

Nodulation of Native Legumes in Pakistani Rangelands

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SUMMARY

Nodulation was studied in 161 legumes (9 Caesalpinioideae, 19 Mimosoideae and 133 Papilionoideae) native in Pakistani rangelands. This consisted of two tribes of Caesalpinioideae, three tribes of Mimosoideae and 16 tribes of Papilionoideae. Legume species in Mimosoideae and Papilionoideae were all nodulated to various degrees. However, all the 9 legume species in Caesalpinioideae (tribe Caesalpinieae and Cassieae) appeared non-nodulated after repeated investigation in the field. Nodulation of a wide range of legume species in Mimosoideae and Papilionoideae indicates a widespread distribution of compatible rhizobia across the Pakistani rangelands. Nodules were observed even under adverse rangeland conditions which included extreme temperatures, salinity, drought, waterlogged, marginal and eroded soils with low fertility. The legume distribution brings out the importance of this family in the rangelands in terms of abundance of leguminous herbs, shrubs and trees. Nodulation study of these legumes will stimulate their utilization in soil fertility improvement programs, up grading rangeland soils and reforestation of derelict sites. Further research on nodulation status, nitrogen fixation capacity, physiological adaptations and genetic diversity of these legumes will provide fundamental knowledge for their conservation and utilization in different agro-climatic and physiographical regions.

KEY WORDS

Rangelands, legumes, nodulation, taxonomy, Pakistan

ACKNOWLEDGEMENTS

Many people contributed to this study, and I am grateful to all of them. Special thanks are due to Joseph H. Kirkbride, USDA-Agricultural Research Service, Beltsville, MD, for his help in checking the legume nomenclature and tribal classification, Prof. Riaz Ahmad, University of Central Oklahoma, Edmond, USA, and Dr. Tahir Rashid, University of Guelph, Ontario, Canada for valuable suggestions and helpful criticism on the manuscript. Sincere gratitude is expressed to Ch. Abbas Ahmad, Ch. Rauf Ahmad, Ch. Mohammad Tahir, Ch. Suhail Saqib, Nisar Ahmad Chaudhary, Shuaib Ahmad Chaudhary (Khanewal), Ch. Ashfaq Ahmad (Multan), Prof. Mahmood Ahmad, Prof. M. Zafar Iqbal (Karachi), Ch. Mohammad Shafique (Hyderabad), Shahbaz Ahmed (Islamabad) and Ali Goher (Gilgit), for their invaluable advice and technical assistance during the field trips which greatly facilitated this work. Their help was also crucial in establishing many contacts and keeping the research going.

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Received: January 21, 2005



INTRODUCTION

Rangeland productivity is frequently limited by soil fertility. Use of fertilizers to increase soil fertility of rangelands is not feasible due to economical returns. Moreover in many developing countries fertilizers are unavailable or are beyond the reach of subsistence farmers. Rangeland productivity may be increased by introducing the nitrogen-fixing legumes into the rangelands (Bala et al. 2003, Odee et al. 1995, Singh and Pokhriyal 1998). Legume-*Rhizobium* symbiosis is currently the most important nitrogen-fixing system, which may have potential to increase N input in rangelands (Amarger 2001, Wolde-meskel et al. 2004). Legumes are distinct and fascinating plants, with a wide range of values and uses including food, fodder, fiber, fuel wood, timber and medicine. The leguminous plants include species or varieties which are extremely well adapted to the drastic conditions of arid lands (Kulkarni et al. 2000). However, still relatively little is known about the nitrogen-fixing value of most of the legume species found in the wild (Sprent 2001b).

Legumes are well distributed in Pakistan, and Leguminosae ranks as the third largest family in order of abundance. Ali and Qaiser (1986) mentioned 107 legume genera from Pakistan, of which 68 genera have one or more native species. A total of 539 legume species occur in Pakistan, of which 426 are native (Kirkbride 1986). As forest ecosystems shrink under human pressure, the survival of many potentially important legume species is threatened (Khan 2000). There are substantial reports on the nodulating status of Pakistani legumes (Athar 1993, 1996, 1997; Athar and Mahmood 1985, 1990; Mahmood and Iqbal 1994, Nasim et al. 1998). However, nodulation studies on rangeland legumes of Pakistan have been limited to fodder and forage legumes (Athar and Johnson 1997). This paper describes nodulation of native legumes in Pakistani rangelands.

MATERIALS AND METHODS

About 65% of the total area of Pakistan consists of rangelands including both arid and mountainous rangelands. These rangelands extend from alpine pastures in the north to arid and semi-arid areas in the south. About 9 million hectares of high potential range can be found in the north and north-western parts of Pakistan, while about 48 million hectares of arid and semi-arid rangelands are located in the Punjab, Sindh and Balochistan (Quraishi et al. 1993). Rangelands are areas devoted to livestock production from natural or semi-natural vegetation. The vegetation includes shrub lands, grasslands and forests. They are generally defined in a negative sense as areas being climatically or

topographically unsuitable for economic cropping or sown pastures.

Pakistan has a continental climate. Precipitation varies widely from less than 125 mm to over 1500 mm per annum. Monsoon precipitation dominates in some areas, while in other parts a winter precipitation pattern prevails. Average maximum daily temperatures vary considerably generally exceeding 38°C during May and June, while in the south and south-west maximum temperature occasionally rises above 49°C. In the winter months, the minimum temperatures in some places, even in the plains, drop several degrees below the freezing point. Soils in Pakistan fall into more than 400 different soil categories. They are generally silty, calcareous and low in organic matter. The cation exchange capacity of these soils ranges from 8-10 milliequivalent per 100 gram soil. The soil structure is poorly developed. Mica, illite, and kaolinite are the dominant mineral phases in clay size fractions with traces of smectite. Soils are predominantly deficient in nitrogen and most crops respond to phosphorus fertilizer application.

Legume species from Pakistani rangelands were surveyed for their nodulating ability. Observations were made as described previously (Athar 1997). Legume examined included herbs, shrubs, vines and trees. Both the young and mature plants were examined for nodulation. The roots of young plants growing close to or under the canopy of mature plants of the same species were excavated and observed for nodulation. At least five plants of each species were examined to minimize error. Nodules were counted in each plant and their colors and shapes were recorded. A list of legume species examined from the rangelands was compiled and their taxonomic position determined. The nomenclature and classification followed Polhill and Raven (1981). The genera were arranged alphabetically within sub-families. Nodules were distinguished from other kinds of morphological modifications or pathogenic root malformations. Nodule smears and nodule slices were prepared and examined under the microscope to distinguish doubtful structures (Somasegaran and Hoben 1994).

RESULTS AND DISCUSSION

Nodulation was studied in 161 legumes (9 Caesalpinioideae, 19 Mimosoideae and 133 Papilionoideae) growing in Pakistani rangelands (Table 1). Two tribes of Caesalpinioideae, three tribes of Mimosoideae and 16 tribes of Papilionoideae were represented and constituted about 30% of legume species found in Pakistan. Legume species in Mimosoideae and Papilionoideae were all nodulated to various degrees. These results agree with earlier

reports (Athar 1993, 1996, 1997; Athar and Mahmood 1985, 1990; Kirkbride 1986, Mahmood and Iqbal 1994, Nasim et al. 1998, Singh and Pokhriyal 1998, Saur et al. 2000, Sprent 2001a, 2001b; Subramaniam and Babu 1994). However, all the 9 legume species belonging to Caesalpinioideae (tribe Caesalpinieae and Cassieae) were non-nodulated after repeated investigation in the field. Lack of nodulation in Caesalpinioideae has been previously reported (Athar 1993, 1996, 1997; Athar and Mahmood 1985, 1990; Kirkbride 1986, Mahmood and Iqbal 1994, Sprent 2001a, 2001b). Nodulating species of Mimosoideae belonged to tribe Acacieae (4 species), Ingeae (5 species), and Mimoseae (10 species). Most of nodulating species of Papilionoideae were distributed in tribe Trifolieae (26 species), Viciae (19 species), and Desmodieae (18 species), followed by Galegeae (15 species), Phaseoleae (12 species) and Indigofereae and Robinieae (11 species each) along with nine other tribes.

Nodules were distributed on the main as well as lateral roots and were found in the top 5-10 cm layer of soil depending on the soil conditions. The majority of the species were abundantly nodulated indicating a widespread distribution of compatible rhizobia across the Pakistani rangelands. Nodules occurred singly or in branched forms and were globose to elongate matching with the description of Sprent (2001a, 2001b). The color and size of nodules varied for various species as well as within the phenological stage of the legume (Table 1). Nodules were mostly pink or brown indicating their effectiveness in nitrogen fixation (Somasegaran and Hoben 1994). However, white and light brown nodules were also observed.

Legumes are nodulated by a diverse group of bacteria collectively known as rhizobia: *Rhizobium*, *Bradyrhizobium*, *Allorhizobium*, *Azorhizobium*, *Mesorhizobium*, and *Sinorhizobium* (Amarger 2001, Vessey et al. 2004). Rhizobia which show effective symbiotic characteristics with their host legumes and survival ability in rangeland soils and arid regions could be identified. Athar and Johnson (1996) reported that antibiotic resistant mutant strains of *Rhizobium meliloti* (*Sinorhizobium meliloti*) from northern rangelands of Pakistan were competitive with naturalized alfalfa rhizobia and were symbiotically effective under drought stress. Their results suggest that nodulation, growth, and nitrogen fixation in rangeland legumes can be improved by inoculation with competitive and drought-tolerant rhizobia. This could be an economically feasible way to increase legume forage production in water-limited rangeland environments. One of the legume adaptations to arid lands poor in N and P and those with low moisture availability, is their infection by mycorrhizal fungi

in addition to *Rhizobium*. Mycorrhizal inoculation has been reported to alleviate the effects of drought stress on *Acacia* and *Leucaena* under arid conditions (Requena et al. 1997).

Factors like waterlogging, salinity and soil erosion have decreased fertility of rangeland soils. Stress imposed by drought, extreme temperatures, and increased evaporation rates have seriously affected the growth and distribution of rangeland vegetation. Overstocking, overgrazing and firewood collection in most areas have resulted in degradation of many rangeland communities (Khan 2000). Legume-*Rhizobium* symbiosis is superior to other nitrogen-fixing systems with respect to nitrogen-fixing potential and adaptation to severe conditions (Amarger 2001, Vessey et al. 2004, Zahran 2001). Several symbiotic systems of rangeland legumes which are tolerant to extreme conditions like temperature, salinity, drought, waterlogging and low fertility, have been identified (Kulkarni et al. 2000, Saur et al. 2000, Zahran 2001). These associations have sufficient traits necessary to establish successful growth and nitrogen fixation under the conditions prevailing in rangeland conditions. These rhizobia may be used to inoculate wild, as well as, crop legumes, cultivated in reclaimed desert lands. Recent report indicated that the wild-legume rhizobia formed successful symbioses with some grain legumes (Lalani Wijesundara et al. 2000, Zahran 2001).

The livestock industry plays an important role in the economy of Pakistan by contributing a large portion of gross agricultural products. Increased demand for livestock products has led to corresponding increases in demand for forage. Pakistani rangelands need special attention and we should be very selective in reseeding rangelands for their restoration, improvement and productivity by employing range management techniques. The range managers, soil scientists and foresters in Pakistan can be the intermediaries for this intervention. Planting of legume species would help provide the communities with sustained supplies of forage and fuel wood while protecting the core zone for biodiversity conservation. Re-introducing legumes has the potential to provide multiple benefits of plant nutrition, soil stabilization, wildlife forage and refuge. It would also improve range condition through enhanced soil fertility, soil permeability and increased level of organic matter. Nodulation study of these legumes will increase their utilization in soil fertility improvement programs, up grading rangeland soils and reforestation of derelict sites. Further research on nodulation status, nitrogen fixation capacity, physiological adaptations and genetic diversity of these legumes will provide fundamental knowledge for their conservation and utilization in different agro-climatic and physiographical regions.

Table 1. Nodulation in Pakistani rangeland legumes.

Species	Plant habit	Nodule						
		Frequency	Color	Shape				
CAESALPINIOIDEAE								
<i>Caesalpinieae</i>								
<i>Caesalpinia bonduc</i> (L.) Roxb.	Shrub	—	—	—				
<i>Delonix regia</i> (Bojer ex Hook.) Raf.	Tree	—	—	—				
<i>Parkinsonia aculeata</i> L.	Tree	—	—	—				
<i>Cassieae</i>								
<i>Senna alexandrina</i> Mill.	Herb	—	—	—				
<i>Senna corymbosa</i> (Lam.) H.S. Irwin & Barneby	Shrub	—	—	—				
<i>Senna holosericea</i> (Fresen.) Greuter	Herb	—	—	—				
<i>Senna italica</i> Mill.	Herb	—	—	—				
<i>Senna sophora</i> (L.) Roxb.	Shrub	—	—	—				
<i>Senna surattensis</i> (Burm. f.) H.S. Irwin & Barneby	Shrub	—	—	—				
MIMOSOIDEAE								
<i>Acacieae</i>								
<i>Acacia farnesiana</i> (L.) Willd.	Tree	+++	Brown	Elongated				
<i>Acacia modesta</i> Wall.	Tree	++	Brown	Elongated				
<i>Acacia nilotica</i> (L.) Delile	Tree	++	Dark Brown	Elongated				
<i>Acacia senegal</i> (L.) Willd.	Tree	+	Brown	Elongated				
<i>Ingeae</i>								
<i>Albizia julibrissin</i> Durazz.	Tree	+	Brown	Globose				
<i>Albizia lebbeck</i> (L.) Benth.	Tree	++	Pink	Globose				
<i>Albizia odoratissima</i> (L. f.) Benth.	Tree	+	Brown	Globose				
<i>Albizia procera</i> (Roxb.) Benth.	Tree	++	Pink	Globose				
<i>Pithecellobium dulce</i> (Roxb.) Benth.	Tree	++	Brown	Elongated				
<i>Mimoseae</i>								
<i>Faidherbia albida</i> (Delile) A. Chev.	Tree	+	Dark Brown	Elongated				
<i>Leucaena leucocephala</i> (Lam.) de Wit	Tree	+++	Pink	Elongated				
<i>Mimosa rubicaulis</i> Lam.	Shrub	++	Brown	Globose				
<i>bimalayana</i> (Gamble) H. Ohashi								
<i>Mimosa bamata</i> Willd.	Shrub	+	Brown	Globose				
<i>Mimosa pudica</i> L.	Shrub	+	Brown	Globose				
<i>Mimosa tenuiflora</i> (Willd.) Poir.	Shrub	+	Brown	Globose				
<i>Prosopis cineraria</i> (L.) Druce	Shrub	+	Pink	Globose				
<i>Prosopis farcta</i> (Banks & Sol.) J.F. Macbr.	Tree	+	Brown	Globose				
<i>Prosopis glandulosa</i> Torr.	Tree	+	Pink	Globose				
<i>Prosopis juliflora</i> (Sw.) DC.	Tree	+	Brown	Globose				
PAPILIONOIDEAE								
<i>Aeschynomeneae</i>								
<i>Aeschynomene indica</i> L.	Tree	++	Pink	Globose				
<i>Crotalariaeae</i>								
<i>Crotalaria albida</i> B. Heyne ex Roth.	Herb	+	White	Elongated				
<i>Crotalaria burbia</i> Buch.—Ham.	Herb	++	Brown	Elongated				
<i>Crotalaria juncea</i> L.	Herb	++	White	Elongated				
<i>Crotalaria medicaginea</i> Lam.	Herb	+++	White	Elongated				
<i>Crotalaria prostrata</i> Rottler ex Willd.	Herb	+	White	Elongated				
<i>Crotalaria sessiliflora</i> L.	Herb	++	Brown	Elongated				
<i>Crotalaria spectabilis</i> Roth	Herb	+	Brown	Elongated				
<i>Dalbergieae</i>								
<i>Dalbergia lanceolaria</i> L. f.	Tree	++	Pink	Elongated				
<i>Dalbergia latifolia</i> Roxb.	Tree	+++	Brown	Globose				
<i>Dalbergia sissoo</i> Roxb. ex DC.	Tree	+++	Pink	Globose				
<i>Desmodieae</i>								
<i>Alysicarpus bupleurifolius</i> (L.) DC.	Herb	++	Brown	Globose				
<i>Alysicarpus heterophyllus</i> (Baker) Jafri & Ali	Herb	++	Brown	Globose				
<i>Alysicarpus longifolius</i> (Rottler ex Spreng.) Wight & Arn.	Herb	+	White	Globose				
<i>Alysicarpus monilifer</i> (L.) DC.	Herb	++	Brown	Globose				
<i>Alysicarpus ovalifolius</i> (Schumach.) J. Léonard	Herb	++	Pink	Globose				
<i>Alysicarpus rugosus</i> (Willd.) DC.	Herb	++	Brown	Globose				
<i>Alysicarpus scariosus</i> (Rottler ex Spreng.) J. Graham ex Thwaites	Herb	++	Brown	Globose				
<i>Alysicarpus tetragonolobus</i> Edgew. Schindl.	Herb	+++	White	Globose				
<i>Campylotropis meebildii</i> (Schindl.) Schindl.								
<i>Codariocalyx motorius</i> (Houtt.) H. Ohashi	Shrub	++	Brown	Globose				
<i>Desmodium canadense</i> (L.) DC.	Vine	+++	Pink	Globose				
<i>Desmodium gangeticum</i> (L.) DC.	Shrub	++	Pink	Globose				
<i>Desmodium laxiflorum</i> DC.	Shrub	++	Pink	Globose				
<i>Desmodium podocarpum</i> DC.	Shrub	++	Pink	Globose				
<i>Desmodium triflorum</i> (L.) DC.	Herb	+++	Pink	Globose				
<i>Lepedeza floribunda</i> Bunge	Shrub	++	Brown	Globose				
<i>Lepedeza juncea</i> (L. f.) Pers.	Shrub	+++	Light Brown	Globose				
<i>Uraria picta</i> (Jacq.) Desv. ex DC.	Shrub	++	Brown	Globose				
<i>Galegeae</i>								
<i>Albagi mourorum</i> Medik.	Shrub	++	White	Globose				
<i>Astragalus alopecuroides</i> L.	Shrub	++	Brown	Elongated				
<i>Astragalus amberstianus</i> Benth.	Herb	++	Pink	Elongated				
<i>Astragalus ammophilus</i> Kar. & Kir.	Herb	++	Pink	Elongated				
<i>Astragalus glycyphyllos</i> L.	Herb	++	Pink	Elongated				
<i>Astragalus leucocephalus</i> Bunge	Herb	+++	Brown	Elongated				
<i>Astragalus psilocentros</i> Fisch.	Shrub	++	Pink	Elongated				
<i>Astragalus subumbellatus</i> Klotzsch	Shrub	++	Light Brown	Elongated				
<i>Astragalus tribuloides</i> Delile	Herb	+++	Pink	Elongated				
<i>Astragalus trichocarpus</i> J. Graham ex Benth.	Herb	+++	Pink	Elongated				
<i>Colutea nepalensis</i> Sims	Shrub	++	Light Brown	Elongated				
<i>Galega officinalis</i> L.	Herb	+++	Pink	Elongated				
<i>Gueldenstaedtia verna</i> (Georgi) Boriss.	Herb	++	Brown	Globose				
<i>Oxytropis mollis</i> Royle ex Benth.	Herb	+	Brown	Globose				
<i>Podolotus bosackioides</i> Royle ex Benth.	Herb	+++	Pink	Elongated				
<i>Genisteae</i>								
<i>Argyrolobium flaccidum</i> (Royle) Jaub. & Spach.	Herb	+++	Pink	Globose				
<i>Argyrolobium roseum</i> (Cambess.) Jaub. & Spach.	Herb	+++	Pink	Globose				
<i>Argyrolobium stenophyllum</i> Boiss.	Herb	+++	Pink	Globose				
<i>Hedysareae</i>								
<i>Onobrychis cornuta</i> (L.) Desv.	Shrub	+	Brown	Globose				
<i>Taverniera lappacea</i> (Forssk.) DC.	Shrub	+	Brown	Globose				
<i>Indigoferaeae</i>								
<i>Indigofera argentea</i> Burm. f.	Herb	+	White	Globose				
<i>Indigofera cordifolia</i> B. Heyne ex Roth.	Herb	+	White	Globose				
<i>Indigofera hamiltonii</i> Graham ex Duthie & Prain	Shrub	++	Brown	Globose				
<i>Indigofera hebeptala</i> Benth. ex Baker	Shrub	++	Brown	Globose				
<i>Indigofera heterantha</i> Wall. ex Brandis	Shrub	++	Brown	Globose				
<i>Indigofera bimalayensis</i> Ali	Herb	+	White	Globose				
<i>Indigofera hochstetteri</i> Baker	Herb	+	White	Semi-globose				
<i>Indigofera linifolia</i> (L. f.) Retz	Herb	++	White	Semi-globose				
<i>Indigofera oblongifolia</i> Forssk.	Shrub	+	White	Globose				
<i>Indigofera sessiliflora</i> DC.	Herb	+++	Pink	Globose				
<i>Indigofera tinctoria</i> L.	Shrub	++	Brown	Globose				
<i>Longocarpeae</i>								
<i>Millettia pinnata</i> (L.) Panigrahi	Tree	++	Pink	Globose				
<i>Loteae</i>								
<i>Lotus corniculatus</i> L.	Herb	+++	Pink	Elongated				
<i>Phaseoleae</i>								
<i>Cajanus mollis</i> (Benth.) Maesen	Vine	+++	Light Brown	Elongated				
<i>Cajanus platycarpus</i> (Benth.) Maesen	Herb	++	Light Brown	Elongated				

<i>Flemingia fruticulosa</i> Wall. ex Benth.	Herb	+++	Light Brown	Elongated	<i>Lathyrus humilis</i> (Ser.) Fisch. ex Spreng.	Herb	++	Pink	Elongated
<i>Flemingia strobilifera</i> (L.) W.T. Aiton	Shrub	++	Light Brown	Elongated	<i>Lathyrus odoratus</i> L.	Vine	++	Pink	Elongated
<i>Rhynchosia himalensis</i> Benth. ex Baker	Trailing	++	Pink	Globose	<i>Lathyrus pratensis</i> L.	Herb	+	Pink	Elongated
<i>Rhynchosia minima</i> (L.) DC.	Herb	+	Light Brown	Semi-globose	<i>Lathyrus sphaericus</i> Retz.	Herb	++	Pink	Elongated
<i>Rhynchosia pseudocajan</i> Cambess.	Shrub	++	Pink	Globose	<i>Lathyrus sylvestris</i> L.	Vine	++	Pink	Elongated
<i>Rhynchosia pulverulenta</i> Stocks	Herb	++	Brown	Globose	<i>Vicia bakeri</i> Ali	Herb	+	Pink	Elongated
<i>Rhynchosia rothii</i> Benth. ex Aitch.	Twig	++	Pink	Globose	<i>Vicia benthamiana</i> Ali	Herb	+	Pink	Elongated
<i>Vigna aconitifolia</i> (Jacq.) Maréchal	Herb	++	Pink	Globose	<i>Vicia hirsuta</i> (L.) Gray	Herb	+++	Pink	Elongated
<i>Vigna dalzelliana</i> (Kuntze) Verdc.	Herb	+++	Brown	Globose	<i>Vicia monantha</i> Retz.	Herb	+++	Brown	Semi-globose
<i>Vigna trilobata</i> (L.) Verdc.	Herb	++	Pink	Globose	<i>Vicia peregrina</i> L.	Herb	+	Pink	Elongated
<i>Robinieae</i>									
<i>Robinia pseudoacacia</i> L.	Shrub	++	Pink	Globose	<i>Vicia rigidula</i> Royle	Herb	+	Pink	Elongated
<i>Sesbania bispinosa</i> (Jacq.) W. Wight	Shrub	+++	Pink	Globose	<i>Vicia sativa</i> L.	Vine	++	Pink	Elongated
<i>Sesbania concolor</i> J.B. Gillett	Shrub	+++	Pink	Globose	<i>Vicia sepium</i> L.	Herb	++	Pink	Elongated
<i>Sesbania grandiflora</i> (L.) Pers.	Tree	+++	Pink	Globose	<i>Vicia villosa</i> Roth	Vine	++	Pink	Elongated
<i>Sesbania punicea</i> (Cav.) Benth.	Shrub	+++	Pink	Globose					
<i>Sesbania sesban</i> (L.) Merrill	Shrub	+++	Pink	Globose					
<i>Tephrosia purpurea</i> (L.) Pers.	Herb	++	White	Globose					
<i>Tephrosia strigosa</i> (Dalzell) Santapau & Maheshw.	Herb	++	White	Globose					
<i>Tephrosia subtriflora</i> Hochst. ex Baker	Herb	++	White	Globose					
<i>Tephrosia uniflora</i> Pers.	Herb	++	White	Globose					
<i>Tephrosia villosa</i> (L.) Pers.	Herb	++	White	Globose					
<i>Sophoreae</i>									
<i>Sophora alopecuroides</i> L.	Shrub	++	Pink	Globose					
<i>Sophora mollis</i> (Royle) Graham ex Baker	Shrub	++	Pink	Globose					
<i>Thermopsidaeae</i>									
<i>Thermopsis inflata</i> Cambess.	Shrub	++	Pink	Globose					
<i>Trifolieae</i>									
<i>Medicago edgeworthii</i> Sirj.	Herb	++	Pink	Elongated					
<i>Medicago laciniata</i> (L.) Mill.	Herb	++	Pink	Elongated					
<i>Medicago lupulina</i> L.	Herb	+++	Pink	Elongated					
<i>Medicago minima</i> (L.) Bartal.	Herb	++	Pink	Elongated					
<i>Medicago orbicularis</i> (L.) Bartal.	Herb	++	Pink	Elongated					
<i>Medicago polymorpha</i> L.	Herb	++	Pink	Elongated					
<i>Medicago sativa</i> L.	Herb	+++	Pink	Elongated					
<i>Medicago sativa</i> L. subsp. <i>falcata</i> (L.) Arcang.	Herb	++	Pink	Elongated					
<i>Melilotus albus</i> Medik.	Herb	+++	Pink	Elongated					
<i>Melilotus indicus</i> (L.) All.	Herb	+++	Pink	Elongated					
<i>Melilotus officinalis</i> (L.) Lam.	Herb	+++	Pink	Elongated					
<i>Trifolium barbigerum</i> Torr.	Herb	++	Pink	Elongated					
<i>Trifolium bifidum</i> A. Gray	Herb	++	Pink	Elongated					
<i>Trifolium campestre</i> Schreb.	Herb	++	Pink	Elongated					
<i>Trifolium ciliolatum</i> Benth.	Herb	++	Pink	Elongated					
<i>Trifolium dubium</i> Sibth.	Herb	+	Pink	Elongated					
<i>Trifolium fucatum</i> Lindl.	Herb	+	Pink	Elongated					
<i>Medicago monantha</i> (C.A. Mey.) Trautv.	Herb	++	Pink	Elongated					
<i>Trifolium resupinatum</i> L.	Herb	+++	Pink	Elongated					
<i>Trifolium uniflorum</i> L.	Herb	++	Pink	Elongated					
<i>Trifolium variegatum</i> Nutt.	Herb	++	Pink	Elongated					
<i>Trigonella corniculata</i> (L.) L.	Herb	+	Pink	Elongated					
<i>Trigonella emodi</i> Benth.	Herb	+	Pink	Elongated					
<i>Trigonella glabra</i> Thunb. subsp. <i>uncata</i> (Boiss. & Noë) Lassen	Herb	+	Pink	Elongated					
<i>Trigonella gracilis</i> Benth.	Herb	++	Pink	Elongated					
<i>Trigonella hierosolymitana</i> Boiss.	Herb	+	Pink	Elongated					
<i>Vicieae</i>									
<i>Lathyrus aphaca</i> L.	Vine	++	Pink	Elongated					
<i>Lathyrus emodii</i> (Wall. ex Fritsch) Ali	Herb	++	Pink	Elongated					
<i>Lathyrus inconspicuus</i> L.	Herb	++	Pink	Elongated					
<i>Lathyrus hirsutus</i> L.	Herb	++	Pink	Elongated					

+ Indicates sparse nodulation (1–5 nodules per plant)
 ++ Indicates moderate nodulation (6–10 nodules per plant)
 +++ Indicates abundant nodulation (more than 10 nodules per plant)

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