Distribution, Diversity and Species Relationships of Wild *Vigna* species in *Mungo-Radiata* Complex

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A total of 107 populations of 5 *Vigna* species in the *mungo-radiata* complex from different phytogeographical regions of India were collected. These species occurred in different associations as components of the herbaceous and grassy undergrowth or are seen twining on bushes in scrub vegetation. *V. mungo* var. *silvestris* was widespread in northern parts of the Western Ghats. Sporadic occurrence of this species was recorded from parts of Rajasthan, Madhya Pradesh and Maharashtra. *V. radiata* var. *sublobata* was widespread in the Western Ghats. Sporadic distribution of this species was recorded from the north-western Himalayas, parts of Rajasthan, Madhya Pradesh, Maharashtra, and southern parts of the Western Ghats. *V. radiata* var. *setulosa* populations were of sporadic occurrence in northern parts of the Western Ghats and north-eastern region of the Eastern Ghats. *V. hainiana* populations were widespread in central plateau region and parts of the Eastern Ghats. Sporadic distribution of this species was also recorded from north-western Himalayas. *V. khandaklensis*, was endemic to northern parts of Western Ghats. Diversity of the collected germplasm for various morphological characters was assessed. Data on 45 selected qualitative and quantitative traits were subjected to multivariate analysis for establishing species relationships and assessing the pattern of inter- and intra-specific variation. Except for *V. khandalensis*, all other species, *V. radiata* var. *sublobata*, *V. radiata* var. *setulosa*, *V. mungo* var. *silvestris* and *V. hainiana* showed greater homology in growth habit. The species, however, differed in other plant, flower, pod and seed characteristics. *V. khandalensis* was distinct from all other species in an erect growth habit, large foliaceous stipules and broad leaves. Within species variations were more in *V. mungo* var. *silvestris* populations. The cultigen types of *V. mungo* and *V. radiata* showed greater homology to the conspecific wild species in morphological characteristics, the former were however more robust in growth, with large vegetative parts, erect growth and three to fivefold increase in seed size and seed weight. Wild species have a great potential as sources of disease resistance and other useful traits. Intensive collection, characterisation and conservation of the species diversity and intraspecific variation, particularly of the conspecific wild relatives with valuable characters, therefore assumes great priority to make extended cultivation economically attractive.

Key words: Asian *Vigna*, *Ceratotropis*, Distribution, Diversity, Species relationships, *Vigna mungo-radiata* complex

The Asian *Vigna* in the subgenus *Ceratotropis*, with 16 to 17 recognised species distributed across Asia (Verdcourt, 1970; Marechal *et al.*, 1978; Tateishi, 1996), constitute an economically important group of cultivated and wild species for which a rich diversity occurs in India. Taxonomically, cultigen and conspecific wild forms are recognised in all cultivated Asiatic pulses, *V. radiata* (L.) Wilczek (mungbean), *V. mungo* (L.) Hepper (urdbean), *V. umbellata* (Thunberg) Ohwi & Ohashi (ricebean) and *V. angularis* (Willdenow) Ohwi & Ohashi (azukibean) except for *V. aconitifolia* (Jacquin) Marechal (mothbean) which has retained a wild type morphology (Marechal *et al.*, 1978; Lukoki *et al.*, 1980). The cultivated species, *V. radiata* and *V. mungo* are of Indian origin as is borne out of their remains in archaeological sites in the sub-continent (Arora *et al.*, 1973; Chandel *et al.*, 1984). The domestication of *V. aconitifolia* is also apparently Indian, whereas that of *V. angularis* and *V. umbellata* is far eastern. Wild *V. angularis* is distributed in Japan and Korea; *V. umbellata* has its origin in Indo-China and Southeast Asia (Marechal *et al.*, 1978; Baudoin and Marechal, 1988).

The Asian *Vigna* are considered to be a morphologically homogenous group which have very specialised and complex floral organs. The work of Maekawa (1955), Baudet (1974) and Tateshi (1996) clearly demonstrated three groups in Asian *Vigna* based on the position of cotyledons on germination and the petiolate or sessile nature of first and second leaves. This was also confirmed by several other workers (Jaaska and Jaaska, 1990; Kaga *et al.*, 1996; Tomooka *et al.*, 1996; Konarev *et al.*, 2000). Lawn (1995), based on

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cross compatibility studies, also proposed that Asian *Vigna* consists of three more or less isolated genepools corresponding with groups based on seedling characteristics proposed by Taiteshi (1996). The proposed groups were *radiata-mungo* (mungbean group), *angularis-umbellata* (azukibean group) and *aconitifoila-trilobata* (mothbean group). Tomooka *et al.* (2000) proposed a revised list of taxa in the subgenus *Ceratotropis* and suggested three groups giving them taxonomic rank as Section *Angulares* (azukibean group), *Radiateae* (mungbean group), *Aconitifoliae* (mothbean group), and an undetermined section for *V. khandalensis*. Tomooka *et al.* (2002, 2003) describe relationships among the Asian *Vigna* species under subgenus *Ceratotropis*.

Fourteen species of *Vigna* under the subgenus *Ceratotropis* are reported to occur in India (Arora, 1985). The cultivated species in the *mungo-radiata* complex with conspecific wild forms are *V. mungo* and *V. radiata*. The conspecific wild species in *V. mungo* is *V. mungo* var. *silvestris* Lukoki, Marechal & Otoul. In *V. radiata*, more diversity in wild types occur and two conspecific species *V. radiata* var. *setulosa* (Dalzell) Ohwi and Ohashi and *V. radiata* var. *sublobata* (Roxburgh) Verdcourt are reported. Two more wild species, *V. hainiana* Babu, Gopinathan & Sharma and *V. khandalensis* (Santapau) Raghavan & Wadhwa, endemic to India, have also been accommodated in the *mungo-radiata* complex owing to their similarity to both cultivated *V. mungo* and *V. radiata*. The status of these two species is, however, yet to be resolved.

Other cultivated species with conspecific wild forms include *V. umbellata* (wild type occurring, conspecific with cultigen types – *V. umbellata* var. *gracilis* (Prain) Marechal, Mascherpa & Stainier), *V. aconitifolia* (wild occurring variability conspecific with cultigen types) and the semi-domesticated *V. trilobata* (L.) Verdcourt (wild occurring variability conspecific with cultigen type). No wild types are reported to occur in India for *V. angularis*. *V. dalzelliana* (O. Kuntze) Verdcourt (akin to *V. umbellata*), *V. minima* (Roxburgh) Ohwi and Ohashi, *V. bourneae* Gamble and *V. glabrescens* Marechal, Mascherpa & Stainer are other species in the subgenus *Ceratotropis* reported to occur in India. *V. unguiculata* (L.) Walp. in the subgenus *Vigna* which is of African origin also exhibits much diversity in India, its wild related types do not occur there, the wild types *V. vexillata* (L.) A. Rich. (under subgenus *Plectotropis*) is quite different. *V. pilosa* (Willd.) Baker and *V. marina* (Burm.) Merr. under sub-genus *Dolichovigna*, *V. luteola* (Jacq.) Benth. under subgenus *Vigna* and *V. grahamianus* (Wt. & Arn.) Verdcourt under subgenus *Macrorhyncha* are also naturalised in some parts of the country (Arora, 1985; Bisht *et al.*, 2002).

Most earlier studies demonstrated species relationships based on a limited number of accessions of individual species and information on intraspecific diversity, particularly in *mungo-radiata* complex, is lacking. Information on intraspecific diversity is essential for effective use of wild species germplasm in crop improvement programmes. The use of wild relatives as sources of new germplasm is well established in breeding programmes for crop improvement on a world wide level, however, the efficiency of introduction of useful traits from wild germplasm such as disease resistance and other agronomic characters into elite cultivars varies greatly. Wild *Vigna* species have great potential for use in crop improvement programmes. Bruchids are serious pest of grain legumes during storage. A wild mungbean accession, *Vigna radiata* var. *sublobata* was reported to be highly resistant to bruchid, *Callosobruchus chinensis* (L.) at the AVRDC (Talekar, 1994). Mungbean yellow mosaic virus (MYMV) has been a major problem in mungbean. The wild species *Vigna radiata* var. *sublobata* is an important source to incorporate resistance to MYMV into cultivated varieties (Singh, 1994). In addition to the landraces and cultivars, the wild species therefore needs to be collected, characterised and conserved carefully for use in crop improvement programmes.

In India, the National Bureau of Plant Genetic Resources (NBPGR) has the major responsibility of collecting, maintaining and conserving the crop plant genetic resources including wild related species. Systematic survey and collection of the wild *Vigna* species occurring in India was undertaken during 1999-2001. In the present communication the information on distribution, habitat and ecology of naturally occurring wild species in *mungo-radiata* complex from different phytogeographical regions of India, their diversity for different morphological characters based on characterisation data and species relationships are discussed.

Material and Methods

Survey and Germplasm Collection

Exploration and collection missions were undertaken during 1999-2001. The areas covered under the exploration

missions include (Figure 1, A-E) the North-western Himalayas (parts of Uttaranchal and Himachal Pradesh); central plateau region (parts of Madhya Pradesh, Chhattisgarh and Maharashtra); parts of Rajasthan, Western Ghats (parts of Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu) and Eastern Ghats (parts of Orissa and Chhatisgarh). Explorations were conducted following a coarse grid survey. Detailed passport data on place of collection, latitude, longitude, altitude, frequency of occurrence, sample type, sampling method, associated vegetation type, habitat/ecology etc., for collected germplasm accessions were recorded.

Germplasm characterisation

The collected germplasm accessions (107 populations) of 5 wild *Vigna* species in *mungo-radiata* complex (Table 1) were grown at the National Bureau of Plant Genetic Resources (NBPGR) Regional Station, Thrissur (Kerala) for detailed morphological characterisation during the 2002 cropping season. The wild species accessions together with ten accessions each of conspecific cultigen types (*V. mungo* and *V. radiata*) were grown both under field conditions and in earthen pots. Data were recorded for 71 characters, both qualitative and quantitative, based on IPGRI (International Plant Genetic Resources Institute) descriptors with little modifications (Mahajan *et al.*, 2001). Data on qualitative traits were recorded from pot-grown plants whereas field grown plants in Augmented Block Design were used for recording data on quantitative traits. Data for quantitative traits were recorded on five randomly selected individuals per accession. Frequency distribution for qualitative characters and range, mean, and variance for quantitative traits were computed using MSTAT-C statistical package developed at the Michigan State University, USA.

Cladistic and phenetic analysis

The scores for various character states of different accessions were converted to a binary code. The character states X species accessions data matrix was used to calculate the frequency of occurrence of a particular character state in a species. This frequency matrix was used to construct a cladogram based on Fitch optimality criteria. The cladogram obtained was rerooted with *Vigna*

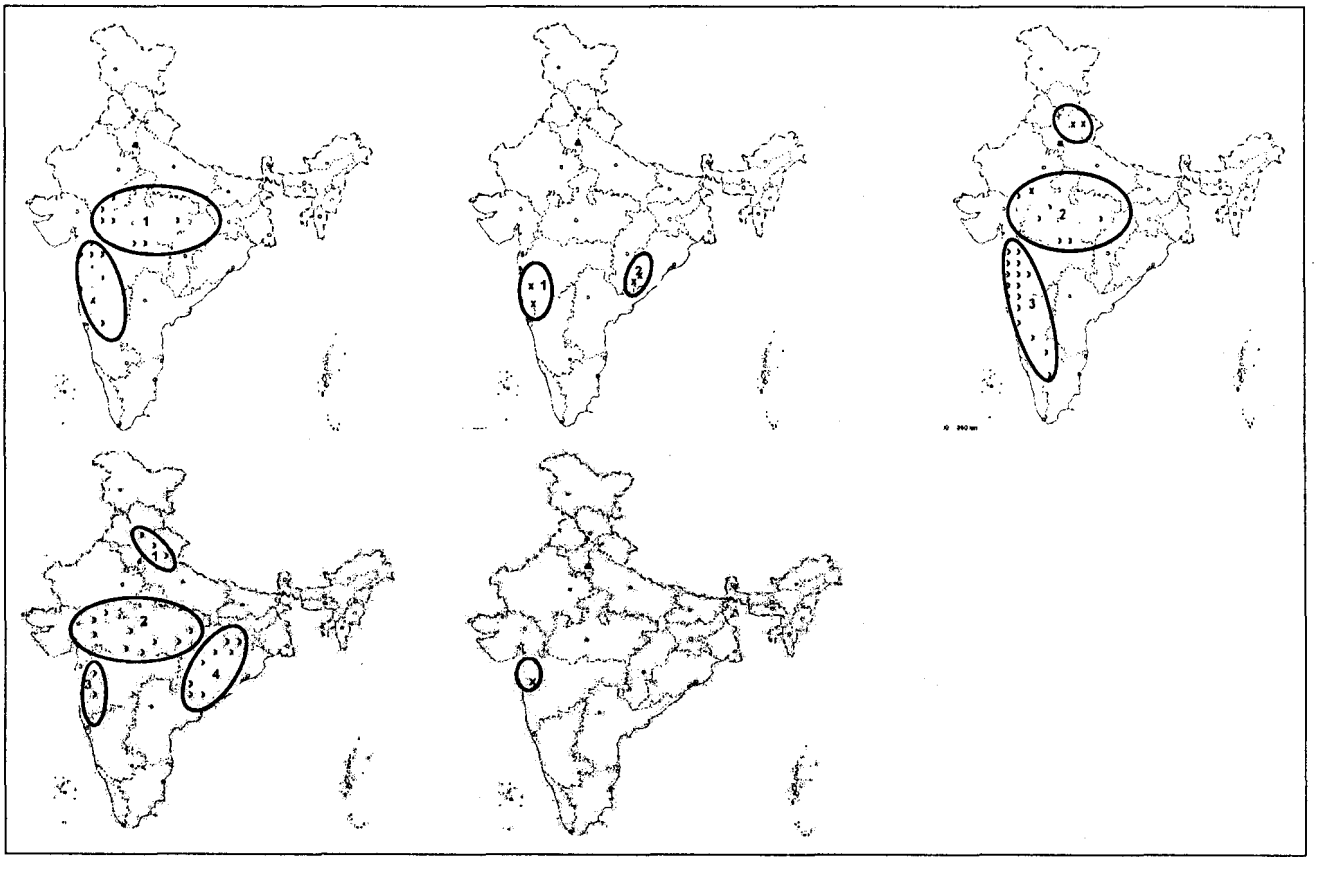

Fig. 1: Distribution of wild *Vigna* species
a) *V. mungo* var. *silvestris*, b) *V. radiata* var. *setulosa*, c) *V. radiata* var. *sublobata*, d)*V. hainiana*, e) *V. khandalensis*

khandalensis as the outgroup since this species is morphologically most distinct in the *mungo-radiata* complex. The branches of the cladogram were reordered using the "Retree" option in "PHYLIP" ver. 3.60 (Felsenstein, 1993). Various alternate positions for each branch were considered, but the cladogram requiring least number of steps was chosen for presentation here.

Principal components analysis

Data on 45 distinct qualitative and quantitative characters (Table 2) were subjected to multivariate analysis using NTSYS ver. 1.80 statistical package (Rohlf, 1992). Multivariate statistics was used to establish species relationships and the pattern of inter- and intra-specific diversity.

The species accessions X qualitative character states data matrix was used to calculate correlations among various character states scored. The correlation coefficient matrix was subjected to eigenvectors analysis. The eigenvectors derived were used to extract the first three most informative principal components. These three components were plotted in both three dimensional and biplot mode in various combinations. Only the biplots of the first two most informative components are presented. Similar principal components analysis (PCA) was also performed for quantitative traits.

Results

a) *Distribution, habitat and ecology of wild Vigna species in mungo-radiata complex*

The distribution, habitat, ecology and characteristics of different species are as follows and are illustrated in Figure 1 and Table 1:

V. mungo var. *silvestris*

The species is more closely related to cultivated black gram (*V. mungo*). It is widely distributed in Western Ghat region of Maharashtra with sporadic distribution in Melghat (Maharashtra), Mt. Abu (Rajasthan) and parts of Madhya Pradesh. These habitats were open, steep hill slopes with little shrub or tree cover. Plants in some habitats, particularly in northern part of Western Ghats, were very vigorous, had 6-7 thick pods per inflorescence and seeds fairly large for wild types. Two distinct type of populations were collected from the Western Ghats: i) types twining on shrubs of *Jatropha*, *Ixora* and *Gymnosporia*, near habitations along forest edges with sub-capitate clumps of 6-8 hairy pods each, 3-5 cm long, thick, slightly beaked, 6-8 seeded, seeds dull black with rough surfaces, hilum raised, cracked or split; ii) wild types occurring mainly in disturbed grassy (grazed) patches with *Dicanthium/Sechima/Alpuda/ Themeda* and *Centrathemum* species near forest edges in Western Ghats of Maharashtra (Matheran, 800m; Khandala, 800m and Bhimashankar Ghats, 1000m) which were more prostrate, the plants being comparatively less hairy, with 2-4 hairy pods/peduncle, smaller compared to the above type, with less split/ raised hilum. While former type invariably possessed sub-erect, ascending pods, conforming to the variety *V. mungo* var. *silvestris*, the latter type possessed more intermediate characters, with both deflexed and ascending pods or pods more horizontally borne much like the greengram *(V. radiata)*.

V. radiata var. *setulosa*

Plants were of sporadic occurrence in Konkan (Western Ghats) – Panhala hills in South Ratnagiri, Kolhapur

Table 1. Geographical distribution of wild species of *V. mungo-radiata* complex and associated vegetation types

Vigna species	Accessions collected	Geographical distribution	Association with major vegetation types
1. *V. hainiana*	24	Eastern Ghats (parts of Orissa), Central Plateau region (Chhatisgarh, Madhya Pradesh, Maharashtra), North-western Himalayas (Parts of Uttaranchal and Himachal Pradesh)	Sub-tropical wet hills
2. *V. khandalensis*	1	Western Ghats (Pune district)	Tropical moist evergreen scrub
3. *V. mungo* var. *silvestris*	38	Western Ghats and Melghat in Maharashtra, Parts of Rajasthan (Mt. Abu), Central Plateau Region (parts of Madhya Pradesh)	Tropical moist evergreen scrub, Desert scrub, Xerophyllous grasslands
4. *V. radiata* var. *setulosa*	11	Western Ghats (parts of Maharashtra), Eastern Ghats (parts of Orissa)	Tropical moist evergreen scrub
5. *V. radiata* var. *sublobata*	33	Western Ghats, sporadic distribution in Rajasthan, Madhya Pradesh and North-western Himalayas	Tropical moist evergreen scrub, Hygrophyllous grasslands, Temperate scrub, Montane sub tropical hill Savannah

and the Koraput region in Eastern Ghats (800-1000m elevation). The places were moist but devoid of tree or shrub cover. In Western Ghats, populations occurred in the outskirts of evergreen forests, in the bushy thickets of *Litera sebyfera*, *Memecylon edule*, *Mappia foetida*, *Ixora brachiata*, *Randia brandisii*, *Zizyphus rugosa* and *Carissa congesta*. The plants were stouter and often climbed on hardy tall herbs. The pods were densely hairy, borne deflexed or horizontally on the peduncle, comparatively larger pods (8 cm), higher number of pods/peduncle (8-10), each pod 12-14 seeded, seeds blackish with more linear hilum.

V. radiata* var. *sublobata

Plants are closely related to *V. radiata* (greengram) and have much wider distribution. Collections were made from parts of western Himalayas (600-1800 m), Western Ghats (100-600m), Madhya Pradesh (500-800m), Rajasthan (400-600m). Maximum distribution was recorded in the northern part of Western Ghats. Disjunct and sporadic distribution occurs in Nilgiris and southern parts of Western Ghats. In the North-western region *sublobata* types were associated with *Heterpogon contortus*, *Alpuda mutica*, *Themeda triandra* and *Aeschenomene indica* and also on sub-temperate forest undergrowth predominantly on eroded, exposed slopes. Habitats, in general, were open, sloppy grasslands on waste places, forest trails and steep hill sides. The plants had thinner stems, smaller pods and seeds as compared to *V. radiata* var. *setulosa*.

V. hainiana

The species has a wider distribution; collections were made from Madhya Pradesh, Orissa, Chhatisgarh, parts of Rajasthan, Uttaranchal and Himachal Pradesh ranging from 500 to 2000 m elevations. The habitats of this species are open dry places, often loose rocky mounds, steep sides of hill roads. Under favourable dry habitat, free from competition in rocky hill slopes, dense populations covering a considerable area were found.

***V. khandalensis* (*V. grandis*)**

Sparsely distributed populations of this endemic species could be located in Pune district (Purandar hills, Bhimashankar hills and Khandala, 600-800m elevation). Habitat of species is open, humid hill slopes. A few populations of this species were also collected from paddy field bunds along the hill slope on way to Bhimashankar hill in Pune. This species is distinct from other Asian *Vigna* species as it is tall, erect, thick stemmed, herbaceous type with large foliaceous stipules. Racemes close, usually 2-6 pods per peduncle, pods up to 8 cm long, sub-erect, thick, glabrous, 8-10 seeded, bold, brownish-black, rough, with minute, sub-split partially raised hilum.

Figure 1 (A to E) shows the distribution of wild *Vigna* species in the *mungo-radiata* complex. The biogeographical considerations and association of wild *Vigna* species with major vegetation types is presented in Table 1. Ecologically, wild *Vigna* species in the *mungo-radiata* complex occur in different associations as components of the herbaceous and grassy undergrowth or are seen twining on bushes in scrub vegetation. More density occurs in the moist tropical and sub-tropical zones. Maximum species were concentrated in the northern parts of the Western Ghats. These include 2 endemic types *viz. V. khandalensis* and *V. radiata* var. *setulosa*. The distributional range of these overlap with *V. radiata* var. *sublobata*, *V. mungo* var. *silvestris* and other *Vigna* species including, *V. dalzelliana* and *V. vexillata*. *V. khandalensis* is very sparsely distributed. In the Eastern Ghats, *V. hainiana* is the most widespread species. *V. radiata* var. *setulosa* being more of sporadic distribution. In the western Himalayas (medium elevation zone, upto 1800 m), *V. hainiana* and *V. radiata* var. *sublobata* exhibit sporadic distribution. Paucity of species diversity occur in *mungo-radiata* complex in the north-western plain zones with sporadic distribution of other *Vigna* species, *V. trilobata* and *V. aconitifolia*. In the Deccan plateau region, sporadic distribution of *V. hainiana* and *V. trilobata* occurs.

Sporadic distribution of *V. radiata* var. *sublobata*, *V. mungo* var. *silvestris*, *V. hainiana* together with *V. aconitifolia* and *V. trilobata* was recorded in the western drier parts of the country, parts of Rajasthan (Mt. Abu, Chittorgarh, Udaipur, Sirohi), MP (Dhar, Mandu) and adjoining Maharashtra (Melghat).

b) *Diversity analysis and species relationships in mungo-radiata complex*

The common key distinguishing features of wild species under *mungo-radiata* complex are epigeous cotyledons; sessile first and second leaves; predominantly climbing growth habit; moderate to dense pubescence of various plant parts- stem, petiole, leaves and pods; straight and round pods, borne horizontally or deflexed; mottling on seed surface slight to none and absence of lustre on seed surface. All the species had flower colour in various shades of yellow. Between species variation,

Table 2. Important descriptors used for characterisation of wild *Vigna* species germplasm in *mungo-radiata* complex

S.No.	Characters/Descriptors	Descriptor states
Qualitative descriptors		
1.	Seed germination habit	1. Epigeal, 2. Hypogeal
2.	Attachment of primary leaves (at two leaf stage)	1. Sessile, 2. Sub-sessile, 3. Petiolate
3.	Growth habit (recorded at first pod maturity)	1. Erect, 2. Semi-erect, 3. Spreading, 4: Semi- prostrate, 5. Prostrate, 6. Climbing
4.	Leafiness (at 50% flowering)	1. Sparse, 2. Intermediate, 3. Abundant
5.	Leaf pubescence	1. Glabrous, 2. Very sparsely pubescent, 3. sparsely pubescent, 4. Moderately pubescent, 5. Densely pubescent
6.	Petiole pubescence	1. Glabrous, 2. Pubescent, 3. Moderately pubescent, 4. Densely pubescent
7.	Lobing of terminal leaflet (at first pod maturity)	1. Unlobed, 2. Shallow, 3. Intermediate, 4. Deep 5. Very deep
8.	Terminal leaflet lobe shape	1. Lanceolate, 2. Broadly ovate, 3. Ovate, 4. Rhombic, 5. Others
9.	Stipule size	1. Small, 2. Medium, 3. Large
10.	Stipule shape	1. Ovate; 2. Lanceolate, 3. Others
11.	Stem pubescence	1. Glabrous, 2. Sparsely pubescent, 3. Moderately pubescent, 4. Highly pubescent
12.	Raceme position (at first pod maturity)	1. Mostly above canopy, 2. In upper canopy, 3. Throughout canopy
13.	Calyx colour	1. Green; 2. Purplish green, 3. Greenish purple, 4. Others
14.	Corolla colour	1. Yellow, 2. Greenish yellow, 3. Yellowish green, 4. Green-purplish yellow, 5. Others
15.	Bracteole size	1. Small, 2. Intermediate, 3. Large
16.	Bracteole shape	1. Linear, 2. Lanceolate, 3. Others
17.	Flowering period	1. Asynchronous, 2. Intermediate, 3. Synchronous
18.	Pod attachment to peduncle	1. Erect, 2. Horizontal, 3. Horizontal-pendent, 4. Pendent, 5. Others
19.	Pod pubescence	1. Glabrous, 2. Sparsely pubescent, 3. Moderately pubescent, 4. Densely pubescent
20.	Pod curvature	1. Straight, 2. Slightly curved, 3. Curved (sickle shaped)
21.	Pod beak shape	1. Pointed, 2. Blunt, 3. Others
22.	Constriction of pod between seeds	1. Absent, 2. Slight, 3. Pronounced
23.	Pod cross section	1. Semi flat, 2. Round, 3. Others
24.	Seed shape	1. Globose, 2. Ovoid, 3. Narrowly ellipsoid, 4. Cubical to oblong, 5. Kidney shaped, 6. Drum shaped, 7. Others
25.	Seed colour	1. White, 2. Cream, 3. Light brown, 4. Intermediate brown, 5. Dark brown, 6. Grey, 7. Mottled grey, 8. Mottled brown, 9. Mottled cream, 10. Light cream, 11. Green brown, 12. Chocolate, 13. Black
26.	Lusture on seed surface	1. Absent, 2. Present
27.	Mottling on seed surface	1. Absent, 2. Slight, 3. Intermediate, 4. Heavy
28.	Hilum shape	1. Concave, 2. Plain, 3. Convex, 4. Others

Quantitative Descriptors

29. Terminal leaflet length (cm), 30. Terminal leaflet width (cm), 31. Petiole length (cm), 32. Plant height (m), 33. Days to flowering, 34. Flower bud size (cm), 35. No. of flower per raceme, 36. Peduncle length (cm), 37. No. of pods per peduncle, 38. Days to maturity, 39. Pod length (cm), 40. No. of pods per plant, 41. No. of seeds per pod, 42. 100-seed weight (g), 43. Seed size (mm^2), 44. Hilum length (mm), 45. Yield per plant (g)

except for the two characters, number of pods per plant and seed yield, was significantly greater than within species variation for most of the quantitative characters.

Table 3 lists the inter- and intra-specific morphological variation in different wild *Vigna* species populations in *mungo-radiata* complex. All the species, except *V. khandalensis,* showed greater homology in growth habit and other vegetative parts. These species, however, differed in pubescence of various plant parts, and pod and seed characteristics. *V. hainiana* populations had exceptionally small flowers and seeds as compared to the other species in the group. Within species variation was more prominent in *V. mungo* var. *silvestris* and *V. radiata* var. *sublobata*. *V. khandalensis* was remarkably distinct from other species by having erect plant habit, large foliaceous stipules and broad leaflets. In flower and pod characteristics it resembled with both *V. mungo* and *V. radiata*.

Table 4 lists the mean values of 17 important quantitative traits on cultigen types and conspecific wild species in *mungo-radiata* complex. Table 5 lists the comparative measurement of mean, range and variation

Table 3. Inter- and intra-specific variation in wild Vigna species in the mungo-radiata complex of subgenus *Ceratotropis*

Species	Interspecific variation	Intraspecific variations
V. hainiana	Climbing growth habit, petioles and peduncles clothed with deflexed, greyish or greenish brown hairs. Early flowering/ maturing; small flowers; more number of pods per peduncle; thin round glabrous to slightly hairy pods; comparatively smaller seeds, blackish grey or brown, low 100- seed weight.	The population revealed greater homology for floral organs. Variation between populations observed for terminal leaflet size, plant height, flower bud size, pubescence of various plant parts, seed shape and mottling of seed surface.
V. mungo var. *silvestris*	More closely related to urdbean (*V. mungo*). Medium maturity; relatively low number of flowers per raceme and fewer pods per peduncle; highly pubescent pods; pods ascending or deflexed; relatively bold seeds as compared to other species of the group and low number of seeds per pod usually varying from 4-8.	Two distinct types of populations were noticed: a) highly twining/climbing types with low branching potential with sub-capitate clumps of of 6-8 hairy pods, sub-erect or ascending, each 3-5 cm long, thick slightly beaked, 3-6 seeded; seeds dull black with rough surface; hilum much raised, cracked or split; some population have very high yield potential b) more prostrate types; low plant height; plants being comparatively less hairy with 2-4 hairy pods peduncle, both deflexed and ascending, each 6-8 seeded; seeds blackish dull, smaller to above type, with less split/raised hilum.
V. radiata var. *sublobata*	Loose sub-capitate heads, thinner, sparsely hairy or glabrous pods as compared to *setulosa* types, borne deflexed or horizontally on the peduncle.	Between population variation was observed for leafiness, leaf pubescence, lobing of terminal leaflets, leaflet shape, days to flowering, raceme position, seed shape and size.
V. radiata var. *setulosa*	Early flowering/maturing; comparatively longer hairy pods, borne deflexed or horizontally; higher number of pods per peduncle, each with 12-14 seeds; seed blackish black with more linear hilum.	Populations varied for seed shape and mottling of seeds. Variation was also observed for flower bud size, peduncle length and seed size.
V. khandalensis	It is characterised by erect growth habit and thick stem; shows more akinness to blackgram with its close raceme of 3-6 pods per peduncle; pods 6-7 cm long, sub-erect, medium thick; glabrous/ minutely strigose (like greengram); 8-10 seeds per pod; seeds comparatively bold, blackish brown, rough, occasionally mottled with minute sub-split partially raised hilum.	

of 8 quantitative traits of cultigen types and conspecific wild species in the *mungo-radiata* complex of subgenus *Ceratotropis*. It is evident that the range of variation particularly for number of pods per plant and yield per plant is more for wild species than the cultigen types. The conspecific cultigen types were however more robust with erect growth habit and recorded three to five fold increase in seed size and seed weight.

The cladogram (Fig 2) appears to contain two clades, one comprising the collections *V. radiata* var. *setulosa, V. radiata* var. *sublobata, V. radiata* (cultigen) and *V. hainiana* and the second clade had only *V.mungo* (cultigen) and *V. mungo* var. *silvestris*. From the cladogram it is very much apparent that the variation within *V. hainiana* collections is closer to *V. radiata* group. *V. khandalensis* occupies the third clade.

The principal components analysis ordination of the species in *mungo-radiata* complex (Fig. 3) shows

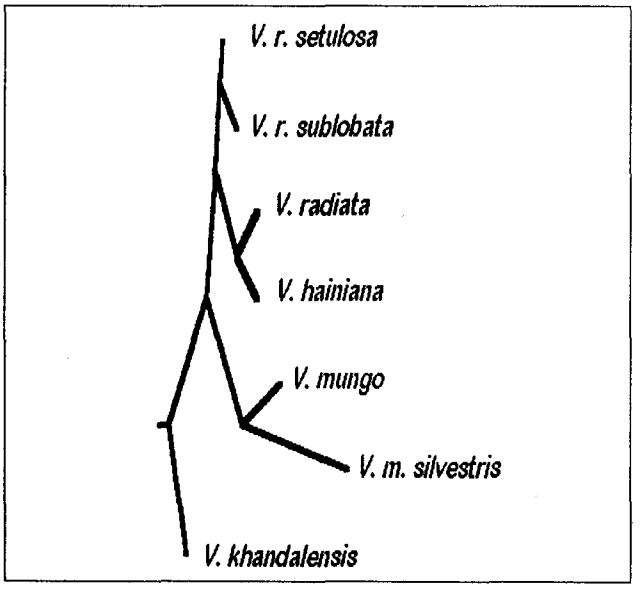

Fig. 2: Cladogram of wild Vigna species and conspecific cultigen types in mungo-radiata complex

that *V. radiata* var. *sublobata* and var. *setulosa* are close in PCA ordination forming a distinct overlapping group with the conspecific cultigen types, *V. radiata*. *V. mungo* var. *silvestris* populations formed two distinct groups, quite apart in ordination. Only one group overlapped with cultigen types, *V. mungo*. Majority of the *V. hainiana* populations formed a distinct group and showed more homology among its populations. However, overlapping populations of different species in the in PCA ordination were also recorded (Fig. 3).

The PCA performed on the quantitative traits revealed that the first three components accounted for 57.27% variation (Table 6). The Table also shows the characters with greater weightage in each of the three most informative principal components.

Discussion

Wild *Vigna* species occupy over 16 different vegetation types, largely biotic/bio-edaphic in status (Arora, 1985). More diversity occurs in the moist tropical/sub-tropical habitats than in the hot arid or cold temperate zones; the tropical evergreen scrub, the montane sub-tropical hill savannah, and the mesophyllous grasslands support as many as 12 out of 16 species occurring in India.

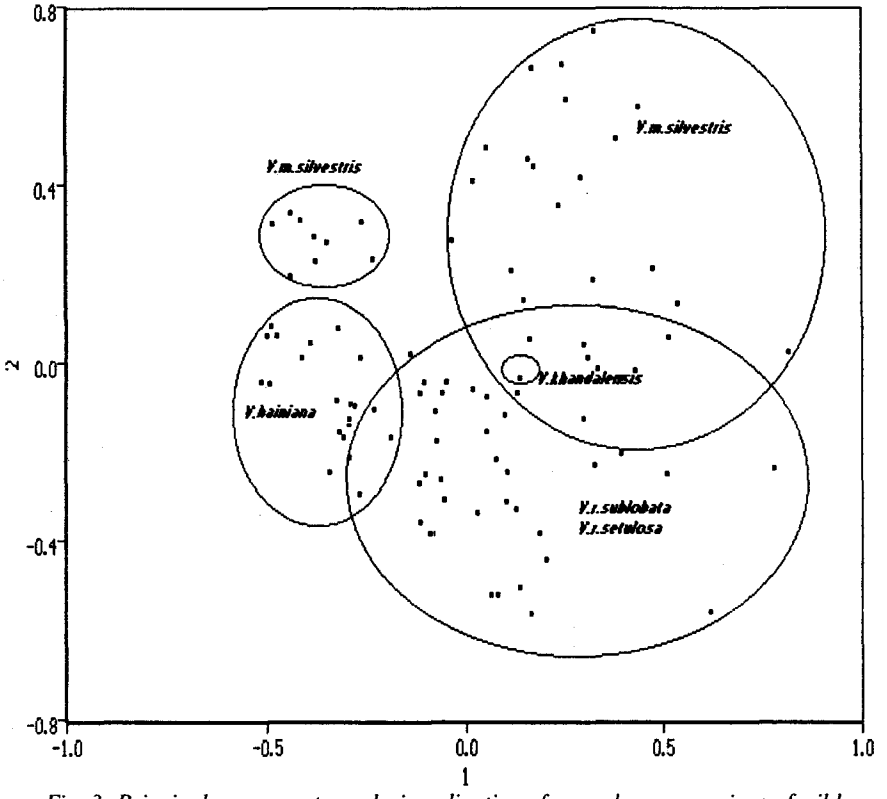

Fig. 3: Principal components analysis ordination of germplasm accessions of wild Vigna species and conspecific cultigen types in mungo-radiata complex

Table 4. Means of selected quantitative characters* of wild *Vigna* species and conspecific cultigen types in *mungo-radiata complex*

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
V. mungo (cultigen)	13.28	8.63	13.74	1.27	47.36	0.63	6.63	7.48	4.63	77.09	4.42	63.97	6.54	4.03	16.99	2.15	6.16
V. m. silvestris	9.52	6.64	10.49	1.96	65.40	0.64	3.93	8.72	2.46	94.78	3.77	151.61	7.71	1.60	8.89	2.05	4.65
V. radiata (cultigen)	8.71	6.60	8.52	0.34	44.50	0.81	4.71	7.60	3.57	60.00	6.61	49.79	10.92	2.70	12.07	1.83	1.34
V. r. setulosa	11.11	9.73	10.76	2.04	49.43	0.68	5.85	8.94	2.86	65.43	5.60	25.17	10.43	1.22	6.54	1.22	2.05
V. r. sublobata	7.75	6.60	9.48	1.51	60.13	0.63	5.90	9.47	3.31	78.38	4.80	91.30	10.10	1.16	6.63	1.43	2.13
V. hainiana	10.61	8.97	11.32	2.42	49.83	0.26	6.16	6.63	5.16	74.50	3.93	159.06	9.67	0.68	4.52	1.14	3.26
V. khandalensis	13.43	12.67	10.10	1.98	155.00	0.60	4.00	17.50	5.00	175.00	5.66	15.33	10.00	4.08	15.22	1.52	2.29

*1: Terminal leaflet length, 2: Terminal leaflet width; 3: Petiole length, 4: Plant height; 5: Days to flowering, 6: Flower bud size, 7:No. of flowers per raceme, 8: Peduncle length, 9: Pods per peduncle, 10: Days to maturity, 11: Pod length, 12: Pods per plant, 13: Seeds per pod, 14: Seed weight, 15: Seed size, 16: Hilum length, 17: Yield per plant

Table 5. Mean, range* and variance for important quantitative traits of cultivated and wild *Vigna* species in the *mungo-radiata* complex

Character		*V. hainiana*	*V. mungo*	*V. m. silvestris*	*V. radiata*	*V. r. setulosa*	*V.r. sublobata*	*V. khandalensis*
Plant height	Mean	2.42	0.75	1.96	0.54	2.04	1.51	1.98
	Range	1.00-6.67	0.44-1.95	0.95-3.18	0.24-0.83	1.37-2.62	0.40-3.01	-
	CV	57.80	25.90	29.08	61.70	20.00	39.70	-
Days to flowering	Mean	49.83	47.36	65.40	44.50	49.43	60.13	155.00
	Range	41.00-64.00	31.00-73.00	36.00-139.00	34.00-93.00	30.00-78.00	34.00-147.00	-
	CV	15.70	35.30	32.60	13.32	37.00	39.70	-
Days to maturity	Mean	75.50	77.09	94.78	68.00	65.43	78.38	175.00
	Range	67.00-90.00	67.00-117.00	68.00-158.00	58.00-94.00	54.00-83.00	51.00-175.00	-
	CV	10.90	20.10	23.00	9.50	14.60	31.00	-
No. of pods per plant	Mean	159.06	63.97	151.61	49.79	25.17	91.30	15.33
	Range	27.00-418.00	18.60-94.00	6.00-697.00	8.66-111.00	10.00-40.57	5.74-289.00	-
	CV	81.40	19.70	100.80	71.20	44.80	91.00	-
100-seed weight	Mean	0.68	4.03	1.60	2.90	1.22	1.16	4.80
	Range	0.53-0.84	2.33-5.10	1.20-2.54	1.57-4.06	10.43-2.22	0.55-2.40	-
	CV	14.70	11.90	21.30	25.50	47.50	41.70	-
Seed size	Mean	4.52	16.99	8.89	12.07	6.54	6.63	15.22
	Range	0.96-5.51	14.09-20.82	5.47-14.40	8.46-15.99	1.02-9.48	1.83-11.53	-
	CV	25.80	12.60	25.00	14.80	42.80	34.40	-
Hilum length	Mean	1.14	2.15	2.05	1.83	1.22	1.43	1.52
	Range	0.59-1.83	1.86-2.46	1.47-3.04	0.72-8.55	0.42-1.91	0.22-2.00	-
	CV	30.00	7.90	14.60	18.00	36.00	22.30	-
Yield per plant	Mean	3.26	6.16	4.65	5.34	2.05	2.13	2.29
	Range	0.81-7.88	1.67-9.88	0.34-60.90	0.72-8.85	0.30-5.61	0.30-4.72	-
	CV	58.70	41.30	228.80	41.79	77.10	60.00	-

* Range (minimum-maximum), *CV*= Coefficient of Variation

Table 6. Variation explained by each eigenroot and important characters with maximum weightage in Principal Components Analysis of wild *Vigna* species in *mungo-radiata* complex

PC axes	Total variation explained		Important characters with maximum weightage
	%	Cumulative	
I	28.41	28.41	Terminal leaflet width, terminal leaflet length, petiole length
II	16.94	45.35	Seed size, seed weight, days to maturity, days to flowering
III	11.92	57.27	Seed yield, peduncle length, no. of pods per plant, plant height

About 9 species are concentrated in the northern parts of the Western Ghats. Among the two widely distributed species in *mungo-radiata* complex, *V. mungo* var. *silvestris* and *V. radiata* var. *sublobata,* the former showed greater intraspecific variability as compared to the latter. Two distinct population types in *V. mungo* var. *silvestris,* were noticed. The highly twining type populations had more number of pod bearing clusters with 6-8 hairy sub-erect or ascending pods. The prostrate type populations with low plant height had 2-4 hairy pods per peduncle, both deflexed and ascending. These two population types were clearly distinct in PCA ordination (Fig 3) based on characterisation data and only one group overlapped with cultigen types, *V. mungo*. *V. radiata* var. *sublobata* populations were comparatively more homogeneous. *V. radiata* var. *setulosa*, with restricted distribution, is closely related to var. *sublobata*. The *setulosa* types possessed comparatively larger and densely hairy pods. *V. hainiana* populations were of sporadic occurrence in Western Ghats. *V. hainiana* shows akinness to both *V. mungo* and *V. radiata* wild types. In pod characteristics *V. hainiana* resembles *V. radiata* var. *sublobata*. It however, differed from the latter in having flexuous stems, large peltate stipules, long greyish or greyish brown hairs on stem and petioles (like *V. mungo* var. *silvestris*). Morphologically this species is more primitive than wild related species of *V. radiata* and *V. mungo* with comparatively small flowers and very

small seeds. *V. khandalensis*, endemic to India with sporadic distribution in northern parts of Western Ghats, is quite distinct from other Asian *Vigna* species. It is tall, erect, thick stemmed and shrub like with large foliaceous stipules. However, it shows morphological akinness to both *V. mungo* (close raceme) and *V. radiata* (sub-erect, glabrous/ minutely strigose medium thick pods). About 10 species occur in the Nilgiris and adjoining parts in Southern India with sporadic distribution of *V. radiata* var. *sublobata*.

In the Eastern Ghats, 5 or 6 species exhibit overlapping distribution. *V. hainiana* is the most widely distributed species in the *mungo-radiata* complex. *V. radiata* var. *setulosa*, has sporadic distribution in higher elevations (more than 800m) around Koraput district in Orissa. In, the Western Himalayas, *V. hainiana* and *V. radiata* var. *sublobata* were of sporadic occurrence. Paucity of species diversity was observed in the north-western plain zones extending eastwards to the Indo-Gangetic belt.

From an exploration standpoint, pockets of species diversity exhibiting sympatric and disjunct distribution are important, as is also their collection from ecologically variable sites within their range of distribution (Arora, 1985). More variability was collected in the widely distributed taxa. More collection efforts are needed in *V. radiata* var. *sublobata* particularly from Eastern Ghats, north-eastern region and Southern parts of Western Ghats (disjunct distribution occurs) which are less represented in the present collection. Sporadic pockets of wild species diversity which could not be surveyed under the present programme, particularly the north-eastern region, the Chhota Nagpur region, and from sites where wild types occur in proximity to the cultivated types.

In order to collect more infraspecific variation in *mungo-radiata* complex, fine grid sampling needs to be done in areas where diverse populations overlap. The overlapping populations are clearly reflected in the PCA ordination (Fig 4) based on characterisation data. More populations exhibiting greater morphological variations need to be collected from areas of higher species diversity in order to capturing higher genetic diversity in these species. These collections would have greater utility in crop improvement programmes as well as in evolutionary studies (Arora *et al.*, 1973; Chandel *et al.*, 1984; Dana, 1966; Jain and Mehra, 1980; Mayazaki, 1982; Bisht *et al.*, 2002)). Serious efforts also need to be made to collect as much variation as possible of *V. khandalensis*, a species with very restricted distribution in the disjunct high elevation areas in the northern parts of Maharashtra and adjoining Gujarat. Some areas around Purandar hill and Bhimashankar hill might even be developed as gene sanctuary for this endemic species. Extensive fine grid survey and intensive collection efforts, staring from Mt Abu (Rajasthan) to Nilgiris (Southern India) needs to be undertaken as the Western Ghats ranges are the macrocentre of origin and diversity particularly for most of the species in the *mungo-radiata* complex.

The wild species has a great potential for use in crop improvement programmes. Successful hybridization between *V. radiata* and *V. glabrescens*, resulted into four pure lines carrying moderate resistance to thrips (AVRDC, 1990). Srinivas *et al.* (1999) attempted inter-specific hybridization between mungbean and its related *Vigna* species. Pod setting percentage was high when *V. radiata* was female parent. The cross *V. radiata* x *V. radiata* var. *sublobata* gave the highest pod setting (26.1%). Inter-specific crosses combined with embryo rescue were successful when male parents were *V. radiata* var. *sublobata*, *V. mungo*, *V. mungo* var. *silvestris*, *V. umbellata* (wild), *V. angularis* and *V. glabrescens*, but was not successful in crosses involving mothbean (*V. aconitifolia*).

In common with most grain legume crop species, the wild related species do not form a particularly extensive or accessible genetic resource. Many of these wild species, *Vigna radiata* var. *sublobata*, *V. mungo* var. *silvestris*, *V. khandalensis*, *V. trilobata*, and *V. hainiana* are gathered for their ripe seeds, which are boiled and eaten (unripe seeds are also eaten raw) by the tribal/local communities during famines and their over exploitation has threatened their preponderance in natural habitats. More variability in wild conspecific forms is to be collected, characterised and conserved carefully in addition to the fullest range of landraces and cultivars. Greater exploitation of the conspecific wild species with valuable characters needs to be made to make extended cultivation economically attractive (Smartt, 1990). Some populations of *V. mungo* var. *silvestris*, *V. radiata* var. *sublobata* and *V. radiata* var. *setulosa* with valuable characters like more number of pod bearing clusters and pods per cluster have great agronomic potential for use in crop improvement programmes beside the resistance/ tolerance to biotic stresses. Sources of resistance available in *Vigna radiata*

var. sublobata (Singh, 1994) needs to be exploited more vigorously with the help from biotechnological tools.

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