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SEED SOURCE DEPENDENT VARIATION IN MYCORRHIZAL COLONISATION AND NUTRIENT UPTAKE IN *DALBERGIA SISSOO* SEEDLINGS

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DEVAGIRI, G. M., DHIMAN, R. C., SINGH, Y. P. & PATIL, S. K. 2001. Seed source dependent variation in mycorrhizal colonisation and nutrient uptake in *Dalbergia sissoo* seedlings. Thirty seed sources of *Dalbergia sissoo* were screened to evaluate the variations in mycorrhizal colonisation and nutrient uptake and to identify good mycorrhizae forming seed sources. VAM colonisation rate varied significantly between 24 to 54% and 17 to 46% while mycorrhizal root length ranged from 6 to 32 cm and 5 to 22 cm among seed sources during the first and second year respectively. This showed influence of seed source on mycorrhizal colonisation. Variations in number of nodules and nodule dry weight were significant and were positively correlated with mycorrhizal colonisation and seed source. Seedling growth, dry matter accumulation and nutrient uptake varied significantly and improved in seed sources with good mycorrhizae formation which indicated mycorrhizal effect and this response was likely to be seed source dependent.

Among the seed sources tested, Lukhimpurkheri, Tanakpur, Allahabad, Badaun and Kalpi appeared to be the best germplasms with regard to mycorrhizal formation, seedling growth and biomass production. Therefore, these seed sources could be considered while making selection of genotypes with good symbiotic response and for raising nursery stock for afforestation of degraded lands. The utility of seed source/fungus genotype-dependent differences in VAM symbiosis in tree breeding is discussed.

Keywords: Shisham - seed source - variation - mycorrhizal colonisation - nutrient uptake - nodulation - selection - genotype - breeding

DEVAGIRI, G. M., DHIMAN, R. C., SINGH, Y. P., & PATIL, S. K. 2001. Perubahan yang bergantung pada sumber biji benih dalam pengkolonian mikoriza dan pengambilan nutrien di dalam anak benih *Dalbergia sissoo*. Tiga puluh sumber *Dalbergia sissoo* disaring untuk menilai perubahan dalam pengkolonian mikoriza serta pengambilan nutrien dan untuk mengenal pasti sumber biji benih yang boleh menghasilkan mikoriza yang baik. Kadar pengkolonian VAM berubah dengan bererti antara 24 hingga 54% dan 17 hingga 46% manakala panjang akar mikoriza di kalangan sumber-sumber biji benih adalah antara 6

hingga 32 cm dan 5 hingga 22 cm masing-masing pada tahun pertama dan kedua. Ini menunjukkan terdapatnya pengaruh sumber biji benih terhadap pengkolonian mikoriza. Perubahan dalam bilangan nodul dan berat kering nodul adalah bererti dan berkorelasi secara positif dengan pengkolonian mikoriza dan sumber biji benih. Pertumbuhan biji benih, pengumpulan bahan kering dan pengambilan nutrien berubah dengan bererti dan meningkat dalam sumber biji benih yang mempunyai pembentukan mikoriza yang baik. Ini menunjukkan adanya pengaruh mikoriza dan kesan ini berkemungkinan bergantung pada sumber biji benih. Antara biji benih yang diuji, Lukhimpurkheri, Tanakpur, Allahabad, Badaun dan Kalpi merupakan germplasma terbaik dari segi pembentukan mikoriza, pertumbuhan anak benih dan pengeluaran biojisim. Oleh itu, sumber biji benih ini dapat dipertimbangkan semasa membuat pemilihan genotip yang mempunyai tindak balas simbiotik yang baik serta untuk menyimpan stok di tapak semaian untuk penghutanan tanah usang. Kebaikan perbezaan yang bergantung pada genotip sumber biji benih/kulat dalam simbiosis VAM dalam pembiakbaikan pokok juga dibincangkan.

Introduction

Shisham (*Dalbergia sissoo*), being an important member of leguminosae with the ability to fix atmospheric nitrogen, is able to accumulate a considerable amount of nitrogen rich biomass which decomposes quickly and improves the organic matter and nutrient status of the soil. These attributes of shisham enlist it amongst the principal tree species commonly recommended for afforestation of degraded lands in arid and semi-arid tropics where nutrient status is poor. Leguminous trees develop symbiotic association with rhizosphere microflora, particularly with root nodule forming bacteria (*Rhizobium* spp.) and vesicular-arbuscular mycorrhizal (VAM) fungi. Improved productivity of plant in association with these microorganisms is usually attributed to increased N_2 fixation by *Rhizobium* and enhanced uptake of immobile nutrients like P, Zn, Cu and other essential elements due to VAM fungi (Jeffries 1987). An essential requirement for good host plant response to mycorrhizae is a rapid colonisation of roots during the early growth stages of the host plant. Plant growth response to mycorrhizal symbiosis depends on three major components: the plant, the mycorrhizal fungus and the soil environment. An improvement in plant response can be made by manipulating any of these three components. Many workers have attempted to identify and select mycorrhizal fungi which could improve plant performance in a particular environment (Menge 1983). Carling and Brown (1980) screened various fungal isolates under low and high soil fertility regimes.

Interspecific variation in mycorrhizal colonisation has been documented (Mosse 1980). However, there is little work on intraspecific variation particularly in tree species. Krishna *et al.* (1985) tested 30 genotypes of pearl millet across three field locations and observed wide ranges of mycorrhizal colonisation intensity (25–56%) between genotypes. Further, they suggested the use of this heritable trait in evolving P-efficient genotypes in pearl millet. Significant differences are also observed between seed sources of *Pseudotsuga menziesii* and *Pinus ponderosa* for mycorrhizae colonisation (Wright 1971). The author showed that optimum growth in the nursery is greatly affected by the selection of good mycorrhizae forming seed sources. Similarly, Dixon (1988) studied seedlings of *Juglans nigra* (black walnut) from three seed sources inoculated with *Gigaspor margarita, Glomus deserticola* and *G. etunicatum.* VAM development varied significantly between fungal symbionts. *Glomus deserticola* and *G. etunicatum* produced the highest level of root colonisation in all sources. Differences

in seedling shoot and root growth are attributed to root colonisation by specific VAM fungi in each black walnut source. Dixon (1988) observed that *G. deserticola* stimulated seedling leaf area and root weight by 26 and 32 per cent respectively in W_2 seed source. Seedling leaf N, P and K concentrations are significantly improved by VAM in W_2 and W_3 seed sources. Significant differences in nutrient concentrations of mycorrhiza-infected sweet gum seedlings were also reported from nine mother trees (Kormanik *et al.* 1981). Since mycorrhizae are considered to play a role in nutrient absorption especially P, it would be reasonable to expect that seed source differences for mycorrhizal symbiosis and responses might also exist. However, such studies are completely lacking in shisham, a species that is commonly used in afforestation of wastelands where early establishment and seedling growth is of paramount importance. This necessitates screening for improved seed sources having increased symbiotic response. Such sources could be recommended for afforestation of degraded lands where nutrient status is poor. With this view, the present investigation was carried out with the following objectives:

(1) to study the nature and amount of variation in mycorrhizal colonisation in relation to the seed source, and
(2) to screen and evaluate good mycorrhizae forming seed sources.

Materials and methods

Twenty nine seed sources representing natural distributional range of *D. sissoo* in India and one from Nepal, with geographic isolation between each seed source, were selected for the present study (Table 1). Seeds collected from different seed sources were surface-sterilised and sown in polythene bags of 15 × 22 cm size in March 1995. Rhizosphere soil containing natural spore population of mycorrhizae was collected from several shisham stands in a new forest area at Dehra Dun and used as potting media in combination with sand and farmyard manure in equal proportion. Soil medium used to raise the seedlings was analysed for physical and chemical properties and for determination of the number of spores at the beginning of the experiment (Table 2). The experiment was laid in a simple randomised block design with three replicates under nursery conditions. Watering was done daily until the completion of germination and thereafter weekly. Ten randomly selected seedlings per seed source and per replication were harvested at 6 (first year) and 18 months (second year) after sowing. At the time of harvest, rhizosphere soil was carefully collected from all seedlings and 20% of secondary lateral roots were excised, cleared and stained (Phillips & Hayman 1970) and evaluated to determine VAM colonisation using methods described by Giovanetti and Mosse (1980). Density gradient centrifugation method was used to quantify the number of spores/gram soil (Jeniks 1964). Seedling height, collar diameter, leaf area, root length and root volume were measured and number of nodules on intact root system of each seedling were counted. Nodules formed on each seedling were carefully removed into a small paper bag and then oven-dried at 60 °C for 24 h. Total nodule dry weight was recorded in mg/seedling. Total seedling dry matter was measured after drying the root, shoot and leaf for 24 h at 80 °C.

Uptake of various nutrient elements was determined only in seedlings of the second year. Leaf tissue was digested with nitric-perchloric acid to estimate total N by

Table 1. Geographic location of seed sources (seed collection sites)

Seed source	State	Latitude (°N)	Longitude (°E)	Altitude (m asl)	Rainfall (mm/year)
1. Lukhimpurkheri	U. P.	27.9	80.8	147	1132
2. Tanakpur	U. P.	29.1	80.1	118	1235
3. Pathankot	Punjab	32.3	75.7	312	1486
4. Jhansi	U. P.	25.4	78.6	251	1000
5. Muzaffurnagar	U. P.	29.5	77.7	222	838
6. Sontinursery	Haryana	28.3	76.4	210	475
7. Sahajanpur	U. P.	27.9	79.9	221	714
8. Kalpi	U. P.	26.1	79.7	128	1096
9. Sahajanwa	U. P.	27.0	81.1	235	1013
10. Bareilly	U. P.	28.4	79.5	173	1068
11. Koshitappu	Nepal	28.3	83.1	356	1800
12. Sweeti	Haryana	29.2	79.7	221	446
13. Simblewala	J & K	32.3	74.8	324	978
14. Etawah	U. P.	26.8	79.1	130	850
15. Ramsai	W. B.	26.7	88.9	81	2146
16. Sukna	W. B.	26.5	88.7	80	1346
17. Moradabad	U. P.	28.8	78.8	88	628
18. Allahabad	U. P.	25.5	80.9	98	1027
19. Chiriyapur	U. P.	22.5	76.4	154	873
20. Najibabad	U. P.	29.6	78.3	214	1465
21. Badaun	U. P.	22.9	86.5	224	1267
22. Sibsagar	Assam	27.0	94.6	97	2504
23. Jorhat	Assam	26.8	94.2	110	2243
24. Central Diana	W. B.	26.7	89.2	83	2357
25. Muzaffurpur	Bihar	26.1	85.4	57	125
26. Gauribazar	U. P.	28.7	80.5	162	991
27. Rampur	U. P.	26.6	83.8	78	634
28. Mirzapur	U. P.	25.2	82.6	141	683
29. Sultanpur	U. P.	26.5	78.2	85	745
30. Farinda	Punjab	30.5	73.9	276	678

U. P.–Uttar Pradesh, J & K–Jammu and Kashmir, W. B.–West Bengal

microkjeldahl (Loomis & Shull 1937), P by molybdate blue method (Vogel 1961), K and Ca by EEL flame photometer (Vogel 1961) and Mg by thiozole yellow method (Young & Gill 1951). Final observation was based on the average of ten randomly selected seedlings.

All data were subjected to one-way analysis of variance (Panse & Sukhatme 1978).

Results and discussion

Mycorrhizal status

Effect of seed source on mycorrhizal colonisation rate and total root length infected was highly significant (Table 3). Degree of mycorrhizal formation varied greatly during the first as well as the second year of growth. Overall, the seed sources that had high levels of colonisation in the first year consistently maintained their superiority with maximum infection during the second year. For seedlings grown under common nursery conditions, colonisation varied from 24 to 54 per cent and 17 to 46 per cent

Table 2. Physical and chemical analysis of nursery soil used as potting media

Parameters	Method employed	Quantity in soil
Bulk density (g/cc)	Tube core method (Piper 1966)	1.19
Water holding capacity (%)	Keen's cup method (Piper 1966)	42.39
Clay (%)	International pipette method (Piper 1966)	13.73
Silt (%)	International pipette method (Piper 1966)	16.67
Coarse sand (%)	International pipette method (Piper 1966)	28.20
Fine sand (%)	International pipette method (Piper 1966)	41.30
pH	1:2.5 soil:water suspension glass electrode pH meter (Jackson 1973)	6.50
Organic C (%)	Rapid titration method (Walkley and Black 1934)	0.87
Available N (%)	Alkaline permanganate method (Subbiah and Asija 1956)	0.133
Available P (%)	Olsen's method (Olsen *et al.* 1954)	0.029
Available K (%)	N 1N ammonium acetate, flame photometer (Jackson 1973)	0.113
Exchangeable Ca (%)	Varsanate titration method (Jackson 1973)	0.120
Exchangeable Mg (%)	Varsanate titration method (Jackson 1973)	0.023
Number of spores/gram soil	Density gradient centrifugation method (Jeniks 1964)	2.0

among 30 seed sources in the first and second year respectively. Good amount of mycorrhizal infection (52–54%) was observed in seedling roots of Lukhimpurkheri, Kalpi, Allahabad, Badaun and Sahajanwa seed sources in the first year. Seeds from these seed sources could be used for raising planting stock for afforestation of degraded land where nutrient status is poor. Seedlings with high degree of VAM infection in the initial stage could withstand stressful conditions in the field due to enhanced nutrient uptake and increased resistance to drought. Thus, VAM influences the plant growth in nutrient and moisture deficient soils and thereby improves seedling survival in the field, which is a crucial factor for afforestation of degraded lands. Trappe (1977) noted that the absence of mycorrhizae from planting stock could reduce field performance due to reduced nutrient uptake. Poor root colonisation by mycorrhizae was observed in seedlings of Koshitappu, Mirzapur, Jorhat, Jhansi, Sukna, Sibsagar (24–29%) and hence these sources should not be considered for afforestation programme.

Total mycorrhizal infected root length followed a trend similar to mycorrhizal colonisation with maximum length being observed in Lukhimpurkheri (32 and 22 cm) and minimum in Koshitappu (6 and 5 cm) seed source during the first and second year respectively. This differential VAM formation in seedlings of different seed sources suggests the influence of host genotype on mycorrhizal root colonisation. This view is supported by earlier studies conducted by Rink & Stelzers (1981) on black walnut, who hypothesised that variable response to VAM fungi is an indicator of host genotype and fungal interactions which controls the VAM colonisation process and early seedling growth. Similar studies in *Juglans nigra* have shown that the potential for mycorrhizae formation was highly dependent on seed source (Dixon 1988). Menge (1983) believes that rapid and high levels of colonisation may be the prime

Table 3. Effect of seed source on mycorrhizal colonisation and associated traits in *Dalbergia sissoo* seedlings

Seed Source	Mycorrhizal colonisation (%)		Total root length infected (cm)		Number of spores/gram soil	
	(1st year)	(2nd year)	(1st year)	(2nd year)	(1st year)	(2nd year)
1. Lukhimpurkheri	54 (65)	46 (51)	32	22	8	5
2. Tanakpur	47 (53)	40 (41)	24	16	6	4
3. Pathankot	37 (36)	33 (30)	18	13	4	2
4. Jhansi	27 (21)	24 (16)	11	8	3	1
5. Muzaffurnagar	41 (44)	35 (32)	21	15	5	2
6. Sontinursery	36 (34)	25 (18)	15	9	3	2
7. Sahajanpur	37 (36)	28 (22)	15	10	4	2
8. Kalpi	54 (65)	44 (47)	31	19	8	5
9. Sahajanwa	52 (61)	42 (44)	28	16	7	4
10. Bareilly	43 (46)	37 (37)	24	16	7	4
11. Koshitappu	24 (16)	20 (11)	6	5	2	1
12. Sweeti	43 (46)	36 (34)	27	15	5	3
13. Simblewala	30 (25)	23 (15)	13	6	2	1
14. Etawah	30 (25)	25 (18)	12	7	2	1
15. Ramsai	48 (55)	38 (38)	28	15	6	4
16. Sukna	28 (22)	23 (15)	10	7	2	1
17. Moradabad	38 (37)	28 (22)	21	10	3	1
18. Allahabad	54 (65)	42 (45)	30	18	8	5
19. Chiriyapur	33 (30)	27 (20)	16	11	3	1
20. Najibabad	30 (25)	25 (18)	12	11	3	1
21. Badaun	52 (62)	40 (42)	28	16	7	3
22. Sibsagar	29 (23)	21 (13)	11	7	2	1
23. Jorhat	26 (20)	18 (9)	9	6	2	1
24. Central Diana	46 (52)	39 (39)	26	15	5	5
25. Muzaffurpur	37 (36)	31 (25)	19	13	4	2
26. Gauribazar	34 (31)	23 (15)	16	14	4	2
27. Rampur	34 (32)	29 (23)	19	14	3	2
28. Mirzapur	24 (17)	17 (8)	10	6	2	0
29. Sultanpur	33 (30)	27 (21)	13	11	3	1
30. Farinda	31 (26)	21 (12)	12	10	3	1
Mean	38 (36)	30 (26)	19	12	4	2
Range: min	24	17	6	5	2	0
max	54	46	32	22	8	5
F-ratio for $p < 0.01$	1.6	0.8	1.6	0.6	0.3	0.1
C.D. at 1%	4	2	4	1	0.7	0.3
S.D.	10.2	8.4	5.1	4.4	1.8	1.4

(C.D. = Critical difference, S.D. = Standard deviation)
Values in parentheses are original means and those outside are arc-sin transformations

determinant of the efficiency of symbiosis. Other factors such as host susceptibility to infection, phenology of short root formation, fungal specificity or rhizosphere compatibility of the host and fungi may influence mycorrhizal formation (Harley & Smith 1983).

Degree of mycorrhizal infection was reduced in all seed sources consistently during the second year. Possible reasons for reduced infection are the reduction of the population of viable spores in the soil owing to the size of polythene bags, large root volume and nutritional status of soil. Spore population during the first growing season varied from 2 to 8 per gram soil, while in the second year spore population was much less, namely from 0 to 5 per gram soil. Wright and Ching (1962) observed significant

differences in mycorrhizal development in the initial stage of growth, although these are not significant after one-year growth in Douglas-fir seed sources.

Root system

Root length and root volume of different seed sources varied significantly (Table 4). These differential root formations may have influenced the percentage of colonisation and total root lengths infected. However, for several seed sources with almost similar root length there was a large difference in the extent of VAM colonisation. For example, seedlings of Lukhimpurkheri, Moradabad, Najibabad and Central Diana seed sources had root length of 30–31cm but the degree of infection differed greatly among seed sources. This suggests that only very little amount of

Table 4. Seed source variation in root and nodulation parameters in *Dalbergia sissoo*

Seed Source	Root length (cm)		Root volume	Number of nodules/seedling		Nodule dry weight (mg/seedling)	
	(1st year)	(2nd year)	(2nd year)	(1st year)	(2nd year)	(1st year)	(2nd year)
1. Lukhimpurkheri	27.4	30.5	10.2	29.1	31.5	17.4	16.4
2. Tanakpur	13.3	32.3	8.2	19.7	26.4	11.5	14.3
3. Pathankot	16.4	36.2	6.8	22.1	22.0	10.4	10.3
4. Jhansi	17.5	27.2	5.5	20.8	14.2	7.8	5.3
5. Muzaffurnagar	23.2	38.4	17.3	21.9	20.3	9.3	9.7
6. Sontinursery	11.7	24.8	4.2	23.3	15.3	8.4	5.3
7. Sahajanpur	20.4	26.3	6.5	24.1	16.2	11.3	7.3
8. Kalpi	16.4	37.7	9.5	26.2	28.4	12.2	16.3
9. Sahajanwa	25.5	46.2	8.2	28.1	21.5	16.3	11.6
10. Bareilly	22.7	41.5	8.6	26.9	26.6	14.7	14.3
11. Koshitappu	13.8	18.4	3.4	14.3	7.6	6.1	2.3
12. Sweeti	17.5	42.5	8.7	24.1	23.5	13.1	13.5
13. Simblewala	20.2	17.4	3.3	8.2	2.3	3.2	1.7
14. Etawah	18.6	22.3	4.1	8.1	5.0	4.5	2.5
15. Ramsai	21.0	38.5	9.1	22.8	24.6	13.6	13.5
16. Sukna	16.6	26.4	5.4	16.4	7.1	7.3	3.3
17. Moradabad	20.1	31.3	6.3	19.1	12.4	9.6	4.2
18. Allahabad	18.9	43.6	9.6	26.6	28.3	16.9	18.4
19. Chiriyapur	17.6	29.4	6.2	20.3	14.0	9.6	6.6
20. Najibabad	21.3	31.3	6.5	13.1	16.1	8.5	7.1
21. Badaun	19.9	40.5	8.7	39.9	30.5	20.8	15.5
22. Sibsagar	11.2	15.2	3.1	15.2	4.2	6.6	1.5
23. Jorhat	11.5	11.6	2.9	14.7	3.1	6.0	1.3
24. Central Diana	19.2	31.5	7.7	18.7	18.0	10.2	11.6
25. Muzaffurpur	27.2	29.5	6.7	20.4	9.6	10.1	3.9
26. Gauribazar	26.2	32.3	6.5	13.0	14.4	8.1	6.9
27. Rampur	28.5	33.3	6.7	15.7	10.8	9.9	5.6
28. Mirzapur	10.6	13.3	3.3	6.0	5.2	2.6	1.9
29. Sultanpur	14.9	24.6	5.5	11.7	11.8	5.3	7.0
30. Farinda	13.1	13.7	3.7	10.0	6.1	4.4	2.6
Mean	18.8	29.6	6.7	19.4	15.9	9.9	8.3
Range : min	10.6	11.6	2.9	6.0	2.3	2.6	1.3
max	28.5	46.2	17.3	39.9	31.5	20.8	18.4
F-ratio for p > 0.01	1.5	3.9	0.5	2.1	1.3	1.2	0.4
C.D. at 1%	4.0	10.3	1.2	5.6	3.6	3.3	1.2
S.D.	11.8	10.2	3.0	10.7	8.8	6.1	5.3

(C.D. = Critical difference, S.D. = Standard deviation)

variation in percentage colonisation and root length infected could be attributed to the variation of root length. Huisman (1982) pointed out that percentage colonisation is often, if not always, confounded by differential root growth rates between genotypes. Seed source variation in root colonisation and response to VAM could be due to an interaction between host genotype and VAM strain preferences (Mosse 1980). The number of infection sites on the root could also play a role (Buwalda *et al.* 1982). Different levels of colonisation between genotypes could arise from differences in the rate of growth of the fungus through root cortex (Smith & Walker 1981). This differential rate of growth of fungus could be partly related to the balance of inhibitory substances such as phenols, coumarins, phytoalexins, etc. However, the present study cannot differentiate between the two factors proposed by Buwalda *et al.* (1982) and Smith & Walker (1981). These emphasise the need for further investigation on these aspects of this species.

Nodulation

Number of nodules and nodule dry weight per seedling exhibited significant variation among different seed sources and followed a trend similar to mycorrhizal and associated traits. Of the 30 seed sources, some had very good nodulation in the first year, numbering up to 39.9 nodules per seedling, whereas seedlings of some seed sources such as Mirzapur, developed very few nodules (6.0). Table 4 also reveals that seed sources which developed more nodules and had higher nodule weight also recorded higher degree of VAM colonisation. This suggests the existence of relationship among seed source, bacteria and fungus. According to Linderman (1988), the existence of tripartite relationship among legume-*Rhizobium*-arbuscular mycorrhizae is very certain. Thus, the association of these microsymbionts with a particular host type is very specific in nature and, presumably, has a strong genetic background. Abott & Robson (1977) observed that in addition to the stimulus brought about in growth due to generally improved phosphate nutrition, mycorrhizal infection may also stimulate growth via other processes such as nodulation and N_2 fixation. Smith & Daft (1978) demonstrated that in *Medicago sativa* VAM infection increased total plant phosphate, growth, nodulation and nitrogen fixation. These show the presence of a more specific biological interaction between host-*Rhizobium*-VAM fungi that can be of great value in identifying and selecting adaptive and productive seed sources (genotypes) in this species.

Nutrition and growth

Seedling growth, dry matter and nutrient uptake varied significantly among seed sources (Tables 5 & 6). Seedlings raised from Lukhimpurkheri, Tanakpur, Kalpi, Allahabad and Badaun were taller, thicker and recorded high dry matter. Nutrient uptake, especially N, P and K, was also high in these sources. Seedlings raised from Sahajanwa, Bareilly, Sweeti, Ramsai and Central Diana seed sources showed intermediate performance in nutrient uptake and dry matter production. Poor growth coupled with low nutrient uptake was observed in seedlings raised from Koshitappu, Simblewala, Sukna, Sibsagar, Jorhat, Mirzapur and Farinda seed sources. Results obtained also revealed that seedling roots of these sources had low intensity of VAM

Table 5. Seed source dependent variation in seedling growth and dry matter yield in *Dalbergia sissoo*

Seed Source	Seedling height (cm)		Collar diameter (mm)		Leaf area (cm^2)		Seedling dry matter (g/seedling)	
	(1st year)	(2nd year)	(1st year)	(2nd year)	(1st year)	(2nd year)	(1st year)	(2nd year)
1. Lukhimpurkheri	42.6	94.2	4.6	7.3	7.0	12.6	4.5	20.4
2. Tanakpur	36.6	86.5	3.8	6.2	6.9	11.4	3.7	15.5
3. Pathankot	30.5	76.5	3.3	5.7	4.4	7.8	3.0	13.3
4. Jhansi	35.2	52.6	3.3	4.7	7.4	7.6	2.6	9.2
5. Muzaffurnagar	32.4	74.8	3.4	5.2	5.4	10.2	2.1	11.3
6. Sontinursery	33.3	48.4	3.0	3.9	5.0	7.1	2.1	7.9
7. Sahajanpur	33.9	61.5	3.2	5.2	7.8	7.3	2.5	10.1
8. Kalpi	41.2	90.4	2.9	7.1	5.8	13.7	3.2	18.5
9. Sahajanwa	35.8	89.5	2.9	6.7	5.0	8.8	2.2	16.5
10. Bareilly	35.9	83.6	3.0	5.8	4.7	9.6	2.8	15.8
11. Koshitappu	25.1	33.4	2.5	3.2	4.0	4.5	1.0	6.3
12. Sweeti	39.4	88.4	3.2	6.6	9.1	9.1	3.0	16.4
13. Simblewala	26.8	26.7	2.3	2.8	3.1	4.2	1.0	5.1
14. Etawah	30.6	40.5	2.3	3.7	5.8	4.7	1.1	6.4
15. Ramsai	31.0	86.3	2.7	6.3	5.5	8.9	2.9	14.6
16. Sukna	32.7	53.4	2.7	4.3	5.1	5.5	1.8	9.3
17. Moradabad	39.7	64.2	3.0	5.2	4.8	7.2	2.4	11.8
18. Allahabad	43.4	86.3	3.4	6.9	7.1	14.6	3.1	16.7
19. Chiriyapur	39.6	61.5	3.0	5.6	5.6	6.5	2.1	9.8
20. Najibabad	31.3	65.9	2.7	5.7	4.7	6.8	1.4	10.4
21. Badaun	44.2	89.4	3.4	6.6	9.0	12.7	3.0	16.6
22. Sibsagar	18.5	29.3	2.3	2.9	4.2	4.3	0.6	4.7
23. Jorhat	15.9	26.7	1.9	3.2	3.8	3.8	0.6	4.4
24. Central Diana	30.3	61.4	2.6	5.8	5.6	8.8	1.8	12.5
25. Muzaffurpur	40.7	69.7	3.3	5.4	7.2	9.3	2.2	11.8
26. Gauribazar	30.7	63.4	2.3	4.9	3.8	6.2	1.7	12.4
27. Rampur	36.2	65.8	3.5	4.9	6.6	6.7	2.2	11.2
28. Mirzapur	18.4	33.4	2.0	3.5	4.0	4.7	0.8	6.8
29. Sultanpur	31.6	54.4	2.7	4.1	7.1	7.5	1.4	10.5
30. Farinda	26.5	37.3	3.0	3.7	4.9	5.1	1.1	5.6
Mean	33.0	63.2	2.9	5.1	5.7	7.9	2.1	11.4
Range: min	15.9	26.3	1.9	2.8	3.1	3.8	0.6	4.4
F-ratio for $p < 0.01$	2.4	5.0	0.3	0.2	0.9	0.4	0.5	0.6
C.D. at 1%	6.5	13.3	0.7	0.6	2.5	1.1	0.7	1.5
S.D.	23.2	21.8	1.7	1.3	3.4	2.9	6.7	4.4

(C.D. = Critical difference, S.D. = Standard deviation)

and nodule formation. These differences among seed sources may be partially attributed to mycorrhizal status that is seed source-dependent. Thus, seed source indirectly influences seedling growth and biomass accumulation by controlling mycorrhizal formation. These results are similar to previous studies with *Citrus*, which demonstrated that seedling benefits from colonisation were related to host genotype rather than the degree of VAM colonisation (Menge *et al.* 1978). Similarly, Marx & Bryan (1971) also suggested that in Slash pine, genotype controls the benefits obtained by seedlings from ectomycorrhizal relationships.

Mycorrhizal infection can affect the biochemical and physiological activities of seedlings (Carling & Brown 1980), and these responses are likely to be seed source or genotype dependent. *Dalbergia sissoo* showed differences between seed sources in uptake of various nutrient elements in response to VAM colonisation. Therefore, the

Table 6. Seed source dependent variation in nutrient uptake in *Dalbergia sissoo* seedlings

Seed source	N (mg/seedling)	P (mg/seedling)	K (mg/seedling)	Ca (mg/seedling)	Mg (mg/seedling)
1. Lukhimpurkheri	511.9	29.6	206.3	220.5	113.9
2. Tanakpur	492.8	24.9	149.5	164.4	120.8
3. Pathankot	251.6	6.0	112.3	146.4	58.6
4. Jhansi	116.8	2.6	71.6	76.3	25.7
5. Muzaffurnagar	140.2	5.8	112.2	121.3	37.4
6. Sontinursery	77.2	2.8	59.1	74.8	32.1
7. Sahajanpur	100.4	4.3	74.1	113.6	31.5
8. Kalpi	350.0	17.6	190.7	258.9	141.4
9. Sahajanwa	344.8	13.2	197.8	297.0	155.1
10. Bareilly	405.6	11.5	148.3	225.6	98.9
11. Koshitappu	62.5	1.5	27.5	58.7	21.4
12. Sweeti	223.1	10.3	167.3	246.0	68.8
13. Simblewala	59.4	1.3	18.7	48.4	28.8
14. Etawah	81.6	1.4	23.2	57.6	21.7
15. Ramsai	274.1	12.6	147.2	233.5	80.3
16. Sukna	78.8	2.8	41.4	90.9	23.7
17. Moradabad	181.2	4.6	85.2	157.5	41.5
18. Allahabad	487.3	21.7	163.6	267.7	103.6
19. Chiriyapur	133.5	4.5	71.6	104.7	41.2
20. Najibabad	177.3	5.0	65.7	153.3	39.6
21. Badaun	482.5	24.8	177.1	331.6	91.8
22. Sibsagar	40.3	1.2	17.1	44.6	19.4
23. Jorhat	31.1	1.2	15.1	33.8	19.4
24. Central Diana	295.7	15.2	133.5	249.8	73.9
25. Muzaffurpur	248.8	7.8	48.7	1262	43.3
26. Gauribazar	181.7	5.6	96.5	247.3	68.1
27. Rampur	194.0	5.9	108.8	223.1	68.3
28. Mirzapur	59.3	1.5	22.4	56.6	23.6
29. Sultanpur	164.2	5.5	40.8	106.7	42.8
30. Farinda	35.7	0.8	20.2	53.3	18.2
Mean	209.4	8.5	93.8	153.0	58.5
Range: min	31.1	0.8	15.1	33.8	18.2
max	511.9	29.6	206.3	331.6	155.1
F-ratio for $p < 0.01$	0.7	0.2	0.8	0.7	1.1
C.D. at 1%	1.8	0.6	2.0	1.7	2.9
S.D.	0.8	0.1	0.3	0.4	0.3

(C.D. = Critical difference, S.D. = Standard deviation)

VAM activity with regards to nutrient uptake, especially P and its translocation, may be under the control of host genetic constitution and the physiological need for this element. Dixon (1988) observed a similar kind of variation in nutrient element concentrations and partially attributed the variability to host × symbiont compatibility. The significantly larger root systems of seedlings inoculated with compatible fungal symbionts promote efficient uptake of soil nutrients.

Conclusion

The present study demonstrates significant variation in VAM colonisation and associated traits among seed sources and suggests that these are strongly genetic in nature. Therefore, the possibility to select and breed genotypes for increased mycorrhizal infection and nodulation exists. Among the 30 seed sources tested in this

study, Lukimpurkheri, Tanakpur, Allahabad, Badaun and Kalpi showed better performance with regard to VAM colonisation, growth, dry matter production and nutrient uptake. Therefore, these seed sources can be considered for selection of superior genotypes and for future breeding programmes.

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