, M. F., Srinivasan, V., Sankar, S. M., & George, P. (2024). Optimizing mycorrhizal fungi application for improved nutrient uptake, growth, and disease resistance in cardamom seedlings (Elettaria cardamomum (L.) Maton). Heliyon, 10(20). https://doi.org/10.1016/j.heliyon.2024.e39227
41. Ferrol, N., Azcon-Aguilar, C. and Perez-Tienda, J. (2019) Review: Arbuscular Mycorrhizas as Key Players in Sustainable Plant Phosphorus Acquisition: An Overview on the Mechanisms Involved. Plant Science, 280, 441-447. https://doi.org/10.1016/j.plantsci.2018.11.011
42. Ghorui, M., Chowdhury, S., Balu, P., & Burla, S. (2024). Arbuscular Mycorrhizal Inoculants and its regulatory landscape. Heliyon, 10(9). https://doi.org/10.1016/j.heliyon.2024.e30359
43. Lin, G., McCormack, M. L., & Guo, D. (2015). Arbuscular mycorrhizal fungal effects on plant competition and community structure. Journal of Ecology, 103(5), 1224-1232. https://doi.org/10.1111/1365-2745.12429
44. Othman, Y. A., Tahat, M., Alananbeh, K. M., & Al-Ajlouni, M. (2022). Arbuscular mycorrhizal fungi inoculation

improves flower yield and postharvest quality component of Gerbera grown under different salinity levels. Agriculture, 12(7), 978. https://doi.org/10.3390/agriculture12070978

45. Arcidiacono, M., Ercoli, L., Piazza, G., & Pellegrino, E. (2025). Field inoculation with a local arbuscular mycorrhizal (AM) fungal consortium promotes sunflower agronomic traits without changing the composition of AM fungi coexisting inside the crop roots. Applied Soil Ecology, 206, 105830. https://doi.org/10.1016/j.apsoil.2024.105830

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