CULTIVARS RESPONSE TO *RHIZOBIUM* AND PHOSPHORUS SOLUBILISING BACTERIA FOR NODULATION, GROWTH AND YIELD IN GARDEN PEA (*Pisum sativum* var. *hortense*)

By

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(J-18-M-591)

Thesis submitted to Faculty of Postgraduate Studies
in partial fulfillment of requirements
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M.Sc.

CULTIVARS RESPONSE TO *RHIZOBIUM* AND PHOSPHORUS SOLUBILISING BACTERIA FOR NODULATION, GROWTH AND YIELD IN GARDEN PEA (*Pisum sativum* var. *hortense*)

Verinder Kour

2021

CERTIFICATE-I

This is to certify that the thesis entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)"** submitted in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture Horticulture (Vegetable Science)** to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is a record of bonafide research carried out by **Ms. Verinder Kour (Registration No. J-18-M- 591)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that all the help and assistance received during the course of investigation have been duly acknowledged.

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We, the members of the Advisory Committee of **Ms. Verinder Kour (Registration No. J-18-M-591)**, a candidate for the degree of **Master of Science in Agriculture Horticulture (Vegetable Science)** have gone through the manuscript of the thesis entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)"** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the degree.

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This is to certify that the thesis entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*) "submitted** by **Ms. Verinder Kour**, Registration No. **J-18-M-591** to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, in partial fulfillment of the requirements for the degree of Master of Science in Agriculture Horticulture (Vegetable Science) was examined and approved by the Advisory Committee and External Examiner on **26.03.2021.**

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To err is human, I solely claim the responsibility for the shortcomings and limitations in this work.

Verinder Kour.

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Place: Jammu

Date: _____

ABSTRACT

Title of Thesis	:	**Cultivars Response to *Rhizobium* and Phosphorus Solubilizing Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)**
Name of Student	:	**Verinder Kour**
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Major Advisor	:	**Dr. Sandeep Chopra**
Degree to be awarded	:	M.Sc. Agriculture Horticulture (Vegetable Science)
Year of award of degree	:	2021
Name of University	:	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu

The present investigation entitled "**Cultivars Response to *Rhizobium* and Phosphorus Solubilizing Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)**" was conducted during the year 2019-20 with the objectives (i) Effect of *Rhizobium* and PSB on nodulation ability of garden pea cultivars (ii) To study yield response of different garden pea cultivars under co-inoculation of *Rhizobium* and PSB (iii) To study nitrogen and phosphorus uptake in different garden pea cultivars. The experiment was laid in Split-Split Plot Design. The main plot consisted of five pea cultivars, i.e., P-89, AP-3, Bonneville, Arka Karthik and Arka Apoorva. The sub plot contained Rhizobium inoculation, and the sub-sub plot contained PSB inoculations. Each variety had 4 treatments, i.e. uninoculated control, *Rhizobium*, PSB and *Rhizobium* + PSB. With respect to growth and yield parameters, minimum days to 50% flowering was recorded in AP-3. Maximum plant height was in Arka Apoorva (109.93 cm). Cultivar P-89 had maximum leaf area index (0.59) and maximum shelling percentage (51.01 %). This cultivar was found superior among all the yield parameters, i.e., pod weight (7.34 g), number of pods per plant (41.99) and green pod yield (126.75 q/ha), while Arka Apoorva showed poor performance in yield parameters among all the varieties. Among the inoculation treatments, *Rhizobium* and PSB inoculations was found to be significant.

Among the quality parameters, Bonneville pods yielded maximum TSS content (16.90 ^{0}Brix), and maximum dry matter content was recorded in AP-3 (23.60%). In the nodulation studies, P-89 recorded highest number of nodules per plant (75.56). The highest uptake of both nitrogen and phosphorus was also recorded in variety P-89. However, it was noted that in all the parameters recorded above, the dual inoculation of *Rhizobium* + PSB found superior than single inoculation and uninoculated control.

Key words: Garden pea, *Rhizobium*, PSB, Varieties, Nodulation.

Signature of Major Advisor

Verinder Kour

Signature of Student

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ABBERIVIATIONS

%	Percentage
/	Per
@	At the rate of
^{0}C	Degree Celsius
CD	Critical difference
cm	Centimetre
d.f.	Degree of freedom
DAS	Days after sowing
df	Degrees of freedom
dS/m	Deci siemens per metre
EC	Electrical conductivity
et al.	et alia (Co-workers)
etc.	Etcetera
Fig.	Figure
g	Gram
ha	Hactare
i.e.	(id. Est.) That is
K	Potassium
kg	Kilo gram
kg /ha	Kilogram per hectare
m	Metre
m^2	Square metre
Max	Maximum
mg	Milligram
Min	Minimum
mm	Millimetre
MSS	Mean sum of squares
MT	Metric tonnes
N	Nitrogen
No.	Number
NPK	Nitrogen, Phosphorus and Potassium
NS	Non-significant
P	Phosphorus
pH	Potential of Hydrogen
PSB	Phosphate solubilizing bacteria
q/ha	Quintals per hactare
RDF	Recommended Dose of Fertilizers
RH	Relative Humidity
SEm+	Standard error of mean
SS	Sum of squares
TSS	Total soluble solids
viz.	videlicet (namely)

Chapter-1

Introduction

CHAPTER- I

INTRODUCTION

Pea (*Pisum sativum* L.) is the most commonly grown leguminous vegetable of the world, belonging to family leguminoceae. It is a widely grown cool season crop of the tropical and sub-tropical regions. Green peas are all time favourite vegetable and are marketed fresh, canned or frozen while the ripe dried peas are used as whole, split or made into flour. It is highly nutritive and contains high percentage of a digestible protein (25%), essential amino acids and sugars (12%) along with carbohydrates, vitamins and minerals. It is also a rich source of vitamin A, B and C. In India it was grown on an area of 540 thousand hectares with an production of 5422 thousand MT during 2017-18. In Union territory of Jammu & Kashmir, area under peas is 2.38 thousand hectares with its production is 30.82 thousand MT (Anonymous, 2018).

Being a legume crop, vegetable pea is capable to fix atmospheric nitrogen symbiotically in its nodules on the roots by a specific rhizobial bacterium called *Rhizobium leguminosarum*. These bacteria have special ability to fix nitrogen from atmospheric, molecular nitrogen (N_2) into ammonia (NH_3). Ammonia is then converted to another form, ammonium (NH_4^+). The root nodules of peas are the sources of nitrogen that they can use to make amino acids, a constituent of proteins. Hence, legumes are good sources of plant protein.

The nodulation in legumes plays an important role in the fixation of atmospheric nitrogen. Since nitrogen fixation is dependent on the formation and maintenance of nodules; hence, the degree of nodulation in legumes is used as a measure of symbiotic activity. The legume-rhizobia symbiosis actively fixes nitrogen and is quite important for agriculture crop production (Pepper, 2000) .

Peas form an extremely distinctive relationship with its rhizobial micro-symbiont (Ahemad & Khan, 2010). Peas are able to fix most of the required nitrogen from environment in the presence of *rhizobia* and not only to support its own growth without nitrogen fertilizer application but also spare some of its biologically fixed N in the soil for subsequent crop (Shah *et al.*, 2003). Thus, they also enhances the

growth and productivity of subsequent crops through improvement in the fertility status of the soil.

The association between legume crop and *Rhizobium* bacteria can supply 80-90 per cent of the total N requirement of the crop and increased the grain yields by 10-15 per cent following the inoculation (Tilak and Singh, 1994). It has been observed that seed inoculation with effective *Rhizobium* improves nodulation as well as crop yield (Sharma *et al.*, 1999).It also tends to improve the root architecture of pea through their potential of colonization and nitrogen fixing ability.

Phosphorus, second only to nitrogen, is a vital nutrient for plants. It is an important constituent of nucleic acid, phospholipids, coenzymes, NAD, NADP, and ATP, etc. Only about 25-30 percent of the applied phosphorus becomes available to the crop in a year of its application and remaining portion gets converted into insoluble unavailable forms. The phosphorus solubilizing bacteria (*PSB*) provides a solution for sustaining the provision of available phosphorus to plants as they are able to convert both organically and in organically bounded forms of phosphorus (Chen *et al.*, 2002). The inoculation of Phosphorus solubilizing microorganisms in the rhizosphere of crop and soil increases the availability of P from insoluble sources of phosphate, desorption of fixed phosphates and also increases the efficiency of phosphatic fertilizers (Gaur, 1991; De and Singh 2010).The inoculated phosphate solubilizing bacteria secrete acidic substances and solubilize unavailable soil phosphorus and make available to plants. The phosphate solubilizing bacteria (PSB), phosphate solubilizing fungi (PSF) and actinomycetes have been reported to be effective in transformation of fixed phosphorus to available forms of phosphorus by many investigators (Chabot *et al.*,1996; Pal, 1998).

However, the combined inoculation of *PSB* and nitrogen fixing bacteria could be more efficient for supplying a more balanced nutrition for the pea plants (Belimov *et al.*, 1995). In this perspective, the combined application of *Rhizobium* and PSM (Perveen *et al.*, 2002) have been reported to enhance growth of plants more than individual inoculation of microbes in certain conditions when the soil have inadequate phosphorus. Hence, Co-inoculation of *Rhizobium* and phosphorus solubilizing bacteria (PSB) strain can further improve the nutrient availability to pea plants.

In case of peas (*Pisum sativum*) both the variety and nutrient management plays a significant role in influencing the quantity and quality of the crop. (Singh *et al.*, 2005). Further more, due to inherent differences among different varieties with respect to particular requirement, it would not be feasible to extend such recommendations to all the varieties.

Considering the facts and views highlighted above, the present field experiment entitles "**Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)**" was planned with the following objectives:

1. Effect of *Rhizobium* and PSB on nodulation ability of garden pea cultivars
2. To study yield response of different garden pea cultivars under co-inoculation of *Rhizobium* and PSB
3. To study nitrogen and phosphorus uptake in different garden pea cultivars

Chapter-2

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

In this chapter, an attempt has been made to review the important and relevant research work done by various scientist in the past throughout the world concerning related to the effect of *Rhizobium* and PSB on various cultivars of pea. A brief summary of research work related to the aspects have been highlighted and reviewed under the following broad topics.

2.1 Effect of *Rhizobium* and PSB on growth and yield parameters

2.2 Effect of *Rhizobium* and PSB on nodulation studies

2.3 Effect of *Rhizobium* and PSB on uptake studies

2.1 Effect of *Rhizobium* and PSB on growth and yield parameters

Shamad *et al.* (2019) conducted an experiment on "Effect of phosphorus levels and *Rhizobium* culture on growth, yield and quality of early varieties of Garden pea (*Pisum sativum* L.)" at the Horticulture Research Farm, A.K.S University, Satna (M.P). Interactive use of Jawahar matar-3 + with *Rhizobium* inoculation produced a large quantity of pod yield i.e., 48.50 q/ha which was significantly better than rest of the combinations. Shelling percent was found to be significantly more and it was 43.68% due to individual use of phosphorus @ 60kg P_2O_5/ha respectively.

Bhutia *et al.* (2019) conducted the study on edible Podded Pea (*Pisum sativum* var. *macrocarpon*) var. Arka Apoorva at CAU, Pasighat, Arunachal Pradesh. Application of organic manures along with biofertilizers and wood ash increased the growth and yield of edible podded pea. The outcome uncovered that the application of vermi bonemeal @ 5t/ha, *Rhizobium*, PSB and wood ash @ 0.5t/ha demonstrated significantly higher plant height, root length, fresh and dry shoot and root weight, no. of pods/plant, pod length, pod weight/plant and pod yield/ha. The minimum days taken to 50% flowering and fruiting as well node at which first flowering was recorded with vermi bonemeal @ 5t/ha, *Rhizobium*, PSB and wood ash @ 0.5t/ha.

Bunker *et al.* (2018) conducted a field experiment at Instructional Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner. The treatment 20 Kg/ha N + 40 kg/ha P + *Rhizobium* + PSB showed

significant increase in the growth and yield attributes as compared to control but statistically at par with 20kg/ha N + 40 kg/ha P + *Rhizobium* and 20 kg/ha N + 40 kg/ha P + PSB.

Ade *et al.* (2018) conducted a study on pigeon pea and found that the dual seed inoculation with *Rhizobium* + PSB was recorded higher growth and yield attributes than the individual seed inoculation of *Rhizobium* or PSB. Similarly, Chauhan and Umrao (2017) conducted an experiment to study the effect of different levels of NPK in combination with *Rhizobium* and PSB culture on growth of green gram .The result revealed that during summer season green gram cultivar of cv. HUM-16 performed best fertilized with (T7- 30-30-15 kg NPK/ha) with dual seed inoculation of *Rhizobium* and PSB culture.

Lakshmipathy *et al.* (2017) evaluated the influence of *Rhizobium* and phosphate solubilising bacteria (PSB) on the growth and yield of cluster bean. Inoculation of *Rhizobium* and PSB enhanced the plant growth and yield over un-inoculated control. This study clearly showed that cluster bean growth and yield can be enhanced by the inoculation of *Rhizobium* and PSB along with FYM and 75 percent RDF and can save the cost on 25 percent chemical fertilizer.

Nissa *et al*. (2017) conducted field experiments during Kharif season for the two consecutive years at the crop research farm, Department of soil science, RRS Wadura, Sopore, SKUAST-K to study the effect of PSB, *Rhizobium* and different levels of phosphorus on growth, nutrient uptake, yield of green gram (*Vigna radiata* L) and soil properties. The combined application of phosphorus @ 60 kg/ha and *Rhizobium* resulted in significant higher plant height (cm), seed yield (qt/ha), available N, P and K in soil. It gave highest yield (14.39 q/ha).

Heisnam *et al*. (2017) carried out an investigation to study the effects of *Rhizobium,* PSB inoculation and phosphorus management on soil nutrient status and performance of cowpea at College of Horticulture and Forestry, CAU, Pasighat during *pre-kharif* seasons of 2017. The present study shows the effects of *Rhizobium,* PSB in single and dual combination with or without P_2O_5 on cowpea. The results of these experiment reveals that duel inoculation with fertilizer (P_2O_5) significantly increase plant growth parameters *viz.* Plant height, yield attributes, green pod yield, soil available N, P, K status and root nodulation. It is concluded duel inoculation along

with P2O5 fertilizer (PSB + *Rhizobium* + 40 kg P2O5) is 34 % better than duel inoculation without phosphatic fertilizer for improving pod yield of cowpea.

Abid *et al.* (2016) evaluated the response of peas to *Rhizobium* and PSB inoculation individually and together at 20 and 40 mg kg^{-1} phosphorus (P) application *in-vitro* and pot culture experiment. The co-inoculation of *Rhizobium* + PSB at 40 mg P kg-1 soil significantly increased number of pods per plant, and nodules per plant, 100 grain weight and number of grains per pod. Further results showed that co-inoculation at 20 and 40 mg kg^{-1} P application can improve the nodulation, growth parameters, yield and nutrient concentrations and uptake.

A experiment was conducted by Teli(2016)at Horticulture farm of Rajasthan College of Agriculture, Udaipur (Rajasthan) to study the effect of phosphorus and bio-fertilizers on yield and quality of pea. Results revealed that seed inoculation with PSB + *Rhizobium* significantly increased the plant height (74.13cm), fresh weight per pod (6.75g), green pod yield (5.51 kg plot-1 and 91.91 q/ha). The combined application of 100 per cent RDP with PSB + *Rhizobium* as seed inoculation proved to be effective treatment combination in terms of green pod yield (6.28 kg/plot and 104.74 q/ha), grain yield (37.59 q/ha)

Kant *et al.* (2016) reported the increase the growth and yield attributes viz, plant height, number of branches/plant, nodulation, dry matter accumulation/plant, number of pods per plant, test weight (g), grain yield, straw yield and biological yield (q/ha) of Urd bean. All these characters were recorded higher in treatment by application of (75 kg/ ha P_2O_5 + PSB + *Rhizobium*.) as compared to all other treatments. However, combination of *Rhizobium*, PSB and P levels had proved significant influence on plant growth, yield and its attributing traits in Black gram.

Das *et al.* (2015) studied the synergistic effects of *Rhizobium* inoculation along with phosphorus and molybdenum fertilizers on root nodulation as well as on growth and yield of garden pea. The highest plant height (79.40cm) was found from 0.5 kg Mo, 80 kg P/ha &*Rhizobium* inoculation. The significantly higher number of pods per plant (108.16), pod weight (9.34 g) and yield/ha (13.90 ton/ha) were found when the plants were provided with *Rhizobium* inoculation along with P @ 40 kg/ha and Mo @ 0.5 kg/ha.

Rana *et al*. (2014) conducted experiment at CSKHPKV, Palampur during *Kharif* 2011 to study the effect of phosphorus solubilizing bacteria on the growth attributes and benefit cost ratio in soybean. Results revealed that growth attributes of soybean increased with the application of 60 kg P_2O_5/ha along with *Rhizobium* and phosphorus solubilizing bacteria but found to be at par with the treatment getting 45 kg P_2O_5/ha along with *Rhizobium* and phosphorus solubilizing bacteria.

Tagore *et al.* (2013) reported that the *Rhizobium* + PSB had positive effect in enhancing all the yield attributing parameters in chickpea. The dual inoculation of both *Rhizobium* and PSB significantly increased the plant height, number of pods per plant, number of seeds per pod, over no inoculation. Further, inoculation of *Rhizobium* and PSB alone also enhanced the yield attributing factors when compared with no inoculation.

In studies conducted at SKUAST-J Bhat *et al.* (2013) revealed that among various levels of phosphorus and bio-fertilizers, 100 *percent* recommended dose of phosphorus and dual inoculation of *Rhizobium* + PSB recorded significantly higher values of growth and yield attributes studied of field pea. Among seed inoculation treatments, dual inoculation of *Rhizobium* + PSB produced significantly higher seed yield of 15.01 q ha-1 than inoculation of *Rhizobium* and PSB alone, but significantly superior over control.

Pramanik and Bera (2012) observed that the growth parameters like plant height significantly improved by inoculation with biofertilizers (*Rhizobium*, PSB and VAM) in chickpea (*Cicer arietinum* L.). Yadav and Yadav (2011) revealed that inoculation of garden pea with *Rhizobium* + PSB proved significantly superior over no inoculation with respect to the growth and yield attributes of garden pea. Seed inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB resulted in significantly higher number of pods/plant, grain weight/pod and shellingpercentage and green pod yield over no inoculation. Seedinoculated with *Rhizobium* + PSB increased the green podyield by 16.8, 9.1 and 5.3 percent over control, *Rhizobium* andPSB, respectively.

Kumar (2011) conducted a field experiment on sandy loam soil to study the effect of *Rhizobium* inoculation and phosphorus on growth, nodulation and yield of garden pea (*Pisumsativum* L.) cv. “Mattar Ageta-6”. The results revealed that plant height number of pods per plant, number of seeds per pod and yield of mature green

pods (q/ha) was significantly increased by the application of 120 kg P_2O_5/ha and *Rhizobium* inoculation.

El Nagar *et al.* (2012) revealed that application of 100% and 50% of the recommended dose for both N at (40 and 20 kg N/fed.) and P at (31 and 15.5 kg P2O5/fed.) in the form of combination *Rhizobium* and Phosphorein significantly increased stem length, number of leaves and branches/plant, fresh, dry weight/plant. Also, it showed an increment in number and weight of pods/plant, total green pod yield, average pod length, pod diameter, pod weight, number and weight of seeds/pod, followed by (Rhizo. + Phosp. + 25% of N + P2O5), (Rhizo.+ 100% N), (Rhizo. + 50% N), (Phosp. + 25% P2O5), (Rhizo. +25% N), mineral fertilizers with combination of nitrogen and phosphorus in a recommended levels then bio-fertilizers (*Rhizobium* and Phosphorein) compared to the both seasons.

The combined application of 100% RDF and seed inoculation with *Rhizobium* +PSB +PGPR improved all the growth and yield attributes in field pea (cv. Jai). Fresh and dry weight/plant, nodules number and dry weight/plant were also maximum under Kanpur conditions. The number of grains/pod, number and weight of pods/plant or maturity attributed significantly increasing the grain yield upto 31.00 q/ha and net return upto Rs.26187/ha with the application of 100% RDF and seed inoculation of *Rhizobium* + PSB + PSPR. (Mishra *et al.*, 2010)

Similarly, Rather *et al.* (2010) also reported that the co-inoculation of all the three bio-fertilizers i.e. *Rhizobium, Azotobacter* and PSB produced significantly higher growth characters as compared to absolute control and when inoculated them individually. The treatment comprising of *Rhizobium* +*Azotobacter* + PSB gave highest growth in terms of plant height (45.26 cm) and the yield attributes like pod length, number of pods/ plant, number of seeds/ pod and 1000 grain weight (g) and yield of grain and straw of pea.

Singh and Yadav (2008) conducted a field experiment in Varanasi, Uttar Pradesh on pigeonpea. They concluded that among the biofertilizers, *Rhizobium*+PSB produced significantly taller plants (198.7 cm), dry matter per plant (156.4 g), grain yield (2060 kg/ha), and stalk yield (7560 kg/ha) than other biofertilizers treatments. The combined effect of 60 kg P + *Rhizobium* + PSB produced significantly higher dry

matter (165.8 g/plant), grain yield (2510 kg/ha) than other combinations, except 45 kg P_2O_5 + *Rhizobium* + PSB.

Bahadur *et al.* (2006) conducted an experiment to investigate the effect of organic amendments and bio-fertilizers on growth, yield and quality attributes of garden pea cv. Azad P-3. The treatments comprised of individual application of FYM, in combination with bio-fertilizers *viz.* Azotobacter, PSM, *Rhizobium* and VAM. The results showed that seed inoculation with *Rhizobium* inoculation increased maximum nodulation and root proliferation and pod yield than conventional fertilizer application.

Singh *et al.* (2006) observed that inoculation of *Rhizobium* + VAM + PSB along with 75% NPK recorded significantly higher yield attributes and finally seed yield over each and all treatments in pea. Likewise, Rudresh *et al.* (2005) studied the effect of a combined inoculation of *Rhizobium*, a phosphate solubilizing bacteria and a biocontrol fungus Trichoderma spp. on growth, nutrient uptake and yield of chickpea. Combined inoculation of these three organisms showed increased plant height, pea yield of chickpea compared to either individual inoculations or an uninoculated control. Increased growth and yield parameters were more pronounced when T. harzianum- PDBCTH 10 was inoculated along with the phosphate solubilizing bacterium and *Rhizobium*.

Singh *et al.* (2005) conducted a field experiment for two years with broad bean (*Vicia fabia* L.) at inoculum rates of 10, 20 and 30 g kg-1 seed. The study revealed that seed inoculation with *Rhizobium* @ 30 g kg-1 seed along with 20 kg N ha-1 produced the highest number of nodules per plant, maximum number of pods per plant and seed yield but failed to produce any significant influence on the number of seeds per pod and 100-seed weight.

Patil *et al.* (2004) conducted a field experiment at the Research fields of Agricultural Research Station, Gulbarga on pigeonpea cultivar ICP-8863 (Maruthi) under rainfed conditions. The maximum yield and growth parameters were recorded in the treatment involving RDF 50% + compost 5 tons/ha + dual inoculation of *Rhizobium* and PSB and it was statistically significant over uninoculated control; however the increase over other treatment combination was not significant.

The combined influence of *Rhizobium* and phosphate solubilizing bacteria were studies on peas with the application of two levels of nitrogen (0 and 10 kg ha^{-1}),

five P sources and levels i.e. control, two P sources {single super phosphate (SSP) and mussoorie rock phosphate (MRP)} with two levels of each (30 and 60 kg P_2O_5 ha^{-1}) and five biofertilizer treatments including control, *Rhizobium*, PSB, Compositculture of *Rhizobium* + PSB and single culture of *Rhizobium* and PSB. The highest number of nodules, grain and dry matter yield was recorded with combined inoculation o composit nd single culture of *Rhizobium* and PSB.(Tyagi *et al*., 2003)

Bhattarai *et al.* (2003) observed significant increase in yield due to application of *Rhizobium* + PSB compared with uninoculated control. Rajput and Pandey (2004) at Morena (M.P.) on sandy loam soil observed significantly higher seed yield of pea with application of *Rhizobium* + PSB along with 20 kg FYM or the 50% NPK application.

Results of experiment conducted at Jobner (Rajasthan) on loamy sand soil revealed that cowpea seed inoculated with PSB significantly enhanced the plant height, dry matter and weight of nodules per plant as compared to untreated control (Yadav, 2001).

Vimala and Natarajan (2000) carried out an investigation on pea cv, Bonnevillae under Udhagamandalam condition and observes that application of 2kg each of phosphobacteria and *Rhizobium* with 120 kg N and 80 kg P recorded the highest yield of 3.98 kg/plot (10q/ha) which also showed the highest values for pod length, width, weight and shelling percentage. Similarly, Mathur (2000) also reported that inoculation of mungbean seeds with *Rhizobium* significantly influenced growth attributes namely plant height, dry matter, LAI, nodule number and dry weight compared with uninoculated control.

According to Hungria *et al*. (1991) *Rhizobium* inoculation in combination with phosphorus application increase in pod yield and quality of French bean. Similarly, the pod length, seeds per pod, pod yield and the crude protein content of pea had significantly increased with *Rhizobium* inoculation along with phosphorus application (Phookan and Shadeque, 1994)

Thakur *et al*. (1999) reported that the *Rhizobium* inoculation significantly decreased days to 50% flowering, and increased number of nodules, branches and pods per plant in French bean. Inoculation of cowpea seeds with *Rhizobium* significantly increase the plant height, numbers of effective branches, number and dry weight of nodules per plant over control. (Mishra, 1999)

Patel *et al.* (1998) at Indore, observed that application of *Rhizobium* + PSB + 50 % NPincreased plant height, number of branches, leaves per plant, number of pods per plant, grains per pods and pod yield compared with recommended level of nutrients (20 kg N + 80 kg P2O5 + 40 kg K2O ha-1) appliedthrough chemical fertilizers.

Inoculation of *Rhizobium* + PSB to pea seeds significantly increased he nodule dry weight, CGR and LAI over alone inoculation of *Rhizobium* and PSB whereas, NAR over uninoculated control (Shrivastava *et al.*,1998).The *Rhizobium* inoculation increased the yield of pea over uninoculated control (Kanaujia *et al.*,1997).

Saraf *et al.* (1997) conducted an experiment on chickpea seed inoculation and found that plant height and branches per plant increased significantly due to inoculation of seeds with *Rhizobium* + PSB over uninoculated control. Shukla and Dixit (1996) observed that inoculation of cowpea seed with *Rhizobium* culture significantly increased the plant height, primary branches per plant, leaf area index, net assimilation rate and dry matter accumulation.

Srivastava and Ahlawat (1995) reported that seed inoculation of pea with *Rhizobium* or PSB and the combined inoculation resulted in conspicuous increase in growth and yield parameters, i.e, plant height, number of pods per plant, seed yield over no inoculation. However, the increase was more pronounced with the combined inoculation than with the single ones.

Prasad and Prasad (1993) stated that inoculation of *Rhizobium* to garden pea seeds significantly increased the plant height, number of leaves per plant, fresh and dry weight of plant.

Sarkar *et al.* (1991) observed a significant increase in growth of green gram in terms of plant dry matter and number of branches due to seed inoculation with PSB as compared to without inoculation. Prasad and Maurya (1989) while working on garden pea reported that inoculation of *Rhizobium* resulted in increase in growth and nodulation as compared to the control. Similarly, Dravid (1990) reported increased dry matter yield of pea by inoculation of *Rhizobium*.

Alagawadi and Gaur (1988) examined the interaction of *Rhizobium* and phosphate-solubilizing bacteria (PSB) and its effect on nodulation, nitrogen fixation and yield of chickpea *(Cicerarietinum* L.) with and without fertilizers. The single

inoculation of *Rhizobium* increased the nodulation and nitrogenise activity, the 'phosphate-solubilizers' increased the available phosphorus content of the soil. Combined inoculation of *Rhizobium* and *P. striata* or *B. polymyxa* increased the above parameters and also the dry matter content, the grain yield and nitrogen and phosphorus uptake significantly over the uninoculated control.

2.2 Effect of *Rhizobium* and PSB on nodulation studies

Nissa *et al*. (2017) conducted field experiments at SKUAST-K to study the effect of PSB, *Rhizobium* and different levels of phosphorus on growth, nutrient uptake, yield of green gram (*Vigna radiata* L) and soil properties. The combined application of phosphorus @ 60 kg/ha and *Rhizobium* resulted in significant number of nodules per plant.

An investigation was conducted to study the effects of *Rhizobium*, PSB inoculation and phosphorus management on soil nutrient status and performance of cowpea. The study shows that the application of bio-fertilizer (PSB and *Rhizobium*) along with 40 kg P_2O_5 improves root nodulation and *Rhizobium* population in soil. (Heisnam *et al.,* 2017)

Kant *et al.* (2016) conducted the field experiment in *Kharif* 2011 at Crop Research Centre, Chirori of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (U.P.) India, to evaluate the effect of *Rhizobium*, PSBand P-levels on growth, yield attributes and yield of Urd bean (*Vignamungo* L.). The maximum number of nodules at 30 and 60 DAS was recorded 53.66 and 40.24 in treatment T13 (75 kg P2O5 ha-1 + PSB + *Rhizobium)* respectively, which were superior to rest of the treatments, while minimum number of nodules was recorded in T1 (control).

Rani *et al.* (2016) conducted a study on field pea at HAU, Hisar. They got maximum number of nodules, their fresh and dry weight per plant in RDF + *Rhizobium* +PSB + PGPR.The treatment was at par with treatments RDF+ *Rhizobium* and RDF + *Rhizobium* + PSB at 40 and 60 DAS. Inoculation with *Rhizobium* alone produced significantly higher number and more weight of nodules over control at 40 and 60 DAS. Similarly, Abid *et al*. (2016) reported the co-inoculation of *Rhizobium* + PSB at 40 mg P kg-1 soil significantly increased nodules per plant in peas, thus improves the nodulation in peas.

Das *et al.* (2015) carried out at investigation Horticultural Research Station, Mondouri, Bidhan Chandra KrishiViswavidyalaya, Nadia during the autumn-winter season of 2012-13 and 2013-14, to study the synergistic effectsof *Rhizobium* inoculation (bio-fertilizer) along with phosphorus (macro nutrient) and molybdenum (micronutrient) fertilizers on root nodulation as well as on growth and yield of garden pea. The highest number of nodules were counted as 23.68 nodules per plant, when the plants were applied with *Rhizobium* inoculation along with P @ 40 kg ha-1 and Mo @ 0.5 kg ha-1, whereas the heaviest nodules of 386.08 mg was found from 0.5 kg Mo, 80 kg P ha-1 &*Rhizobium* inoculation.

In chickpea, Tagore *et al.* (2013) reported that the *Rhizobium* + PSB was most effective in terms of nodule number (27.66 nodules plant−1), nodule fresh weight (144.90mg/plant), nodule dry weight (74.30 mg/plant) and leghemoglobin content (2.29 mg/g of fresh nodule) and also showed its positive effect in enhancing all the yield attributing parameters.

Kumar Jitender (2011) conducted a field experiment on garden pea. The results revealed that the application of 120 kg P2O5/ha with *Rhizobium* inoculation significantly increased the number of nodules per plant, fresh weight of nodules per plant and dry weight of nodules per plant followed by 100 kg/ha phosphorus application with *Rhizobium* inoculation of pea seeds. Similarly, Yadav and Yadav (2011) reported that the *Rhizobium* + PSB inoculated seeds significantly increased the total and effective nodules per plant over control and *Rhizobium* inoculation.

Mishra and Prasad (2010) evaluated the effect of pre-sowing inoculation of pea seeds with *Rhizobium*, Phosphate Solubilizing Bacteria and Plant Growth Promoting Rhizobacteria. They reported that the inoculants alone or in combination significantly increased the number of nodules, dry weight of nodules, straw and grain yield over control. Increase in number and dry weight of nodules was also recorded at 30, 45, and 65 DAS. Dual inoculation with *Rhizobium*+ PGPR and *Rhizobium*+ PSB was also found significantly superior over *Rhizobium* alone.

A field experiment was carried out during the *Rabi* season of 2002 on the Research Farm of A.S. (P.G.)College, Lakhoati, Bulandshahr (U.P.). It was reported that the treatment comprising of *Rhizobium* +*Azotobacter* + PSB gave highest number of nodules/ plant (38.46), fresh weight and dry weight of nodules (562.34 mg and

122.62 mg respectively) as compared to absolute control and when inoculated them individually. (Rather *et al.* 2010).

Singh and Yadav (2008) conducted a field experiment at Varanasi (U.P.), and showed that the application of *Rhizobium* + PSB to pigeon pea produced significantly taller plants than all other treatments.

Singh *et al*. (2005) recorded the maximum nodule number and nodule weight when the vegetable pea was treated with pressmud plus *Rhizobium* and PSM inoculums. Superiority in dual inoculation of N and P fixing microorganism compared to single inoculation of *Rhizobium* has been reported.

Rudresh *et al*. (2005) conducted a study on the effect of a combined inoculation of *Rhizobium*, a phosphate solubilizing bacteria and a biocontrol fungus Trichoderma spp. on growth, nutrient uptake and yield of chickpea. It was found that combined inoculation of these three organisms showed increased nodulation of chickpea compared to either individual inoculations or an uninoculated control.

Yadav and Malik (2005) conducted an experiment during kharif season of 1999 at Hisar and observed that highest number of nodules per plant and dry weight of nodules was obtained with *Rhizobium* inoculation in cowpea.

Tyagi *et al.* (2003) conducted a field experiment at the experimental farm of CCS· Haryana Agricultural University, Hisar during *rabi* season 1996-97. Among the various biofertilizer treatments, the maximum number of nodules per plant, maximum fresh and dry weight of nodule in pea were recorded where composit culture of *Rhizobium* + PSB or single inoculum culture of *Rhizobium* and PSB were used.

Wasule *et al.* (2003) conducted a study on soyabean in which he found that the treatment with (*Rhizobium* + PSB) produced highest number of nodules (67.13) per plant. This treatment also gave highest dry weight of nodules(107.73 mg). Further, it was reported that mungbean seeds inoculated with PSB showed significantly high rate of nodulation than no inoculation. (Chatterjee and Bhattacharjee, 2002). Sibbal *et al.* (2002) while working on pea at Ludhiana, observed significant fresh weight and dry weight of nodules per plant by *Rhizobium* inoculation over uninoculated control.

Meena *et al.* (2001) conducted a study at Rajasthan during the Rabi season of 1996-97and revealed that *Rhizobium* + PSB inoculation significantly increased the

number of seeds per pod and pods per plant as well as the seed and straw yields of chickpea. The yield obtained with this treatment was higher with that produced by I*Rhizobium* inoculation, but was at par with the yield obtained with PSB inoculation.

Santalla *et al.* (2001) studied three pea elite cultivars in order to characterize the cultivars' variability in symbiotic characters using two *Rhizobium leguminosarum biovar viceae* commercial strains and the indigenous soil strain, and three N-fertilization rates. Significant differences were observed among pea elite cultivars for the weight and length of plant parts, and the traits associated with N fixation. Pea cultivars showed a significant cultivar±strain interaction for shoot fresh weight and significant differences among strains were found for nodule fresh weight.

According to Thakur *et al.* (1999) *Rhizobium* inoculation significantly increased number of nodules per plant in French bean. Mishra (1999) observed that inoculation of cowpea seeds with *Rhizobium* significantly increase number of nodules per plant and dry weight of nodules per plant over control.

Rana *et al.* (1998) observed that *Rhizobium* inoculation increased root length , nodules per plant along with dry matter and yield in pigeonpea. Srivastava and Ahlawat (1995) observed that the maximum number of nodules per plant and dry weight of nodules was obtained when seed was inoculated with both *Rhizobium* and PSB. Similarly, Mundra and Bhati (1994) reported that seed inoculation with *Rhizobium* significantly enhanced the number of nodules per plant in cowpea, representing an increase of 38.0 per cent over uninoculated control..

Prasad and Prasad (1993) stated that inoculation of *Rhizobium* to garden pea seeds significantly increased dry weight of nodules. However, Sinde and Saraf (1992) stated that inoculation of chickpea seeds with PSB significantly increased the nodulation over no inoculation.

2.3 Effect of *Rhizobium* and PSB on uptake studies

Abid *et al.* (2016) evaluated the response of peas to *Rhizobium* and PSB inoculation individually and together at 20 and 40 mg kg^{-1} phosphorus (P) application *in-vitro* and pot culture experiment. The results showed that plant nutrient uptake i.e. phosphorus and nitrogen content in straw and grain were enhanced by inoculation of *Rhizobium* and phosphate solubilizing bacteria.

Rani *et al.* (2016) conducted a study on effect of biofertilizers on nodulation, nutrient uptake, yield and energy use efficiency of field pea at HAU, Hisar. The results showed that the highest and the lowest N and P uptake in grain and straw were recorded in RDF + *Rhizobium* +PSB + PBGR and control treatments respectively.

Teli(2016)conducted an experiment to study the effect of phosphorus and bio-fertilizers on yield and quality of pea. Results revealed that the combined application of 100 per cent RDP with PSB + *Rhizobium* as seed inoculation proved to be effective treatment combination in terms of total nitrogen uptake (191.37 kg ha-1) and phosphorus uptake by grain (17.79 kg ha-1).

Singh *et al*. (2013) carried out field experiments from 2005-06 to 2006-07 at Lakhaoti, Bulandshahr (U.P.) to evaluate the performance of intercropping system with phosphorus fertilization and bio-fertilizer application. It was found that seed inoculation with *Rhizobium* + PSB recorded significantly higher nutrient uptake (N and P2O5) over *Rhizobium* alone and un-inoculation in both the crops (pigeon pea and mung bean).

A field study was conducted by Bhat *et al.* (2013) in *Rabi* season of year 2009-10 at the Agronomy Farm of SKUAST-J to evaluate the response of field pea (*Pisum sativum* cv. Rachna) to levels of phosphorus and bio-fertilizers under sun-tropical conditions of Jammu. The results showed that Combined inoculation of *Rhizobium* +PSB recorded highest total N uptake (76.83 kg ha-1), P uptake (14.05 kg ha-1) and K uptake (41.90 kg ha-1) which marked a superiority of 54.74, 50.42 and 44.18 percent over no-inoculation in case of N, P and K uptake, respectively.

Ismail and Bodkhe (2013) conducted a field experiment during rainy season of 2009 and 2010 at parbhani (Maharashtra) and revealed that the combined inoculation of Bradyr*Rhizobium* + PSB recorded significantly higher N, P, K, and S uptake (131.07, 22.53, 54.51 and 12.25 kg/ha) of soyabean.

Rokhzadi and Toashih (2011) carried out research to evaluate the effects of single and combined inoculation with plant growth-promoting rhizobacteria from four genera including *Azospirillum*, *Azotobacter*, *MesoRhizobium* and *Pseudomonas* on nutrient uptake, growth and yield of chickpea plants under field conditions. Nitrogen & phosphorus uptake of grains were statistically improved by applying every inoculation treatment in comparison with control plants. Similarly, enhancement of

nutrient uptake by chickpea plants with coinoculation of nitrogen-fixing and phosphate-solubilizing bacteria compared to control without inoculation(Wani *et al.*, 2007).

Singh and Yadav (2008) conducted a field on pigeonpea. They reported that the combined effect of *Rhizobium* and PSB improved nitrogen and phosphorus status of soil and ultimately increased N uptake(104.9 kg/ha) and P uptake (16.9 kg/ha) which enhanced growth, yield attributes and yield of the crop.

Rudresh *et al*. (2005) who reported that the simultaneous inoculation of *Rhizobium* and phosphate solubilizing bacteria gave a higher nutrient uptake (Nitrogen and phosphorus) compared to single inoculation and un-inoculated control in Chickpea.

Singh and Pareek (2003) conducted a field experiment at Jobner (Rajasthan) during Kharif season of 1998. They revealed that mung bean seed inoculation with biofertilizers significantly enhanced the N and P uptake. *Rhizobium* and PSB resulted in the highest N (59.743 kg/ha) and P (7.408 kg/ha) uptake. Similarly, Singh and Yadav (2008) conducted a field experiment at Varanasi (U.P.) during the year 2004-05 and 2005-06 rainy seasons and showed that application of *Rhizobium* + PSB to pigeon pea produced significantly higher uptake of nitrogen (104.9 kg/ha) and phosphorus (16.9 kg/ha) than other bio- fertilizers treatments.

Rajpal *et al.* (2002) conducted a field experiment at Bikaner (Rajasthan) during kharif season of 1998. They observed that seed inoculation with *Rhizobium*. PSB and *Rhizobium* + PSB significantly enhanced P content and N and P uptake in cluster bean. *Rhizobium* + PSB were most effective in increasing N and P contents.

Yadav (2001) conducted an experiment at Jobner (Rajasthan) on sandy loam soil and observed that the total uptake of cowpea were significantly enhanced due to seed inoculation with PSB. Similarly, El-Sayed (1999) found that nitrogen and phosphorus uptake by lentil increased significantly with combined inoculation of *Rhizobium* and PSB over uninoculated control.

Srivastava and Ahlawat (1995) conducted a field experiment during winter (rabi) season of 1991-92 and 1992-93 to study the effect of P, Mo and biofertilizers (*Rhizobium* and phosphate-solubilizing bacteria) on growth and yield attributes, yield and nutrient uptake by pea in sandy-loam soil under semi-arid and subtropical climatic

conditions. The results revealed that increased nitrogen and phosphorus uptake by the crop was observed due to dual and single inoculations with *Rhizobium* and PSB. Dual inoculation of *Rhizobium* and PSB had relatively greater increase in N and P uptake than their individual inoculations.

Combined inoculation of *Rhizobium* and 'Phosphate-solubilizing' *Pseudomonas striata* or *Bacillus polymyxa* with and without added chemical fertilizer on chickpea yield and nutrient content was studied under greenhouse conditions. Inoculation of *Rhizobium*, *P. striata* or *B. polymyxa* significantly ($P \sim< 0.05$) increased nitrogen and phosphorus uptake over control. (Alagawadi and Gaur, 1988). Similarly, Gupta *et al.* (1998) found that inoculation of chickpea seeds with *Rhizobium* + PSB along with lower levels of phosphorus significantly increased the nitrogen and phosphorus uptake.

Chapter-3

Materials and Methods

CHAPTER-III

MATERIALS AND METHODS

The present experiment entitled, "Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)" was conducted at the Sher-e- Kashmir University of Agriculture Science and Technology, Chatha, Jammu during the Rabi (winter) season of 2019-2020. The detailed information on location, soil and experimental site along with climate and weather recorded during the crop season along with methods and material used in experimentation are described in this chapter.

3.1 EXPERIMENTAL SITE AND LOCATION

The experiment was conducted during Rabi season 2019-20 at the Research Farm, Division of Vegetable Science, Sher-e-Kashmir University of Agricultural Science and Technology, Chatha, Jammu. The experimental site was located at 32^0 40′ N latitude and 74^0 53′ E longitude at a height of 300 meter sea level and at a distance of 15 km from the main city of Jammu. Agrometrologically, the location represents zone V of Jammu and Kashmir and is characterized by Sub-tropical climate.

3.2 CLIMATE AND WEATHER CONDITIONS

The climate of Chatha is sub-tropical with hot dry summer and cold winter. The maximum temperature rises up to 30.5°C during winter (October-March) and minimum temperature occasionally falls to 5.1°C during winter. The mean rainfall during crop growing season is 16.85 mm, most of which is received from south-west monsoon during October to 2nd fortnight of January. The data pertaining to weather conditions that prevailed during the crop season was recorded at the meteorological observatory, located at experimental Farm, Chatha. During the crop period from 20 October to 31 March 2020, the mean maximum and minimum temperature showed a fluctuation throughout the crop growth period. The mean relative humidity varied from 95% (maximum) and 44% (minimum).

3.3 COLLECTION AND PREPARATION OF SOIL SAMPLES

Before initiation of experiment representative soil samples were collected from 0-15 cm depth of soil. The samples were air dried and sieved through 2 mm sieve and

were analyzed for various physicochemical properties of the soil which are listed below.

Table 1 Physico-chemical properties of soil.

S.No.	Properties	Optimum Range	Values	Method Employed
1	pH	-	7.40	Glass electrode Black man pH meter (Jackson 1973a)
2	EC(dsm^{-1})	-	0.14	Solubridge method (Jackson, 1973a)
3	Soil Texture			Loamy texture
a)	Sand	-	43.4	International pipette method (Piper 1966)
b)	Silt	-	44.3	
c)	Clay	-	12.3	
4	Organic Carbon (%)	0.65	0.37	Walkley and Black (1934)
5	Available Nitrogen (kg/ha)	230	216.13	Alkaline potassium permanganate method (Subbiah and Asija,1956)
6	Available Phosphorus (kg/ha)	26	17.20	Olsens method (Olsen *et al.* 1954)
7	Available Potassium (kg/ha)	195	130.70	Ammonium acetate method (Jackson 1973a)

The soil of the experiment site was loamy in texture, slightly alkaline in pH, low in organic carbon and available nitrogen while medium in phosphorus, potassium with EC in the normal range.

3.4 TREATMENT DETAILS

The experiment was laid out in Split-Split Plot Design with three replications. The details of the layout are given below:

Treatment combination : 20

Design	:	Split-Split Plot Design
Replications	:	3
Plot size	:	2 m x 1.4 m
Spacing	:	40 cm x 10 cm
No. of plots	:	60

3.5 TREATMENT AND EXPERIMENTAL PROCEDURES

The experiment consists of five garden pea cultivars as main plot treatment, and *Rhizobium* inoculation and PSB inoculation as sub plot treatment and sub-sub plot treatment respectively. The treatments were arranged in a split- split plot design with three replications having a plot size of 2 m x 1.4 m with a spacing of 40 cm x 10 cm.

TREATMENT DETAILS:

Main plot treatment: Cultivars (05)

1. P-89 (V_1)
2. AP-3 (V_2)
3. Bonneville (V_3)
4. Arka Karthik (V_4)
5. Arka Apoorva (V_5)

Sub plot treatment: *Rhizobium* inoculation (02)

1. Un-inoculated control (R_0)
2. Inoculated (R_1)

Sub-sub plot treatment: PSB Inoculation (02)

1. Un-inoculated control (P_0)
2. Inoculated (P_1)

TREATMENT COMBINATIONS:

- $V_1R_0P_0$
- $V_1R_0P_1$
- $V_1R_1P_0$
- $V_1R_1P_1$
- $V_2R_0P_0$
- $V_2R_0P_1$
- $V_2R_1P_0$
- $V_2R_1P_1$
- $V_3R_0P_0$
- $V_3R_0P_1$
- $V_3R_1P_0$
- $V_3R_1P_1$
- $V_4R_0P_0$
- $V_4R_0P_1$
- $V_4R_1P_0$
- $V_4R_1P_1$
- $V_5R_0P_0$
- $V_5R_0P_1$
- $V_5R_1P_0$
- $V_5R_1P_1$

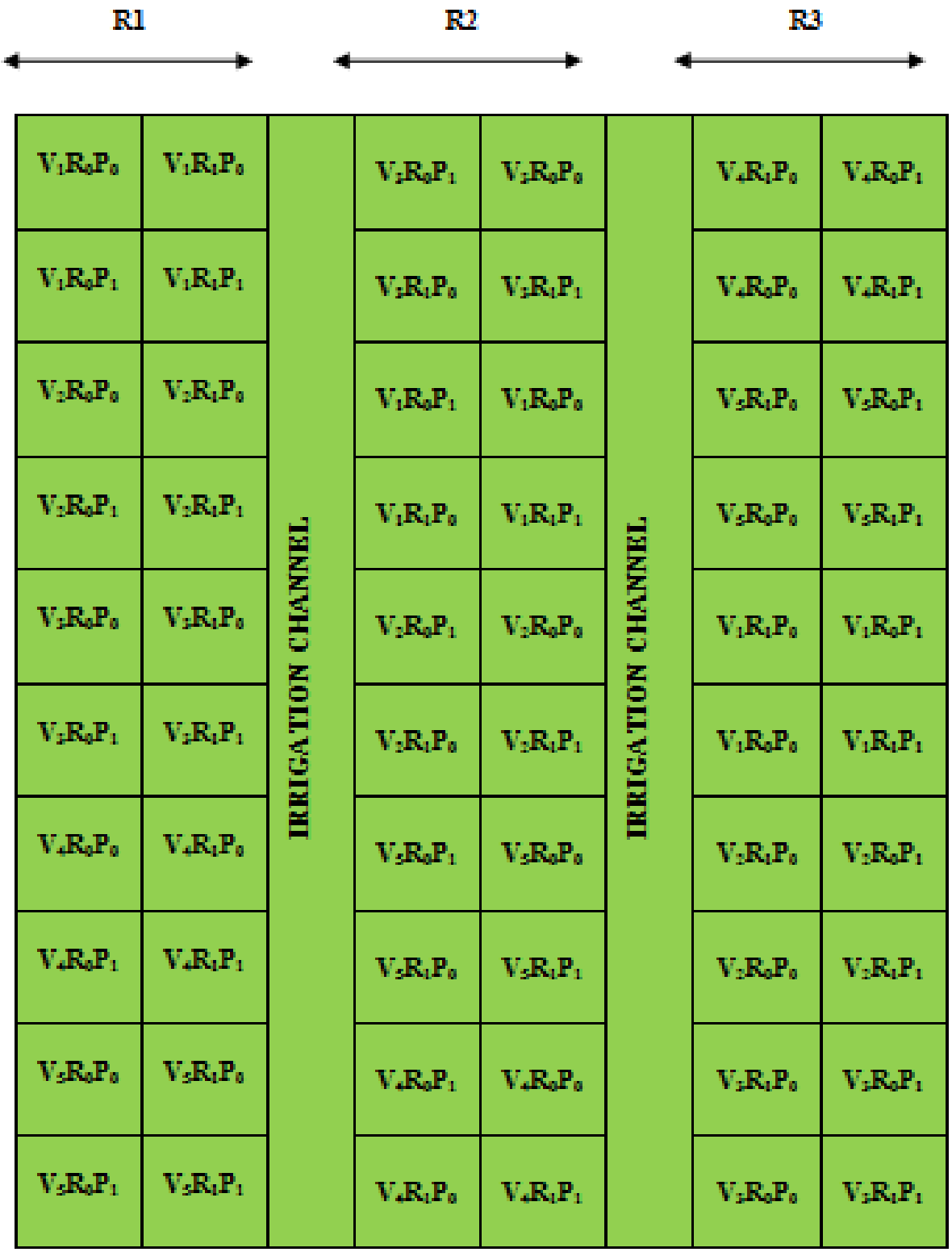
3.6. INOCULATION OF VEGETABLE PEA SEEDS WITH RHIZOBIAL AND PSB CULTURE

The seeds of pea were inoculated with *Rhizobium leguminosarum* and PSB. For this, rice gruel was added in the *Rhizobium* culture and PSB solution. Rice gruel works as a binder. Then the solution was sprinkled on pea seeds. Afterwards, the culture was mixed thoroughly in polythene bags enabling to coat the entire surface of seeds with culture. After 24 hours, the seeds were sown. All these operations were performed under shade.

3.7 CULTURAL PRACTICES

The seed sowing was done on second fortnight of October through line sowing at a depth of 1.5cm. The crop management practices such as irrigation, weeding were applied uniformly to all plots as per recommendation to crop.

TECHNOLOGY PARK



ROAD

Plate 1: Layout plan of the experiment

3.8 PREPARATION OF THE EXPERIMENTAL PLOT

The land was ploughed twice and was brought to fine tilth by repeated harrowing and leveling. The plots were prepared as per the specification and organic fertilizer viz. FYM and vermicompost were applied as per treatment. All the recommended cultural operations were followed as per the Package of Practices (SKUAST-J, 2016)

3.9 IRRIGATION

The irrigation was given by flood method at a 10-15 days interval and in whole crop season 9 irrigations were applied for a satisfactory crop growth and productivity.

3.10 HARVESTING

The crop became ready for harvest when pods turn from dark green to light green and are well filled with grains.

3.11 OBSERVATION RECORDED

3.11.1 Growth and yield parameters

3.11.1.1 Days to 50% flowering

Days to 50% flowering were calculated from the sowing to the date when 50% of the plants have at least one flower per treatment per replication.

3.11.1.2 Plant height (cm)

Five plants of each experimental plot were selected and tagged. Observation were recorded on plant height at the time of final harvest. The height was measured with the help of measuring scale from the base of the plant to the axil of last leaf unfolded at the tip of the shoot. Crop growth was expressed as average plant height in centimeters.

3.11.1.3 Leaf Area Index

In the active growth stage (peak podding stage) three plants per experimental plot were marked at random, uprooted and brought to the laboratory to measure the leaf area of entire plants.

Graph paper method: Here a leaf is taken and traced over graph paper, and the grids covered by the leaf are counted to give the area.

$$LAI = \frac{\text{Leaf area } (m^2)}{\text{Ground area } (m^2)}$$

3.11.1.4 No. of pods/plant

Total number of pods borne on five randomly tagged plant in each treatment were counted at the time of final harvest and average number of pods per plant was calculated.

3.11.1.5 Pod weight (g)

Harvested pods from each treatment were pooled and ten pods selected at random for the use of determining the average pod weight.

3.11.1.6 Shelling percentage (%)

One hundred grams green pods selected at random from each treatment were taken for this purpose. The grain were shelled and weighed. The shelling percentage was worked out as under:

$$\text{Shelling percentage} = \frac{\text{Weight of grains}}{\text{Wt. of pods (including grains \& shells)}} \times 100$$

3.11.1.7 Green pod yield (q/ha)

At the time of harvest the pods were weighed under each treatment and average yield (q/ha) was worked out on the basis of per plot yield.

3.11.2 Quality parameters

3.11.2.1 Dry matter content (%)

The pods were shelled and 50g of pea grains sample from each treatment was taken in a petri dish and oven dried at 65^{o}C till constant weight was obtained. The percent dry matter content was calculated by the following formula:

$$\text{Dry matter content (\%)} = \frac{\text{Final dry weight}}{\text{Initial fresh weight}} \times 100$$

3.11.2.2 TSS content(^{0}Brix)

The estimation of total soluble solids was carried out at room temperature as per the procedure. A pod was shelled and the seed was then squeezed with muslin

cloth and a drop of juice was placed on the refractometer, The number on the scale were visible when the refractometer was pointed towards a light source which represent the percentage concentration of soluble solids in the pea. The refractometer was cleaned after every observation. The value of TSS was observed in percentage.

3.11.3 Nodulation studies

3.11.3.1 Number of nodules per plant

Five plants were taken from each plot at the flowering stage. Roots were gently washed in water to remove the adhering soil. Then the viable nodules separated with the help of forceps from the roots of selected plants were counted and averaged.

3.11.3.2 Size of nodules

Size of nodules were determined using compound microscope. The average length and average width of nodules were taken in millimetres.

3.11.3.3 Nodule fresh weight (mg / plant)

After counting the nodules of five sample plants from each treatment, nodules were carefully removed with the help of forceps. Then the nodules were weighed in electric balance and averaged.

3.11.3.4 Nodule dry weight (mg / plant)

Fresh weighed nodules were put in oven for drying at 65 ^{0}C for 48 hours. After 48 hours of drying, the nodules were weighed on electric balance and averaged for getting their actual dry weight.

3.11.4 Uptake studies

The plant samples were taken from each plot at the time of harvesting for estimation of N and P concentration and uptake in pea plants. The samples were oven dried, grounded and analyzed for nitrogen and phosphorus concentration. N and P uptake in plant samples were calculated by multiplying their percent nutrient content with their respective yield as per the formula given below:

$$\text{Nutrient uptake (Kg/ha)} = \frac{\text{Nutrient content (\%) x Yield (Kg/ha)}}{100}$$

3.11.4.1 Nitrogen uptake

The processed samples of plant weighing 0.5 gram were digested in the Kjeldahl's flask in concentrated sulphuric acid in presence of a digestion mixture consisting of K_2SO_4, $FeSO_4$ and $CuSO_4$ in the ratio of 20:2:1 and nitrogen was estimated by Kjeldhal's method (Jackson, 1973b).

3.11.4.2 Phosphorus uptake

The processed samples of plant weighing about 0.5 gm taken from each treatment were put in conical flask followed by addition of about 10ml tri-acid mixture (HNO_3, $HClO_4$ and H_2SO_4) in the ratio of 10:4:1, respectively and kept on the hot plate till digested P from the extract were estimated by standard methods (Jackson, 1973b).

3.12. Statistical analysis

Experimental data was subjected to statistical analysis as per the Split-Split Plot Design to draw the inferances of the study. Using OPSTAT software developed by Sheoran *et al. (*1998), the data was statistically analyzed with three factor analysis on the CCS HAU website. The critical difference (C.D.) was used to determine the major difference between the means of two-treatment.

The analysis of variance was as follows:

Analysis of variance (ANOVA) for split-split plot design:

Source of Variation	**df**	**SS**	**MSS**	**F-Cal**	**Significance**
Replication	r-1				
Factor A	a - 1				
Error(a)	(r - 1)(a - 1)				
Factor B	b - 1				
Int A X B	(a - 1)(b - 1)				
Error(b)	a(r - 1)(b - 1)				
Factor C	c - 1				
Int A X C	(a - 1)(c - 1)				
Int B X C	(b - 1)(c - 1)				
Int A X B X C	(a - 1)(b - 1)(c - 1)				
Error(c)	ab(r - 1)(c - 1)				
Total	($rabc$) - 1				

The ANOVA for various observations obtained are presented in the Appendix II to V.

Chapter-4

Results

CHAPTER-IV

EXPERIMENTAL RESULTS

The results of the investigation entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum var. hortense*)"** conducted during 2019-2020 have been described in this chapter. The data on various characters was recorded and put to statistical analysis for proper interpretation of the results. The results of the study are presented as under following headings:

4.1 GROWTH AND YIELD STUDIES

4.1.1 Days to 50% flowering

Days to 50% flowering is the indication towards earliness. All the varieties have significant effect towards the 50% flowering. Variety AP-3 (V_2) was earliest in 50% flowering (54.08) which was significantly less than other varieties under study. Arka Karthik (V_4) took maximum number of days for 50% flowering (i.e. 80.66). However, it was at par with Bonnevillae and Arka Apoorva. [Table 2(a)]

Rhizobium inoculation also had significant influence on the days to 50% flowering. When seeds were inoculated with *Rhizobium*, it took lesser number of days (72.83) when compared with uninoculated control (74.36)

Similarly, Inoculation of PSB also had significant effect on days to 50% flowering. PSB decreased days to 50% flowering (72.53) as compared to uninoculated control (74.66).

However, the interaction between Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB, Varieties x *Rhizobium* x PSB was found to be non significant.

4.1.2 Plant Height (cm)

It was evident from the table 3(a) that all the varieties had a significant effect towards the plant height. Arka Apoorva (V_5) recorded with maximum plant height, i.e., 109.93 cm which was significantly higher than all other varieties. Similarly, minimum plant height was recorded in P-89(V_1) (98.27 cm), which was significantly lower than other pea varieties.

Rhizobium inoculation also had a significant influence on plant height. *Rhizobium* inoculation resulted in significantly taller plants (107.84 cm) than the uninoculated control (102.58 cm).

All the varieties differed significantly towards plant height when inoculated with *Rhizobium*. Arka Apoorva showed maximum plant height (113.20 cm), which remained at par with Arka Karthik (112.01 cm). The minimum plant height was recorded in P-89 (100.29 cm), which was significantly lower than all other varieties inoculated with *Rhizobium*.

Similarly, PSB inoculation also showed significant effects over the uninoculated control.

However, the interactions of Varieties x PSB, *Rhizobium* x PSB, Varieties x *Rhizobium* x PSB interaction were found to be insignificant for plant height.

4.1.3 Leaf Area Index

The data presented in the table 4(a) showed that all the effect of varieties were found to be non-significant for leaf area index.

Rhizobium inoculation had a significant effect on leaf area index. Maximum leaf area index was observed when the seeds were inoculated with *Rhizobium* (0.61), which was significantly more than the uninoculated control (0.50).

Similarly, it was recorded that the seed inoculated with PSB gave significantly more leaf area index (0.58) than the uninoculated control (0.53).

Moreover, the interactions between Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB, Varieties x *Rhizobium* X PSB yielded insignificant for leaf area index.

4.1.4 No. of Pods/Plant

It was evident from the table 5(a) that the varieties had a significant effect on number of pods per plant. The maximum number of pods per plant was found in P-89 (41.99), which was significantly higher than all other varieties. Arka Apoorva recorded minimum number of pods per plant (16.67), which was found significantly lower than all other varieties

Table 2(a): Effect of *Rhizobium* and PSB on days to 50% flowering

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	75.66	73.66	74.67
P_1	72.66	72.33	72.50
Mean	74.17	73.00	73.58
	Variety V_2		
	R_0	**R_1**	
P_0	55.66	54.66	55.17
P_1	54.33	51.66	53.00
Mean	55.00	53.17	54.08
	Variety V_3		
	R_0	**R_1**	
P_0	82.00	80.00	81.00
P_1	79.33	78.33	78.83
Mean	80.67	79.17	79.91
	Variety V_4		
	R_0	**R_1**	
P_0	81.66	81.00	81.33
P_1	80.33	79.66	80.00
Mean	81.00	80.33	80.66
	Variety V_5		
	R_0	**R_1**	
P_0	82.66	79.66	81.17
P_1	79.33	77.33	78.33
Mean	81.00	78.50	79.75

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (uninoculated), P_1= PSB (inoculated)

Table 2(b): Interaction effect of *Rhizobium* and PSB on days to 50% flowering

	R_0	**R_1**	**Mean**
P_0	75.53	73.80	74.66
P_1	73.20	71.86	72.53
Mean	74.36	72.83	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	1.01	0.31
Rhizobium	0.46	0.14
Varieties X Rhizobium	N.S.	0.32
PSB	0.54	0.18
Varieties X PSB	N.S.	0.41
Rhizobium X PSB	N.S.	0.26
Varieties X Rhizobium X PSB	N.S.	0.58

Table 3(a): Effect of *Rhizobium* and PSB on plant height (cm)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	95.83	98.92	97.37
P_1	96.68	101.67	99.17
Mean	96.25	100.29	98.27
	Variety V_2		
	R_0	**R_1**	
P_0	103.56	106.11	104.83
P_1	104.74	107.56	106.15
Mean	104.15	106.83	105.49
	Variety V_3		
	R_0	**R_1**	
P_0	105.03	106.19	105.61
P_1	105.68	107.49	106.58
Mean	105.35	106.84	106.09
	Variety V_4		
	R_0	**R_1**	
P_0	99.93	111.95	105.94
P_1	101.04	112.08	106.56
Mean	100.48	112.01	106.25
	Variety V_5		
	R_0	**R_1**	
P_0	105.19	111.25	108.22
P_1	108.14	115.15	111.645
Mean	106.66	113.20	109.93

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (uninoculated), P_1= PSB (inoculated)

Table 3(b): Interaction effect of *Rhizobium* and PSB on plant height

	R_0	**R_1**	**Mean**
P_0	101.91	106.88	104.39
P_1	103.25	108.79	106.02
Mean	102.58	107.84	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	2.66	0.81
Rhizobium	1.95	0.62
Variety X *Rhizobium*	4.36	1.38
PSB	1.42	0.48
Variety X PSB	N.S.	1.07
Rhizobium X PSB	N.S.	0.68
Variety X Rhizobium X PSB	N.S.	1.52

Table 4(a) : Effect of *Rhizobium* and PSB on leaf area index

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	0.51	0.62	0.56
P_1	0.58	0.66	0.62
Mean	0.54	0.64	0.59
	Variety V_2		
	R_0	**R_1**	
P_0	0.51	0.61	0.56
P_1	0.53	0.66	0.60
Mean	0.52	0.63	0.58
	Variety V_3		
	R_0	**R_1**	
P_0	0.44	0.60	0.52
P_1	0.57	0.61	0.59
Mean	0.51	0.60	0.55
	Variety V_4		
	R_0	**R_1**	
P_0	0.46	0.61	0.53
P_1	0.51	0.62	0.56
Mean	0.48	0.61	0.55
	Variety V_5		
	R_0	**R_1**	
P_0	0.43	0.56	0.49
P_1	0.49	0.62	0.56
Mean	0.46	0.59	0.52

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* uninoculated, R_1= *Rhizobium* inoculated, P_0= PSB uninoculated, P_1= PSB inoculated

Table 4(b) Interaction effect of *Rhizobium* and PSB on leaf area index

	R_0	**R_1**	**Mean**
P_0	0.47	0.60	0.53
P_1	0.54	0.63	0.58
Mean	0.50	0.61	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	N.S.	0.01
Rhizobium	0.03	0.01
Varieties X Rhizobium	N.S.	0.02
PSB	0.02	0.01
Varieties X PSB	N.S.	0.02
Rhizobium X PSB	N.S.	0.01
Varieties X Rhizobium X PSB	N.S.	0.02

Rhizobium inoculation also had a significant effect on number of pods per plant. The seed inoculated with *Rhizobium* (30.09) were found to be significantly superior than the uninoculated seed (27.93) for number of pods per plant.

Similarly, the seeds inoculated with PSB (30.56) were found to be statistically superior than the uninoculated seeds (27.46).

All the varieties showed significant results towards number of pods per plant, when inoculated with PSB. P-89 recorded with maximum number of pods per plant, which was significantly more than all other varieties. However, the minimum number of pods per plant was recorded in Arka Apoorva, which was significantly lower than all other varieties.

The interaction between *Rhizobium* and PSB was found to be significant. R_1P_1 (31.95) was found to be superior than the uninoculated control (R_0P_0) i.e., 26.68

Further, the interaction between between Varieties x *Rhizobium* and Varieties x *Rhizobium* x PSB yielded non significant effects towards the number of pods per plant.

4.1.5 Pod Weight(g)

The perusal of the data depicted in the table 6(a) showed that all the varieties under study had a significant effect towards pod weight. P-89 with a pod weight of 7.34 g was found to be superior than all other varieties. The minimum pod weight was recorded in Arka Apoorva (4.45 g), which was at par with Arka Karthik with a pod weight of 4.65 g.

Rhizobium inoculation also had a significant effect on pod weight. The seeds inoculated with *Rhizobium* (6.02 g) had significantly more pod weight than uninoculated seeds (5.41 g). Similarly, the seeds inoculated with PSB had more pod weight (5.94 g) than uninoculated control (5.48 g).

Further, it was noted from the table that the interaction between varieties and *Rhizobium* also had significant effects. All the varieties differed significantly towards pod weight, when inoculated with *Rhizobium*. The maximum pod weight were recorded in P-89 (7.62 g), which was significantly more than all other varieties. However, Arka Apoorva recorded minimum pod weight (4.75 g), which remained at par with Arka Karthik (4.78 g).

Similarly, all the varieties also differed significantly towards pod weight, when inoculated with PSB. P-89 found to be statistically superior than all other varieties. Likewise, minimum pod weight was recorded in Arka Apoorva (4.53 g), which revealed at par pod weight with Arka Karthik (4.70 g).

However, the interaction studies between *Rhizobium* x PSB and Varieties x *Rhizobium* x PSB were found to be non-significant for pod weight.

4.1.5 Shelling Percentage (%)

The data in table 7(a) revealed significant effect of varieties on shelling percentage. The maximum shelling percentage was recorded in P-89 (51.01%), which was statistically at par with AP-3 (50.77%). Bonneville recorded minimum shelling percentage (42.76 %), which was found to be statistically lower than all other varieties tested.

Significantly more shelling percentage (48.53 %) was recorded in *Rhizobium* inoculated seeds, than the uninoculated seeds (47.46%).

Similarly, Shelling percentage also showed significant response towards PSB inoculation. PSB inoculated seeds shows significantly more shelling percentage (48.67%) than the uninoculated seeds (47.32%).

The interaction between *Rhizobium* and PSB also had a significant response towards shelling percentage. The seeds inoculated with both *Rhizobium* and PSB (R_1P_1) found to be statistically superior (49.41 %) than the uninoculated control (46.99 %).

However, the interactions between Varieties x *Rhizobium*, Varieties x PSB and Varieties x *Rhizobium* x PSB were found to be non significant towards shelling percentage.

4.1.6 Green Pod Yield (q/ha)

The data presented in the table 8(a) showed significant response of varieties towards green pod yield. The maximum green pod yield was recorded in P-89 (126.75 q/ha) which was statistically superior than other varieties. However, statistically lower green pod yield of 77.27 q/ha was recorded in Arka Apoorva,

The seeds inoculated with *Rhizobium* was found to be statistically superior than the uninoculated seeds yielding 99.08 q/ha over the uninoculated control. Similarly, the

Table 5(a) : Effect of *Rhizobium* and PSB on number of pods per plant

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	38.06	41.35	39.70
P_1	42.07	46.47	44.27
Mean	40.07	43.91	41.99
	Variety V_2		
	R_0	**R_1**	
P_0	30.03	32.17	31.10
P_1	32.76	34.13	33.44
Mean	31.39	33.15	32.27
	Variety V_3		
	R_0	**R_1**	
P_0	25.65	26.28	25.96
P_1	28.83	30.57	29.70
Mean	27.24	28.42	27.83
	Variety V_4		
	R_0	**R_1**	
P_0	23.94	25.32	24.63
P_1	25.64	30.25	27.94
Mean	24.79	27.78	26.29
	Variety V_5		
	R_0	**R_1**	
P_0	15.72	16.06	15.89
P_1	16.58	18.33	17.45
Mean	16.15	17.19	16.67

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 5(b) : Interaction effect of Rhizobium and PSB on number of pods per plant

	R_0	**R_1**	**Mean**
P_0	26.68	28.24	27.46
P_1	29.17	31.95	30.56
Mean	27.93	30.09	

	C.D.(0.05)	**SE(m±)**
Varieties	1.472	0.452
Rhizobium	0.682	0.216
Varieties x *Rhizobium*	N.S.	0.484
PSB	0.478	0.162
Varieties x PSB	1.069	0.362
Rhizobium x PSB	0.676	0.229
Varieties x *Rhizobium* x PSB	N.S.	0.513

Table 6(a) : Effect of *Rhizobium* and PSB on pod weight (g)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	6.72	7.43	7.07
P_1	7.42	7.81	7.61
Mean	7.07	7.62	7.34
	Variety V_2		
	R_0	**R_1**	
P_0	5.18	6.54	5.86
P_1	6.39	7.22	6.80
Mean	5.78	6.88	6.33
	Variety V_3		
	R_0	**R_1**	
P_0	5.22	5.85	5.53
P_1	5.83	6.30	6.06
Mean	5.53	6.07	5.80
	Variety V_4		
	R_0	**R_1**	
P_0	4.50	4.68	4.59
P_1	4.52	4.89	4.70
Mean	4.51	4.78	4.65
	Variety V_5		
P_0	4.12	4.61	4.37
P_1	4.18	4.88	4.53
Mean	4.15	4.75	4.45

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 6(b) : Interaction effect of *Rhizobium* and PSB on pod weight (g)

	R_0	**R_1**	**Mean**
P_0	5.15	5.82	5.48
P_1	5.67	6.22	5.94
Mean	5.41	6.02	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.23	0.07
Rhizobium	0.12	0.04
Variety x *Rhizobium*	0.28	0.09
PSB	0.14	0.04
Variety x PSB	0.31	0.10
Rhizobium x PSB	N.S.	0.06
Variety x *Rhizobium* x PSB	N.S.	0.15

Table 7(a) : Effect of *Rhizobium* and PSB on shelling percentage (%)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	49.98	50.19	50.09
P_1	50.84	53.04	51.94
Mean	50.41	51.62	51.01
	Variety V_2		
	R_0	**R_1**	
P_0	48.91	50.80	49.86
P_1	51.14	52.24	51.69
Mean	50.03	51.52	50.77
	Variety V_3		
	R_0	**R_1**	
P_0	41.98	42.32	42.15
P_1	42.34	44.39	43.36
Mean	42.16	43.35	42.76
	Variety V_4		
	R_0	**R_1**	
P_0	47.19	47.73	47.46
P_1	47.87	49.01	48.44
Mean	47.53	48.37	47.95
	Variety V_5		
P_0	46.90	47.17	47.03
P_1	47.44	48.38	47.91
Mean	47.17	47.77	47.47

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 7(b): Interaction effect of *Rhizobium* and PSB on shelling percentage (%)

	R_0	**R_1**	**Mean**
P_0	46.99	47.64	47.32
P_1	47.93	49.41	48.67
Mean	47.46	48.53	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.64	0.19
Rhizobium	0.23	0.07
Variety x *Rhizobium*	N.S.	0.16
PSB	0.31	0.10
Variety x PSB	N.S.	0.24
Rhizobium x PSB	0.44	0.15
Variety x *Rhizobium* x PSB	N.S.	0.33

Table 8(a) : Effect of *Rhizobium* and PSB on green pod yield (q/ha)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	121.88	127.16	124.52
P_1	123.54	134.42	128.98
Mean	122.71	130.79	126.75
	Variety V_2		
	R_0	**R_1**	
P_0	83.90	95.59	89.75
P_1	93.03	101.05	97.04
Mean	88.47	98.32	93.39
	Variety V_3		
	R_0	**R_1**	
P_0	82.65	84.07	83.13
P_1	83.61	87.71	85.89
Mean	83.36	85.66	84.51
	Variety V_4		
	R_0	**R_1**	
P_0	93.88	97.83	95.85
P_1	95.92	100.23	98.07
Mean	94.90	99.03	96.96
	Variety V_5		
	R_0	**R_1**	
P_0	70.95	80.42	75.68
P_1	75.39	82.32	78.85
Mean	73.17	81.37	77.27

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 8(b) : Interaction effect of *Rhizobium* and PSB on green pod yield (q/ha)

	R_0	**R_1**	**Mean**
P_0	90.65	97.01	93.83
P_1	94.30	101.14	97.72
Mean	92.47	99.08	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	1.44	0.44
Rhizobium	0.57	0.18
Variety x *Rhizobium*	1.27	0.40
PSB	0.76	0.25
Variety x PSB	1.70	0.57
Rhizobium x PSB	N.S.	0.36
Variety x *Rhizobium* x PSB	2.41	0.81

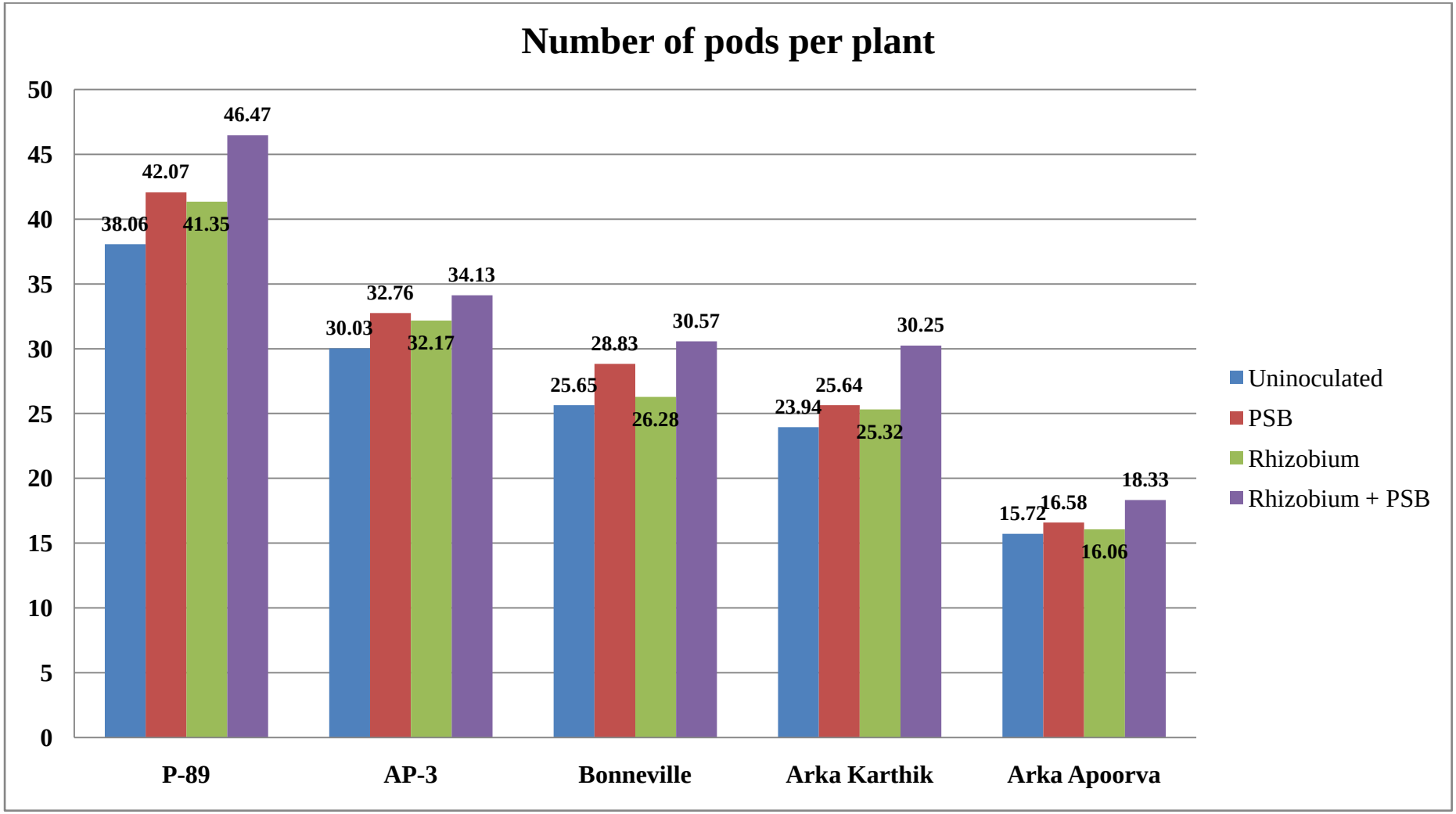


Fig. 1. Effect of *Rhizobium* and PSB on number of pods per plant

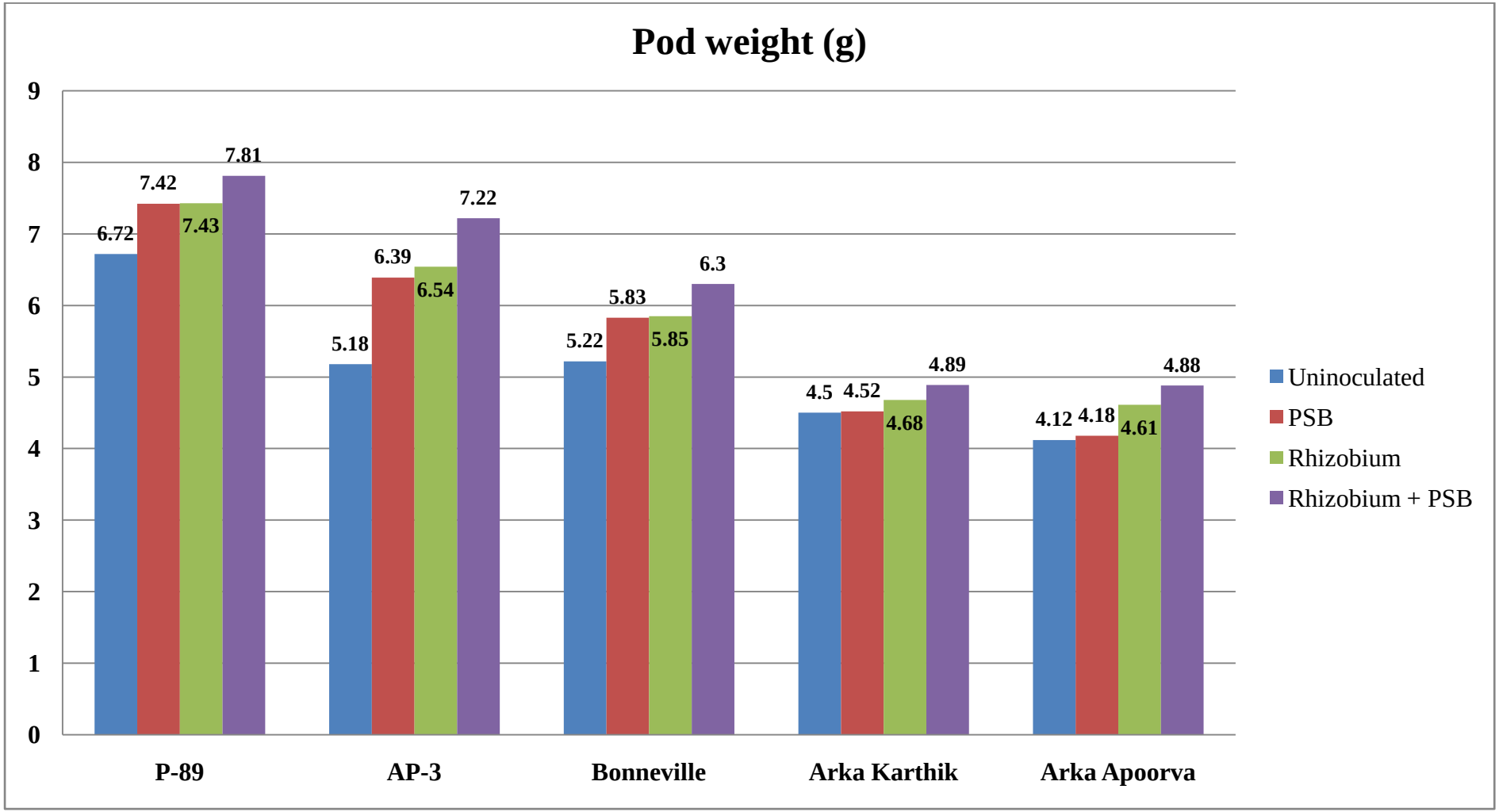


Fig.2. Effect of *Rhizobium* and PSB on pod weight (g)

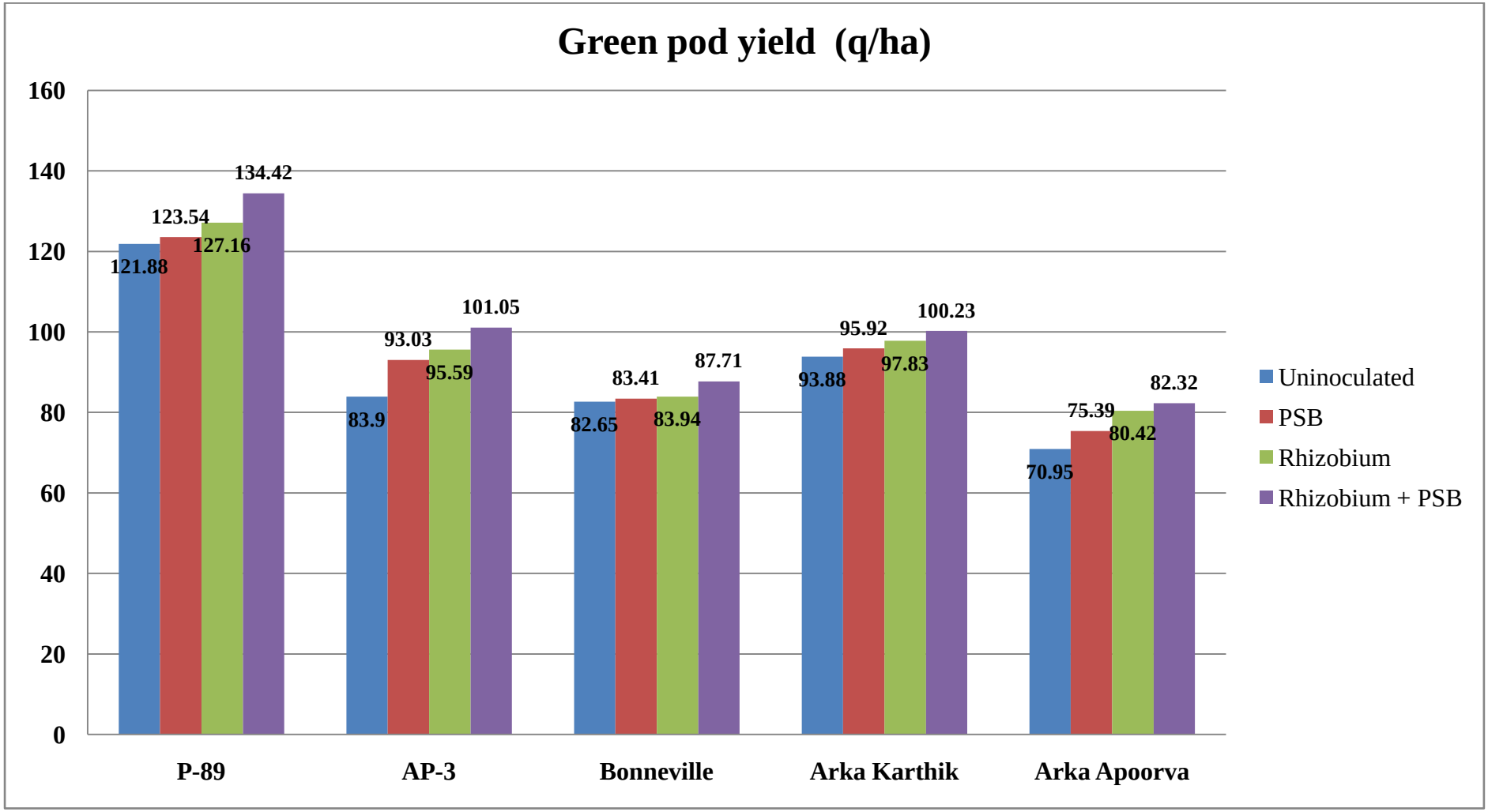


Fig.3. Effect of *Rhizobium* and PSB on green pod yield (q/ha)

PSB inoculated seeds were also found to be statistically superior than the uninoculated seeds for the green pod yield.

All the varieties differed significantly towards green pod yield when inoculated with *Rhizobium*. P-89 recorded maximum green pod yield (130.79 q/ha), which was found to be statistically superior than all other varieties. The minimum green pod yield was recorded in Arka Apoorva (81.37 q/ha), which was found to be statistically lower than all other varieties under study.

The interaction between Varieties and PSB was found to be significant towards green pod yield. The maximum green pod yield (128.98 q/ha) was recorded in P-89, which was found to be statistically superior than all other varieties. However, the minimum green pod yield was recorded in Arka Apoorva (78.85 q/ha), which was found to be statistically lower than all other varieties.

The interaction between the varieties and their inoculation with *Rhizobium* and PSB also had significant results. Variety P-89 had recorded maximum green pod yield, i.e., 134.42 q/ha when inoculated with both *Rhizobium* and PSB collectively ($V_1R_1P_1$), which was significantly more than all other varieties. Similarly, Arka Apoorva recorded statistically lowest green pod yield (70.95 q/ha) when not inoculated with any bio inoculant. In general all the varieties recorded an increase in green pod yield when inoculated with *Rhizobium* and PSB as compared to uninoculated control.

4.2 QUALITY PARAMETERS

4.2.1 TSS (°Brix)

The data represented in the table 9(a) showed that the varieties had a significant effect towards TSS content. Bonneville had recorded with maximum TSS content (16.90 °Brix), which was statistically more than all other varieties. The minimum TSS content was found in Arka Apoorva (12.40 °Brix), which was found to be statistically lower than all other varieties studied.

Rhizobium and PSB alone had a significant effect towards TSS. Significantly more TSS content was found in inoculated seeds than uninoculated seeds.

However the interactions between Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB and Varieties x *Rhizobium* x PSB was found to non significant towards total soluble solids.

4.2.2 Dry Matter Content (%)

The perusal of the data depicted in table 10(a) indicated that all the varieties had significant effect towards dry matter content. The variety having maximum dry matter content is V2 (AP-3) with dry matter content 23.60 % which was at par with variety V3 (Bonneville) recording a dry matter content of 23.43%, and Arka Karthik (23.46 %). Arka Apoorva had minimum dry matter content (22.32%) which remained at par with variety P-89 yielding dry matter content of 22.47 %.

The inoculation of *Rhizobium* and PSB individually had significant effect on the dry matter content. The inoculation of seeds with *Rhizobium* and PSB produced more dry matter content in pods.

Further, all interactions effects i.e., Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB, Varieties x *Rhizobium* X PSB failed to influence the dry matter content.

4.3 NODULATION STUDIES

4.3.1 No. of Nodules/Plant

It was evident from the data depicted in table 11(a) that all the varieties differed significantly towards the number of nodules in their roots. P-89 (V_1) had highest number of nodules (75.56) which were significantly more than all other varieties. Arka Apoorva had lowest number of nodules (63.37), which were significantly less than all other varieties. However, the varieties Bonneville and Arka Karthik had at par results in terms of number of nodules.

Rhizobium inoculation also had significant influence on the number of nodules. The inoculation of seed with *Rhizobium* resulted in more number of nodules, i.e., 82.24 which were significantly more than the inoculated control which resulted in 56.84 nodules in their roots.

All the varieties differed significantly towards number of nodules when inoculated with *Rhizobium*. P-89 recorded maximum number of nodules (87.85) which had significantly more number of nodules than all other varieties. Minimum number of nodules were recorded in Arka Apoorva (73.55) when inoculated with *Rhizobium*, which were significantly lower than all other varieties.

Table 9(a): Effect of *Rhizobium* and PSB on TSS of pods (°Brix)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	15.65	16.25	15.95
P_1	15.85	16.62	16.23
Mean	15.75	16.43	16.09
	Variety V_2		
	R_0	**R_1**	
P_0	14.45	15.08	14.76
P_1	14.58	15.18	14.88
Mean	14.51	15.13	14.82
	Variety V_3		
	R_0	**R_1**	
P_0	16.55	17.03	16.79
P_1	16.81	17.24	17.02
Mean	16.68	17.13	16.90
	Variety V_4		
	R_0	**R_1**	
P_0	15.48	16.25	15.86
P_1	16.08	16.76	16.42
Mean	15.78	16.50	16.14
	Variety V_5		
	R_0	**R_1**	
P_0	12.03	12.56	12.29
P_1	12.42	12.60	12.51
Mean	12.22	12.58	12.40

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 9(b) : Interaction effect of *Rhizobium* and PSB on TSS of pods (°Brix)

	R_0	**R_1**	**Mean**
P_0	14.83	15.43	15.13
P_1	15.15	15.68	15.41
Mean	14.99	15.55	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.22	0.06
Rhizobium	0.19	0.06
Varieties X *Rhizobium*	N.S.	0.13
PSB	0.15	0.05
Varieties X PSB	N.S.	0.11
Rhizobium X PSB	N.S.	0.07
Varieties X *Rhizobium* X PSB	N.S.	0.16

Table 10 (a) : Effect of *Rhizobium* and PSB on dry matter content of pods (%)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	21.62	22.93	22.27
P_1	22.24	23.09	22.66
Mean	21.93	23.01	22.47
	Variety V_2		
	R_0	**R_1**	
P_0	23.16	23.74	23.40
P_1	23.35	24.14	23.74
Mean	23.25	23.94	23.60
	Variety V_3		
	R_0	**R_1**	
P_0	22.67	23.52	23.09
P_1	23.36	24.18	23.77
Mean	23.01	23.85	23.43
	Variety V_4		
	R_0	**R_1**	
P_0	23.03	23.54	23.28
P_1	23.53	23.75	23.64
Mean	23.28	23.64	23.46
	Variety V_5		
	R_0	**R_1**	
P_0	21.51	22.31	21.91
P_1	22.23	22.86	22.54
Mean	21.87	22.58	22.32

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 10(b): Interaction effect of *Rhizobium* and PSB on dry matter content of pods (%)

	R_0	**R_1**	**Mean**
P_0	22.40	23.20	22.80
P_1	22.94	23.60	23.27
Mean	22.67	23.40	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.50	0.15
Rhizobium	0.23	0.07
Variety x *Rhizobium*	N.S.	0.17
PSB	0.23	0.08
Variety x PSB	N.S.	0.17
Rhizobium x PSB	N.S.	0.11
Variety x *Rhizobium* x PSB	N.S.	0.25

Similarly, PSB inoculation also had significant effect on the number of nodules developed in the roots of different varieties. PSB increased the number of nodules to 78.51 over the uninoculated control which recorded 60.56 number of nodules per plant.

All the varieties different significantly towards the number of nodules when seeds were inoculated with PSB. Maximum number of nodules were recorded in variety P-89 (84.99) which was significantly more than all other varieties tested. Minimum number of nodules were recorded in Arka Apoorva (69.98) which had significantly lesser number of nodules in comparison to other varieties.

The supplemental increase in nodule number was recorded when the seeds were uninoculated with both *Rhizobium* and PSB. R_1P_1 had significantly more number of nodules (93.91) followed by R_1P_0. However, the uninoculated seeds R0P0 had significantly lesser number of nodules (50.56) in their roots.

The interaction between the varieties and their inoculation with *Rhizobium* and PSB also had significant results. Variety P-89 had recorded maximum number of nodules, i.e., 101.17 when inoculated with both *Rhizobium* and PSB collectively ($V_1R_1P_1$). However, it had at par results with AP-3 ($V_2R_1P_1$) which yielded 98.32 nodules in the roots. Similarly, Arka Karthik recorded statistically lowest number of nodules (45.04) when uninoculated with both *Rhizobium* and PSB ($V_4R_0P_0$). However it had at par results with Bonneville when not inoculated with any bio inoculant. In general all the varieties recorded an increase in number of nodules when inoculated with *Rhizobium* and PSB as compared to uninoculated control.

4.3.2 Size of Nodules

4.3.2.1. Length of nodules (mm)

It was recorded from the table 12(a) that the effect of varieties WAS found to be non significant towards length of nodules. Further it was noted that only *Rhizobium* and PSB alone had a significant effect towards length of nodules. *Rhizobium* inoculated seeds had significantly more length of nodules (2.10 mm) than the uninoculated control (1.77 mm).

Similarly, PSB inoculation also had a significant effect on length of nodules. PSB increased length of nodules (2.03 mm) over uninoculated control (1.84 mm).

However the interactions between Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB and Varieties x *Rhizobium* x PSB was found to be non significant towards the length of nodules.

4.3.2.2. Width of nodules (mm)

It was recorded in the table 13(a) that the varieties had a significant effect towards width of nodules. The maximum width of nodules was found in variety Bonneville (1.65 mm), which remained at par with variety AP-3 (1.50 mm). However, P-89 recorded minimum width of nodules, and was at par with Arka Karthik and Arka Apoorva.

Rhizobium inoculation also had a significant influence on the width of nodules. The inoculation of seeds with *Rhizobium* resulted in more width of nodules (1.53 mm) over the uninoculated control (1.26 mm)

All the varieties differed significantly towards the width of nodules when inoculated with *Rhizobium*. Bonneville recorded with maximum width of nodules (2.00 mm), which was significantly higher than all other varieties. The minimum width of nodules was recorded in P-89 (1.27 mm), when inoculated with *Rhizobium*, which remained at par with Arka Karthik (1.38 mm) and Arka Apoorva (1.33 mm).

Further, it was noted that PSB inoculation also had a significant influence on width of nodules. The inoculated seeds with PSB resulted in more with of nodules (1.44 mm) than uninoculated control (1.35 mm), but it remained at par with each other.

However the interactions between Varieties x PSB, *Rhizobium* x PSB and Varieties x *Rhizobium* x PSB was found to be insignificant towards width of nodules.

4.3.3 Fresh Weight of Nodules (mg)

It is evident from the table 14(a) that the varieties have significant effect on fresh weight of nodules. None of the varieties found to be statistically at par with maximum value of 396.37 mg in AP-3. The lowest fresh weight of nodules was observed in Bonneville (377.38 mg), which was found to be statistically at par with Arka Karthik and Arka Apoorva.

The seeds inoculated with *Rhizobium* had more fresh weight of nodules (399.83 mg) than the uninoculated control (371.10 mg). Similarly, PSB inoculation increased fresh weight of nodules (393.35 mg) than the uninoculated control (377.58 mg).

Table 11 (a) : Effect of *Rhizobium* and PSB on number of nodules per plant

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	57.71	74.54	66.12
P_1	68.82	101.17	84.99
Mean	63.26	87.85	75.56
	Variety V_2		
	R_0	**R_1**	
P_0	54.12	67.09	60.60
P_1	64.91	98.32	81.61
Mean	59.51	82.70	71.11
	Variety V_3		
	R_0	**R_1**	
P_0	46.25	76.12	61.18
P_1	58.90	93.28	76.09
Mean	52.57	84.70	68.64
	Variety V_4		
	R_0	**R_1**	
P_0	45.04	71.26	58.15
P_1	66.26	93.49	79.87
Mean	55.65	82.37	69.01
	Variety V_5		
	R_0	**R_1**	
P_0	49.68	63.84	56.76
P_1	56.70	83.27	69.98
Mean	53.19	73.55	63.37

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 11 (b) : Interaction effect of *Rhizobium* and PSB on number of nodules per plant

	R_0	**R_1**	**Mean**
P_0	50.56	70.57	60.56
P_1	63.12	93.91	78.51
Mean	56.84	82.24	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	1.54	0.47
Rhizobium	0.76	0.24
Variety x *Rhizobium*	1.72	0.54
PSB	1.02	0.34
Variety x PSB	2.28	0.77
Rhizobium x PSB	1.44	0.48
Variety x *Rhizobium* x PSB	3.22	1.09

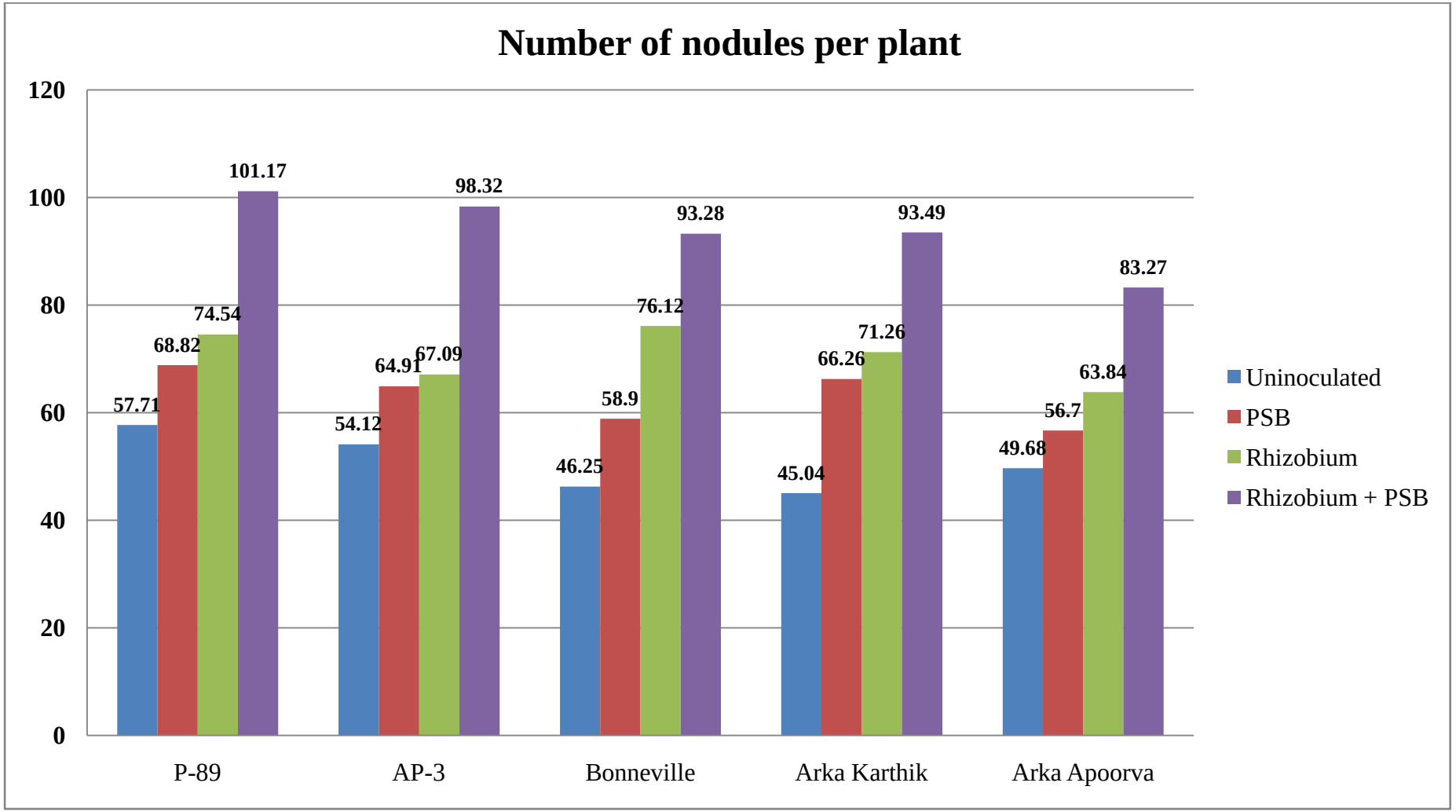


Fig.4. Effect of *Rhizobium* and PSB on number of nodules per plant

PLATE 2: ROOT NODULES OF VARIETY P-89 (UNINOCULATED)

PLATE 3: ROOT NODULES OF VARIETY P-89 (RHIZOBIUM INOCULATED)

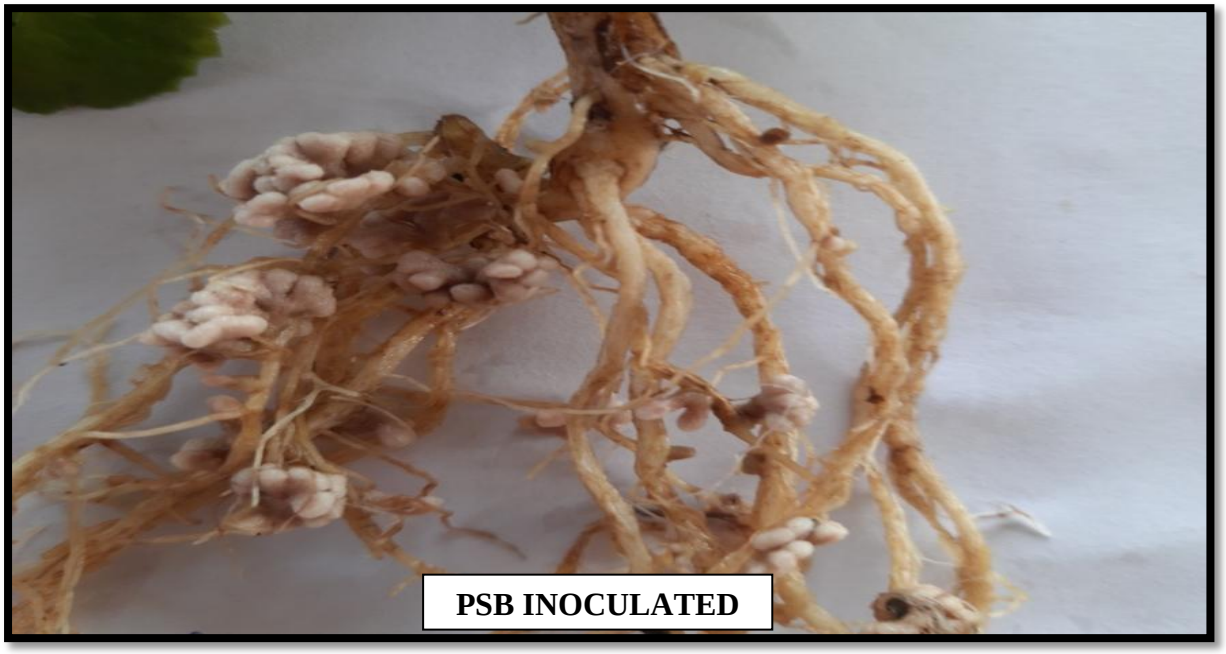


PLATE 4: ROOT NODULES OF VARIETY P-89 (PSB INOCULATED)

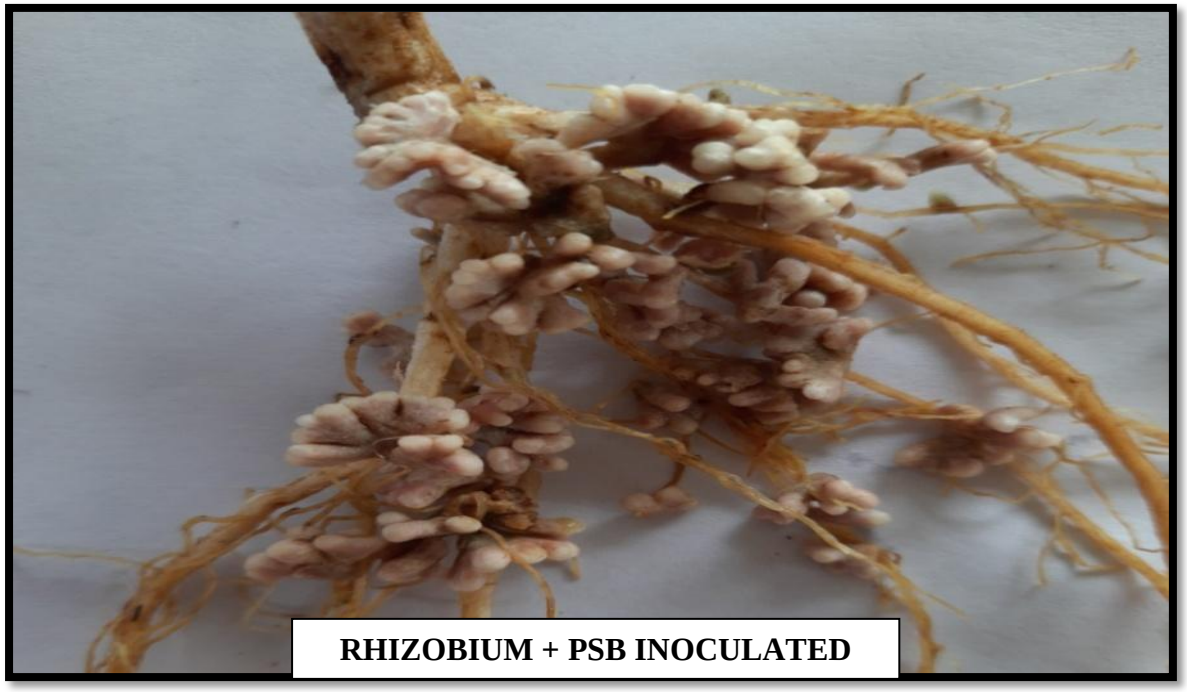


PLATE 5: ROOT NODULES OF VARIETY P-89 (RHIZOBIUM + PSB INOCULATED)

PLATE 6: ROOT NODULES OF VARIETY AP-3 (UNINOCULATED)

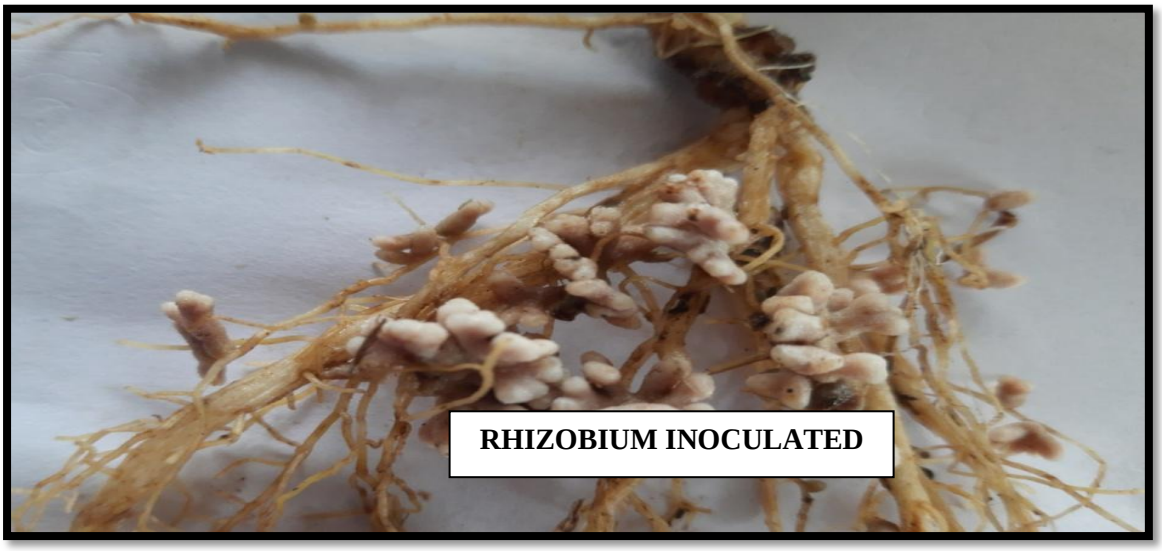


PLATE 7: ROOT NODULES OF VARIETY AP-3 (RHIZOBIUM INOCULATED)

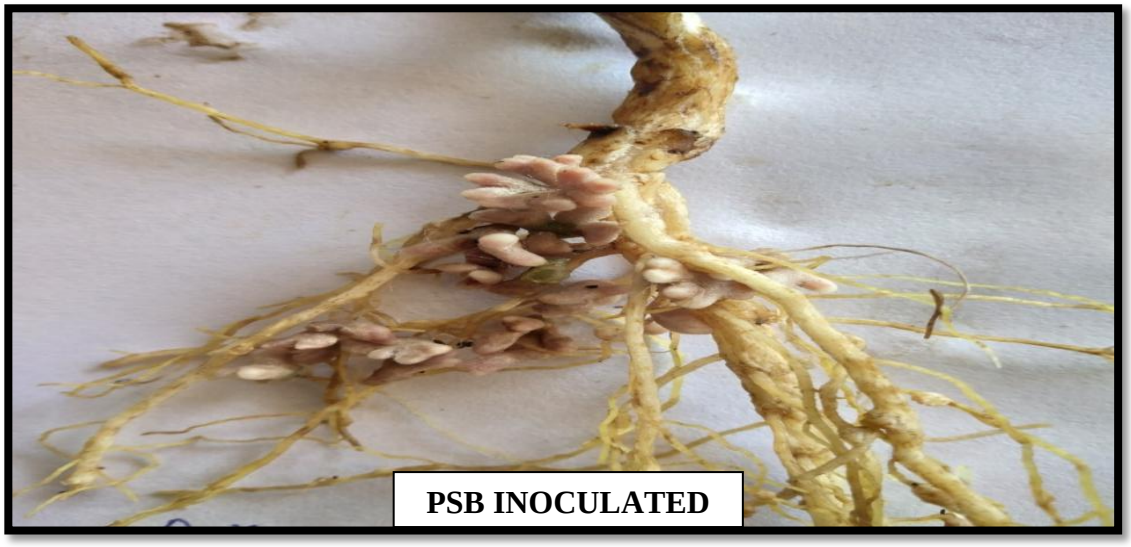


PLATE 8: ROOT NODULES OF VARIETY AP-3 (PSB INOCULATED)

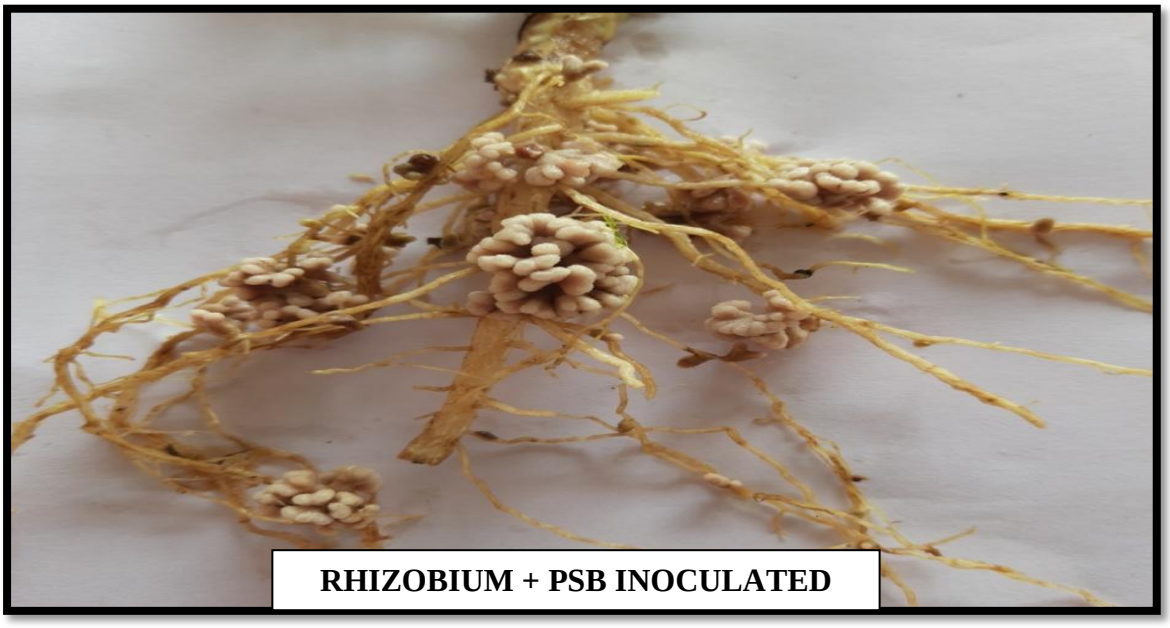


PLATE 9: ROOT NODULES OF VARIETY AP-3 (RHIZOBIUM + PSB INOCULATED)

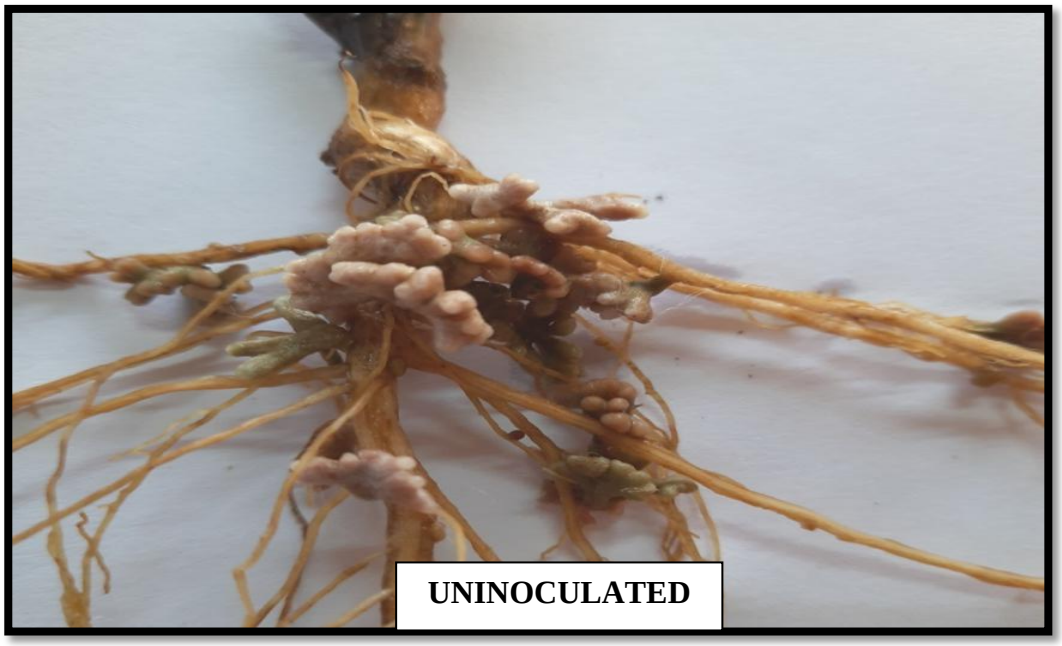


PLATE 10: ROOT NODULES OF VARIETY BONNEVILLE (UN-INOCULATED)

PLATE 11: ROOT NODULES OF VARIETY BONNEVILLE (RHIZOBIUM INOCULATED)

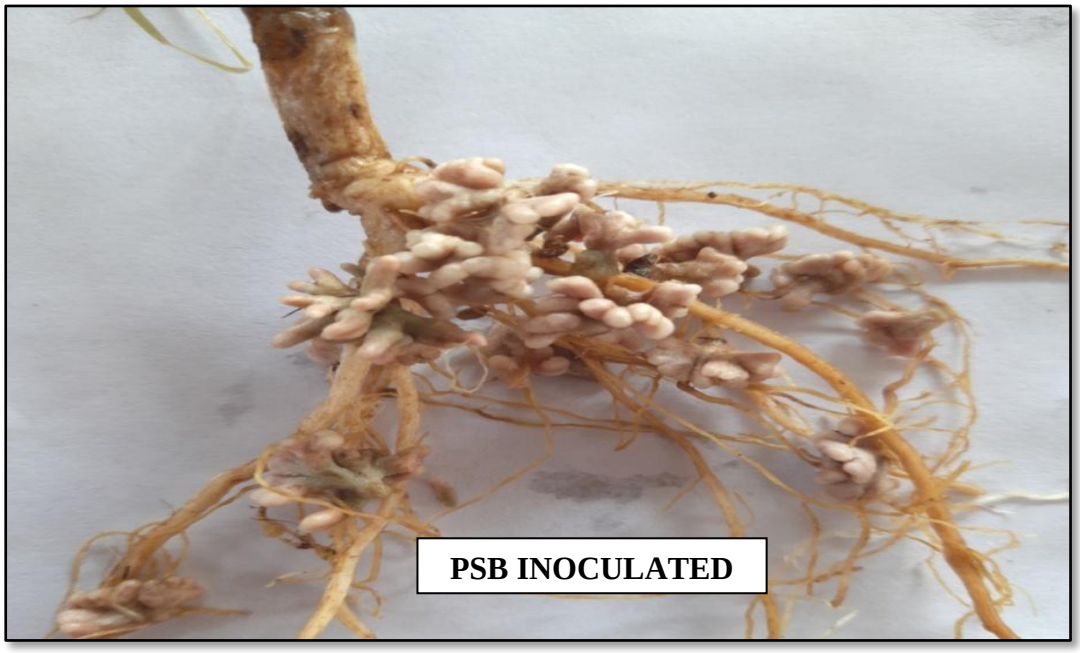


PLATE 12: ROOT NODULES OF VARIETY BONNEVILLE (PSB INOCULATED)

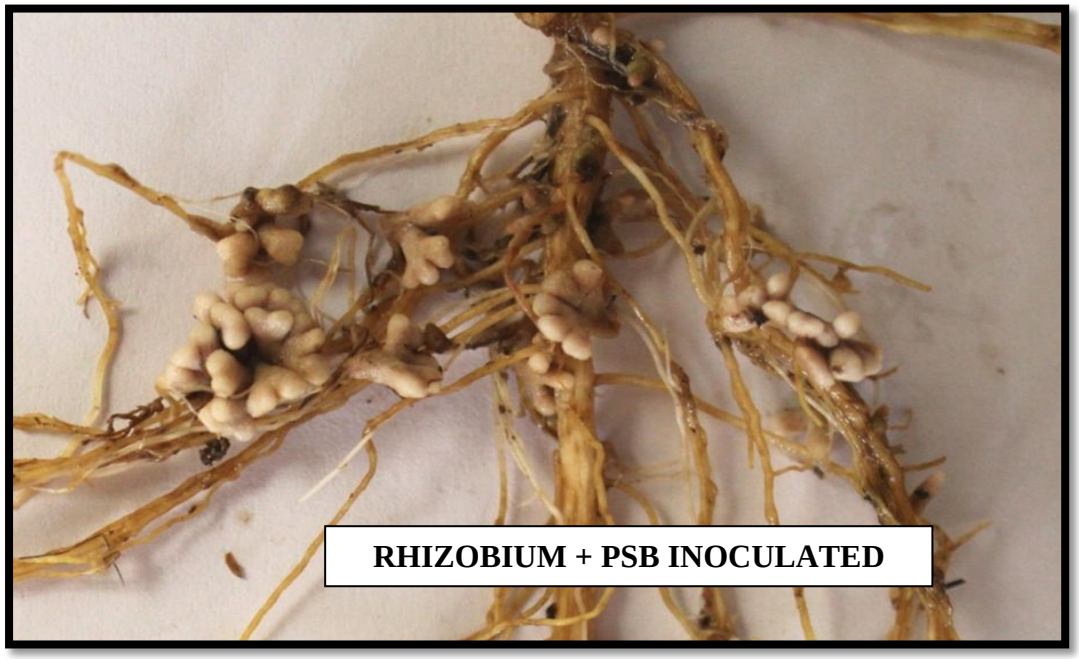


PLATE 13: ROOT NODULES OF VARIETY BONNEVILLE (RHIZOBIUM + PSB INOCULATED)

PLATE 14: ROOT NODULES OF VARIETY ARKA KARTHIK (UN-INOCULATED)

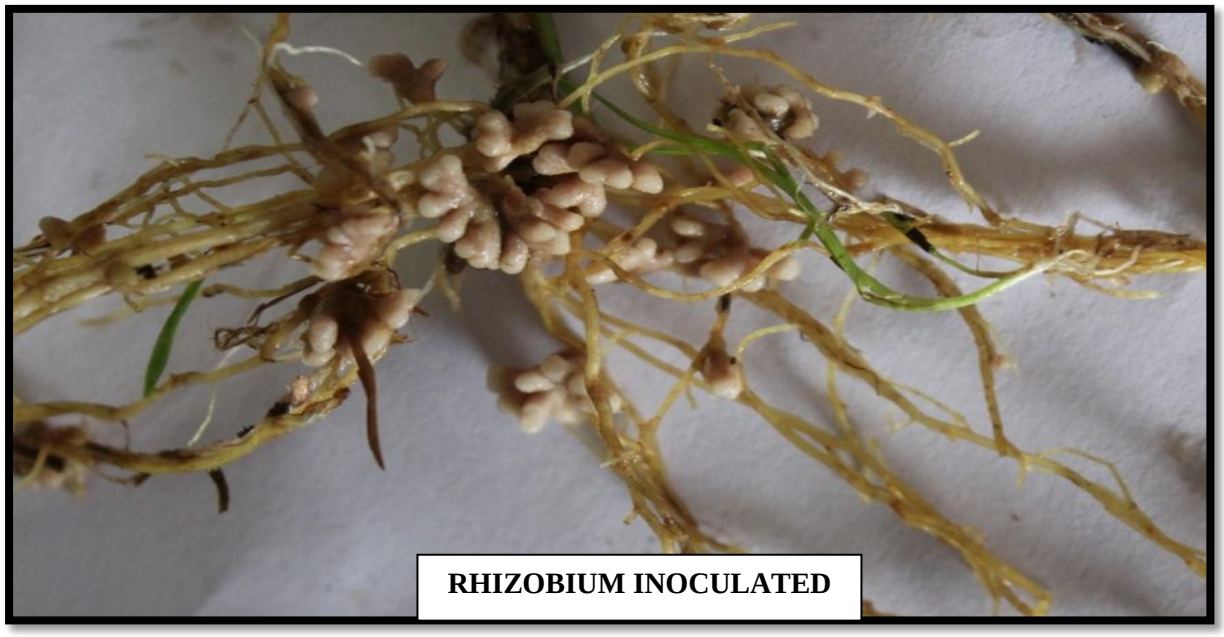


PLATE 15: ROOT NODULES OF VARIETY ARKA KARTHIK (RHIZOBIUM INOCULATED)

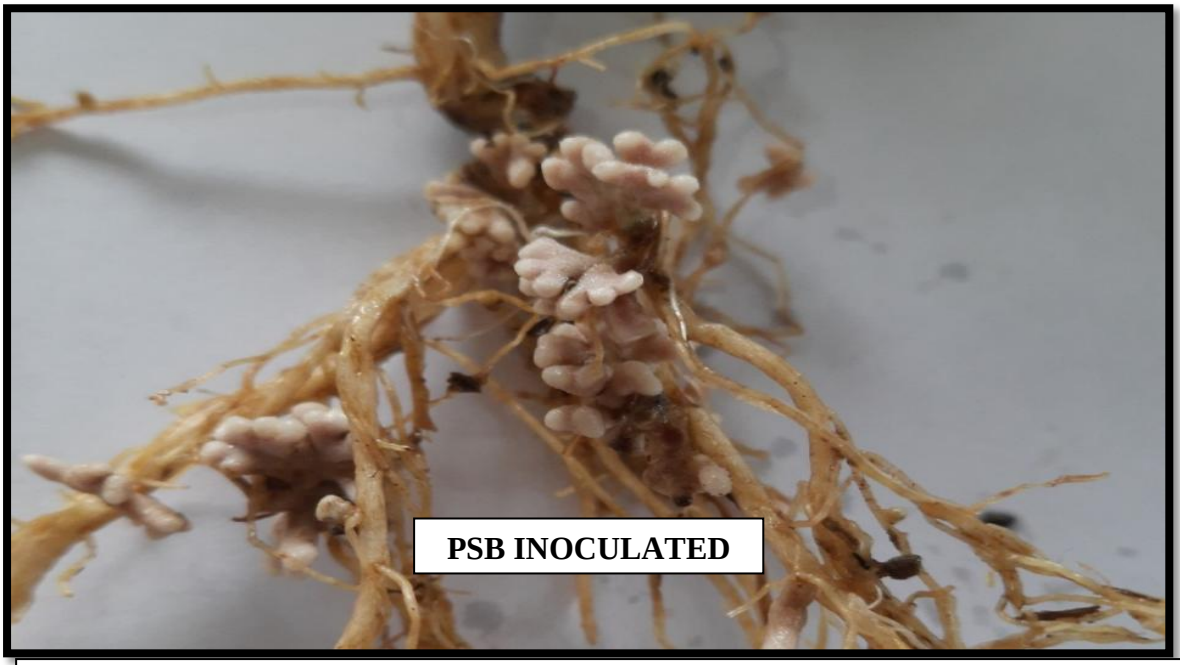


PLATE 16: ROOT NODULES OF VARIETY ARKA KARTHIK (PSB INOCULATED)

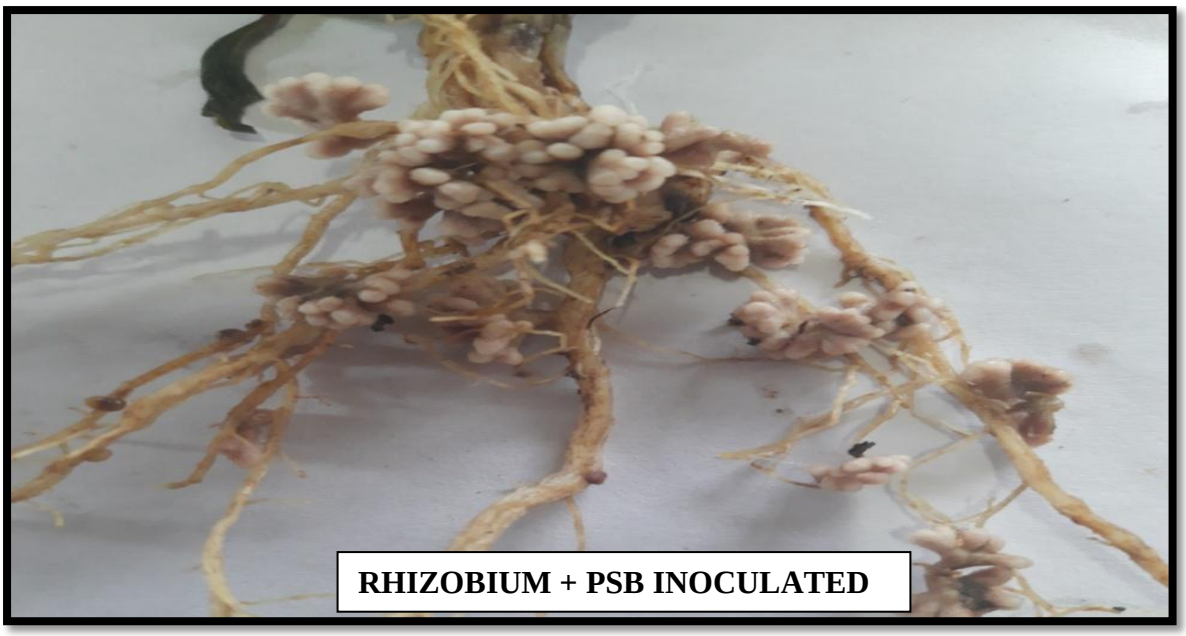


PLATE 17: ROOT NODULES OF VARIETY ARKA KARTHIK (RHIZOBIUM + PSB INOCULATED)

PLATE 18: ROOT NODULES OF VARIETY ARKA APOORVA (UN- INOCULATED)

PLATE 19: ROOT NODULES OF VARIETY ARKA APPORVA (RHIZOBIUM INOCULATED)

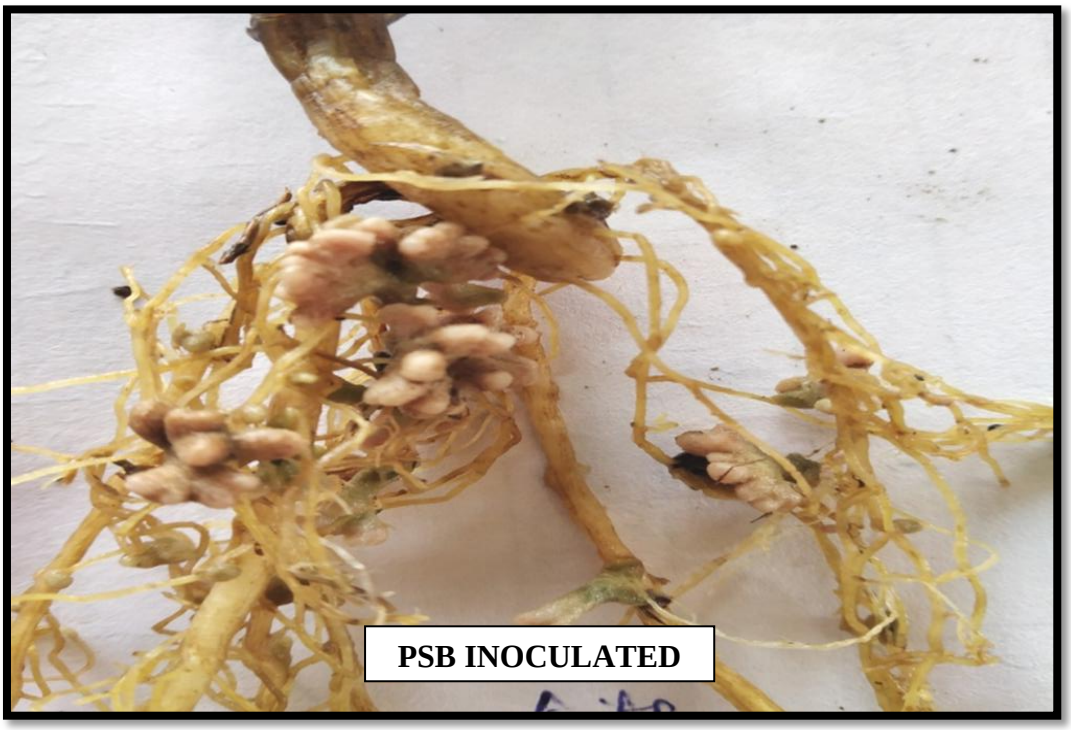


PLATE 20: ROOT NODULES OF VARIETY ARKA APOORVA (PSB INOCULATED)

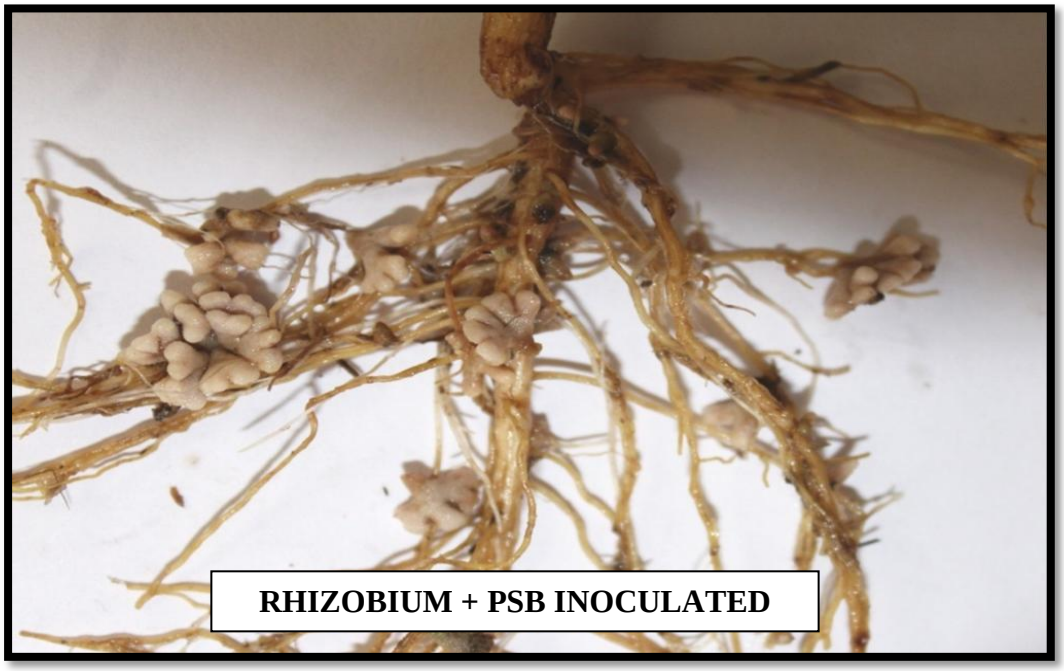


PLATE 21: ROOT NODULES OF VARIETY ARKA APOORVA (RHIZOBIUM + PSB INOCULATED)

Moreover, the interactions between Varieties x *Rhizobium*, Varieties x PSB, *Rhizobium* x PSB, Varieties x *Rhizobium* X PSB were found to be non-significant for fresh weight of nodules.

4.3.4 Dry Weight of Nodules (mg)

An examination of the data in table 15(a) revealed that all the varieties had significant dry weight of nodules. The maximum dry weight of nodules recorded in P-89 (123.16 mg), that remained at par with AP-3 (121.62 mg). Bonneville had minimum dry weight of nodules (117.06 mg) , which remained at par with Arka Karthik and Arka Apoorva.

Further, it was noted from the table that the *Rhizobium* had a significant effect towards dry weight of nodules. The *Rhizobium* inoculated seeds recorded more dry weight of nodules (125.32 mg) over the uninoculated control (114.11 mg). Similarly, PSB inoculation also had a significant effect on the dry weight of nodules. PSB inoculation increased dry weight of nodules (123.31 mg) over the uninoculated control (116.12 mg).

However, the interactions between Varieties x *Rhizobium*, Varieties X PSB, *Rhizobium* X PSB, Varieties X *Rhizobium* X PSB were non significant for dry weight of nodules.

4.4 UPTAKE STUDIES

4.4.1 Nitrogen uptake (kg/ha)

It was evident from the data depicted in table 16(a) that all the varieties differed significantly towards the nitrogen uptake. The maximum nitrogen uptake was found in P-89 (93.23 kg/ha), which was significantly higher than all other varieties. Arka Karthik was recorded with minimum nitrogen uptake (87.40 kg/ha), which was found to be significantly lower than all other varieties.

Rhizobium inoculation also had a significant influence on nitrogen uptake. The inoculation of seed with *Rhizobium* resulted in more nitrogen uptake i.e. 97.25 kg/ha, which was significantly more than inoculated control, which resulted in 83.08 kg/ha nitrogen uptake. Similarly, PSB inoculation also had a significant effect on nitrogen uptake. PSB increased the nitrogen uptake (96.61 kg/ha) over uninoculated control (83.72 kg/ha).

Further, the interaction between varieties and PSB was also found to be significant for nitrogen uptake. Maximum nitrogen uptake was recorded in P-89 (99.11 kg/ha), which remained at par with AP-3 (98.89 kg/ha). Minimum nitrogen uptake was recorded in Arka Karthik (94.21 kg/ha) which had at par results with Arka Apoorva (94.87 kg/ha)

The supplemental increase in nitrogen uptake was recorded when the seeds were inoculated with both *Rhizobium* and PSB. The maximum nitrogen uptake was found in R_1P_1 (103.04 kg/ha) followed by R_1P_0 (91.46 kg/ha). However, the uninoculated seeds R_0P_0 had significantly lowest nitrogen uptake (75.99 kg/ha).

The interaction between the varieties and their inoculation with *Rhizobium* and PSB also had a significant results. Varieties P-89 and AP-3 both had highest nitrogen uptake (103.81 kg/ha) when inoculated with both *Rhizobium* and PSB ($V_1R_1P_1$). At par results was recorded in all other varieties, i.e., Bonneville, Arka Karthik and Arka Apoorva, when inoculated with both *Rhizobium* and PSB. However, the minimum nitrogen uptake was found in interaction $V_2R_0P_0$ (73.69 kg/ha), when uninoculated with both *Rhizobium* and PSB, which had at par results with Arka Karthik and Arka Apoorva, both with uninoculated control.

4.4.2 Phosphorus uptake (kg/ha)

The perusal of data presented in table 17(a) showed that all the varieties had a significant effect on phosphorus uptake. The maximum phosphorus uptake was recorded in P-89 (13.19 kg/ha), which was significantly higher than all other varieties. However, Arka Apoorva is recorded with minimum phosphorus uptake (12.07 kg/ha), which was significantly lower than all other varieties.

It was found that when seeds were inoculated with *Rhizobium*, it resulted more phosphorus uptake (13.77 kg/ha), than the uninoculated seeds (11.69 kg/ha) [Table 17(b)]

Similarly PSB inoculation also had a significant effect on phosphorus uptake. PSB increased phosphorus uptake (14.09 kg/ha) over the uninoculated control which was recorded as 11.37 kg/ha.

All the varieties differed significantly towards phosphorus uptake, when the seeds were inoculated with PSB. Maximum phosphorus uptake was found in P-89 (14.67 kg/ha), which remained at par with AP-3 (14.62 kg/ha). Minimum phosphorus

Table 12 (a) : Effect of *Rhizobium* and PSB on size of nodules (length) mm

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	1.77	1.96	1.86
P_1	1.94	2.12	2.03
Mean	1.85	2.04	1.95
	Variety V_2		
	R_0	**R_1**	
P_0	1.75	2.08	1.91
P_1	1.98	2.14	2.06
Mean	1.87	2.11	1.99
	Variety V_3		
	R_0	**R_1**	
P_0	1.55	1.81	1.68
P_1	1.84	2.33	2.09
Mean	1.70	2.07	1.88
	Variety V_4		
	R_0	**R_1**	
P_0	1.71	2.01	1.86
P_1	1.78	2.05	1.91
Mean	1.74	2.03	1.89
	Variety V_5		
	R_0	**R_1**	
P_0	1.67	2.09	1.88
P_1	1.70	2.38	2.04
Mean	1.68	2.23	1.96

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 12(b) : Interaction effect of *Rhizobium* and PSB on size of nodules (length) mm

	R_0	**R_1**	**Mean**
P_0	1.69	1.99	1.84
P_1	1.85	2.20	2.03
Mean	1.77	2.10	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	N.S.	0.072
Rhizobium	0.202	0.064
Variety x *Rhizobium*	N.S.	0.144
PSB	0.134	0.046
Variety x PSB	N.S.	0.102
Rhizobium x PSB	N.S.	0.064
Variety x *Rhizobium* x PSB	N.S.	0.144

Table 13 (a): Effect of *Rhizobium* and PSB on size of nodules (width) mm

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	1.23	1.27	1.25
P_1	1.25	1.28	1.26
Mean	1.24	1.27	1.26
	Variety V_2		
	R_0	**R_1**	
P_0	1.31	1.55	1.43
P_1	1.37	1.77	1.57
Mean	1.34	1.66	1.50
	Variety V_3		
	R_0	**R_1**	
P_0	1.29	1.99	1.64
P_1	1.32	2.02	1.67
Mean	1.30	2.00	1.65
	Variety V_4		
	R_0	**R_1**	
P_0	1.15	1.3	1.22
P_1	1.32	1.47	1.39
Mean	1.23	1.38	1.31
	Variety V_5		
	R_0	**R_1**	
P_0	1.18	1.25	1.21
P_1	1.23	1.41	1.32
Mean	1.20	1.33	1.27

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 13 (b): Interaction effect of *Rhizobium* and PSB on size of nodules (width) mm

	R_0	**R_1**	**Mean**
P_0	1.23	1.47	1.35
P_1	1.30	1.59	1.44
Mean	1.26	1.53	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.14	0.04
Rhizobium	0.11	0.03
Variety x *Rhizobium*	0.25	0.08
PSB	0.09	0.03
Variety x PSB	N.S.	0.06
Rhizobium x PSB	N.S.	0.04
Variety x *Rhizobium* x PSB	N.S.	0.09

Table 14 (a): Effect of *Rhizobium* and PSB on fresh weight of nodules (mg)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	372.20	384.94	378.57
P_1	377.35	417.92	397.63
Mean	374.77	401.43	388.10
	Variety V_2		
	R_0	**R_1**	
P_0	377.93	401.40	389.66
P_1	392.83	413.34	403.09
Mean	385.38	407.37	396.37
	Variety V_3		
	R_0	**R_1**	
P_0	362.75	378.09	370.42
P_1	374.71	393.96	384.33
Mean	368.73	386.02	377.38
	Variety V_4		
	R_0	**R_1**	
P_0	354.38	389.59	371.99
P_1	370.71	413.33	392.02
Mean	362.55	401.46	382.00
	Variety V_5		
	R_0	**R_1**	
P_0	361.41	393.12	377.26
P_1	366.73	412.61	389.67
Mean	364.07	402.86	383.47

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 14 (b) : Interaction effect of *Rhizobium* and PSB on fresh weight of nodules (mg)

	R_0	**R_1**	**Mean**
P_0	365.73	389.43	377.58
P_1	376.46	410.23	393.35
Mean	371.10	399.83	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	6.00	1.84
Rhizobium	6.67	2.12
Variety x *Rhizobium*	N.S.	4.73
PSB	5.48	1.86
Variety x PSB	N.S.	4.16
Rhizobium x PSB	N.S.	2.63
Variety x *Rhizobium* x PSB	N.S.	5.88

Table 15 (a) : Effect of *Rhizobium* and PSB on dry weight of nodules (mg)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	114.34	124.90	119.62
P_1	121.41	132.01	126.71
Mean	117.87	128.45	123.16
	Variety V_2		
	R_0	**R_1**	
P_0	116.75	122.87	119.81
P_1	118.65	128.22	123.43
Mean	117.70	125.54	121.62
	Variety V_3		
	R_0	**R_1**	
P_0	109.74	117.35	113.55
P_1	115.50	125.66	120.58
Mean	112.62	121.51	117.06
	Variety V_4		
	R_0	**R_1**	
P_0	102.95	121.41	112.18
P_1	119.41	130.24	124.82
Mean	111.18	125.82	118.50
	Variety V_5		
	R_0	**R_1**	
P_0	110.11	120.77	115.44
P_1	112.28	129.74	121.01
Mean	111.19	125.26	118.22

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 15 (b) : Interaction effect of Rhizobium and PSB on dry weight of nodules (mg)

	R_0	**R_1**	**Mean**
P_0	110.78	121.46	116.12
P_1	117.45	129.17	123.31
Mean	114.11	125.32	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	3.36	1.03
Rhizobium	2.86	0.90
Variety x *Rhizobium*	N.S.	2.03
PSB	2.97	1.01
Variety x PSB	N.S.	2.26
Rhizobium x PSB	N.S.	1.43
Variety x *Rhizobium* x PSB	N.S.	3.20

uptake was recorded in Arka Apoorva (13.29 kg/ha), which was significantly lower than all other varieties.

The supplemental increase in phosphorus uptake was recorded when the seeds were inoculated with both *Rhizobium* and PSB (15.62 kg/ha). R_1P_1 had significant increase in Phosphorus uptake (15.62 kg/ha), followed by R_0P_1 (12.56 kg/ha). However, the minimum phosphorus uptake was found in uninoculated control (R_0P_0) i.e., 10.82 kg/ha.

The interaction between the varieties and their inoculation with both *Rhizobium* and PSB also had a significant effect towards phosphorus uptake. Variety P-89 had recorded maximum phosphorus uptake, i.e., 16.02 kg/ha when inoculated with both *Rhizobium* and PSB collectively ($V_1R_1P_1$), which had at par results with AP-3 and Bonneville when inoculated with both *Rhizobium* and phosphorus. Similarly, Arka Karthik recorded statistically lowest phosphorus uptake (10.59 kg/ha) when not inoculated with any bioinoculant. However, at par results was found in varieties P-89, AP-3, Bonneville and Arka Apoorva, under the uninoculated control.

In general, the *Rhizobium* and PSB inoculation resulted in an increase in the phosphorus uptake in all the varieties under study.

Table 16 (a) : Effect of *Rhizobium* and PSB on nitrogen uptake (kg/ha)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	78.17	96.52	87.34
P_1	94.42	103.81	99.11
Mean	86.29	100.17	93.23
	Variety V_2		
	R_0	**R_1**	
P_0	73.69	94.42	84.05
P_1	93.97	103.81	98.89
Mean	83.83	99.12	91.47
	Variety V_3		
	R_0	**R_1**	
P_0	78.86	89.89	84.37
P_1	88.72	103.17	95.94
Mean	83.79	96.53	90.16
	Variety V_4		
	R_0	**R_1**	
P_0	73.81	87.36	80.58
P_1	86.13	102.30	94.21
Mean	79.97	94.83	87.40
	Variety V_5		
P_0	75.43	89.10	82.26
P_1	87.65	102.10	94.87
Mean	81.54	95.60	88.57

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 16 (b): Interaction effect of *Rhizobium* and PSB on nitrogen uptake (kg/ha)

	R_0	**R_1**	**Mean**
P_0	75.99	91.46	83.72
P_1	90.18	103.04	96.61
Mean	83.08	97.25	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	1.03	0.31
Rhizobium	0.81	0.25
Variety x *Rhizobium*	N.S.	0.57
PSB	0.66	0.22
Variety x PSB	1.48	0.50
Rhizobium x PSB	0.93	0.31
Variety x *Rhizobium* x PSB	2.10	0.71

Table 17 (a) : Effect of *Rhizobium* and PSB on phosphorus uptake (kg/ha)

	Variety V_1		
Inoculation	**R_0**	**R_1**	Mean
P_0	10.63	12.79	11.71
P_1	13.32	16.02	14.67
Mean	11.98	14.40	13.19
	Variety V_2		
	R_0	**R_1**	
P_0	11.18	11.45	11.31
P_1	13.34	15.90	14.62
Mean	12.26	13.68	12.97
	Variety V_3		
	R_0	**R_1**	
P_0	11.08	12.26	11.67
P_1	12.29	15.88	14.09
Mean	11.68	14.07	12.88
	Variety V_4		
	R_0	**R_1**	
P_0	10.59	12.08	11.33
P_1	12.24	15.33	13.79
Mean	11.42	13.70	12.56
	Variety V_5		
P_0	10.62	11.07	10.84
P_1	11.61	14.97	13.29
Mean	11.12	13.02	12.07

NOTE: V_1=P-89, V_2=AP-3, V_3= Bonneville, V_4= Arka Karthik, V_5= Arka Apoorva, R_0= *Rhizobium* (uninoculated), R_1= *Rhizobium* (inoculated), P_0= PSB (un-inoculated), P_1= PSB (inoculated)

Table 17 (b): Interaction effect of *Rhizobium* and PSB on phosphorus uptake (kg/ha)

	R_0	**R_1**	**Mean**
P_0	10.82	11.93	11.37
P_1	12.56	15.62	14.09
Mean	11.69	13.77	

Factors	**C.D.(0.05)**	**SE(m±)**
Varieties	0.20	0.06
Rhizobium	0.23	0.07
Variety x *Rhizobium*	N.S.	0.17
PSB	0.21	0.07
Variety x PSB	0.48	0.16
Rhizobium x PSB	0.30	0.10
Variety x *Rhizobium* x PSB	0.66	0.23

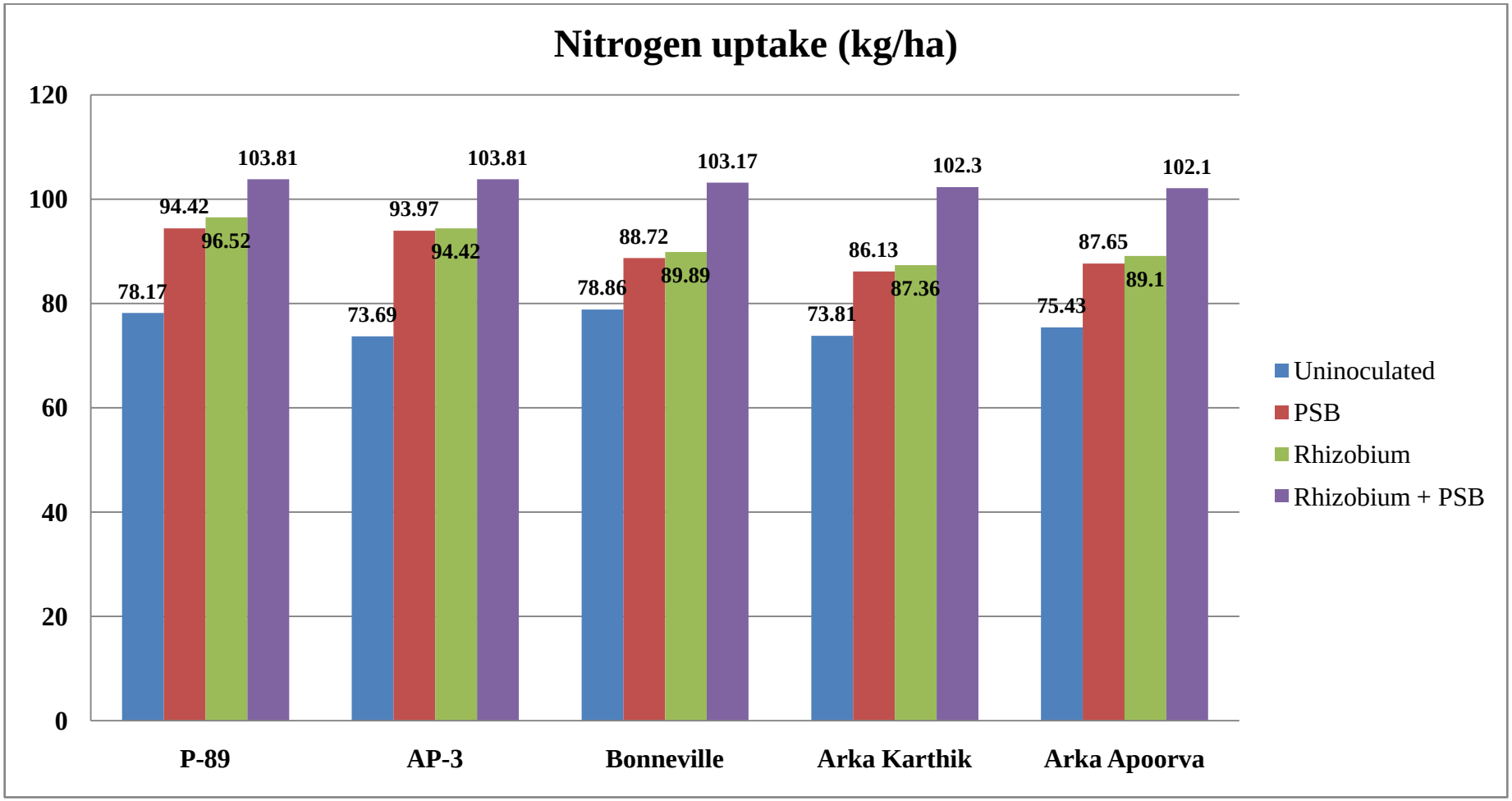


Fig. 5. Effect of *Rhizobium* and PSB on nitrogen uptake (kg/ha)

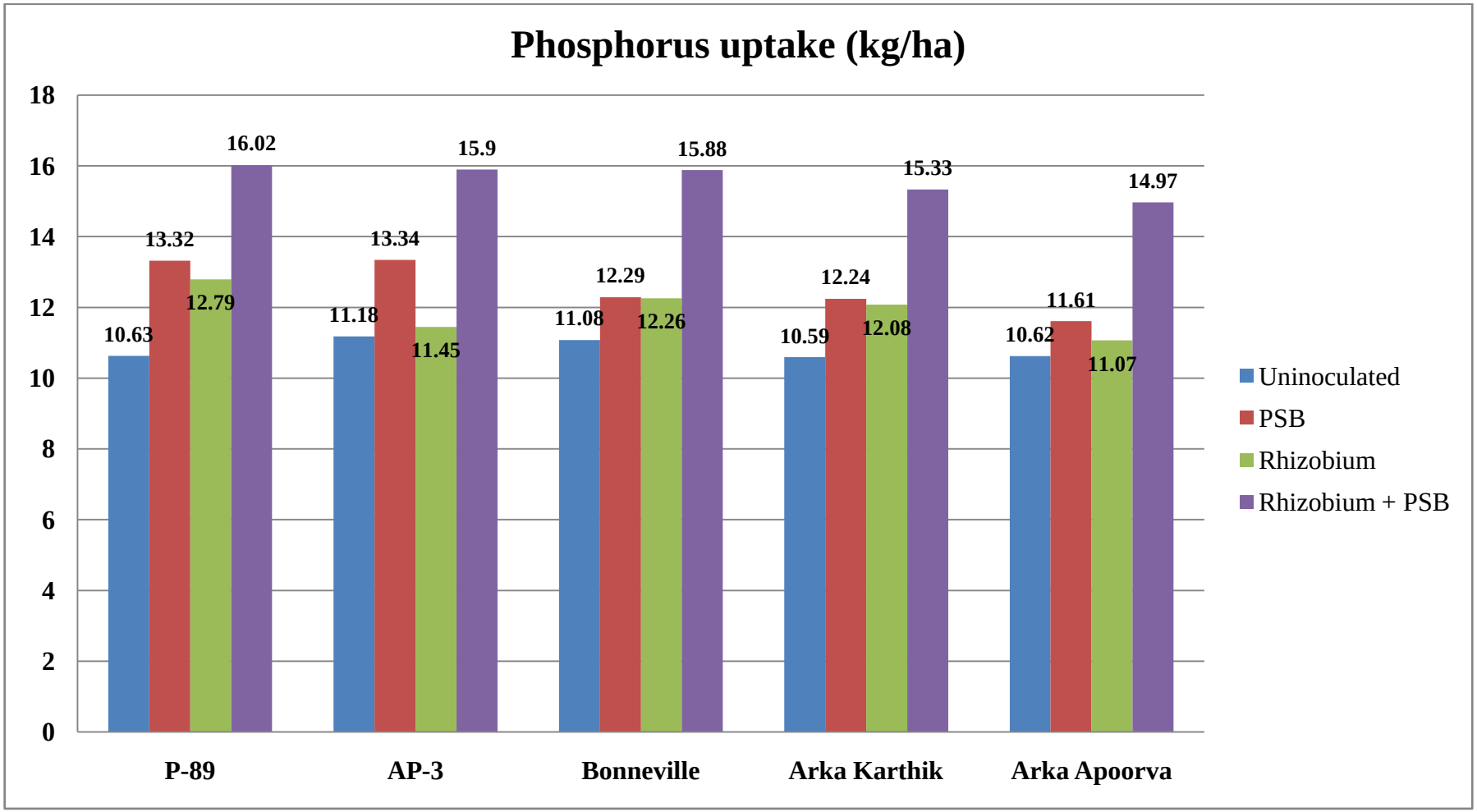


Fig.6. Effect of *Rhizobium* and PSB on phosphorus uptake (kg/ha)

Chapter-5

Discussion

CHAPTER-V

DISCUSSION

In this chapter an attempt has been made to study the possible reasons of the effect of seed inoculation with *Rhizobium* and Phosphorus Solubilising Bacteria on various growth parameters, yield and nutrient uptake in garden pea. In order to make the findings more illustrative, reasons for effects been discussed separately. The results have been duly supported by references available in the literature as and where necessary. The findings of the experiment entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)"** has been described and explained with ample support as well as the reported postulation from various works within the country and abroad.

5.1 GROWTH AND YIELD STUDIES

Days to 50% flowering indicates the earliness of the crop. All the varieties varied significantly towards this parameter due to inherent genetic makeup of the varieties. The variety AP-3 was significantly earliest in 50% flowering and Arka Karthik was the late one. The inoculation of *Rhizobium* and Phosphorus Solubilising Bacteria also influenced 50% flowering. The phosphorus through PSB increased the availability of nitrogen and nitrogen further increased the cell division and cell differentiation. Thus, the plant came into flowering in the early stages of its reproductive phase. The results are in accordance with the findings of Mandloi *et al.* (2020), and Yadav and Yadav (2011)

Statistical analysis for plant height showed significant differences among the varieties and their inoculation with *Rhizobium* and Phosphorus Solubilising Bacteria. Arka Apoorva was tallest among all the varieties, and P-89 was the smallest one. The variation in plant height was due to the inherent genetic makeup of the varieties, and nitrogen and phosphorus application certainly improved the growth of the pea plant. It is an established fact that nitrogen and phosphorus are the major essential nutrients needed in adequate quantity in available form for proper growth and development of pea. It helps in securing good establishment and better root development of plants particularly at early growth stages. The phosphorus also increases the availability of nitrogen which is the most essential element for the early growth of plants. Similar

results have been reported by Mandloi *et al.* (2020), Das *et al.* (2015), Patel *et al.* (2013). Similarly, the improvement of plant height due to PSB and *Rhizobium* inoculation in mung bean was also reported by Prasad *et al.* (2014). Kumawat *et al.* (2010) reported that since the phosphorus has a specific role in nodule formation and microbial activity in the soil. The adequate supply of this nutrient might have increased the height of the plants in gram.

All the varieties had non-significant effect towards leaf area index. As most of the varieties had viney stature and similar expansion pattern. So, they did not differ towards the leaf area. However, the inoculation of seeds with *Rhizobium* and PSB increased the LAI. It might be due to the greater assimilation of major nutrients and more activity of *Rhizobium* and PSB which lead to effective nodule formation and more activity in the soil. (Das *et al.*, 2015)

Number of pods per plant varied significantly among all the varieties and their inoculation with *Rhizobium* and PSB. Maximum number of pods were recorded in P-89 and minimum in Arka Apoorva. Moreover, the number of pods per plant were also more in inoculated as compared to uninoculated control. The single inoculation either with *Rhizobium* or PSB and dual inoculation with both of them had significant effect on number of pods per plant. This could be ascribed to enhanced availability of nitrogen in *Rhizobium* inoculation, phosphorus in PSB inoculation, and both nitrogen and phosphorus in dual inoculation. Bhandal *et al.* (1989) and Alagawadi and Gaur (1988) also reported similar results. The increase in number of pods due to dual inoculation by *Rhizobium* and PSB may be attributed to profused nodulation leading to increase nitrogen fixation, which in turns had a positive effect on the photosynthetic organs and rates. This is in close agreement with findings of Sharma and Ahlawat (1989).

The results further revealed that all the varieties varied significantly for their pod weight. The cultivar P-89 had maximum green pod weight and the minimum was recorded in Arka Apoorva and Arka Karthik. This variation might be due to the inherent potential of the cultivars and their interaction with the soil and climatic conditions. Agarwal *et al.* (2006) had reported similar results in garden pea. In general, the pod size is a varietal character, but it is also affected by vigour of plant (Bozoghu *et al.* (2007). Single and dual inoculation with *Rhizobium* and PSB improved the pod weight. The associated effect of *Rhizobium* and APSB in dual

inoculation increased and balance availability of both nitrogen and phosphorus in the inoculated plots. Similar results were also reported by Srivastava and Ahlawat (1995), and Yadav and Yadav (2011)

The results also showed that the varieties had a significant effect in shelling percentage, whereas the minimum was recorded in Bonneville. The single and dual inoculation of *Rhizobium* and PSB also had a significant response towards shelling percentage. The inoculated ones found superior than control. Vimala and Natrajan (2000) also reported increase in shelling percentage with the application of biofertilizers (*Rhizobium* and PSB) Das *et al.* (2015) also reported lower shelling percentage in treatments where no inoculation of pea seed was done with *Rhizobium*. They also reported the synergistic effect of *Rhizobium* and PSB that played a significant role in the improvement of shelling percentage of peas. The findings are in agreement with that of Yadav (2004) and Yadav and Yadav (2011).

The green pod yield increase might be explained on the basis of enhancement of plant growth as a result of nutrient application leading to more pod weight and favourable effect on pod characters. All the varieties varied significantly towards this parameter. The maximum pod yield was recorded in P-89 and minimum in Arka Apoorva. Single and dual inoculation improved the pod yield over the control. These results corroborated the findings of Yadav and Yadav (2011), Vimala and Natrajan (2000), Yadav (2004), Bhattari *et al.* (2003), Srivastava and Ahlawat (1995). Moreover, green pod yield was also more in inoculated as compared to uninoculated control. Greater availability of nutrients due to inoculation by the biofertilizers especially during the pod formation and development stages of more vigorous varieties like P-89 might have translocated the maximum of its reserved food material towards pod formation and development, ultimately increasing the pod yield (Habib and Zamin, 2003). Similarly, Dalal and Nandkar (2010) obtained the highest pod yield in pigeon pea with triple inoculation of *Rhizobium* species + Azotobacter + *Pseudomonas striata* along with the application of phosphorus @ 30 kg /ha. Shamad (2019) also reported that the interactive use of Jawahar Matar-3 + *Rhizobium* inoculation produced large quantity of pod yield, i.e., 48.50 qt/ha which was significantly outstanding among other treatments.

5.2 QUALITY PARAMETERS

All the varieties differed significantly for TSS contents when inoculated with *Rhizobium* and PSB. The increase in the values of TSS due to inoculation of seeds with *Rhizobium* was probably due to more fixation of nitrogen resulting in better utilization of nutrients by the plants which led to more chlorophyll formation and other quality parameters (Yadav, 2006). The PSB enhanced the availability of phosphorus to the plant which might have utilized for the crop for greater root development and nodulation which in turn resulted in high nitrogen fixation in the soil by the nodules. Thus, increased availability of nitrogen and phosphorus might have resulted in greater uptake by the plant for proper development and ultimately increased the TSS content. However, the combined inoculation of seeds with *Rhizobium* + PSB was more beneficial in enhancing the TSS content due to increased solubility of Phosphorus and higher nitrogen fixation in nodules as corroborated by the findings of Gupta *et al.* (1998), El- Sayed (1999), Vimala and Natrajan (2000).

The dry matter content being an important processing attribute varied significantly among all the varieties. It also varied in response to the inoculation of seeds with *Rhizobium* and PSB, thus increase in dry matter content might be due to the better cell division and meristematic tissues (Singh and Ahuja, 1985).

5.3 NODULATION STUDIES

The development of effective root nodules is generally used as an index for measuring the nitrogen fixing capacity of legumes (Rani *et al.*, 2016). All the varieties differed significantly for the number of nodules in their roots. P-89 developed maximum number of nodules in their roots. Thus, depicting more utilization of the nitrogen and thus corresponding towards the earliness. Moreover, all the varieties responded significantly towards the inoculation of seeds with *Rhizobium* and PSB either singly or dual inoculation. The increase in number of nodules enhanced the nitrogenase activity and leghaemoglobin content of the nodules. Thus contributing greatly towards the atmospheric nitrogen fixation. The increase in number of nodules per plant due to dual inoculation was also reported by Srivastava and Ahlawat (1995), who reported that the PSB resulted in more phosphorus uptake, which is associated with vital functions such as utilization of sugar and starch, nucleus formation, cell, photosynthesis and root growth. Dual inoculation of *Rhizobium* and PSB was also

reported by Mishra and Prasad (2010). The favourable effect of *Rhizobium* inoculation has also been reported by Singh (2007). The *Rhizobium* inoculation increased the nitrogenase activity and also synthesis of growth promoting substances like Indole Acetic Acid, which took part in the nodulation process.

The size of nodules varied significantly in response to the inoculation of *Rhizobium* and Phosphorus Solubilising Bacteria. The length of nodules varied significantly in response to the individual inoculation of *Rhizobium* and Phosphorus Solubilising Bacteria; whereas all the varieties varied significantly for the width of nodules in response to the inoculation. The increase in length and width of nodules in response to *Rhizobium* and PSB might be due to the additive effect of *Rhizobium* and PSB. The favourable effect of *Rhizobium* and PSB inoculation resulted in more nitrogenase activity and secretion of organic acids such as acetic, formic, propionic , lactic, glycolic, fumaric and succinic acids, resulting in active solubilisation and utilization of phosphates by the crop, thus increasing the size of the nodules in the roots. Similar studies have also been conducted by Singh (2007).

The fresh and dry weight of nodules indicated their healthiness resulting in higher capacity to fix atmospheric nitrogen. The maximum weight was obtained with composite culture of *Rhizobium* and PSB followed by *Rhizobium* and PSB containing treatment. (Tyagi *et al.,* 2003). All the varieties having significant effect on fresh weight and dry weight. The maximum fresh weight was recorded in AP-3, whereas the maximum dry weight was recorded in P-89. However, both minimum fresh weight and dry weight was recorded in Bonneville. Both the parameters also varied significantly when inoculated with *Rhizobium* and PSB alone. When the seed were inoculated with *Rhizobium* and PSB, either alone or in combination, it gives more fresh and dry weight, when compared with uninoculated control. Similar results was recorded by Rani *et al.* (2016) and Rather *et al.* (2010). Srivastava and Ahlawat (1995) also observed that the maximum dry weight of nodules per plant of pea was obtained when the seeds was inoculated with both *Rhizobium* and PSB.

5.4 UPTAKE STUDIES

Plant nutrient uptake, i.e., phosphorus and nitrogen content was also enhanced by inoculation of *Rhizobium* and Phosphate Solubilizing Bacteria. The increase in nitrogen content in soil was due to favourable effect of *Rhizobium* and PSB on root

nodulation and thereby, nitrogen fixation. PSB helps in the solubilisation of insoluble phosphate into available phosphorus in the soil. These findings are in agreement with Rudresh *et al.* (2005) who reported that the simultaneous inoculation of *Rhizobium* and PSB gave a higher nutrient uptake as compared to single inoculation and uninoculated control. Enhancement of nutrient uptake by plants with inoculation has also reported by Abid *et al.* (2016), Rokhzadi and Toashish (2011) and Wani *et al.* (2007). All the varieties varied significantly towards nitrogen and phosphorus uptake. In P-89, both nitrogen and phosphorus uptake were highest. However, the minimum nitrogen uptake and phosphorus uptake was recorded in Arka Karthik and Arka Apoorva respectively. According to Rani *et al.* (2016), the highest and the lowest nitrogen and phosphorus uptake was recorded in RDF + *Rhizobium* +PSB + PGPR and control treatments, respectively. Combined inoculation of *Rhizobium* + PSB recorded highest total nitrogen uptake and phosphorus uptake over no inoculation in case of nitrogen and phosphorus uptake respectively (Bhat *et al.*, 2013).

Chapter-6

Summary and Conclusion

CHAPTER-VI

SUMMARY AND CONCLUSION

The present study entitled "**Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)**" was carried out for various growth, yield and quality parameters with nodulation and uptake studies. The main objectives were to study the effect of *Rhizobium* and PSB on nodulation ability of garden pea cultivars, to study yield response of different garden pea cultivars under co-inoculation of *Rhizobium* and PSB, and to study nitrogen and phosphorus uptake in different garden pea cultivars. The experiment was carried out in Split-split plot design with three replications during year 2019-2020. The results obtained from the study are summarized below:

6.1 GROWTH AND YIELD STUDIES

The variety AP-3 was earliest in 50% flowering as compared to other varieties, and the inoculation of *Rhizobium* and PSB also influenced this parameter. Maximum plant height was recorded in Arka Apoorva and P-89 was the smallest one. Similarly, the inoculation of *Rhizobium* and PSB also increased the plant height. All the varieties had non- significant effect Leaf Area Index. P-89 had recorded maximum values for almost all the yield contributing factors, i.e., number of pods per plant, pod weight, shelling percentage and ultimately the green pod yield. All these parameters were also influenced by the *Rhizobium* and PSB inoculation, which clearly indicates the synergistic effect of these bio agents. Arka Apoorva recorded minimum values of the yield contributing parameters.

6.2 QUALITY PARAMETERS

There was a variable response of the varieties towards the quality parameters. Maximum TSS content was recorded in Bonneville; whereas AP-3 recorded maximum dry matter content. As visible from the trends, Arka Apoorva had recorded minimum values of the parameters.

6.3 NODULATION STUDIES

Root nodules are an index for measuring the nitrogen fixing capacity and all the varieties differed significantly towards the nodulation ability. P-89 had developed the maximum number of nodules in their roots and Arka Apoorva had recorded the

minimum number of nodules per plant. The supplemental effect of dual inoculation of *Rhizobium* and PSB was also visible in the development and growth of nodules. The interaction studies showed that all the interaction were non-significant towards the size of the nodules. AP-3 recorded maximum fresh weight of the nodules because of its earliness, whereas P-89 had recorded the maximum dry weight of nodules.

6.4 UPTAKE STUDIES

The uptake of phosphorus and nitrogen content was enhanced by the inoculation of *Rhizobium* and PSB, and all the varieties varied significantly towards the nutrient uptake. Maximum nitrogen and phosphorus uptake was recorded in P-89, and minimum uptake was recorded in Arka Apoorva.

CONCLUSION

So, it can be concluded from the investigation that variety P-89 inoculated with *Rhizobium* and Phosphorus Solubilizing Bacteria had maximum values of yield contributing factors, nodulation ability and ultimately enhanced the uptake of nitrogen and phosphorus nutrients.

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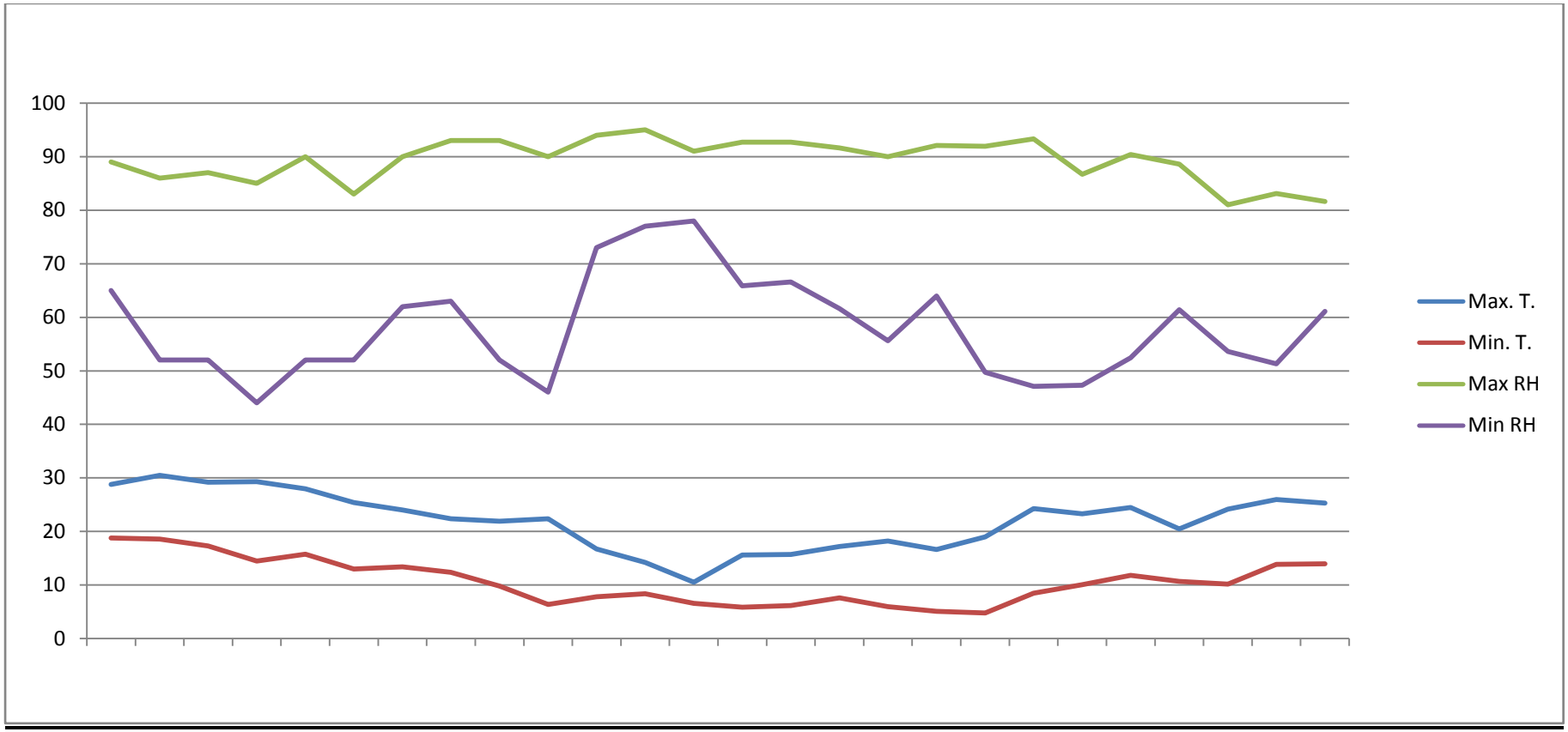
APPENDIX I(B)

METEOROLOGICAL DATA DURING THE CROPPING SEASON 2019-2020



Appendix

APPENDIX I(A)

METEROLOGICAL DATA DURING THE CROPPING SEASON 2019-2020

Standard Week	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum	
1-7 Oct	28.8	18.8	89	65	21.4
7-14 Oct	30.5	18.6	86	52	0
15-21 Oct	29.2	17.3	87	52	9.2
22-28 Oct	29.3	14.5	85	44	0
29-4 Nov	28	15.8	90	52	0
5-11 Nov	25.4	13	83	52	51.8
12-18 Nov	24	13.4	90	62	2.8
19-25 Nov	22.4	12.4	93	63	0.8
26-2 Dec	21.9	9.8	93	52	22
3-9 Dec	22.4	6.4	90	46	0
10-16 Dec	16.7	7.8	94	73	82.6
17- 23 Dec	14.2	8.4	95	77	1.2
24-31 Dec	10.5	6.6	91	78	0
1-7 Jan	15.6	5.9	92.7	65.9	7.8
8-14 Jan	15.7	6.2	92.7	66.6	55.6
15-21 Jan	17.2	7.6	91.6	61.6	0.0
22-28 Jan	18.2	6.0	90.0	55.6	0.0
29-4 Feb	16.6	5.1	92.1	64.0	18.2
5-11 Feb	19.0	4.8	91.9	49.7	0.0
12-18 Feb	24.3	8.5	93.3	47.1	0.0
19-25 Feb	23.3	10.1	86.7	47.3	9.2
26-4 Mar	24.5	11.8	90.4	52.4	20.0
5-11 Mar	20.5	10.7	88.6	61.4	35.4
12-18 Mar	24.2	10.2	81.0	53.6	40.8
19-25 Mar	26.0	13.9	83.1	51.3	9.0
26-1 Apr	25.3	14.0	81.6	61.1	50.4

Source: Meterological section, Division of Agronomy,Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha-180009

APPENDIX II

ANALYSIS OF VARIANCE FOR GROWTH AND YIELD PARAMETERS OF GARDEN PEA

DAYS TO 50% FLOWERING

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	4.9			
Factor A	4	6,102.73	1,525.68	1,317.14	0
Error(a)	8	9.267	1.158		
Factor B	1	35.267	35.267	54.256	0.00002
Int A X B	4	5.733	1.433	2.205	0.14159
Error(b)	10	6.5	0.65		
Factor C	1	68.267	68.267	66.065	0
Int A X C	4	3.4	0.85	0.823	0.52608
Int B X C	1	0.6	0.6	0.581	0.45495
Int A X B X C	4	5.067	1.267	1.226	0.33139
Error(c)	20	20.667	1.033		
Total	59	6,262.40			

PLANT HEIGHT (cm)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	18.225			
Factor A	4	867.837	216.959	26.972	0.00011
Error(a)	8	64.35	8.044		
Factor B	1	414.175	414.175	35.971	0.00013
Int A X B	4	190	47.5	4.125	0.03147
Error(b)	10	115.142	11.514		
Factor C	1	39.655	39.655	5.695	0.02701
Int A X C	4	14.457	3.614	0.519	0.72272
Int B X C	1	1.228	1.228	0.176	0.67905
Int A X B X C	4	3.182	0.795	0.114	0.976
Error(c)	20	139.266	6.963		
Total	59	1,867.52			

LEAF AREA INDEX

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.014			
Factor A	4	0.034	0.008	2.183	0.16133
Error(a)	8	0.031	0.004		
Factor B	1	0.187	0.187	58.661	0.00002
Int A X B	4	0.003	0.001	0.263	0.89479
Error(b)	10	0.032	0.003		
Factor C	1	0.038	0.038	15.929	0.00072
Int A X C	4	0.003	0.001	0.322	0.86017
Int B X C	1	0.004	0.004	1.548	0.22785
Int A X B X C	4	0.01	0.002	0.996	0.43275
Error(c)	20	0.048	0.002		
Total	59	0.403			

NUMBER OF PODS/PLANT

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.901			
Factor A	4	4,081.59	1,020.40	416.132	0
Error(a)	8	19.617	2.452		
Factor B	1	70.42	70.42	50.093	0.00003
Int A X B	4	17.638	4.409	3.137	0.06492
Error(b)	10	14.058	1.406		
Factor C	1	144.526	144.526	183.41	0
Int A X C	4	16.505	4.126	5.236	0.00473
Int B X C	1	5.519	5.519	7.004	0.01549
Int A X B X C	4	6.047	1.512	1.918	0.14665
Error(c)	20	15.76	0.788		
Total	59	4,392.58			

POD WEIGHT (g)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0			
Factor A	4	69.377	17.344	270.846	0
Error(a)	8	0.512	0.064		
Factor B	1	5.617	5.617	112.556	0
Int A X B	4	1.062	0.266	5.32	0.01469
Error(b)	10	0.499	0.05		
Factor C	1	3.155	3.155	46.103	0
Int A X C	4	1.366	0.342	4.991	0.00591
Int B X C	1	0.06	0.06	0.871	0.36186
Int A X B X C	4	0.309	0.077	1.13	0.37075
Error(c)	20	1.369	0.068		
Total	59	83.327			

SHELLING PERCENTAGE (%)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	1.859			
Factor A	4	534.452	133.613	281.48	0
Error(a)	8	3.797	0.475		
Factor B	1	17.068	17.068	99.99	0
Int A X B	4	1.468	0.367	2.149	0.14885
Error(b)	10	1.707	0.171		
Factor C	1	27.432	27.432	79.407	0
Int A X C	4	2.606	0.652	1.886	0.15233
Int B X C	1	2.594	2.594	7.509	0.01262
Int A X B X C	4	3.615	0.904	2.616	0.06598
Error(c)	20	6.909	0.345		
Total	59	603.507			

GREEN POD YIELD (q/ha)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	2.499			
Factor A	4	17,229.54	4,307.38	1,833.74	0
Error(a)	8	18.792	2.349		
Factor B	1	654.67	654.67	661.339	0
Int A X B	4	108.26	27.065	27.341	0.00002
Error(b)	10	9.899	0.99		
Factor C	1	226.896	226.896	112.682	0
Int A X C	4	53.019	13.255	6.583	0.0015
Int B X C	1	0.677	0.677	0.336	0.56863
Int A X B X C	4	43.275	10.819	5.373	0.00419
Error(c)	20	40.272	2.014		
Total	59	18,387.80			

APPENDIX III

ANALYSIS OF VARIANCE FOR QUALITY PARAMETERS OF GARDEN PEA

TSS (^{0}Brix)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.443			
Factor A	4	150.446	37.611	665.844	0
Error(a)	8	0.452	0.056		
Factor B	1	4.805	4.805	41.387	0.00008
Int A X B	4	0.296	0.074	0.637	0.64778
Error(b)	10	1.161	0.116		
Factor C	1	1.198	1.198	15.005	0.00095
Int A X C	4	0.33	0.083	1.034	0.41411
Int B X C	1	0.017	0.017	0.211	0.65074
Int A X B X C	4	0.098	0.024	0.306	0.87036
Error(c)	20	1.596	0.08		
Total	59	160.842			

DRY MATTER CONTENT (%)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.26			
Factor A	4	19.513	4.878	17.111	0.00055
Error(a)	8	2.281	0.285		
Factor B	1	8.117	8.117	46.859	0.00004
Int A X B	4	0.819	0.205	1.181	0.37614
Error(b)	10	1.732	0.173		
Factor C	1	3.336	3.336	17.263	0.00049
Int A X C	4	0.355	0.089	0.459	0.76452
Int B X C	1	0.086	0.086	0.446	0.5117
Int A X B X C	4	0.193	0.048	0.25	0.90607
Error(c)	20	3.865	0.193		
Total	59	40.558			

APPENDIX IV

ANALYSIS OF VARIANCE FOR NODULATION STUDIES OF GARDEN PEA

NUMBER OF NODULES/PLANT

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	6.079			
Factor A	4	870.134	217.533	99.531	0
Error(a)	8	17.485	2.186		
Factor B	1	9,678.42	9,678.42	4,350.09	0
Int A X B	4	233.935	58.484	26.286	0.00003
Error(b)	10	22.249	2.225		
Factor C	1	4,832.00	4,832.00	1,350.34	0
Int A X C	4	198.552	49.638	13.872	0.00001
Int B X C	1	435.646	435.646	121.744	0
Int A X B X C	4	223.178	55.794	15.592	0.00001
Error(c)	20	71.567	3.578		
Total	59	16,589.24			

SIZE OF NODULES

(a)Length (mm)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.172			
Factor A	4	0.1	0.025	0.396	0.80619
Error(a)	8	0.502	0.063		
Factor B	1	1.61	1.61	13.024	0.00478
Int A X B	4	0.247	0.062	0.499	0.73752
Error(b)	10	1.237	0.124		
Factor C	1	0.525	0.525	8.435	0.00877
Int A X C	4	0.204	0.051	0.822	0.52648
Int B X C	1	0.011	0.011	0.176	0.67965
Int A X B X C	4	0.102	0.026	0.411	0.79889
Error(c)	20	1.244	0.062		
Total	59	5.953			

Width (mm)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.072			
Factor A	4	1.456	0.364	16.364	0.00064
Error(a)	8	0.178	0.022		
Factor B	1	1.072	1.072	28.118	0.00035
Int A X B	4	0.832	0.208	5.453	0.0136
Error(b)	10	0.381	0.038		
Factor C	1	0.129	0.129	4.49	0.0468
Int A X C	4	0.055	0.014	0.475	0.75345
Int B X C	1	0.011	0.011	0.39	0.53933
Int A X B X C	4	0.02	0.005	0.174	0.94903
Error(c)	20	0.574	0.029		
Total	59	4.779			

FRESH WEIGHT OF NODULES (mg)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	155.222			
Factor A	4	2,486.23	621.558	15.233	0.00082
Error(a)	8	326.427	40.803		
Factor B	1	12,379.70	12,379.70	91.854	0
Int A X B	4	1,158.12	289.529	2.148	0.149
Error(b)	10	1,347.76	134.776		
Factor C	1	3,728.30	3,728.30	35.907	0.00001
Int A X C	4	149.657	37.414	0.36	0.83383
Int B X C	1	381.799	381.799	3.677	0.06956
Int A X B X C	4	408.936	102.234	0.985	0.43834
Error(c)	20	2,076.66	103.833		
Total	59	24,598.81			

DRY WEIGHT OF NODULES (mg)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	13.572			
Factor A	4	315.054	78.764	6.154	0.01454
Error(a)	8	102.384	12.798		
Factor B	1	1,882.89	1,882.89	75.914	0.00001
Int A X B	4	111.078	27.769	1.12	0.40027
Error(b)	10	248.03	24.803		
Factor C	1	776.23	776.23	25.245	0.00006
Int A X C	4	135.47	33.867	1.101	0.38312
Int B X C	1	4.006	4.006	0.13	0.72192
Int A X B X C	4	88.169	22.042	0.717	0.59029
Error(c)	20	614.961	30.748		
Total	59	4,291.84			

APPENDIX V

ANALYSIS OF VARIANCE FOR UPTAKE STUDIES OF GARDEN PEA

NITROGEN UPTAKE (kg/ha)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.312			
Factor A	4	255.642	63.911	52.959	0.00001
Error(a)	8	9.654	1.207		
Factor B	1	3,008.91	3,008.91	1,496.30	0
Int A X B	4	11.705	2.926	1.455	0.28648
Error(b)	10	20.109	2.011		
Factor C	1	2,489.92	2,489.92	1,638.56	0
Int A X C	4	22.255	5.564	3.661	0.02148
Int B X C	1	25.612	25.612	16.855	0.00055
Int A X B X C	4	137.83	34.457	22.676	0
Error(c)	20	30.392	1.52		
Total	59	6,012.34			

PHOSPHORUS UPTAKE (kg/ha)

Source of Variation	df	SS	MSS	F-Cal	Significance
Replication	2	0.357			
Factor A	4	9.069	2.267	46.748	0.00001
Error(a)	8	0.388	0.048		
Factor B	1	65.228	65.228	377.596	0
Int A X B	4	2.169	0.542	3.139	0.06481
Error(b)	10	1.727	0.173		
Factor C	1	110.649	110.649	692.482	0
Int A X C	4	1.906	0.477	2.983	0.04403
Int B X C	1	14.271	14.271	89.311	0
Int A X B X C	4	2.509	0.627	3.926	0.01642
Error(c)	20	3.196	0.16		
Total	59	211.469			

Vita

CURRICULUM VITA

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OGPA	7.97
Title of Master's Thesis	Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)

CERTIFICATE-IV

Certified that all the necessary corrections as suggested by the external examiner and the Advisory Committee have been duly incorporated in the thesis entitled **"Cultivars Response to *Rhizobium* and Phosphorus Solubilising Bacteria for Nodulation, Growth and Yield in Garden Pea (*Pisum sativum* var. *hortense*)"** submitted by **Ms. Verinder Kour, Registration No. J-18-M-591.**

Dr. Sandeep Chopra
Major Advisor and Chairman
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Place: Jammu

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