

List of Figures

Figures.	Title	Page #
3.1	Maps showing collection sites.	37
3.2	Sample Collection Data Sheet.	38
3.3	<i>In vivo</i> green house experiment. A: Pouring of <i>Rhizobium</i> inoculums in the carrier medium (charcoal); B: Curing of the carrier based inoculants; C: Pouches containing the carrier based inoculant; D: A plate with healthy seeds; E: A beaker containing 10% jaggery solution; F: Sprinkling of carrier based <i>Rhizobium</i> inoculants on the sticker coated seeds; G: Drying of the treated seeds; H-I: Sowing of the treated seeds in the earthen pots; J: Dried aerial part of the plants after harvest; K: Dried roots after harvest.	50
3.4	EMBL format used for submission of 16SrRNA sequences of <i>Rhizobium</i> isolated from root nodules of <i>Phaseolus vulgaris</i> .	62
4.1	Root of <i>Phaseolus vulgaris</i> with mature nodules.	70
4.2	<i>Rhizobium</i> colonies in YEM+Congo red medium.	70
4.3	(A) Germination of French bean seeds in water agar medium; (B) French bean seedlings grown on the sterilized sand in the improvised Leonard jar Assembly; (C & D) Formation of nodules by Koch's postulation; (E) Sub-culturing and maintenance of pure colony of <i>Rhizobium</i> in a slant.	71
4.4	Scanning electron microscopic images of <i>Rhizobium</i> cells examined under Carl Zeiss Scanning Electron Microscope.	72
4.5	Pure <i>Rhizobium</i> colonies on YEM plates	72
4.6	Result of various biochemical tests: (A) Acid alkaline production test (B) Methylene blue test (C) Starch hydrolysis test (D) Triple sugar iron agar test (E) Catalase test (F) Urease test (G) Nitrate reduction test (H) Carbohydrate utilization test.	75
4.7	Dendrogram of <i>Rhizobium</i> strains generated by NTSYS-pc2 program based on the carbohydrate utilization test.	79
4.8	Ai: Growth of <i>Rhizobium</i> strains grown in different NaCl concentration; Aii: KyPlot representing the statistical data of the <i>Rhizobium</i> growth in different NaCl concentration; Bi: Growth of <i>Rhizobium</i> strains grown in different pH; Bii: KyPlot representing the statistical data of the <i>Rhizobium</i> growth in different pH concentration; Ci: Growth of <i>Rhizobium</i> strains grown in different temperature; Cii: KyPlot representing the statistical data of the <i>Rhizobium</i> growth in different temperature.	81
4.9	Growth of <i>Rhizobium</i> strains in different concentration of heavy metals (A) CuSO ₄ , (B) Pb(NO ₃) ₂ , (C) CoCl ₂ . (D) KyPlot representing the statistical data of the <i>Rhizobium</i> growth in different heavy metal concentration.	83

Figures.	Title	Page #
4.10	IAR test showing the zone of inhibition by the <i>Rhizobium</i> strain RSm-3.	84
4.11	Heatmap of the antibiotic resistance property of studied <i>Rhizobium</i> strains .	85
4.12	(A) Halo zone formation shown by the <i>Rhizobium</i> strains indicating phosphate solubilization activity, (B) <i>Rhizobium</i> strains showing siderophore producing activity, (C) <i>Rhizobium</i> strains showing HCN producing activity, (D,E) <i>Rhizobium</i> strains showing IAA producing activity, (F) <i>Rhizobium</i> strains showing ammonia producing activity, (G) Plate showing pure culture of fungus <i>Fusarium solani</i> , (H,I) <i>Rhizobium</i> strain RSm-3 and <i>Rhizobium</i> strain NBU-8 showing antagonistic activity against the fungus <i>Fusarium solani</i> respectively.	87
4.13	(A) Greenhouse pot experiment showing forty-five days old <i>P. vulgaris</i> inoculated with different <i>Rhizobium</i> strains. (B) <i>P. vulgaris</i> during the flowering stage.	91
4.14	Crude DNA of <i>Rhizobium</i> .	96
4.15	Gel showing the DNA bands of eighteen <i>Rhizobium</i> strains amplified by the RAPD primers (A)OPQ 01 (B) OPA 18 (C) OPA 02.	98
4.16	Dendrogram derieved from UPGMA cluster analysis of RAPD markers illustrating the genetic relationships among the 18 <i>Rhizobium</i> strains.	99
4.17	Gel showing the DNA bands of eighteen <i>Rhizobium</i> strains amplified by REP primer	102
4.18	Dendrogram derived from UPGMA cluster analysis generated by REP-PCR primer illustrating the genetic relationship among 18 <i>Rhizobium</i> strains.	103
4.19	Gel showing the DNA bands of eighteen <i>Rhizobium</i> strains amplified by ERIC primer.	105
4.20	Dendrogram derived from UPGMA cluster analysis generated by ERIC-PCR primer illustrating the genetic relationship among 18 <i>Rhizobium</i> strains.	106
4.21	Gel showing the DNA bands of eighteen <i>Rhizobium</i> strains amplified by BOX primer.	108
4.22	Dendrogram derived from UPGMA cluster analysis generated by BOX-PCR primer illustrating the genetic relationship among 18 <i>Rhizobium</i> strains.	108
4.23	Dendrogram derived from UPGMA cluster analysis generated by combined rep-PCR (REP, ERIC and BOX) illustrating the genetic relationship among 18 <i>Rhizobium</i> strains.	110
4.24	Amplification of partial <i>Rhizobium</i> DNA with 16SrDNA primers (337F and 907R)	112
4.25	Restriction digestion products of partial region of 16SrDNA (A) AluI (B) Hpa II (C) MboI.	113

Figures.	Title	Page #
4.26	Dendrogram based on the restriction digestion products data of the partial region of 16S rDNA .	114
4.27	Dendrogram generated by RAxML representing the relationship of the eleven <i>Rhizobium</i> strains with the standard GenBank partial sequences of rhizobial 16SrDNA . A high resolution figure of this tree has been given in supplementary figure SF1.	118
4.28	Snapshot of <i>Rhizobium</i> sp. RSm-3 available in IMG/ER database.	120
4.29	Codon usage analysis of Nitrogen fixing genes in 5 <i>Rhizobium</i> strains.	122
4.30	Codon usage analysis of Siderophore forming genes in 5 <i>Rhizobium</i> strains.	125
4.31	Codon usage analysis of IAA producing genes in 5 <i>Rhizobium</i> strains.	127
4.32	Absence of replication-transcriptional selection in <i>Rhizobium</i> . RSm-3 strain.	129
4.33	Pan-core plot of 5 <i>Rhizobium</i> strains.	130
4.34	COG analysis of <i>Rhizobium</i> sp. RSm-3 strain.	130