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Impact of different *Rhizobium* isolates on yield attributes, yield and post-harvest soil available nitrogen in chickpea (*Cicer arietinum* L.)

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Abstract
This study evaluated the impact of different Rhizobium isolates on yield attributes, overall yield, and post-harvest soil available nitrogen in chickpea (*Cicer arietinum* L.). Various *Rhizobium* isolates were applied individually and in combination with recommended fertilizer doses under field conditions. Results demonstrated that inoculation with effective *Rhizobium* isolates (T_9-RDF + Rhizobium Local Isolate 21) significantly enhanced number of pod plant^{-1}(64.71), number of seed pod^{-1}(2.67), test weight (186.25 g, grain yield (17.09 q ha^{-1}) and straw yield (24.75 q ha^{-1}). Furthermore, treated plots showed a notable increase in residual soil nitrogen (258.49 kg ha^{-1}) after harvest, indicating enhanced biological nitrogen fixation and soil fertility benefits. The findings suggest that selecting and applying suitable *Rhizobium* isolates can be a sustainable strategy to improve chickpea productivity while maintaining soil health.

Keywords: Rhizobium, chickpea, yield, soil nitrogen, inoculation, sustainability

Introduction
Chickpea (*Cicer arietinum* L.), commonly known as Bengal gram or Chana, is a nutrient-rich Rabi pulse crop belonging to the Fabaceae family, with India leading global production. Excessive dependence on synthetic nitrogen fertilizers in chickpea cultivation poses economic and environmental challenges, highlighting the importance of biological nitrogen fixation (BNF) as a sustainable alternative. In legumes, symbiotic association with *Rhizobium*, *Bradyrhizobium*, or *Mesorhizobium* converts atmospheric nitrogen into plant-available forms, improving soil fertility, reducing fertilizer use, and benefiting subsequent crops. In chickpea, *Mesorhizobium* species form root nodules that enhance nitrogen availability and contribute to soil health through deep rooting and canopy shading. However, the efficiency of BNF is influenced by soil moisture, temperature, pH, salinity, nutrient availability, and pesticide use, which affect rhizobial survival and infectivity. Therefore, selecting efficient, stress-tolerant rhizobial strains is crucial for maximising nitrogen fixation, improving yield, and promoting sustainable agricultural practices.

Materials and Methods
A field experiment entitled "Evaluation of different Rhizobium isolates of chickpea (*Cicer arietinum* L.) under field condition responsible to biological nitrogen fixation" was conducted during Rabi 2024-25 at the Instructional Farm, BTC College of Agriculture and Research Station, Bilaspur, Chhattisgarh. The site falls under the Chhattisgarh plains, with a sub-humid climate, annual rainfall of 1200-1400 mm, and clay loam soil (pH 6.9, EC 0.31 dS m^{-1}, organic carbon 0.48%, available N 242.97 kg ha^{-1}, P_2O_5 12.42 kg ha^{-1}, K_2O 286.36 kg ha^{-1}).The experiment was laid out in a Randomized Block Design with 12 treatments (Table 1) and three replications, using chickpea variety *Indira Chana-1*. Treatments included recommended dose of fertiliser (20:50:30 N:P_2O_5:K_2O kg ha^{-1}) alone and in combination with different *Rhizobium* isolates, along with control. Each plot measured 10.08 m² net area with 30 × 10 cm spacing. Standard agronomic practices were followed, including seed treatment with thiram and *Rhizobium* culture, two irrigations, nipping at 30-40 DAS, pre-

pre-emergence weed control, and pest management. Observations recorded included plant growth parameters, nodulation traits, yield attributes, grain and straw yield and soil available nitrogen.

Results and Discussion

Yield attributes

The data pertaining to yield attributes and yield of chickpea are presented in Table 2.

Number of pods plant^{-1}

The number of pods per plant varied significantly among treatments, ranging from 41.35 (T_1-Control) to 64.71 (T_9-RDF + Rhizobium Local Isolate 21). The highest number was recorded in T_9 (64.71), which was statistically at par with T_3 (62.14) and T_8 (58.32) but significantly superior over rest of the treatments. The lowest pod number was observed in the control (T_1: 41.35), indicating a positive impact of *Rhizobium* inoculation on reproductive output. Increased pod number due to *Rhizobium* inoculation is a well-established benefit resulting from improved nitrogen fixation and root growth. Singh *et al.* (2019) [5] reported that combining RDF with effective *Rhizobium* isolates significantly enhances nodulation and assimilate allocation, thereby increasing pod number. Choudhary and Sharma (2021) [6] also found similar trends in chickpea and lentil with native *Rhizobium* strains.

Number of seeds pod^{-1}

A highly significant variation was observed for this trait, with values ranging from 1.43 (T_1-Control) to 2.67 (T_9-RDF + *Rhizobium* Local Isolate 21). T_9 recorded the highest number of seeds per pod (2.67), followed by T_3 (2.63), T_5, T_8 (2.59 each), T_{10} (2.42) and T_{12} (2.47). These treatments were statistically at par and significantly superior to the control and RDF alone. The control (T_1) recorded the lowest value (1.43), while T_{11} also had a lower seed number (1.84), indicating less effective *Rhizobium* interaction. Enhanced seed set per pod is directly related to efficient nitrogen fixation and better nutrient translocation to reproductive organs. Meena *et al.* (2017) [7] showed that *Rhizobium* inoculation improves pollen viability and ovule fertilization in legumes, leading to higher seed numbers. Yadav *et al.* (2020) [8] also emphasized that co-application of RDF and suitable *Rhizobium* strains significantly boosts yield components in pulses.

Test weight (g)

The test weight ranged from 181.51 g (T_1-Control) to 186.25 g (T_9-RDF + *Rhizobium* Local Isolate 21). The highest value was recorded in T_9 (186.25 g), followed closely by T_3 (186.08 g) and T_8 (185.77 g). However, the differences were statistically non-significant, indicating that the treatments did not cause a notable variation in seed weight. The lowest test weight was observed in T_1 (181.51 g), suggesting a marginal improvement due to treatment, though not statistically proven. Test weight is a relatively stable trait, often less responsive to microbial treatments than yield attributes. According to Kumar *et al.* (2020) [9], test weight may show minor changes under biofertilizer application, but these are often non-significant. Rana *et al.* (2018) [10] also noted that test weight in legumes is influenced more by genotypic factors than by microbial inoculants.

Grain yield (q ha^{-1})

Grain yield varied significantly among treatments, ranging from 9.71 q ha^{-1} (T_1-Control) to 17.09 q ha^{-1} (T_9-RDF + Rhizobium Local Isolate 21). The highest grain yield in T_9 was significantly superior to the treatments T_1, T_2 and T_{11} and statistically at par with rest all treatments. The lowest grain yield was observed in Control (T_1) 9.71 q ha^{-1}, indicating that nutrient application and bio-inoculants significantly improve yield performance.Grain yield in legumes is known to increase with effective *Rhizobium* inoculation due to enhanced nodulation and nitrogen fixation. Singh *et al.* (2021) [3] reported that combining RDF with effective *Rhizobium* isolates significantly increased chickpea productivity. Similarly, Yadav and Meena (2020) [8] found that local isolates often outperform state checks due to better adaptation and symbiotic efficiency, resulting in increased grain yield.

Straw yield (q ha^{-1})

Straw yield also showed a significant response to the treatments, ranging from 15.09 q ha^{-1} (T_1-Control) to 24.75 q ha^{-1} (T_9). The highest straw yield in T_9 (24.75 q ha^{-1}) was significantly superior to the T_1, T_2 and T_{11} and statistically at par with rest all treatments. RDF alone (T_2) recorded 21.24 q ha^{-1}, indicating moderate improvement compared to the control but lower than bio-inoculated treatments. The lowest straw yield in T_1 (15.09 q ha^{-1}) reflects the baseline yield without nutrient or microbial input. Straw yield benefits from improved vegetative growth and biomass accumulation, both of which are supported by nitrogen fixation from effective *Rhizobium* strains. Chaudhary *et al.* (2019) [11] noted that inoculation of legumes with compatible *Rhizobium* strains increased shoot biomass and hence straw yield. Sharma and Rana (2018) [10] also reported similar increases in haulm yield due to improved nutrient uptake and photosynthetic activity.

Available nitrogen (kg ha^{-1})

As shown in Table 3, available nitrogen in soil ranged from 209.20 kg ha^{-1} in the control (T_1) to 258.49 kg ha^{-1} in T_9 (RDF + *Rhizobium* Local Isolate 21), with T_9 significantly outperforming T_1, T_2, and T_{11}, and being statistically at par with several other inoculated treatments. T_3 (252.55 kg ha^{-1}) and T_8 (247.85 kg ha^{-1}) also recorded high nitrogen levels, comparable to T_9, indicating the effectiveness of both state check and certain local isolates. The improvement in available nitrogen under inoculated treatments is attributed to enhanced biological nitrogen fixation and nutrient mobilization in the rhizosphere. These results corroborate the findings of Kumar *et al.* (2018) [1] and Sharma *et al.* (2020) [2], who reported that RDF integrated with efficient or locally adapted *Rhizobium* strains significantly improves soil nitrogen status in chickpea.

Table 1: Treatment details

Treatment details	
T_1	Control
T_2	RDF (20:50:30 NPK kg ha^{-1})
T_3	RDF + Rhizobium State Check
T_4	RDF + Rhizobium Local Isolate 1
T_5	RDF + Rhizobium Local Isolate 4
T_6	RDF + Rhizobium Local Isolate 6
T_7	RDF + Rhizobium Local Isolate 7
T_8	RDF + Rhizobium Local Isolate 15
T_9	RDF + Rhizobium Local Isolate 21
T_{10}	RDF + Rhizobium Local Isolate 28
T_{11}	RDF + Rhizobium Local Isolate 29
T_{12}	RDF + Rhizobium Local Isolate 31

Table 2: Impact of rhizobium isolates on yield attributes of chickpea

Treatments		No. of pods plant^{-1}	No. of seed pod^{-1}	Test weight (g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
T_1	Control	41.35	1.43	181.51	9.71	15.09
T_2	RDF (20:50:30 NPK kg ha^{-1})	46.03	1.56	183.59	14.45	21.24
T_3	RDF+Rhizobium State check	62.14	2.63	186.08	16.77	24.65
T_4	RDF+ Rhizobium Local Isolate 1	53.15	2.21	184.38	15.58	22.38
T_5	RDF+ Rhizobium Local Isolate 4	57.28	2.59	185.54	16.36	24.04
T_6	RDF+ Rhizobium Local Isolate 6	51.43	2.08	184.27	14.79	21.74
T_7	RDF+ Rhizobium Local Isolate 7	53.26	2.28	184.55	15.48	22.75
T_8	RDF+ Rhizobium Local Isolate 15	58.32	2.59	185.77	16.67	24.50
T_9	RDF+ Rhizobium Local Isolate 21	64.71	2.67	186.25	17.09	24.75
T_{10}	RDF+ Rhizobium Local Isolate 28	53.84	2.42	185.15	15.45	23.14
T_{11}	RDF+ Rhizobium Local Isolate 29	46.27	1.84	183.78	14.66	21.55
T_{12}	RDF+ Rhizobium Local Isolate 31	57.04	2.47	185.26	16.20	23.21
SEm (±)		2.34	0.09	5.77	0.63	0.84
CD (5%)		6.87	0.27	NS	1.87	2.48

Table 3: Available Nitrogen (kg ha^{-1}) in soil after harvest of chickpea

Treatments		Available N (kg ha^{-1})
T_1	Control	209.20
T_2	RDF (20:50:30 NPK kg ha^{-1})	230.10
T_3	RDF + Rhizobium State Check	252.55
T_4	RDF + Rhizobium Local Isolate 1	238.07
T_5	RDF + Rhizobium Local Isolate 4	245.25
T_6	RDF + Rhizobium Local Isolate 6	233.24
T_7	RDF + Rhizobium Local Isolate 7	238.95
T_8	RDF + Rhizobium Local Isolate 15	247.85
T_9	RDF + Rhizobium Local Isolate 21	258.49
T_{10}	RDF + Rhizobium Local Isolate 28	243.15
T_{11}	RDF + Rhizobium Local Isolate 29	232.16
T_{12}	RDF + Rhizobium Local Isolate 31	244.41
SEm (±)		8.79
CD (5%)		25.77

Conclusion

Inoculation of chickpea with efficient *Rhizobium* isolates, especially when combined with recommended fertilizer doses, significantly improves yield attributes, grain and straw yield, and post-harvest soil nitrogen. The local *Rhizobium* isolate 21 showed the best performance, enhancing biological nitrogen fixation and nutrient uptake. While test weight remained stable, the overall yield benefits and improved soil fertility highlight the potential of integrating effective rhizobial inoculants with fertilization to promote sustainable and productive chickpea cultivation.

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