Cross Current International Journal of Agriculture and Veterinary Sciences
Abbreviated Key Title: Cross Current Int J Agri Vet Sci
ISSN: 2663-2454 (Print) & Open Access
DOI: https://doi.org/10.36344/ccijavs.2024.v06i03.003

Volume-6 | Issue-3 | Jul-Aug, 2024 |

Original Research Article

Effect of *Bradyrhizobium japonicum* Inoculation and Varieties to Nodulation, Maturity and Yield of Soybean [Glycine Max L. (Merrill) at Maale District, South Omo Zone, Southern Ethiopia

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| **Received:** 11.07.2024 | **Accepted:** 21.08.2024 | **Published:** 23.08.2024 |

Abstract: Soybean [Glycine max L.] is a valuable crop, providing protein, oil, and income for farmers. Despite the significance of crop in study area, there was lack of knowledge on crop and response to B. japonicum. The study was conducted at Maale district of South omo zone southern Ethiopia to investigate the response of soybean varieties to B. japonicum. It was consisted of a factorial combination of seven soybean varieties namely, Awassa-95, Nyala, Nova, Awassa-04, Gozella, Afgat, and Pawe-2 with two levels of inoculation, with and without B. japonicum. A randomized complete block design (RCBD) with three replications was used. Data were collected on phonological, nodule, growth, yield, and yield related parameters. The analysis of variance showed all measured parameters, except the number of seed pod-1 such as canopy spread, plant height, number of primary branches, number of nodules, number of effective nodules, above ground biomass yield, 1000 seed weight, harvest index, were significantly ($p< 0.01$) affected by B. japonicum. The interaction of varieties with B.japonicum were also significantly affected the number of pod plant^{-1} and grain yield ha^{-1}.The maximum grain yield (2017.50 kg ha-1) was recorded from Awasssa-04 with B. japonicum. Based on the economic analysis, Awassa-95, Nova and Nyala variety with B. japonicum gave the higher value of economic return respectively, however, these varieties gave a lower grain yield. Therefore, a combination of Awassa-04 with B.japonicum is ideal for achieving maximum grain yield and Awassa-95, Nova and Nyala with B.japonicum was economically feasible options.
Keywords: *Bradyrhizobium japonicum*, Inoculation, Grain yield, Soybean, Variety.

1. INTRODUCTION

Soybean [*Glycine max* L. (Merrill)] is a small, erect, branching, drought-tolerant annual legume plant from the Fabaceae subfamily of the Paplionodae family (Sinclair and Vadez, 2002). Due to its high protein content and availability as a source of vegetable oil, soybean is considered one of the most important oilseed crops (Amer *et al.*, 2022). It is the source of high-quality vegetable protein in the animal feed industry due to its high protein content and essential amino acids in good proportion (Wilkinson & Young, 2020). Additionally, it has a critical role in agriculture and natural ecosystems due to its capacity to fix atmospheric nitrogen in symbiosis *Rhizobium* and supply plant N requirements (Sopov & Sertse, 2015).

The three-year (2015–2017) world average and average production of soybean in Africa was 337,116000 and 2,630,573 metric tons, respectively. In terms of average soybean yield, Ethiopia's yield is number two (2.2 metric tons) next to Egypt (Cornelius & Goldsmith, 2019). According to the CSA (2021) of Ethiopia, the area under soybean production was 83,797.17 ha, with a total annual production of 20, 8676.389 tons and an average national yield of 2.49 tha^{-1}. In the same year, 412.58 ha was covered with soybeans in the SNNP Region, from which about 5747.30 tons were produced, with an average regional yield of 1.39 t ha^{-1} and a zonal yield of 1.28 t ha^{-1}. However, this is far less than the attainable yield (2 to 2.8 t ha^{-1}) under good management conditions (MOANR, 2016) and its potential, which could go up to 4 tha^{-1} if improved varieties are used (Sopov & Sertse, 2015). Limited genetic diversity, narrow genetic bases of soybean cultivars, and low usage of *Rhizobium* inoculant were some of the major reasons for low productivity of soybeans in Ethiopia (Tesfaye *et al.*, 2018).

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Citation: Yihuda Deka, Meseret Fanta, Dereje Tsegaye (2024). Effect of *Bradyrhizobium japonicum* Inoculation and Varieties to Nodulation, Maturity and Yield of Soybean [Glycine Max L. (Merrill) at Maale District, South Omo Zone, Southern Ethiopia. *Cross Current Int J Agri Vet Sci*, *6*(3), 61-72.

There are now 26 released soybean varieties under production, which are divided into early, medium, and late maturity classes (Desissa, 2019) and characterized by high yielding, early maturity, and disease resistance (Delele *et al.*,2021). Comparisons of the yielding potentials of three maturity classes in different years of trials revealed no wide yield gap among them. However, early and medium maturity classes, on average, expressed relatively better yielding potential (Getnet, 2019). Early maturity varieties such as Awassa-95, Williams, Crawford, Nova, Nyala, Cheri, Gozelle, and Awassa-04 are suited for moisture-stressed areas like South Omo (Desissa, 2019). The varieties were adapted to low-land, mid-altitude, and long-growing seasons in the north-west to south-western parts of Ethiopia (Desissa, 2019). Improved soybean varieties had a positive impact on soybean yield (Delele *et al.*, 2021; Tufa *et al*., 2019). Thus, selecting the best varieties in specific locations is necessary for better soybean production and, in turn, to increase household income.

Utilizing fertilizers in agriculture is important for increasing productivity and restoring soil nutrients; however, using too many chemical fertilizers has a negative impact on the environment (Kandpal, 2021). *B. japonicum* is a risk-free alternative substitute for chemical fertilizers. As a result, it is considered a low-cost supply of nitrogen that is also a host-specific and environmentally friendly source (Santos *et al.,* 2019). Many researchers have reported that the inoculation of *Bradyrhizobium* results in increased nodulation, higher dry matter, and grain yield production of soybeans (Leggett *et al*., 2017; Adeyeye *et al*., 2017; Merkeb *et al*., 2016 & Argaw, 2014). According to Chibeba *et al., (2020), Rhizobium* inoculation increases the grain yield of soybeans by the same amount as urea at a rate of 200 kg ha^{-1}. To acquire a high yield and to use its potential, the crop needs association with *B. japonicum* to fix atmospheric nitrogen. In Ethiopia and other countries, the evaluation and selection of different *Rhizobium* strains have given promising results in soybean production. Likewise, soybean nodule forming *Rhizobia* is not harbored in soils that have not been previously inoculated (Argaw, 2014). However, for the study area of Maale district, there is no information available regarding the crop or commercially available strain. As a result, this study is proposed specifically at Maale district to investigate the response of soybean varieties to *B. japonicum* inoculation on yield components and yield.

2. MATERIALS AND METHODS

2.1 Description of study area

The field experiment was conducted on farmer field at South omo zone , Southern, Ethiopia under rain fed conditions during the 2022/2023 cropping season (summer). The area lies between latitudes 5.08 N° 48' and 6°01' North and longitudes 36° 30' and 37° 04' East with mean maximum and minimum air temperatures of district during cropping period were 28.3°C and 17.4°C and long years 28.9 °C and 17.10 °C. The soil of experimental field was deep well drained, red, fertile, and classified sand clay loam textural class.

2.2 Treatments and experimental design

The treatments consisted of a factorial combination of seven soybean varieties (Awassa-95, Nyala, Nova, Awassa-04, Gazelle) with two levels of inoculation (with and without *Bradyrhizobium*). The seed of variety Pawe-2 was obtained from Pawe Agricultural Research Center while, Awassa-04, Awassa-95, Nyala, Afgat, Gazolle and Nova were sourced from Awassa Agricultural Research Center. The *Bradyrhizobium japonicum* (TAL-379) strain was obtained from Managasha Biotechnology Private Limited Company, Addis Ababa,Ethiopia. The experiment was laid out in Randomized Complete Block Design (RCBD) with 3 replications. The total experimental area was 63.40m x11.40m (722.76m^2). The plot size was 3.60 x 2.80 m or 10.08 m^2, distance between plots was 1 m, and distance between blocks was 1.5 m. Total number of rows within plot was 7. The middle 4 rows was used as net rows and the net plot size was 5.76m^2 (3.6m x1.6m). One outer most row on each side of the plot and two plants on each end of rows was considered as border. One row next to the border rows on any side was used for destructive sampling. The experiment was consisted of fourteen treatments with a total of forty- two (42) plots or observations. The treatments were randomly assigned to each plot with in the block.

Data on total nodule number plant, number of effective nodules, canopy spread, total leaf area, leaf area index, plant height, number of primary branches, number of pods plant, number of seeds per pods, 1000 seed weight (gm), grain yield, total above-ground dry biomass (kg ha^{-1}) and harvest index was recorded. The collected data was subjected to analysis of variance (ANOVA) using Statistical Application Systems (SAS) software version 9.0. The interpretation of the results was done following the procedures described by (Gomez, 1988). To assess significant differences among treatment means, the least significant difference (LSD) test was employed. The value-cost ratio (VCR) was used to estimate the economic return on using *Bradyrhizobium japonicum* inoculant because full production costs, including labor, input, and machinery costs, were not available (Xu *et al*., 2009).

3. RESULTS AND DISCUSSION

3.1 Phonological and nodulation parameters.

3.1.1 Days to 50% flowering

The analysis of variance revealed a significant (P<0.01) influence of both inoculation and varieties on the number of days to 50% flowering (Table 1).

Among the treatments, the inoculated plots exhibited the maximum number of days to 50% flowering (48.13 days), while the non-inoculated plots displayed the minimum number of days to 50%

flowering (42.46 days) (Table 1). The prolonged flowering duration in the inoculated plots can be attributed to the increased availability of nitrogen resulting from *Bradyrhizobium* inoculation. This excess nitrogen availability likely promoted extended vegetative growth, consequently leading to delayed flowering. This finding aligns with the observations made by Tairo and Ndakidemi (2013), who reported similar delayed flowering in soybean due to inoculation in both greenhouse and field experiments. Additionally, Yoseph and Worku (2014) found that inoculation significantly affected the timing of flowering and pod setting. Similarly, Mosupiemang *et al*., (2021) reported a significant impact of *Bradyrhizobium* inoculation on the number of days to 50% flowering. In contrasts with the current findings, Argaw (2014) reported a non-significant effect of *Bradyrhizobium japonicum* inoculation on the number of days to 50% flowering.

Table 1: Effects of soybean varieties and Inoculation on Phonological and nodulation parameters

Phonological and nodulation parameters					
Variety	DOF(days)	DOM(days)	NNP	NEN	NENP (%)
Awassa-95	45.33^{ab}	76.00^{b}	32.68^{c}	28.28^{b}	84.71^{a}
Nyala	41.33^{b}	76.50^{b}	31.29^{c}	27.70^{b}	83.44^{a}
Nova	42.83^{b}	73.66^{b}	38.54^{ab}	31.88^{ab}	82.41^{ab}
Awassa-04	46.02^{ab}	76.17^{b}	42.25^{a}	36.58^{a}	85.62^{a}
Gozella	51.01^{a}	91.00^{a}	34.16^{bc}	30.04b	86.85^{a}
LSD(0.05)	6.28	2.00	5.49	5.16	6.81
Inoculation					
Un-inoculated	42.46^{b}	82.28^{b}	28.26^{b}	22.52^{b}	75.48^{b}
Inoculated	48.13^{a}	84.52^{a}	41.92^{a}	37.71^{a}	83.48^{a}
LSD(0.05)	3.97	2.65	1.65	2.75	3.64
CV (%)	11.45	4.39	12.57	6.71	7.23

Mean values with in column followed by the same letters in superscript are not significantly different. LSD (0.05) = Least significant difference at 5% level; CV (%) = Coefficient of variation; DOF =Days to 50% flowering, DOM = Days to 90% physiological maturity, NNP = Number of nodule plant^{-1}; NEN = Number of effective nodule plant^{-1}; NENP=Number of effective nodule percentage plant^{-1}.

Among the five soybean varieties tested, Nyala displayed the earliest flowering time (41.33 days), with no significant difference observed compared to Nova, Awassa-95, and Awassa-04 (Table 1). In contrast, Gozella exhibited a significantly delayed flowering time (51.01 days) with no significant differences with Awassa-04 and Awassa-95 varieties.

These findings indicate the presence of genetic variation in flowering time among the tested varieties. This genetic diversity contributes to the observed differences in the timing of flowering. This aligns with the study conducted by Sileshi *et al*., (2022), which also reported genotypic differences in flowering time. Specifically, their study found that the Nova genotype exhibited the earliest days to 50% flowering, while the Gishama variety displayed a delayed flowering period. Similarly, previous research by Pagano and Miransari (2016) also indicated variations in the number of days to flowering among different soybean genotypes.

3.1.2 Days to 90% physiological maturity

Analysis of variance revealed that inoculation and varieties had a significant (P< 0.05) effect on days to maturity, but their interaction had no significant effect (Table 1). The inoculated plots showed the longest time until physiological maturity (84.52 days), while the non-inoculated treatment exhibited the shortest time to physiological maturity (82.28 days) (Table 1).

The delay in maturity observed with inoculation can be attributed to the enhanced nitrogen availability resulting from nitrogen fixation, which in turn promotes vegetative growth. This result was in agreement with those of Dabesa & Tana (2021) who reported seed inoculation with *Bradyrhizobium* prolonged days to **90%** physiological maturity.

The number of days required for a crop to attain maturity is a crucial factor in determining the suitability of a particular cultivar for a given environment and cropping system. The analysis revealed that the Nova variety had the shortest time to reach physiological maturity (73.66 days), while Gozella required the longest period (91.00 days) (Table 1). These findings are in line with the observations made by Aweke (2022), who reported significant differences among soybean varieties in reaching 90% physiological maturity. Similarly, Sign *et al*., (2014) noted significant variations among soybean cultivars in terms of days to reach physiological maturity.

3.1.3 Total nodule number plant^{-1}

Total number of nodules plant^{-1} was significantly (p<0.01) affected by the main effect of inoculation and variety, while their interaction had no significant effect (Table 1).

The mean separation analysis revealed that the inoculated plots had a significantly higher number of nodules (41.92) compared to the non-inoculated plots (28.26) (Table 1). This increase in nodules can be attributed to the inoculation with *Bradyrhizobium*, which likely contributed to higher bacterial populations and consequently led to the production of more nodules. This finding aligns with a study conducted by Solomon *et al*., (2012), which reported that *Bradyrhizobium japonicum* inoculated treatments exhibited significantly higher numbers of nodules compared to the un-inoculated treatments. Furthermore, Ksiezak and Bojarszczuk (2022) stated that inoculation with *B. japonicum* can enhance both the number and size of nodules. This result was also supported by several authors including Kyei-Boahen *et al*., (2022); Chimdi (2022); Mosupiemang *et al*., (2021); Jarecki (2020); Tarekegn & Kibret (2017); Merkeb *et al*., (2016) & Argaw, (2014) who observed significant increment in number of nodules due to inoculation of *Bradyrhizobium.*

Among the tested varieties, Awassa-04 exhibited the highest number of nodules per plant (42.25), while Nyala had the lowest number (31.29). However, there was no significant difference observed between Nyala and the varieties Awassa-95 and Gozella (Table 1). This high variability in nodule formation can be attributed to genetic differences among the genotypes. These findings are consistent with the research conducted by Sharma *et al*., (2018), Islam *et al*., (2017), and Muthuri (2013), who also reported significant differences in the number of nodules among soybean varieties.

3.1.4 Number of effective nodule plant^{-1}

The number of effective nodules plant^{-1} was significantly ($P<0.01$) influenced by the main effect of inoculation and variety, but not significantly affected interaction (Table 1).

The highest number of effective nodules per plant (37.71) and the highest percentage of effective nodules per plant (83.48%) were recorded in the inoculated treatment, while the lowest number of effective nodules per plant (37.71) and the lowest percentage of effective nodules per plant (75.48%) were observed in the non-inoculated treatments (Table 1). This might be due to the compatibility between the inoculant and the host plant. Effective nodulation is an essential feature of an efficient legume *Rhizobium* symbiosis. Plants, most susceptible to infection and capable of producing effective nodules should have a greater potential to fix more atmospheric nitrogen. In line with this finding, Anhar *et al*., (2021) and Abeje *et al*., (2022) observed significant differences in number of effective nodule due to inoculation. According to Gwata *et al*., (2004), if the atmospheric nitrogen (N_2) in the root nodules is effectively symbiotically fixed, then mineral nitrogen fertilization is not required.

Among the tested soybean varieties, Gozella demonstrated the highest percentage of effective nodules (86.85%) and a count of 30.04 effective nodules per plant. Similarly, Awassa-04 displayed the highest number of effective nodules (36.58) and an effective nodule percentage of 85%. In contrast, Nova exhibited the lowest percentage of effective nodules (82.41), and Nyala had the lowest count of effective nodules (27.70) (Table 1). These findings indicates the existence of genetic variations among the soybean varieties concerning their capacity to form effective nodules. In line with this finding Diptaningsari & Rivaie (2021), reported some soybean cultivars results in the formation of a few pink effective nodules.

3.2 Growth Parameters

3.2.1 Plant height (cm)

The result showed that plant height was significantly ($p<0.01$) affected by Brady rhizobium inoculation (Table 2). The maximum plant height (66.47cm) and the minimum plant height (60.99 cm) obtained from inoculated and non-inoculated plots respectively (Table 2). This growth increment in the inoculated plot might be due to, *Bradyrhizobium* inoculation promoted availability of nitrogen and initiate growth circumstances of plants. In conformity with this finding, Dabesa & Tana (2021); Tarekegn & Kibret (2017); Ntambo *et al.,* (2017) & Fituma *et al.,* (2017) reported that seed inoculation resulted in a significant increase in plant height. Similarly, Mosupiemang *et al*., (2021) stated that *Bradyrhizobium japonicum* inoculation had a substantial impact on soybean plant height compared to the un-inoculated treatments.

Plant height also significantly ($p<0.01$) differ among soybean varieties. The longest plant height recorded from Awassa-04 (81.78 cm) and the shortest plant height obtained from Awassa-95 (54.66 cm) (Table 2). Crops compete with other crops and weeds for light and other growth resources. Plant height is an important plant genetic attribute for outcompeting weeds and shading them. This result was in agreement with that of. (Adeyeye (2017); Tefera (2011); Anwar *et al.*, (2010) & Mahamood *et al*., (2009) who reported that plant height was significantly different among soybean genotype. According to Getnet (2019) the height differences were reported even within the same maturity groups.

3.2.2 Canopy Spread (cm)

In this study both inoculation and variety had a significant influence on canopy spread ($P<0.01$), although their interaction did not show a significant effect. The maximum canopy spread of 36.81 cm was recorded in the inoculated plots, while the minimum canopy spread of 34.56 cm was observed in the non-inoculated plots (Table 2).

Table 2: Effect of soybean varieties and Inoculation on growth parameters

Varieties	Growth parameters		
	CS	**PH**	**NPB**
Awassa-95	35.50^{bc}	54.66^{c}	4.41^{b}
Nyala	35.83^{b}	55.66^{c}	4.49^{b}
Nova	34.50^{bcd}	72.64^{b}	5.57^{a}
Awassa-04	39.50^{a}	81.78^{a}	5.60^{a}
Gozella	33.16^{c}	55.83^{c}	5.43^{a}
Afgat	32.25^{d}	55.66^{c}	4.62^{b}
Pawe-2	39.00^{a}	69.86^{b}	5.32^{a}
LSD (0.05)	2.52	6.38	0.29
Inoculation			
Non- inoculated	34.56^{b}	60.99^{b}	4.98^{b}
Inoculated	36.81^{a}	66.471^{a}	5.18^{a}
LSD (0.05) 1.35 3.41 0.16			
CV (%) 5.96 8.44 4.95			

Mean values with in column followed by the same letters in superscript are not significantly different. CS = canopy spread, PH = Plant height, NPB= Number of primary branches, CV (%) = Coefficient of variation; LSD (0.05) = least significant difference at 5% levels of significance.

This difference in canopy spread can be attributed to the promotion of leaf canopy growth through inoculation. The rate at which a plant canopy develops and closes is of great agronomic importance. A closed plant canopy has several advantages, including increased absorption of solar radiation, reduced nutrient loss due to soil erosion, suppression of young weeds, and prevention of weed seed germination. Therefore, the observed increase in canopy spread in the inoculated plants can be attributed to the enhanced shoot growth stimulated by the inoculation treatment. Similar findings were reported by Lamptey *et al.,* (2014), who observed an increase in canopy cover in inoculated plants. This further indicates that, inoculation promotes the growth and development of the plant canopy.

The tested soybean varieties were vary significantly in relation to canopy spread (Table 2). The result of this study indicated that maximum (39.50cm) canopy spread was recorded for soybean variety Awassa -04 and the minimum (32.25cm) from soybean variety Afgat. This significant difference among the varieties might be due to the existence of genetic difference among varieties. According to Desissa (2019) canopy coverage is one of important genetic trait of soybean varieties that helps to regulate soil fertility.

3.2.3 Number of primary branches

The analysis of variance revealed that both inoculation and soybean varieties had a significant impact on the number of primary branches ($P<0.05$), however, their interaction did not show a significant effect. The highest number of primary branches per plant (5.18) was observed in plants inoculated with *Bradyrhizobium japonicum,* while the lowest number (4.98) was recorded in the non-inoculated treatments (Table 2). This increase in the number of primary branches could be attributed to the inoculation of seeds with *Bradyrhizobium japonicum*, which enhances nitrogen availability to the plants and promotes vegetative growth and branching. These findings are consistent with the research conducted by Fikadu *et al*., (2022) and Dabesa & Tana (2021), who also obtained a higher number of primary branches through the application of *Bradyrhizobium japonicum*.

Furthermore, the analysis of variance demonstrated that the number of primary branches were significantly influenced by the main effect of soybean varieties. The maximum number of primary branches (5.60) was obtained from Awassa-04, which was statistically similar to the varieties Nova, Gozella, and Pawe-2. Conversely, the minimum number of primary branches (4.41) was observed in the variety Awassa-95, which was statistically similar to Nyala and Afgat (Table 2). These variations in the number of primary branches among the different soybean varieties are likely due to genetic differences among them. These findings are in line with the observations made by Awoke (2022), Adeyeye *et al*., (2017), Sarkodie-Addo & Mahama (2012) who reported significant differences in the number of primary branches among tested soybean varieties.

3.3 Yield and yield related parameters

3.3.1 Number of seed pod^{-1}

The number of seed per pod was significantly influenced by soybean varieties ($P<0.01$), but there was no significant difference in the number of seed per pod due to inoculation as well as the interaction between inoculation and varieties.

This suggests that the control of seed per pod formation is primarily determined by the genetic makeup of the plant. These findings align with the results reported by Patra *et al*., (2012), who observed that *Rhizobium* inoculation had no significant effect on the number of seeds per pod in different genotypes of soybean. Similarly, Yoseph & Worku (2014) and Jarecki (2023) also reported that the number of seeds per pod was not altered by *Bradyrhizobium japonicum* inoculation.

The mean separation result has indicated that variety Gozella recorded significantly the highest (2.84) number of seed pod^{-1}, while variety Nova recorded the lowest (2.20) number of seed pod^{-1}(Table 3). In line with this, Yeshitila *et al.*, (2022) reported the highest number of seed per pod (2.69) from variety Awassa-04 and the lowest (2.35) number of seed per pod from variety Gozella. This suggests that different varieties have different genetic makeups that result in differences in the number of seeds per pod.

Table 3: Effect of soybean varieties and Inoculation on yield related parameters

Variety	NSP	SW
Awassa-95	2.67^{a}	178.36^{c}
Nyala	2.72^{a}	207.97^{a}
Nova	2.20^{b}	144.95^{d}
Awassa-04	2.71^{a}	196.90^{ab}
Gozella	2.84^{a}	187.52^{bc}
Afgat	2.7^{a}	179.03^{c}
Pawe-2	2.75^{a}	183.38^{c}
LSD(0.05)	0.19	13.03
Inoculation		
Un-inoculated	2.64^{a}	178.45^{b}
Inoculated	2.68^{a}	186.72^{a}
LSD(0.05)	0.10	6.96
CV (%)	6.07	6.02

Mean values with in column followed by the same letters in superscript are not significantly different at P<0.05 level of significance. TAGB =Total above-ground biomass yield, NSP=Number of seed pod^{-1}, HI=Harvest index, SW=1000 seed weight, LSD (0.05)= Least significant difference at 5%; CV(%) = Coefficient of variation.

3.3.2 1000 seed weight

Analysis of variance indicated that 1000 seed weight significantly (P<0.05) affected by inoculation and varieties, but their interaction had no significant effect.

The maximum (186.72g) of 1000 seed weight was recorded from inoculated treatments, while the minimum (178.45g) obtained from non-inoculated treatments (Table 3). Thousand seeds weight is also an important yield component which reflects the magnitude of seed development which ultimately reflects the final yield of a crop.

This could be improved due to the significant contribution of N_2 fixation, which supplied additional N for the crop as N is a major constituent of amino acids and many biological compounds that play important roles in photosynthesis and ultimately increase seed weight. Consistence with this finding, Fituma *et al*., (2018) reported the highest 100-seeds weight (22 g) in *Bradyrhizobium*, whereas the lowest 100-seeds weight (16.9 g) was recorded the un-inoculated treatment.

Similarly, Zimmer *et al.*, (2016) reported that inoculation of soybeans increased 1000 seed weight by 20% over non-inoculated treatments. Solomon *et al*., (2012) observed the highest (216.39g) 1000 seed weight from *Bradyrhizobium* inoculated treatments and the lowest (190.5g) 1000 seed weight from non-inoculated treatments. Tairo and Ndakidemisi (2013) reported that *Rhizobium* inoculation significantly increased 1000 weight of soybean by 91%. Similarly, Nyoki & Ndakidemi (2014) observed significant improvement in seed weight due to inoculation in sorghum soybean intercropping system.

Regarding varieties, the analysis revealed that the 1000-seed weight was significantly influenced by soybean varieties. The highest value of 1000-seed weight (207.97g) was recorded in the variety Nyala, which was statistically similar to Awassa-04, while the lowest value (144.95g) was observed in the variety Nova (Table 3). This variation in 1000-seed weight can be attributed to the different genetic make-ups of the soybean varieties. These findings are consistent with the research conducted by Sileshi *et al*., (2022), who reported the highest hundred seed weight (21.33g) in the variety Nyala, while the lowest (11.3g) was recorded in the variety Gishama. Similarly, Solomon *et al*., (2012) found that the variety Jalele had the highest recorded 1000-seed weight (212.81g), while the variety Ethio-Yugoslavia had the lowest (181.41g).

3.3.3 Grain yield (kg ha^{-1})

The analysis of variance revealed that both the soybean variety and inoculation had a significant effect on grain yield (p<0.01), and their interaction also had a significant impact (p<0.05) (Table 4).

Similarly, Zimmer *et al*., (2016) observed that grain yield in soybean was significantly influenced by inoculation, variety, and their interaction. Grain yield is a complex trait that represents the final outcome of various growth and developmental processes, influenced by multiple yield components.

The highest grain yield (2017.50 kg/ha) was obtained from the combination of Awassa-04 variety with *Bradyrhizobium japonicum* inoculation, Awassa-04 without inoculation also gave the second highest grain yield (1710.6 kg/ha) which is superior to all other tested varieties both at under inoculation and without inoculation while the lowest yield (465.75 kg/ha) was recorded in the Pawe-2 variety without *Bradyrhizobium japonicum* inoculation. These findings indicate a favorable compatibility between the soybean varieties and the *Bradyrhizobium* inoculant. It suggests that sufficient assimilates were translocate from the vegetative parts of the plant to the developing seeds, resulting in higher grain yield.

Table 4: Interaction effects of varieties and Inoculation on number of pod plant^{-1} and grain yield of soybean

Variety	**Number of pod plant^{-1}**		**Grain yield (kg ha^{-1})**	
	Inoculated	**Non-Inoculated**	**Inoculated**	**Non-inoculated**
Awassa-95	48.83^{bc}	44.33^{de}	1583.30^{b}	1151.80^{e}
Nyala	44.76^{cde}	42.50^{e}	1543.90^{c}	1133.00^{e}
Nova	49.86^{b}	47.33^{bcd}	1272.00^{d}	849.10^{f}
Awassa-04	59.01^{a}	51.33^{b}	2017.50^{a}	1710.60^{b}
Gozella	35.33^{f}	37.02^{f}	1141.90^{e}	857.10^{f}
Afgat	21.00^{g}	19.33^{g}	773.4^{fg}	511.7^{h}
Pawe-2	19.66^{g}	18.96^{g}	680.3^{g}	465.70^{h}
LSD (0.05)	4.33		**96.72**	
CV (%)	6.71		**5.14**	

Mean values with in column followed by the same letters in superscript are not significantly different at P<0.05 level of significance. LSD (0.05) = Least significance difference at 5(%) level of significance; CV (%) = Coefficient of variation.

Consistent with the present findings Anwar *et al*., (2010) reported the highest seed yield (2608 kg/ha) when soybean variety G-2 was combined with a *Bradyrhizobium* inoculant, which is the positive interaction between variety and inoculation. Zimmer *et al*., (2016) observed that inoculated soybean seeds had an average grain yield increase of 57% compared to non-inoculated seeds. Similarly, studies by Janagard *et al*., (2013) demonstrated that soybean seeds inoculated with *Bradyrhizobium japonicum* yielded significantly higher grain yields, with a 33% increase compared to chemical fertilizer application. Fikadu *et al*. (2022) also found that the use of *Bradyrhizobium japonicum* (TAL-379) significantly increased soybean yields compared to non-inoculated treatments and nitrogen fertilizer. Additionally, Anbessa *et al*., (2022) observed that Rhizobium inoculation of soybean seeds significantly improved grain yield.

3.3.4 Total above-ground dry biomass (kg/ha)

Analysis of variance result indicated that the total above-ground dry biomass of soybean was significantly (P< 0.01) affected by varieties and inoculation, but their interaction had no significant effect (Table 5).

This was justified with the finding of Solomon *et al*., (2012) who reported dry matter production and nitrogen uptake at mid flowering stage were significantly affected by the main effects of both variety and inoculation.

Furthermore, the maximum dry biomass yield (9808.30 kg ha^{-1}) was produced from a treatment that inoculated with *Bradyrhizobium japonicum* and the minimum dry biomass yield (7668.80 kg ha^{-1}) was recorded from non-inoculated treatment (Table 5). The result of this study indicated that nitrogen fixation by *Bradyrhizobium japonicum* enhanced the vegetative growth of soybean, which resulted in substantial increase in its biomass yield, which in turn to enhance high dry matter production. Consistence with this findings Fitsum *et al.*, (2018) obtained highest (2804.7 kg ha^{-1}) biomass yield from inoculated treatment. Tarekegn and Kibret (2017) also reported the inoculation of soybean seeds with *Bradyrhizobium japonicum* alone resulted in a 12.8% increase in mean plant biomass per plant when compared to the un- inoculated treatment. According to Fikadu *et al.*, (2022) *Bradyrhizobium* bio fertilizer significantly enhanced the above-ground dry biomass yield (10700kg/ha) of soybean over non-fertilized (7659kg/ha) and chemical fertilizer (10662/ha) treatment. They also reported treatment with *Bradyrhizobial japonicum* (TAL-379) and bio fertilizer gave additional 47kg/ha weight of biomass yield over chemical fertilizer. Similarly, Solomon *et al.*, (2012) said an increased above-ground dry biomass was observed with treatment of *Rhizobium* inoculation of TAL-379 strain. In the same manner, Anwar *et al.*, (2010) reported inoculated treatments produced significantly higher total dry matter weights over control treatments.

Concerning the varieties, the maximum (12372.25 kg ha^{-1}) total above-ground dry biomass was obtained from variety Awassa-04 and the minimum (7423.75kg ha^{-1}) from Nyala (Table 9). This could be attributed to the existence of genetic diversity among soybean cultivars to produce biomass yield. In agreement to this finding, Thuita *et al*., (2012) reported that the average biomass yields of TGx1740-2F variety (16 g $plant^{-1}$) were twice as high as that of Nyala (7.5 g $plant^{-1}$). at the pod formation stage, According to research by Anwar *et al.*, (2010), the PB-1 variety had superior plant dry weight (0.826 g/plant) at seedling stage and 5.39 g/plant at 50% flowering stage compared to other varieties. Adeyeye *et al.*, (2017) reported similar results, indicating that genotypic differences had a significant impact on the dry weight of the stem, leaves, roots, and pods.

3.3.5 Harvest index (HI)

Analysis of variance revealed that harvest index was significantly influenced (P<0.05) by inoculation and (p<0.01) affected by the main effect of variety, but their interaction had no significant effect (Table 5).

The maximum (14.20%) harvest index was obtained from the inoculated treatment, whereas the minimum (12.72%) was from the non-inoculated treatment (Table 6). This might be due to influence of inoculation on vegetative growth than nutrient translocation from plant biomass. The increased harvest index with inoculation of *Bradyrhizobium* strains also implies higher partitioning of dry matter into grain. Concurring to this finding, Dabesa & Tana (2021), reported that inoculation had a significant impact on the soybean harvest index, inoculation with *Bradyrhizobium* strains improving the harvest index by 41%. According to Yoseph & Worku (2014) inoculation greatly affects harvest index. They reported lower (0.41) and higher (0.54) harvest index, from non-inoculated and inoculated treatments respectively. Similarly, Chimdi *et al.*, (2022) obtained the highest harvest index on faba bean by using *Rhizobium* strain.

Table 5: Effects of varieties and inoculation on total above-ground dry biomass and harvest index (HI) of soybean

Variety	TAGB	HI
Awassa-95	7629.11[d]	0.18[a]
Nyala	7423.75[d]	0.17[a]
Nova	7901.80[cd]	0.13[b]
Awassa-04	12372.25 [a]	0.13[b]
Gozella	8451.42[bc]	0.12[b]
Afgat	7763.50[cd]	0.09[c]
Pawe-2	8451.35[bc]	0.07[c]
LSD(0.05)	**725.41**	**0.02**
Inoculation		
Un-inoculated	7668.80[b]	0.12[b]
Inoculated	9808.30[a]	0.14[a]
LSD(0.05)	**387.75**	**0.01**
CV (%)	**6.99**	**15.98**

Mean values with in column followed by the same letters in superscript are not significantly different at P<0.05 level of significance. TAGB =Total above-ground biomass yield, HI=Harvest index, LSD (0.05) = Least significant difference at 5%; CV(%) = Coefficient of variation.

In relation to variety, the maximum harvest index (18%) was recorded from variety Awassa-95 which was statistically no significant different from Nyala, while the minimum harvest index from (7%) was recorded from pawe-2 which was statistically similar with variety Afgat (Table 5). This might be due to existence of genetic variations to translocate nutrient from vegetative part to sink. In line with this finding, Yeshitila *et al*., (2022) found that the soybean variety Nova had the greatest harvest index (0.55) while the variety Gazolia had the lowest harvest index (0.40). Likewise, Alemu (2018) found that the main effect of soybean variety had a highly significant effect on the harvest index. Additionally, Solomon *et al*., (2012) found that there were significant differences in the harvest index of different soybean cultivars, with variety Cheri recorded the greatest harvest index (0.26), and variety Jalele recorded the lowest harvest index (0.20).

3.2 Economic Benefit of using Inoculant

The result of the partial budget analysis revealed that inoculation with a *Bradyrhizobium* inoculant produced a highest net benefit and value cost ratio on investment compared to the un-inoculated treatments.

Table 6: Partial budget analysis of inoculant and soybean varieties

Treatments		AGY/ha	AY/ha	IC/ha	GB(ETB)	NB(ETB)	VCR	MRR(%)
Awassa-95	Non-inoculated	1151.8	1036.6	0	62,196	62,196		
	Inoculated	1583.3	1425.0	360	85,500	85,140	64.73	6473
Nyala	Non-inoculated	1133	1019.7	0	61,182	61,182		
	Inoculated	1543.9	1389.5	360	83,370	83,010	61.63	6163
Nova	Non-inoculated	849.1	764.2	0	45,852	45,852		

Treatments		AGY/ha	AY/ha	IC/ha	GB(ETB)	NB(ETB)	VCR	MRR(%)
	Inoculated	1272	1144.8	360	68,688	68,328	63.43	6343
Gozella	Non-inoculated	857.1	771.4	0	46,284	46,284		
	Inoculated	1141.9	1027.7	360	61,662	61,302	42.71	4271
Awassa-04	Non-inoculated	1710.6	1539.5	0	92,370	92,370		
	Inoculated	2017.5	1815.8	360	108,930	108,570	46.05	4605
Afgat	Non-inoculated	511.7	460.5	0	27,630	27,630		
	Inoculated	773.4	696.0	360	41760	41,400	39.25	3925
Pawe-2	Non-inoculated	465.7	420.1	0	25,206	25,206		
	Inoculated	680.3	612.3	360		36,738	32.03	3203

AGY=Average grain yield, AY=Adjusted grain yield, IC=Inoculant cost (kg), NB=Net benefit, GB=Growth benefit, VCR=Value cost ratio, MRR (%) =Marginal rate of return, Out put price of soybean grain 60 ETB/Kg, Inoculum applied 2kg/ha.

The result of net benefit (NB) analysis indicated that Awassa-04 significantly the highest yielding variety. The combination of Awassa-04 variety (with and without *Bradrhizobium japonicum*) produced the highest net benefits (108,588 Birr/ha and 92,370 Birr/ha) respectively, compared with other soybean varieties. On the other hand, pawe-2 without *Bradyrhizobium japonicium* inoculation produced the lowest net benefit (25,206 Birr/ ha) (Table 6). The yield difference resulting from *Bradyrhizobium japonicum* inoculation was observed to be smaller in the Awassa-04 variety (276.3 kg/ha) compared to the Awassa-95 (388.4 kg/ha), Nova (380.6 kg/ha), and Nyala (369 kg/ha) varieties with the same inoculation (Table 6). Similarly, Anbessa *et al.*, (2022) obtained the highest net benefit of 41644.4 ETB/ ha by using 500 g/ ha bio fertilizer. Yoseph and Worku (2014) have also reported the highest net benefit of 5851.88 ETB/ha from inoculated treatment and the lowest net benefit of 4827.47 ETB/ha from non-inoculated treatments.

According to the value-to-cost ratio (VCR), Awass-95(6473%) had the highest economic net return on investment, followed by Nova (6343%) and Nyala (6163%) (Table 6). On the other hand, pawe-2 with *Bradyrhizobium japonicum* inoculation produced the lowest marginal rate of return (3203%) (Table 6). This result is consistent with the findings of Akley (2019), who found that the soybean variety Afayak with *Bradyrhizobium* had the highest value-to-cost ratio (VCR) and the soybean variety Songda with *Bradyrhizobium* inoculation had the lowest value-to-cost ratio (VCR). According to Geleta & Bekele *(*2022) the highest economic return was obtained from *Rhizobium* inoculation with organic and inorganic fertilizer.

4. CONCULISION

Results of analysis of variance indicated that nodulation, growth, yield and yield components of soybean varieties were significantly affected due to Bradyrhizobium japonicum inoculation. Therefore, it conclude that the combination of Awassa-04 with *Bradyrhizobium japonicum* inoculation resulted in the highest grain yield of 2017.50 kg/ha. The combination of Awassa-95 with *Bradyrhizobium japonicum* also gave the highest marginal rate of return, followed by Nova with *Bradyrhizobium japonicum* and Nyala with *Bradyrhizobium japonicum* inoculation, respectively.

Compliance with ethical standards

Acknowledgments

I would like to thank Southern Agricultural Research institute for financial support. My gratitude also goes to Jinka and Awassa Agricultural Research center for providing Soybean seeds to this research work.

Disclosure of Conflict of Interest: The authors have not declared any conflict of interest.

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