

Isolation and Characterization of Phosphate Solubilising Rhizobia Nodulating Wild Field pea (*Pisum sativum* var. *abyssinicum*) from Southern Tigray, Ethiopia

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Abstract

Phosphorus is the second limiting nutrients next to nitrogen as well as the least mobile element in the soil. This nutrient is one of the major constraint for low productivity of wild field pea in the study site. Hence, the development of environmental friendly and economically accepted to subsistent farmer is undeniably important. Thus, this experiment was initiated to isolate and characterize inorganic phosphate solubilizing rhizobia from root nodules of field pea (*Pisum sativum* var. *abyssinicum*) were characterized for their inorganic phosphate solubilisation ability on Pikovskaya liquid and solid media. Results revealed that all isolates were gram negative, failed to grow on peptone glucose agar, ketolactose test and did not absorb congo-red upon incubation period. Results showed that phosphate solubilisation index of root nodulating bacteria on in vitro Pikovskaya's agar medium varied from 1.54 to 2.70. Inorganic phosphate solubilisation in broth medium dissolved insoluble $\text{Ca}_3(\text{PO}_4)_2$ was within the range of 16.59-23.95 mg plant⁻¹ with pH drop from 7.01 to 5.33. Among the tested rhizobia isolates, HUDRI-8 and HUDRI-25 was found to be highest phosphate solubilisation compared to the remaining isolates, served as efficient phosphate solubilizers, and could be used for further test under field condition. Finally, those isolates effective in N₂ fixation and able to solubilise inorganic P were found to be effective in promoting nodulation and plant growth under greenhouse condition in soil having high and low background rhizobia nodulating wild field pea.

Keywords: Field pea, Phosphate solubilising rhizobia, *Pisum sativum* var. *abyssinicum*, Rhizobium

INTRODUCTION

Phosphorus (P) is a major growth limiting nutrient unlike nitrogen, there is no large atmospheric source that can be made biologically available (Ezawa *et al.*, 2002). In most soils, its content is about 0.05% of which only 0.1% is plant available (Achal *et al.*, 2007). Besides this, inorganic P fertilizer is the main sources of P in the agricultural soils, although 75 to 90% of the added P fertilizer is precipitated by iron, aluminium and calcium complexes present in the soil system (Turan *et al.*, 2006). According to Antoun *et al.*, 1998, report many soil bacteria and fungi have the ability to solubilize phosphorus (P) and make it available to plants. Microorganisms are central point to the soil P cycling and play a significant role in consent the conversion of the element between different inorganic and organic soil P fractions, then releasing available P for plant growth (Oberson, 2001). Phosphorus biofertilizers can help to increase the accessibility of accumulated phosphates for plant growth by solubilization (Gyaneshwar *et al.*, 2002). The involvement of microorganisms in inorganic

phosphates solubilization was reported as early as 1903 (Khan *et al.*, 2007), and the presence of these microorganisms (PSMs) are everywhere, while their numbers are vary from soil to soil. Among the microbial populations present in the soil, P solubilising bacteria constitute 1-50% and P solubilizing fungi are 0.1 to 0.5% (Chen *et al.*, 2006). The most important P solubilizing bacterial genera are *Pseudomonas*, *Bacillus*, *Rhizobium*, *Burkholderia*, *Achromobacter*, *Agrobacterium*, *Micrococcus*, *Aereobacter*, *Flavobacterium* and *Erwinia* (Rodriguez and Fraga, 1999). This study found that out of 13 bacterial strains of different genera that screening on different insoluble mineral phosphate substrates were indicated that *Rhizobium*, *Pseudomonas* and *Bacillus* species were the most powerful P solubilizers. Tandon (1987) observed that in 10 out of 37 experiments phosphate solubilizing bacteria (PSB) inoculations resulted in 10-15% increment in crop yields. Khalil (1995) also investigated 10 bacteria and 3 fungi being able to solubilize phosphate on the basis of large clear zone on solid media. *Rhizobium leguminosarum* is involving in phosphate solubilization as well as biological nitrogen fixation (BNF) through the root nodules of bacteria (Gyaneshwar *et al.*, 2002). During phosphate solubilization process, 2-ketoglucolnic acid is the most synthesized organic acid (Halder *et al.*, 1990). Phosphate solubilizing rhizobia has been shown to increase the growth of maize and lettuce (Chabot *et al.*, 1996). The multi-functionality exhibited by *R. leguminosarum* makes it important in food production in terms of reducing cost and improving efficiency of P fertilization, especially in P-limited soils (Jia Xie, 2008). So far, phosphate solubilizing of fababean and chickpea nodulating rhizobial isolates from Ethiopian soils have been done by several authors (Girmaye *et al.*, 2014, Assefa *et al.*, 2010 and Mulissa *et al.*, 2016). Feredeegn, 2013 also assessed the phosphate solubilization of rhizosphere and endophytic bacteria from sugarcane (*Saccharum officinarum* L.). Although the phenotypic and symbiotic effectiveness of rhizobia nodulating field pea (*pisum sativum* var. *sativum*) in Ethiopian soils were studied by Aregu *et al.*, 2012; Fano, 2010 and Kassa *et al.*, 2015), the phosphate solubilizing efficacy, symbiotic effectiveness of rhizobia nodulating field pea (*pisum sativum* var. *abyssinicum*) is not well investigated. Therefore, this study was designed to isolate and characterizing indigenous phosphate solubilizing root nodulating bacteria of field pea (*pisum sativum* var. *abyssinicum*) and their effect on converting insoluble P in to soluble P and effectiveness on soil culture.

Material and Methods

73 Soil sampling site and sample collection

74 The soil samples for nodule trapping and physico-chemical analysis were collected
 75 from Emba-Alaje and Endamohoni districts of southern Tigray, considering long
 76 history of field pea growing and no history of rhizobium inoculation. The corresponding
 77 GPS data including altitude and soil pH were indicated in Table 1. Twenty two soil
 78 samples were separately collected from the depth of 0-20cm and stored at 4 °C
 79 refrigerator for further experimentation. Soil chemical properties were done following
 80 standard methods compiled in Sahlemedhin and Taye (2001).

81 Table 1. Sampling sites including geographical location and soil pH

District	Kebele	Longitude	Latitude	Elevation (m.a.s.l)	Cropping History	Soil H ₂ O(1:2.5)	pH
Emba-Alaje	Betmera	12°58.787'	039°32.116'	2925	Field pea	6.6	
	Betmera	12°58.822'	039°32.069'	2923	Field pea	7.47	
	Atsela	12°55.615'	039°32.040'	2471	Field pea	7.37	
	Atsela	12°58.408'	039°31.722'	2989	Field pea	7.85	
	Ayba	12°53.589'	039°30.811'	2745	Field pea	6.6	
	Ayba	12°53.660'	039°30.818'	2709	Field pea	6.59	
	Ayba	12°53.611'	039°30.872'	2722	Field pea	5.91	
	Ayba	12°53.973'	039°31.501'	2725	Field pea	6.48	
	Ayba	12°52.584'	039°33.239'	2765	Wheat	7.22	
	Ayba	12°52.614'	039°33.325'	2777	Field pea	6.76	
	Ayba	12°52.077'	039°33.750'	2889	Barley	7.52	
	Tekea	12°54.954'	039°28.254'	2592	Field pea	6.75	
	Tekea	12°55.104'	039°29.343'	2651	Field pea	7.75	
	E/hasti	12°51.481'	039°33.920'	2955	Field pea	7.41	
Endamohoni	E/hasti	12°51.488'	039°33.899'	2952	Field pea	7.36	
	E/hasti	12°51.477'	039°33.895'	2951	Field pea	7.88	
	E/hasti	12°51.514'	039°33.981'	2944	Field pea	7.75	
	E/hasti	12°50.720'	039°34.006'	2935	Field pea	8.11	
	Tsibet	12°50.549'	039°33.844'	2964	Field pea	7.89	
	Tsibet	12°50.537'	039°33.873'	2965	Fababean	7.58	
	Tsibet	12°50.533'	039°33.856'	2958	Wheat	6.3	
	Sh/gaze	12°50.514'	039°33.383'	2956	Field pea	6.28	

82

83 Where; E/Alaje= Embaalaje, E/Mohoni= Endamohoni, H/T/hanot=
 84 hazeboteklehaymanot, E/hasti=Enbahasti

85 Nodule collection and Isolation of Rhizobia

After 45 days of growing period, well grown, large and pink colour nodules were uprooted carefully so as to get intact nodules. The nodules were thoroughly washed with distilled water and surface-sterilized briefly with 70% ethanol and 3% (v/v) solution of hydrogen per oxide (H_2O_2) for 10 sec. and 3 min. respectively (Howieson and Dilworth, 2016). They were then more than 5 times with sterile distilled water, and transferred into sterilized Petri dishes and crushed with flamed glass rod in 0.1 N NaCl. One loop full of the nodule suspension were streaked on freshly prepared Yeast Extract Manitol Agar (YEMA) plates containing 0.0025% Congo red (CR) with pH of 6.8 ± 0.2 , and the plates were incubated at $28 \pm 2^\circ C$ for 3-5 days. After 5 days of incubation, single colonies were picked and purified by re-streaking on newly prepared YEMA plates. The pure isolates were temporarily preserved at $4^\circ C$ on YEMA slants containing 0.3 % (W/V) $CaCO_3$ until further analysis.

Presumptive tests and colony characterization of the isolates

All isolates was examined for presumptive purity using YEMA-CR medium, Gram staining, peptone glucose Agar (PGA) and ketolactose Test (KLT) following the procedures indicated in Somasegaran and Hoben, (1994). The isolates were characterized by colony morphology and acid/base production on YEMA plus 25 μ gml⁻¹ Bromothymole blue (BTB) media (Ahmed *et al.*, 1984).

Authentication and preliminary screening of symbiotic effectiveness (SE) of isolates on sand culture

Seeds of the same variety Raya one (R-1) was surface sterilized as before and five pre-germinated seeds were sown on 1.5 kg surface sterilized capacity pots filled with acid washed sand (95% sulphuric acid). The seedlings were thinned down to three per pot after few days, and inoculated with 1 ml active cells (undiluted cells) grown on YEM broth as the exponential of 10^8 visible cells ml⁻¹. The experimental set up was arranged in a Complete Randomized Block Design (RCBD) with three replications including the positive control (N supplied with 5ml/pot as 1% KNO_3 (w/v)) solution once a week, and un-inoculated unfertilized pots as negative control under semi-controlled greenhouse conditions at Haramaya University. All pots were supplied with quarter strength N-free nutrient solution once a week (Somasegaran and Hoben, 1994) and washed with sterilized distilled water as required to control salt accumulation. After 45 days of growing period, all plants were uprooted and washed

carefully with tap water. The nodules were cut off from the plant roots to count and then dried at 70 °C for 24hrs until constant weight. The rhizobia infectiveness based on the presence and absence of nodules on seedling root were investigated.

Qualitative Phosphate Solubilization Test

The potential of Rhizobium strains for solubilization of insoluble phosphates were checked on the Pikovskaya's agar medium (Pikovskaya, 1948), containing 10g glucose, 0.5g yeast extract, 0.5g NH₂SO₄, 0.1g Magnesium Sulphate (MgSO₄ 7H₂O), 5g Calcium Phosphate (Ca₃(PO₄)₂), 0.2g NaCl₂, 0.2g KCl₂, 0.001g MnSO₄ 2H₂O, 0.001g FeSO₄ 7H₂O and 15g Agar medium per liter of distilled water. Three days old culture isolates with 10⁸ viable cells ml⁻¹ were streaked on the medium and incubated at 28 ± 2 °C for 7 days. After 7 days of incubation, clear halo zone diameter and colony diameter were measured and microbial phosphorus solubilisation index (SI) was calculated following the formula indicated in Edi- Premono *et al.* (1996)

$$SI = \frac{\text{Colony Diameter} + \text{Halo zone diameter}}{\text{Colony Diameter}}$$

Quantitative Phosphate Solubilisation test

Five pure and best rhizobial isolates were selected based on their solubilization index in Pikovskaya agar medium. 100ml of Pikovskaya broth was prepared without phosphate source and dispensed in 250 ml Erlenmeyer flasks. In each flask, about 0.5g of tri-calcium phosphate (Ca₃(PO₄)₂) was added and sterilized at 121 °C at 15 psi for 15 minutes. Then 1ml of culture containing about 10⁸ cells ml⁻¹ suspensions of each isolates was inoculated into the medium and kept at 28 ± 2 °C in shaker incubator for about 12 days. All the experiments were carried out in triplicate. 10ml of each isolate was withdrawn at regular intervals of 3 days and was examined for soluble phosphate and pH changes using spectrophotometer and digital pH meter, respectively, following the method cited in Subba Rao (1993).

Screening Effective Isolates Under Soil Pot Experiment

Two bulky soils collected from filed pea growing areas of southern Tigray were grounded, sieved in to 2 mm size particles and filled into 3 kg capacity surface sterilized as before polyethylene plastic pots, and the experiment were set as

147 randomized complete block design (RCBD) in three replications. Five effective
148 rhizobial isolates based on their symbiotic effectiveness on sand culture were selected
149 including N treated pots supplied with 5ml/pot of 1% KNO₃ (w/v) solution once a week
150 as positive control, and un inoculated unfertilized pots as negative control. All pots
151 were treated once a week with stock solutions of 12.5 mg/kg urea, 20 mg P₂O₅/kg, 10
152 mg/kg KCl₂, 5 mg/kg ZnSO₄, 5 mg/kg NaMoO₄ and 5 mg/kg FeSO₄ (Somasegaren
153 and Hoben, 1994). After 45 days of planting shoot and root fraction were separated to
154 determine nodule number and dry weight, shoot dry weight and total nitrogen.

155

156 Statistical Analysis

157 The collected data was subjected to analysis of variance (ANOVA) using SAS ver. 9.1
158 (2002) and the differences tested for significance was faced to Fisher method using
159 the least significant differences (LSD) test at 0.05 probability level.

160 Result and discussion

161 Qualitative Phosphate Solubilization

162 All the tested isolates induced nodulation on the host plant indicating that the tested
163 isolates are the root nodulating bacteria of field pea (*pisum sativum* var. *abyssinicum*).
164 The qualitative phosphate solubilisation showed a clear halo zones around their
165 colonies. The phosphate solubilisation index was ranged from 1.10 to 2.67 and soil pH
166 of moderately acidic to moderately alkaline (5.90 to 8.11) which is the optimum pH for
167 growth of the isolates. Of the tested isolates, five of them showed greater solubilization
168 index (SI) ranging from 1.5 to 2.7 (Table 2). Isolates HUDRI-8, HUDRI-25 and HUDRI-
169 26 were scored the highest solubilisation index at soil pH range of (6.75-7.75) neutral
170 to slightly alkaline.

171 Table 2. Growth of isolates on Pikovaskaya's agar medium

Isolates	Soil pH (1:2.5)	CD (mm)	HD (mm)	SI
HUDRI-8	7.75	3.0	5.0	2.7
HUDRI-18	6.59	9.3	7.0	1.8
HUDRI-25	7.47	4.3	6.7	2.5

HUDRI-26	6.75	3.0	4.0	2.3
HUDRI-30	6.76	5.7	3.0	1.5

172 Key word(s): CD-colony diameter, HD- holo zone, SI- solubilisation index

173

174 This indicates that some rhizobial isolates had the capacity to mobilize phosphates
175 from in organic tricalcium phosphate (TCP). Similar results were found from *Vicia faba*
176 L. of Ethiopian soils, with soil pH (4.8-6.3) as well as SI in the range of 1.25 to 2.10
177 (Girmaye *et al.*, 2014). Mulissa *et al.* (2016) also obtained related results from *Cicer*
178 *aeritinum* L. in the range of 1.40 to 3.06. Superior solubilisation index was obtained by
179 Alia *et al.* (2013) from phosphate solubilizing bacteria associated with roots of
180 vegetables that found within the range of 1.8 - 5.0.

181 *Quantitative Phosphate Solubilisation*

182 The quantitative phosphate solubilisation efficacy of selected rhizobial isolates were
183 further evaluated by measuring the soluble P (mg L⁻¹) and the changes in pH as
184 presented in Table 3. Accordingly, the amount of solubilised P released by the isolates
185 exhibited wide variation ranging from 16.59 to 23.95 mg L⁻¹, with a significant drop in
186 pH from 7.13 to 5.23. Similar results were obtained by Assefa *et al.* (2010), all bacterial
187 isolates of faba bean (*vicea faba*) were solubilized TCP in the range of 5-39 mg/50ml
188 with a drop in pH ranging from 6.8-4 after 20 days of incubation. Various phosphate
189 solubilization values were obtained by incubating them at different incubation period.

190 The ANOVA result showed a significant difference ($P < 0.05$) at the first 3 days
191 incubation. The highest phosphate solubilizations were recorded from treatments
192 inoculated with HUDRI-30 (21.84 mg L⁻¹) followed by HUDRI-25 (21.72 mg L⁻¹), and
193 the lowest P solubilizations (3.43 mg L⁻¹) were recorded from un-inoculated treatment
194 (Table 3). Phosphorus solubilization in the inoculated treatment was 537% higher than
195 the un-inoculated one, which is seven fold. The same treatments incubated for the
196 next 6 days had also significantly higher P discharge over the un-inoculated one by
197 413%. The highest amount of P discharge 23.95, 23.48 and 23.00 mg L⁻¹ were
198 recorded by isolates HUDRI-8, HUDRI-25 and HUDRI-26, respectively. After 9 days
199 of incubation, the highest P solubilizations (22.83 mg L⁻¹) were recorded by HUDRI-
200 26. Incubation of isolates for uninterrupted 12 days, the highest P solubilization was
201 found by inoculating HUDRI-8 (23.32 mg L⁻¹) followed by HUDRI-26 (22.02 mg L⁻¹);

202 resulting in 354.58% and 329.24% over the un-inoculated. With regard to the
203 incubation period, the highest P solubilisation (23.95 and 23.48 mg L⁻¹) was found at
204 the sixth day, while the lowest P discharge (16.59 mg L⁻¹) was recorded at the first 3
205 days of incubation. The current result was significantly lower than the results obtained
206 by Assefa *et al.* (2010) (39 mg/50ml). Other researches were done by Sharma *et al.*
207 (2012), isolates from tea rhizosphere, Qian *et al.* (2010) from shallow eutrophic lake
208 and Feredeegn (2013), isolates from rhizosphere and endophytic of sugarcane
209 solubilized TCP within the range of 40.62-136.73 mg L⁻¹, 4-170 mg L⁻¹ and 45.12-
210 88.41 mg L⁻¹, respectively.

211 The pattern of interaction between phosphate discharge and pH at different incubation
212 period had a strong negative correlation ($r = -0.613$ and $r = -0.542$) from day 6 and 9,
213 respectively, followed by day 3 and 12 with $r = -0.517$ and $r = -0.202$ (Table 4). This
214 result was corresponding to Assefa *et al.* (2010), inverse correlation between the
215 amounts of P solubilize and reduction in pH ($r \geq -0.93$). Alia *et al.* (2013) also found
216 negative correlation ($r = -0.862$), ($r = -0.94$) correlation from bacterial growth on mung
217 bean by Buddhi and Min-Ho (2013) also found similar trend.

218
219
220

221 Table 3. Tri-calcium phosphate solubilization efficiency of selected isolates

Isolates	3 days ⁴³			6 days			9 days			12 days		
	pH	P (mg L ⁻¹)	18	pH	P (mg L ⁻¹)	18	pH	P (mg L ⁻¹)	18	pH	P (mg L ⁻¹)	18
HUDRI-8	5.93±0.214 ^{bc}	16.59±7.123 ^b		5.54±0.015 ^b	23.95±0.767 ^a		5.37±0.164 ^b	20.41±8.911 ^a		5.25±0.069 ^b	23.32±8.100 ^a	
HUDRI-18	5.93±0.263 ^{bc}	16.81±0.966 ^b		5.27±0.136 ^c	22.77±2.915 ^a		5.53±0.045 ^b	20.72±1.015 ^a		5.38±0.217 ^{ab}	19.76±1.127 ^b	
HUDRI-25	5.61±0.063 ^{bc}	21.72±0.981 ^{ab}		5.49±0.029 ^b	23.48±0.214 ^a		5.59±0.017 ^b	20.67±0.563 ^a		5.97±0.351 ^a	21.41±0.374 ^{ab}	
HUDRI-26	6.21±0.316 ^b	19.17±2.072 ^a		5.45±0.051 ^{bc}	23.00±2.951 ^a		5.40±0.220 ^b	22.83±6.639 ^a		5.23±0.261 ^b	22.02±9.374 ^{ab}	
HUDRI-30	5.31±0.144 ^c	21.84±2.302 ^a		5.26±0.058 ^c	21.18±1.128 ^a		5.24±0.089 ^b	20.17±0.893 ^a		5.23±0.031 ^b	21.27±0.225 ^{ab}	
Control	7.01±0.00 ^a	3.43±0.00 ^c		6.97±0.00 ^a	4.67±0.00 ^b		7.21±0.00 ^a	5.49±0.00 ^b		7.13±0.00 ^b	5.13±0.00 ^c	
G mean	6.00	16.59		5.66	19.84		5.72	18.38		5.69	18.82	
CV (%)	5.77	14.74		2.01	8.11		3.62	8.63		6.49	8.07	
LSD(0.05)	0.62	4.35		0.20	2.86		0.37	2.82		0.62	2.70	

222 Where; Means followed by the same letters are not significantly different at p< 0.05 (Fisher's LSD test)

223

224 **Table 4.** Correlation coefficients of P and pH parameters on phosphate solubilizing
 225 bacteria

		Day 3		Day 6		Day 9		Day 12	
		pH	P	pH	P	pH	P	pH	P
pH			-0.52*		-0.6**		-0.54*		-0.20*
P (<0.05)			0.03		0.01		0.02		0.42
27 P	-0.52*			-0.61**		-0.54*		-0.20*	
P (<0.05)	0.03			0.01		0.02		0.42	

226

227 *Symbiotic Effectiveness of Isolates on Unsterilized Soil:*

228 The physico-chemical properties of the soils are presented in Table 5. The textural
 229 class of the districts were classified as sandy clay loam. Similar results were found by
 230 Amanuel *et al.*, 2015, from Tekea and Shimta kebeles with particle size distribution of
 231 50-54% sand, 18-17% silt and 35-30% clay fractions, respectively. The pH of the two
 232 districts was slightly acidic (6.38-6.42) according to the ratings of Tekalign (1991),
 233 which is the optimum pH range for bacterial growth. Low organic matter (1.7-2%) and
 234 low to medium total nitrogen (0.01-0.14%) was found according to Murphy (1968). This
 235 lower soil organic matter could be due to the presence of continuous cropping system,
 236 cultivation and intensive tillage practice.

237 **Table 5.** The soil physico-chemical properties

Parameters	E/Alaje	E/Mohoni	Status	Refference
OM (%)	1.72	1.96	Low	Murphy (1968)
Available P (mg/kg)	18.78	17.7	high	Olsen <i>et al.</i> (1954)
Total N (%)	0.09	0.14	low to medium	Murphy (1968)
pH	6.42	6.38	slightly acidic	Tekalign (1991)
EC(mhos/cm)	0.09	0.09	low	Horneck <i>et al.</i> (2011)
CEC (meq/100g soil)	40.20	43.40	very high	Landon (1991)
Textural Class	Sand 52%	Sand 59%		
	Silt 18%	Silt 16%	Sandy clay	
	Clay 30%	Clay 30%	loam	

238

239 High available P (18-19 mg kg⁻¹) and very high CEC (40.2-43.4 meq/100gsoil) was
240 found from the study area according to the ratings of Olsen *et al.* (1954) and Landon
241 (1991), respectively. This is in agreement with the findings of (Amanuel *et al.*, 2015)
242 who reported the characterization of agricultural soils of southern Tigray, in capacity
243 building for scaling up of evidence-based best practice in Ethiopia (CASCAPE)
244 intervention woredas. According to Horneck *et al.* (2011), soil test interpretation guide
245 the electrical conductivity was low.

246 After nodulation test on sand culture, five symbiotically effective isolates (HUDRI-15,
247 26, 28, 43 and 44) were selected and further tested for their performance on a soil pot
248 culture. The data showed that the inoculated plants produced significantly ($P < 0.05$)
249 higher nodule number (NN), nodule dry weight (NDW), shoot dry weight (SDW) and
250 total plant nitrogen (TN) (Table 6). The highest nodule numbers (156 and 145) were
251 found from HUDRI-15 and HUDRI-28 isolated from E/Alaje and E/mohoni soils,
252 respectively. The current result was higher than the number of nodules found by Asrat
253 (2017) (112 NN/plant) for field pea treated with commercial strain 1018. The lowest
254 nodule number per plant was recorded from un-inoculated plants (31 NN/plant) (Table
255 5). N treated plants also reduced nodule number per plant by 36% (156-100 NN/plant)
256 and 42% (145-84 NN/plant) compared to other treatments from the two soils,
257 respectively. This result indicates that application of nitrogen somehow inhibited
258 nodule development in field pea. Anteneh and Abere (2017) also reported that
259 application of N reduced nodule number (62 NN/Plant and 20.00NN/Plant) in 2012
260 and 2013 cropping season.

261 Inoculation of the host plant also significantly ($P < 0.05$) affected nodule dry weight.
262 The highest nodule dry weight (NDW) was recorded from HUDRI-15 (0.189 g plant⁻¹)
263 and HUDRI-28 (0.117 g plant⁻¹) relative to the other inoculants and control treatments
264 on both soils (Table 6). This result was in agreement with Asrat (2017) (0.094 and
265 0.009 g plant⁻¹) of field pea *rhizobium* inoculation. However, it was slightly lower than
266 the results obtained by Anteneh and Abere (2017) (0.552 and 0.140 g plant⁻¹) two
267 years report. This might be due to the ecological factors, which are tested on field
268 condition.

269 The effect of inoculation on shoot dry weight (SDW) was found significant ($P < 0.05$)
270 and values were superior to the positive and negative control. Isolates HUDRI-15 and

271 HUDRI-28 gave the highest shoot dry weight (1.64 g plant⁻¹) and (1.42 g plant⁻¹) on
272 both soils, and it was advanced by 43 and 25% over the negative control (Table 6). In
273 contrary to this result Asrat (2017) was found higher shoot dry weight in the range of
274 14 to 29 g plant⁻¹. Anteneh and Abere (2017) also reported that field pea rhizobium
275 inoculation increased shoot dry weight on the range of 57 to 87 g plant⁻¹.

276 A significant effect of *Rhizobium* inoculation on the plant N accumulation of field pea
277 was observed among the treatments including N treated and un-inoculated (Table 6).
278 The highest total N accumulation was obtained from plants treated with HUDRI-15
279 (3.67%) and HUDRI-15 (3.53%) on the two districts, respectively. This result was in
280 agreement with Asrat (2017) found in the range of 3.5-4.1% total N from inoculated
281 field pea. The total N accumulation was found to be 70% and 89% increment over the
282 negative control.

283

40

Table 6. Evaluation of symbiotic effectiveness of isolates on soil culture

Treatment	Nodule number		Nodule dry weight(g plant ⁻¹)		Shoot dry weight (g plant ⁻¹)		Total Nitrogen (%)	
	E/Alaje soil	E/Mohoni soil	E/Alaje soil	E/Mohoni soil	E/Alaje soil	E/Mohoni soil	E/Alaje soil	E/Mohoni soil
HUDRI-15	156.00±3.46 ^a	103.33±2.40 ^c	0.189±0.03 ^{ab}	0.089±0.03 ^c	1.64±0.13 ^a	1.41±0.17 ^{ab}	3.67±0.135 ^a	3.53±0.098 ^a
HUDRI-26	111.67±3.84 ^d	86.00±3.46 ^d	0.097±0.01 ^{bc}	0.092±0.00 ^{bc}	1.31±0.14 ^{ab}	1.28±0.16 ^{ab}	3.36±0.120 ^{ab}	3.05±0.034 ^{ab}
HUDRI-28	138.67±1.76 ^b	145.33±2.91 ^a	0.109±0.03 ^a	0.117±0.00 ^a	1.51±0.17 ^{ab}	1.42±0.11 ^{ab}	2.48±0.057 ^c	3.08±0.045 ^{ab}
HUDRI-43	150.00±7.64 ^{ab}	126.00±3.46 ^b	0.097±0.00 ^{bc}	0.108±0.00 ^{ab}	1.61±0.17 ^a	1.28±0.23 ^{ab}	3.40±0.038 ^{ab}	2.84±0.038 ^b
HUDRI-44	125.67±3.48 ^c	96.00±2.08 ^c	0.121±0.01 ^{ab}	0.100±0.00 ^{abc}	1.53±0.05 ^a	1.34±0.21 ^{ab}	3.48±0.038 ^{ab}	3.07±0.070 ^{ab}
N ⁺	100.00±3.06 ^d	84.33±1.66 ^d	0.046±0.00 ^{bc}	0.005±0.00 ^{bc}	1.22±0.01 ^a	1.24±0.02 ^{ab}	2.60±0.027 ^c	2.42±0.039 ^c
N ⁻	31.00±1.15 ^e	36.33±2.40 ^e	0.065±0.02 ^c	0.014±0.02 ^d	1.15±0.09 ^b	1.14±0.04 ^{ab}	2.16±0.05 ^d	1.87±0.226 ^d
CV (%)	5.875	5.045	34.85	10.87	14.30	19.84	4.65	5.51
LSD (0.05)	11.95	8.51	0.071	0.017	0.37	0.47	0.21	0.27

Where: CV= coefficient of variation, LSD= least significant difference, values are ±SE, numbers in the same column followed by the same letter(s) are not significantly different at $\alpha < 0.05$

287 Conclusion

288 It can concluded that the phosphate solubilizing rhizobia exhibited a broad range of
289 ability of solubilizing TCP *in vitro*. Most of the isolates originated from Emba-alaje are
290 generally able to solubilise inorganic TCP. Among all the isolates, maximum potential
291 to solubilize tri-calcium phosphates are HUDRI-8 and HUDRI-25. Results found an
292 inverse correlation between amount of solubilized phosphate and pH of the culture
293 medium. Isolate that are effective in N₂ fixation and able to solubilise TCP are found
294 to be effective in improving nodulation and plant growth under greenhouse condition.
295 Further research is recommended to investigate its efficacy under field trials in diverse
296 soil types having different amount of soil P.

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