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

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

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