DOI: https://doi.org/10.59983/s2023010301
AgroEnvironmental Sustainability, 2023, 1(3), 199-209

RESEARCH

Effect of *Rhizobium leguminosarum* Inoculation and Mulching on Growth and Yield of Chinese Long Bean (*Vigna unguiculata* subsp. *sesquipedalis*)

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ARTICLE HISTORY
Received: 17 September 2023
Revised: 26 October 2023
Accepted: 28 October 2023
Published: 30 October 2023

KEYWORDS
Chinese long bean
nitrogen fertilizer
nodules
Rhizobium leguminosarum
transparent plastic mulch

EDITOR
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Abstract

An experiment was conducted to evaluate the influence of *Rhizobium leguminosarum* inoculation and mulching on the growth and yield of Chinese long bean (*Vigna unguiculata* subsp. *sesquipedalis*) in Palungtar, Nepal. A split-plot design was used for the experiment, which was replicated four times. Plastic, straw, and no-mulch conditions constituted the main plot factor, while seeds with or without Rhizobium inoculation constituted the sub-plot elements. Growth parameters and yield-related traits of Chinese long beans were recorded at 15-day intervals. Transparent plastic mulching resulted in earlier flowering (46 days), while seed inoculation with Rhizobium resulted in a higher mean number of nodules (106.92) than non-inoculated treatments, with transparent plastic mulching resulting in the highest mean number of nodules (108.21). At 60 days after showing (DAS), plant height was greater in the inoculated treatment (69.23 cm), while at 30 DAS, the non-inoculated treatment had a higher number of leaves (22.28 cm). Similarly, pod length (49.98 cm), pod yield per plant (348.01 g), and total yield per hectare (16.07 t/ha) were all significantly higher with both plastic mulch and seed inoculation with Rhizobium than with the other treatments alone. A positive correlation was observed between plant height (0.81), number of branches (0.44), number of leaves (0.81), number of nodules per plant (0.6), and pod yield. This supports the potential benefits of using seed inoculation with Rhizobium in combination with mulching to improve Chinese long bean growth and increase yield as demonstrated by the results of this study.

Citation: Shrestha, S., Yadav, P. K., Khanal, B. R., Bhujel, P., Neupane, A., Chaudhary, B. & Giri, Dipesh (2023). Effect of *Rhizobium leguminosarum* Inoculation and Mulching on Growth and Yield of Chinese Long Bean (*Vigna unguiculata* subsp. *sesquipedalis*). *AgroEnvironmental Sustainability*, 1(3), 199-209. https://doi.org/10.59983/s2023010301

Statement of Sustainability: Our research on the impact of Rhizobium inoculation and mulching on Chinese long bean growth and yield is novel because of its holistic approach to sustainability. While contributing to increased crop productivity, it also addresses multiple sustainable development goals. By improving nutrient efficiency through Rhizobium, our work advances Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production). At the same time, the use of mulches addresses Goal 15 (Life on Land) by improving soil health and reducing erosion. In this way, our study provides an integrated solution for sustainable agriculture that reflects the ethos of the SDGs.

1. Introduction

Legumes are important food crops in terms of nutrition and belong to the family Leguminosae. Chinese long bean, *Vigna unguiculata* (L.) Walp. *subsp. sesquipedalis*, is one of the important legumes (Nooprom and Santipracha, 2015). It is also known as yard-long bean, string bean, snake bean, vegetable cowpea, asparagus bean, snake pea, snap pea, and so on (Sarutayophat et al., 2007). It is rich in protein, vitamin A, C, and minerals such as calcium (Ca), phosphorus (P), potassium (K), iron (Fe), magnesium (Mg), manganese (Mn), and folate (Huque et al., 2012). It is a warm season crop with an optimum growing temperature of 27–30 °C (Rubatzky and Yamaguchi, 2012). The global production of Chinese long beans is 1.39 t/ha (FAOSTAT, 2019). The estimated area, production, and productivity of Chinese long beans are 4184 ha, 42,896 mt, and 10.25 t/ha, respectively (MoALD, 2020). Per capita consumption of grain legumes in Nepal is about 10 kg/year or 27 g/capita/day, which is three times less than the minimum requirement (80 g/capita/day) prescribed by WHO (Sapkota et al., 2015).

Several species of bacteria and fungi play an important role in improving soil fertility; they increase the organic matter content and improve the availability of N, P, K, and Fe in the soil (Rashid et al., 2016). Rhizobia are bacterial species associated with the formation of root nodules on the roots of their host plant, and they proliferate by extracting nutrients from the host plant and, in turn, providing their host plant with nitrogen resources produced through nitrogen fixation (Fujita et al., 2014). The success of this symbiotic association depends on the ability of plants to form nitrogen-fixing symbioses with rhizobia. However, many agricultural soils do not have sufficient rhizobia in terms of number, quality, and effectiveness to form effective nitrogen fixation and thus cannot increase production (Lindström and Mausavi, 2020). The introduction of Rhizobium inoculants is a practically effective, ecologically safe, and economical substitute for increasing agricultural production (Kebede, 2021). Rhizobium inoculation is beneficial for sustainable agricultural practices used as a biofertilizer, which is the cheapest substitute for chemical fertilizers (Kumar et al., 2022).

Similarly, mulching had beneficial effects on soil moisture conservation and yield enhancement (Sapkota et al., 2015). Mulching is considered as a covering of material spread on the soil surface to reduce moisture loss and weed infestation and increase crop yield (Iqbal et al., 2020). Organic mulching or crop residue mulching is the practice of applying organic residues from the previous crop such as straw, corn stalks, and stubble of leafy organic materials (Erenstein, 2002). The environment created by some organic mulches is conducive to microbes that feed on weed seeds or weed species (Chalker, 2007). Plastic mulching is a technique of applying plastic film to the soil surface that effectively retains moisture evaporated from the soil under the plastic film. It directly affects the microclimate around the plant and accelerates plant growth by increasing soil temperature and maintaining soil moisture (Lalitha et al., 2010). The water droplets condensed under transparent plastic mulch are transparent to incoming shortwave radiation but opaque to outgoing longwave radiation, so the daytime soil temperature is generally 8–14 °F higher at a 2-inch depth compared to bare soil (Lamont, 2017).

Given the paucity of research on Chinese long beans and the effects of mulching and seed Rhizobium inoculation in this area, our study sought to evaluate how different mulching materials and seed Rhizobium inoculation affected the growth, yield, and yield attributes of these long beans. Our goal was also to estimate the benefits that Rhizobium inoculation could provide for increasing yield. Ultimately, our results will have practical implications for farmers growing Chinese long beans by increasing their productivity.

2. Materials and Methods

2.1. Experimental Site and Agro-climatic Conditions

The experiment was conducted at Sapkota tar, Palungtar Municipality - 04, Gorkha, Nepal from March 25 to June 17, 2021. The topography of the site was 579.06 meters above sea level. This site is located in the Gandaki Province of Nepal at 28°01'51.8" north of the Equator and 84°29'42.9" east of the Prime Meridian (Figure 1).

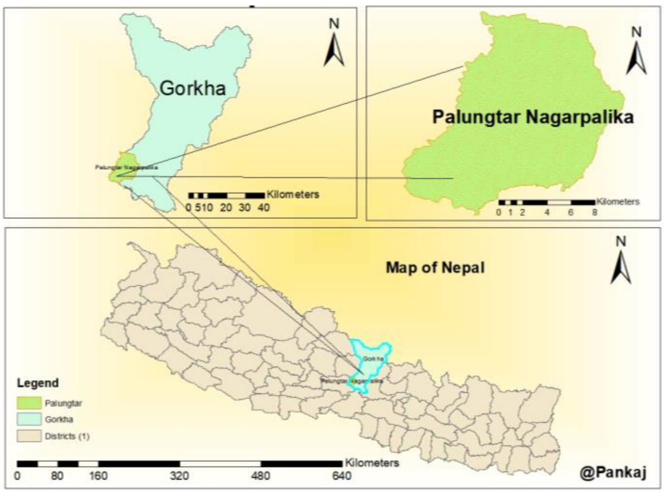

Figure 1. Map of Nepal showing the experimental site.

Palungatar is located in a tropical region of Nepal. During the study period, the average minimum temperature was 15.5 °C and the average maximum temperature was 29.5 °C from March to June (Figure 2). The total rainfall during the cropping period was 618.43 mm (NASA Power, 2021).

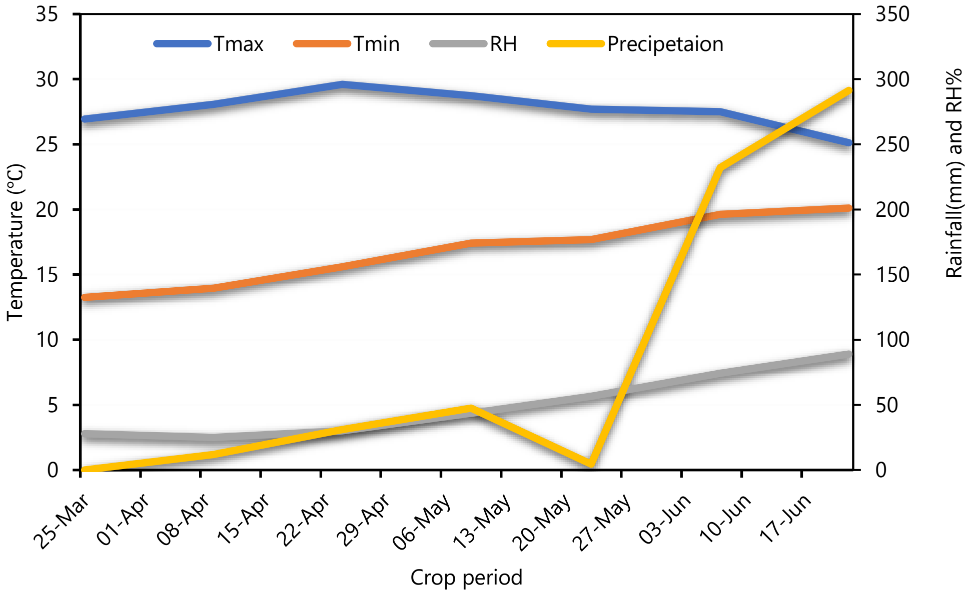

Figure 2. Agro-climate features of Palungtar, Gorkha during the cropping period (Source: NASA Power, 2021).

2.2. Soil and Experimental Materials

The soil of the experimental field was sandy loam. Soil samples were taken randomly from the 15 cm depth of the soil at different locations in the field using a soil auger. All the soil samples were mixed to prepare a composite sample for testing. The soil was sandy loam with slightly acidic pH (5.90), low organic matter (1.33%), low available nitrogen (0.07%), medium available P_2O_5 (37.4 kg/ha), and medium available K_2O (122.3 kg/ha). The crop selected for the experiment was Chinese long bean, and the recommended variety of Meiwujia No.2 Long Bean (312) was used at a seed rate of 300 g per 194 m^2 of land area. *Rhizobium leguminosarum* bacterial species was used for inoculation. Transparent plastic with a thickness of 0.025 mm and rice straw were used as mulching material for the experiment.

2.3. Experimental Design and Treatment Details

The experimental design used was a split-plot design (2 factors) with four replications and six treatments. The main plot factor (3 levels) was mulching, which included transparent plastic mulch, straw mulch, and no mulch, and the subplot factor (2 levels) was seed treatment with *R. leguminosarum* and no seed treatment.

Table 1. Details of the treatments used in this study.

Treatment	Symbol	Description
1	M1R1	Plastic mulch with Rhizobium inoculation
2	M2R1	Straw mulch with Rhizobium inoculation
3	M3R1	No mulch with Rhizobium inoculation
4	M1R0	Plastic mulch without Rhizobium inoculation
5	M2R0	Straw mulch without Rhizobium inoculation
6	M3R0	No mulch without Rhizobium inoculation

2.4. Seed Treatment and Cultural Practice

About 300 g of seeds of Meiwujia No. 2 (312) variety of long bean were taken for the experiment. The seeds were soaked in water for about 5 h. About 200 g of molasses was mixed with water and boiled for 15 min. The solution was cooled to atmospheric temperature and 150 g of seeds were soaked in this mixture for 1 min to create better contact of the sticky surface of the seeds with inoculants. The soaked seeds were taken out and mixed with the soil mass Rhizobium inoculants at the rate of 1 g per 18 g of seeds. The Rhizobium inoculant was procured from the Nepal Agriculture Research Council (NARC) located at Khumaltar, Lalitpur, Nepal.

The experimental field was selected, and field preparation was done on March 23, 2021. The recommended dose of fertilizer (80:120:60) NPK kg/ha was applied to each plot. The nutrient source was nitrogen (urea), phosphorus (SSP), and potassium (MOP). Half a dose of nitrogen and a full dose of phosphorus and potash were applied as basal doses before sowing Chinese long beans. The remaining half dose of nitrogen was applied 30 days after showing (DAS). The seeds were sown in the plots on March 25, 2021, after fertilization, at a sowing depth of 2–3 cm. The total number of plots was 24, and the area of a single plot was 5.4 m^2 (3 m × 1.8 m) with twenty-five plant populations in each plot. Plant-to-plant spacing was 30 cm and row-to-row spacing was 60 cm. The distance between treatments was 0.5 m, while the distance between replications was 0.75 m.

2.5. Data Observation and Analysis

Five plants were randomly selected from each treatment in each replication, excluding the border plants. The plants were marked 20 DAS. Growth parameters such as plant height, number of branches and leaves, phenological parameters such as days to flowering and number of nodules, and yield-related parameters such as pod length, pods per plant, and pod yield were recorded on the tagged plants at 30 DAS, 45 DAS, and 60 DAS. All data were entered into Microsoft Excel (Microsoft Corp., USA) for statistical analysis using R-Studio (version 4.1.1; Boston Massachusetts, USA). Duncan's multiple range test (DMRT) with a 5% significance level was used to separate means.

3 Results and Discussion

3.1 Effects on Growth and Phenological Parameter of Chinese Long Bean

3.1.1 Effect on Plant Height

The plant height of the Chinese long bean was significantly influenced by mulching and Rhizobium inoculation (Table 2). The plastic mulch produced superior plant height compared to straw mulch and no mulch at 30, 45, and 60 DAS. Plant height was significantly higher in clear plastic mulch (77.01 cm) compared to straw mulch (63.14 cm) and no mulch (62.63 cm) at 60 DAS. Straw mulching and no mulching were significantly equal at all stages of development. The superior plant height of the transparent plastic mulch was probably due to the higher availability of soil moisture and optimum soil temperature provided by the mulch so that there was less nutrient volatilization and available nutrients were used for vegetative growth by the plant. These findings are similar to those of Dhakal et al. (2019), who reported superior plant height in the plastic mulch compared to the control plot. The Rhizobium inoculated treatment was found to be higher than the non-inoculated treatment at 60 DAS. The increase in plant height as a result of Rhizobium inoculation may be due to sufficient nitrogen-fixing bacteria to promote plant growth. In their study, Raza et al. (2004) and Sajid et al. (2011) found that Rhizobium inoculation increased the plant height of mung bean and groundnut, respectively.

Table 2. Effect of Mulching and Rhizobium inoculation on plant height (cm) at different DAS.

Treatment	Plant Height		
	30 DAS	45 DAS	60 DAS
Mulching(M)			
Transparent Plastic Mulch	25.60a	40.78a	77.01a
Straw Mulch	20.55b	36.13b	63.14b
No Mulch	18.78b	36.18b	62.63b
SEM (±)	0.68	1.01	0.75
CV (%)	8.7	10.1	3.7
LSD(p<0.05)	2.04	3.07	2.25
F-test	***	**	***
Rhizobium Inoculation (R)			
Inoculated	21.53	38.10	69.23a
Non- Inoculated	21.75	37.28	66.02b
SEM (±)	0.55	0.83	0.61
CV (%)	8.9	5.4	2.7
LSD(p<0.005)	1.66	1.66	1.84
F-test	ns	ns	**
Grand Mean	21.64	37.69	67.62

Values are means. Means followed by a common letter(s) within columns are not significantly different based on DMRT P=0.05; ns: non-significant; *: significant at P < 0.05 value; **: significant at P < 0.01; ***: highly significant at P < 0.001.

3.1.2 Effect on Number of Branches

The number of branches in Chinese long beans was significantly affected by mulching, but there was no significant difference in Rhizobium inoculation (Table 3). The plastic mulch produced a higher number of branches compared to straw mulch and no mulch at 30, 45, and 60 DAS. The number of branches of transparent plastic mulch (18.75) was found to be superior to straw mulch (17) and no mulch (17.28) at 60 DAS. Straw mulching and no mulching were significantly equal on different DAS. The significantly higher number of branches in the transparent plastic mulch is probably due to the trapped moisture under the plastic mulch cover, the warmth that gives the root zone a favorable temperature for nutrient absorption. This observation was similar to that of Mundhe et al. (2019), who found significantly better results in sesamum with the mulching treatment in the number of branches parameter used in their study. There was no significant difference in Rhizobium inoculation parameters. The result was consistent with the findings of Karasu et al. (2011), who reported that inoculation with Rhizobium phaseoli did not have a significant effect on the number of branches per plant in three dwarf dry bean cultivars over three years.

3.1.3 Effect on Number of Leaves

The number of leaves in Chinese long beans was significantly influenced by mulching and Rhizobium inoculation (Table 3). The transparent plastic mulch produced a higher number of branches compared to straw mulch and no mulch at 30, 45, and 60 DAS. The number of leaves was higher in transparent plastic mulch (92.18) compared to straw mulch (64.30) and no mulch (63.60), while there was no significant difference in straw mulch and no mulch parameters. This was probably due to moisture trapped under the plastic mulch, the warmth of which provided the root zone with a favorable temperature for nutrient uptake. There was probably less nutrient volatilization in the plastic mulch, so most of the available nutrients were used by the plant for vegetative growth. The results are like those of Dhakal et al. (2019), who found that the number of leaves was significantly higher in mulch compared to no mulch in cowpeas at 15, 30, and 60 DAS, respectively. In their field trial, Mundhe et al. (2019) found the number of functional leaves per plant significantly higher in the mulched plots of Sesamum. Treatment significantly influenced the number of leaves at 30 DAS only where the uninoculated treatment (22.28) was found to be superior to the inoculated treatment (19.42).

Table 3. Effect of Mulching and Rhizobium inoculation on the number of branches and number of leaves at different DAS.

Treatment	Number of Branches			Number of Leaves		
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
Mulching						
Plastic Mulch	6.05^a	10.55^a	18.75^a	26.45^a	48.05^a	92.18^a
Straw Mulch	4.88^b	9.05^b	17.00^b	18.18^b	36.38^b	64.30^b
No Mulch	4.73^b	9.08^b	17.28^b	17.49^b	35.43^b	63.60^b
SEM (±)	0.18	0.22	0.34	1.08	1.56.08	2.46
CV (%)	10.1	4.9	7.7	14	11.7	9.7
LSD(p<0.05)	0.55	0.67	1.03	3.27	4.69	7.41
F-test	***	***	**	***	***	***
Rhizobium Inoculation						
Inoculated	5.08	9.52	17.50	19.42^b	38.90	72.93
Non- Inoculated	5.35	9.60	17.84	22.28^a	41.00	73.78
SEM (±)	0.14	0.18	0.28	0.88	1.27	2.01
CV (%)	9.7	7.5	3.3	15.2	10.6	9.3
LSD(p<0.005)	0.45	0.54	0.84	2.67	3.83	6.05
F-test	ns	ns	ns	*	ns	ns
Grand Mean	5.22	9.56	17.68	20.85	39.95	73.35

Values are means. Means followed by a common letter(s) within columns are non-significantly different based on DMRT P=0.05; ns: non-significant; *: significant at P < 0.05 value; **: significant at P < 0.01; ***: highly significant at P < 0.001.

3.2 Effects on Yield Parameter of Chinese Long Bean

3.2.1 Effect on Days to Flowering and Number of Nodules

The onset of flowering marks the completion of vegetative growth and the beginning of reproductive activity. As shown in Table 4, field research has shown that Chinese long bean begins to flower about 45 DAS. Our trial results suggest that early flowering occurred in the mulching (at 46 days) and Rhizobium inoculation (at 45.5 days) treatments. This may be due to superior moisture retention and optimal nutrient mobilization within the root zone of the mulched plot, which facilitated accelerated growth and development of long bean plants, resulting in earlier flowering. This finding was in agreement with Steinberga (2008), who observed the shortest flowering period in the Rhizobium-treated plants and the longest in the untreated lupin variety in their field trial. Zaman et al. (2011) reported earlier flowering in inoculated plants than in uninoculated plants in chickpeas. Younis et al. (2019) evaluated chickpea genotype NKC-5-S-24, which showed a minimum day to 50% flowering in a Rhizobium-inoculated field trial. In a research trial, Kasperbauer (2000) observed that the increase in flowering and growth of mulched plants was attributed to the nutrient gain and warming effects of both organic and inorganic mulches.

Nodulation was significantly affected by Rhizobium inoculation and plastic mulch (Table 4). The higher mean number of nodules per plant was obtained in Rhizobium inoculation (106.92) and transparent plastic mulch (108.21). The number of nodules was observed in the non-inoculated (83.13) and no mulching (80.08) treatments. The mean number of nodules of plastic mulch was followed by straw mulch and no mulch respectively. This finding agrees with Dhakal et al. (2019) who observed in their field trial that the number of nodules was significantly higher in mulched plots than in un-mulched plots of cowpeas. In their research trial, Dukare et al. (2017) observed that overall plant root development and root nodulation were positively affected by organic mulches, while black mulch had a negative effect on these plant parameters. Seed inoculation with Rhizobium spp. before planting has also been reported to be a key factor in improving nodulation, early emergence, plant vigor, and high grain yield (Figueiredo et al., 2008). Siczek and Lipiec (2009) found that soil compaction affects nodulation and nitrogen fixation, and that compaction can be mediated by straw mulch in their study. This may be due to the application of inoculants that increase the number of Rhizobium bacteria that infect the roots to form nodules. A high number of bacteria results in a high number of effective nodules per plant. Rhizobium bacteria synthesize phytohormones such as auxin as secondary metabolites in inoculated plants, which play an important role in promoting or regulating plant growth (Ndlovu, 2015).

3.2.2 Effect on Pod Length

Statistical analysis revealed that the pod length was longest in transparent plastic mulch (49.98 cm), while straw mulch (44.76 cm) and no mulch (44.33 cm) pods were significantly at par with each other (Table 4). The result was supported by Bhadauria and Kumar (2006) who in their study on okra observed that black plastic mulch and sugarcane waste mulch gave significantly higher values of transpiration rate, photosynthesis, pod length, and pod yield per plant as compared to those without mulch. The pod length of the Rhizobium inoculated plot (47.32 cm) was higher than the non-inoculated plot (44.73 cm), which was in agreement with the findings of Ravikumar (2012) and Shahid et al. (2009) who reported higher pod length of Rhizobium inoculated plants as compared to uninoculated plants.

3.2.3 Effect on Number of Pods Per Plant

The number of pods per plant was highest in transparent plastic mulch (21.17), while straw mulch (17.73) and no mulch (17.38) were significantly equal (Table 4). This finding was supported by Chaudhary et al. (2013) who found that plastic mulching was significantly better than control, dust, and straw mulching in terms of the number of pods per plant. In their field research on French beans, Kawocharr et al. (2010) observed the highest yield on polyethylene mulch and the lowest yield on the control treatment, which supported the highest number of pods and number of seeds per plant on polyethylene mulch than other treatments. The number of pods per plant was insignificant in the case of Rhizobium inoculation.

3.2.4 Effect on Pod Yield (g/plant) and Total Yield (t/ha)

The mulched treatment achieved a significant increase in pod yield (348.01 g) and total yield (16.07 t/ha) compared to the un-mulched treatments (Table 4). This was probably related to moisture conservation and improved microclimate both below and above the soil surface. In addition to reducing weeds, mulch can improve the physical and biological properties of the soil and enhance plant performance (Ziech et al., 2014). On the other hand, soil not covered by mulch was exposed to more sunlight, which led to more weeds and ultimately damaged the crop, preventing it from reaching its full genetic potential (Meschede et al., 2007). Dhakal et al. (2019) evaluated that the mulched treatment was significantly higher than the un-mulched treatment in the number of nodules and pod yield of cowpeas. According to Gajghate et al. (2020), mulching in water-limited and warm environments usually increases crop yield due to reduced temperature and increased retention. The Rhizobium inoculation treatment achieved a significant increase in pod yield (296.48 g/plant) and total fresh pod yield (13.69 t/ha) compared to non-inoculated treatments. This was associated with the symbiotic relationship between Rhizobium and Chinese long bean plants, which resulted in the fixation of atmospheric nitrogen in the roots and translocation of amino acids to the shoots, leading to increased yield (Ndlovu, 2015). Bambara and Ndakidemi (2010) further reported that the higher yield obtained with inoculation indicates that

Rhizobium inoculation is efficient in supplying nitrogen to legumes as an inorganic nitrogen fertilizer and is a better option for resource-poor farmers who cannot afford to purchase expensive inputs. These results are consistent with those of Abera and Abebe (2014), who reported that inoculation significantly increased grain yield in Faba bean.

Table 4. Effect of mulching and Rhizobium on different yield attributing parameters.

Treatment	Days to Flowering	Numbers of Nodules/Plant	Pod Length (cm)	Pod per Plant	Yield (g/Plant)	Yield (t/ha)
Mulching (M)						
Plastic Mulch	46.00a	108.21a	49.98a	21.17a	348.01a	16.07a
Straw Mulch	46.50b	96.78b	44.76b	17.73b	247.55b	11.46b
No Mulch	48.88c	80.08c	44.33b	17.38b	247.11b	11.44b
SEM (±)	0.64	2.75	1.01	0.42	9.64	0.45
CV (%)	3.4	7.2	5.6	7.2	10.7	11.2
LSD(p<0.005)	1.91	8.29	4.3	1.25	29.07	1.34
F-test	*	***	***	***	***	***
Rhizobium (R)						
Inoculated	45.50a	106.92a	47.32a	19.25	296.48a	13.69a
Non-Inoculated	48.75b	83.13b	44.73b	18.28	265.30b	12.28b
SEM (±)	0.52	2.24	0.63	0.34	7.87	0.36
CV (%)	4.1	8.8	6.6	5.6	9	8.7
LSD(p<0.005)	1.56	6.77	2.48	1.02	23.73	1.09
F-test	***	***	*	ns	*	*
Grand Mean	47.13	95.03	46.02	18.76	280.6	12.99

Values are means; means followed by a common letter(s) within columns are non-significantly different based on DMRT P=0.05; ns: non-significant; *: significant at P < 0.05 value; **: significant at P < 0.01; ***: highly significant at P < 0.001.

The interaction effect was observed in plant height at 45 DAS and total yield (Table 5). In plant height parameter, the interaction effect was found to be highly significant in transparent plastic mulch with Rhizobium inoculated treatment (42.20 cm) and lowest in straw mulch without inoculation (34.65 cm), which was significantly at par with no mulch with inoculation (34.50 cm). In terms of total yield, the interaction effect was highly significant in transparent plastic mulch with Rhizobium inoculated treatment (12.77 t/ha) and lowest in straw mulch (8.55 t/ha, 7.83 t/ha) and no mulch parameters (8.22 t/ha, 8.20 t/ha) which were significantly at par with each other.

Table 5. Interaction effect of mulching and Rhizobium inoculation on plant height and total yield.

Mulching Materials	Plant Height (45 DAS)		Total Yield	
	Inoculated	Non-Inoculated	Inoculated	Non inoculated
Plastic Mulch	42.20a	39.35ab	12.77a	10.43b
Straw mulch	37.60bc	34.65c	8.55c	7.83c
No mulch	34.50c	37.85bc	8.22c	8.20c
SEM (±)	1.44		0.45	
LSD (p<0.05)	3.28*		1.30*	

Means followed by a common letter(s) within columns are non-significantly different based on DMRT P=0.05; *: significant at P < 0.05.

3.3 Relationship Among Various Parameters of Chinese Long Bean

The relationship between various parameters of Chinese long beans, including plant height, number of branches, number of leaves, and number of nodules, plays a crucial role in determining yield. A positive correlation between these parameters indicates that they are interrelated and can collectively influence the overall productivity of Chinese long beans. The correlation between different parameters is shown in Figure 3. Chinese long bean yield was positively correlated with plant height (0.81***), number of leaves (0.81***), number of nodules (0.60**), and pod length (0.64***). Plant height is an important factor in determining Chinese long bean yield. Taller plants often have more access to sunlight and can produce more photosynthetic material, resulting in increased yield. This positive correlation suggests that as plant height increases, Chinese long bean yield is likely to increase as well (Wang et al., 2008). Branches of Chinese long beans were positively correlated with plant height (0.56**), number of leaves (0.55**), yield (0.44*), and pods per plant (0.45*). The number of branches produced by a Chinese long bean plant can significantly affect its yield. More branches mean more flowering sites, which can lead to more pods and ultimately higher yields. The positive correlation between the number of branches and yield suggests that increasing the number of branches may be a practical strategy to improve bean production (Abayomi et al., 2008). Chinese long bean pods per plant were positively correlated with plant height (0.80***), number of leaves (0.76**), yield (0.94*), number of nodules (0.57**), and pod length

(0.58**). The plant height of the Chinese long bean was positively correlated with the number of leaves (0.89***), number of nodules (0.68**), and pod length (0.58**). Number of leaves of Chinese long bean was positively correlated with number of nodules (0.46*) and pod length (0.65***). Chinese long bean number of nodules was positively correlated with pod length (0.74***). The positive correlation between leaf number and yield underscores the importance of a healthy and abundant leaf canopy for maximizing Chinese long bean productivity (Zhu et al., 2010).

Nodules in leguminous plants house nitrogen-fixing bacteria, converting atmospheric nitrogen into plant growth-promoting nutrients. Increased nodule numbers enhance nitrogen supply, leading to higher plant yields (Darini et al., 2023). The positive correlation between nodule number and yield indicates the importance of nitrogen fixation in Chinese Faba bean production (Abayomi et al., 2008). In summary, the positive correlations between plant height, number of branches, number of leaves, and number of nodules with Chinese long bean yield indicate that these parameters are interrelated and collectively influence overall productivity (Manjesh et al., 2019). Farmers and researchers can use this knowledge to make informed decisions and implement strategies to increase yield, such as selecting cultivars with specific growth traits, optimizing plant spacing, and using appropriate soil amendments to promote nodule formation and nitrogen fixation. Selection for these traits may result in a correlated response for increased yield. It is important to note, however, that these relationships indicate that growth traits and yield components are not independent and that increased expression of one growth trait may result in a change in others.

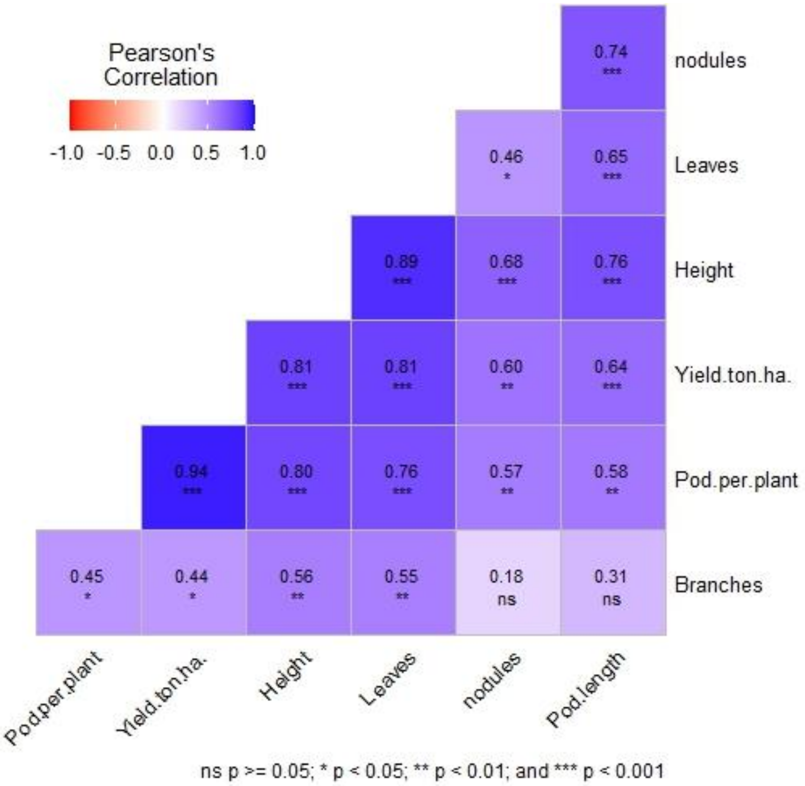

Figure 3. Correlation coefficient showing the relation among various parameters of Chinese long bean as recorded during the experiment. (r-value at P < 0.01= 0.423 ** indicates r value > critical value at P=0.01).

4. Conclusion

The experimental results showed that the use of transparent plastic mulch with a thickness of 0.025 mm increased the growth and yield parameters like plant height, number of branches, number of leaves, pod length, pod per plant, and fresh pod yield. Similarly, the use of Rhizobium at 1 g/18 gm of seed resulted in 11.5% more pod yield. Thus, this paper recommends the use of transparent plastic mulch combined with Rhizobium inoculation in an efficient proportion to increase the yield of Chinese long beans in developing countries like Nepal.

Author Contributions: Conceptualization, Saksham Shrestha, Pankaj Kumar Yadav; Data curation, Saksham Shrestha, Pankaj Kumar Yadav, Apeksha Neupane, Bishal Chaudhary, Dipesh Giri; Investigation, Babu Ram Khanal; Methodology, Saksham Shrestha, Bishal

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Funding: Not applicable.

Acknowledgment: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Institutional/Ethical Approval: Not applicable.

Data/Supplementary Information Availability: Not applicable.

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