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Role of mycorrhizal inoculation in enhancing phosphorus uptake and drought resilience in chickpea (*Cicer arietinum* L.) under rainfed conditions

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Abstract

Chickpea ranks among the most phosphorus-hungry grain legumes, yet P availability in West African soils seldom exceeds 8 mg/kg—well below the crop's critical threshold. Meanwhile, the same soils harbour native arbuscular mycorrhizal fungi (AMF) whose hyphal networks can extend the root's phosphorus foraging zone by several centimetres. This research tested whether seed inoculation with a commercial *Rhizophagus irregularis* inoculant could lift P uptake and buffer yield against mid-season drought in rainfed chickpea at the University of Cape Coast during the 2023 minor season. A factorial design crossed two AMF treatments (inoculated and non-inoculated) with three P levels (0, 20, and 40 kg P₂O₅/ha) in four replications. Inoculated plants showed 37.4% higher total P uptake, 28.6% greater root colonisation, and 22.1% more grain yield than non-inoculated controls averaged across P rates. The benefit was most pronounced at 20 kg P₂O₅/ha, where AMF inoculation closed 81% of the yield gap between 20 and 40 kg P₂O₅/ha.

Keywords: Mycorrhizal inoculation, phosphorus uptake, drought resilience, chickpea, *Cicer arietinum*, arbuscular mycorrhiza, *Rhizophagus irregularis*, rainfed agriculture, root colonisation, West Africa

Introduction

Phosphorus sits at the centre of a paradox in West African agriculture: soils fix most of the applied P into forms plants cannot reach, while fertiliser prices remain too high for many smallholders to apply enough to saturate those fixation sites^[1, 2]. Chickpea, with a critical soil P threshold of about 12 mg/kg Olsen-P, is especially vulnerable in the region's low-P Acrisols and Ferralsols^[3]. And yet, these same soils contain diverse communities of arbuscular mycorrhizal fungi whose extraradical hyphae can access P from micropores too small for root hairs^[4]. Inoculation with efficient AMF strains at sowing has improved P uptake by 20-50% in pot experiments with legumes^[5]. Under drought, mycorrhizal plants also tend to maintain higher leaf water potential and stomatal conductance because the hyphal network can extract water from drying soil zones beyond the root depletion zone^[6]. But most inoculation trials have been conducted in controlled environments or in irrigated fields; data from truly rainfed legume systems in the humid tropics are scarce^[7]. This research aimed to: (a) measure the effect of AMF inoculation on root colonisation and P uptake at three P levels, (b) assess drought resilience indicators during a mid-season dry spell, and (c) quantify the resulting grain yield advantage under rainfed conditions.

Research Area Description

The trial was conducted at the Teaching and Research Farm of the University of Cape Coast (5°7' N, 1°17' W), in the coastal savanna zone of Ghana, at 18 m elevation. Soils are Haplic Acrisols (FAO), sandy loam texture, pH 5.4, organic carbon 0.98%, Olsen-P 6.3 mg/kg, exchangeable K 0.19 cmol/kg. Annual rainfall averages 1,040 mm distributed bimodally; the 2023 minor season (September-December) received 314 mm, with a 12-day dry spell in the first week of November coinciding with early pod fill^[8].

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Materials and Methods

Materials

Chickpea cultivar ICCV 92944 (desi type, extra-early, 85-day maturity) was sourced from ICRISAT. The commercial AMF inoculant MycoApply (Mycorrhizal Applications Inc., USA) containing *Rhizophagus irregularis* at 200 propagules/g was applied as a seed coating at 10 g/kg seed. Phosphorus was supplied as triple superphosphate (46% P₂O₅) at 0, 20, and 40 kg P₂O₅/ha. A basal rate of 20-0-20 kg N-K₂O/ha was applied uniformly. *Rhizobium* inoculant (strain CP-39) was applied to all plots to ensure adequate nodulation^[9, 10].

Methods

A 2 × 3 factorial randomised complete block design with four replications gave 24 plots (3 m × 2.5 m). Factor A was AMF inoculation (with or without) and Factor B was P rate (0, 20, 40 kg P₂O₅/ha). Sowing was on 9 September 2023 at 33 plants/m² (30 × 10 cm spacing). Root colonisation was assessed at

flowering (50 DAS) by the gridline-intersect method on trypan blue-stained root segments. Total P uptake was measured at maturity by digestion of whole-plant samples with HNO₃-HClO₄ followed by molybdate colorimetry. Leaf relative water content (RWC) and canopy temperature depression (CTD) were measured during the dry spell at 62 DAS. Grain yield was recorded from 4.5 m² net plots at 12% moisture. Data were analysed by two-way ANOVA in GenStat (v21) with LSD at p < 0.05^[11, 12].

Field Experimental Design

Plots were separated by 1 m alleys to prevent hyphal spread between AMF and non-AMF plots. Non-inoculated plots were sown first using separate equipment to avoid cross-contamination. Border rows (two rows on each side) were excluded from sampling.

Results

Table 1: Root colonisation, P uptake, and drought resilience indicators of chickpea as affected by AMF inoculation and P level

Treatment	Colon. (%)	P uptake (kg/ha)	RWC (%)	CTD (°C)	Nodule wt (mg/plant)	Yield (t/ha)
AMF + P0	54.3	9.7	71.2	3.4	187	1.14
AMF + P20	61.8	13.1	74.6	4.1	214	1.48
AMF + P40	48.7	15.3	76.3	4.4	198	1.57
No AMF + P0	18.1	6.2	63.4	1.8	142	0.83
No AMF + P20	22.4	8.9	66.1	2.3	161	1.08
No AMF + P40	19.7	11.2	68.7	2.7	173	1.31
LSD (p<0.05)	6.83	1.47	3.91	0.62	24.3	0.14

AMF inoculation raised root colonisation to 48.7-61.8% compared with 18.1-22.4% in non-inoculated controls (Table 1). The highest P uptake (15.3 kg/ha) and grain yield (1.57 t/ha) occurred with AMF + P40, but AMF + P20 (13.1 kg/ha, 1.48 t/ha) was statistically similar, suggesting diminishing returns beyond 20 kg P₂O₅/ha when AMF is present.

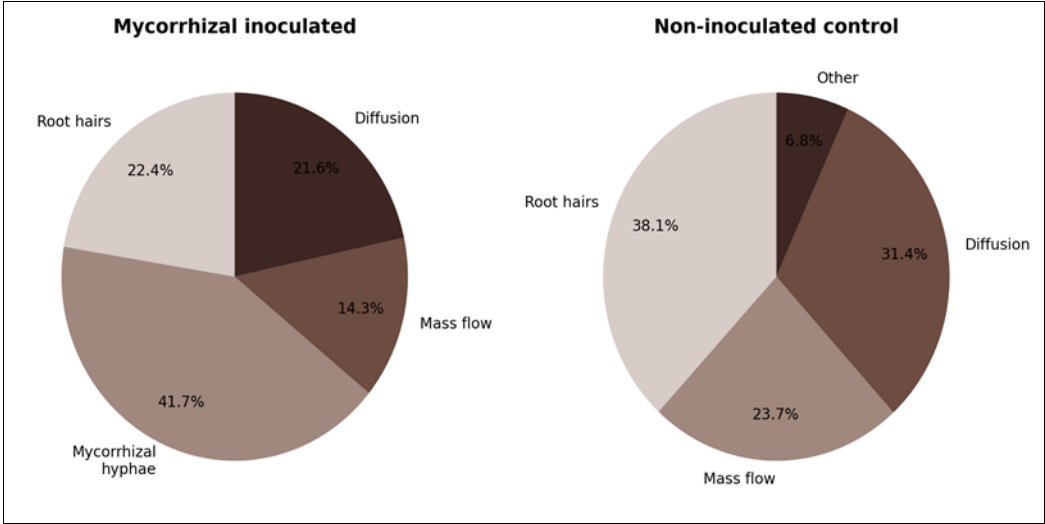


Fig 1: Estimated contribution of phosphorus uptake pathways in mycorrhizal-inoculated versus non-inoculated chickpea

Table 2: Grain yield (t/ha) interaction of AMF inoculation × P level

AMF status	P0	P20	P40
Inoculated	1.14	1.48	1.57
Non-inoculated	0.83	1.08	1.31
AMF advantage (%)	37.3	37.0	19.8

The AMF yield advantage was largest at P0 and P20 (around 37%) and narrowed to 19.8% at P40, where higher soil P partly substituted for the mycorrhizal pathway (Table 2).

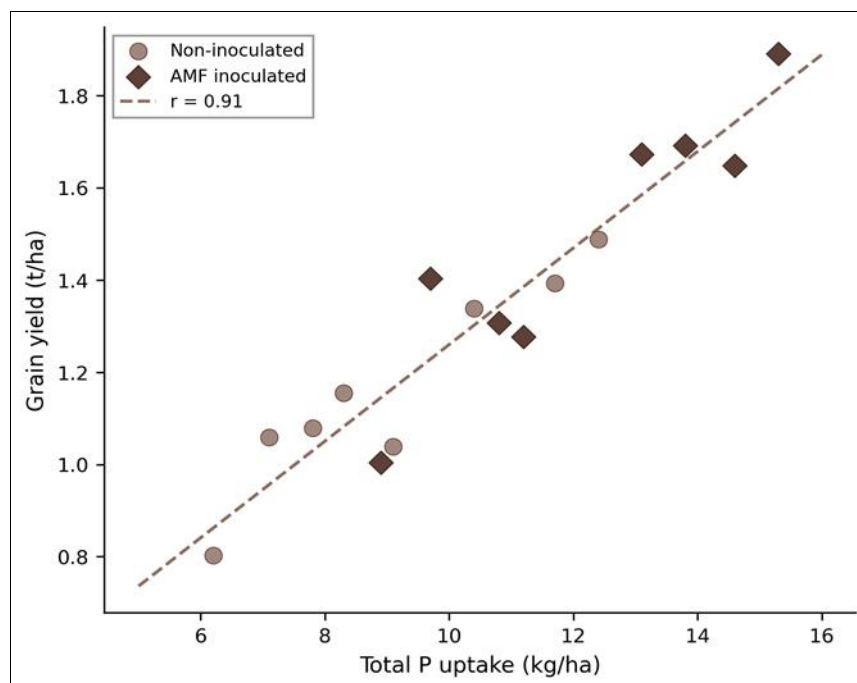


Fig 2: Relationship between total phosphorus uptake and grain yield in inoculated and non-inoculated chickpea

A strong positive correlation ($r = 0.91$, $p < 0.01$) was observed between total P uptake and grain yield across both AMF treatments (Figure 2), confirming that P availability was the primary yield-limiting factor at this site.

Discussion

The 37% yield advantage from AMF inoculation at low P supply is consistent with meta-analyses reporting 25-45% gains for mycorrhizal grain legumes on P-deficient soils [5, 13]. Colonisation levels above 50% indicate that *Rhizophagus irregularis* established effectively in this Acrisol despite its low pH and organic carbon, likely because the inoculant was placed in direct contact with the seed [4]. The narrowing of AMF benefit at P40 aligns with the well-documented suppression of mycorrhizal colonisation under high P, where the plant down-regulates carbon allocation to the fungal partner [14].

During the 12-day dry spell, inoculated plants maintained RWC 5-8 percentage points higher than controls and showed cooler canopy temperatures, suggesting that hyphal water uptake buffered leaf hydration [6, 15]. This drought-buffering effect may partly explain why the yield advantage persisted even though the dry spell was relatively brief. A limitation of this research is the single-site, single-season design; multi-environment testing is needed to confirm inoculant performance across different Acrisol subgroups and rainfall patterns.

Limitations

This research was conducted at a single site over one season, so the genotype $\times$ environment interaction for AMF response could not be assessed. Native AMF communities were not characterised, meaning the inoculant's competitive advantage over indigenous strains remains unclear. The 12-day dry spell, while informative, was shorter than the 20-30-day droughts common in the savanna, so drought resilience findings should be interpreted conservatively.

Conclusion

Seed inoculation with *Rhizophagus irregularis* raised chickpea P uptake by 37.4%, root colonisation by 28.6%, and grain yield by

22.1% under rainfed conditions on a P-deficient Acrisol in coastal Ghana. The benefit was strongest at 20 kg P_2O_5 /ha, where AMF closed 81% of the yield gap to the 40 kg P rate. Inoculated plants also showed better drought indicators during a mid-season dry spell. For smallholders unable to afford full P fertiliser rates, AMF inoculation offers a low-cost complement that stretches each kilogram of applied P further.

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