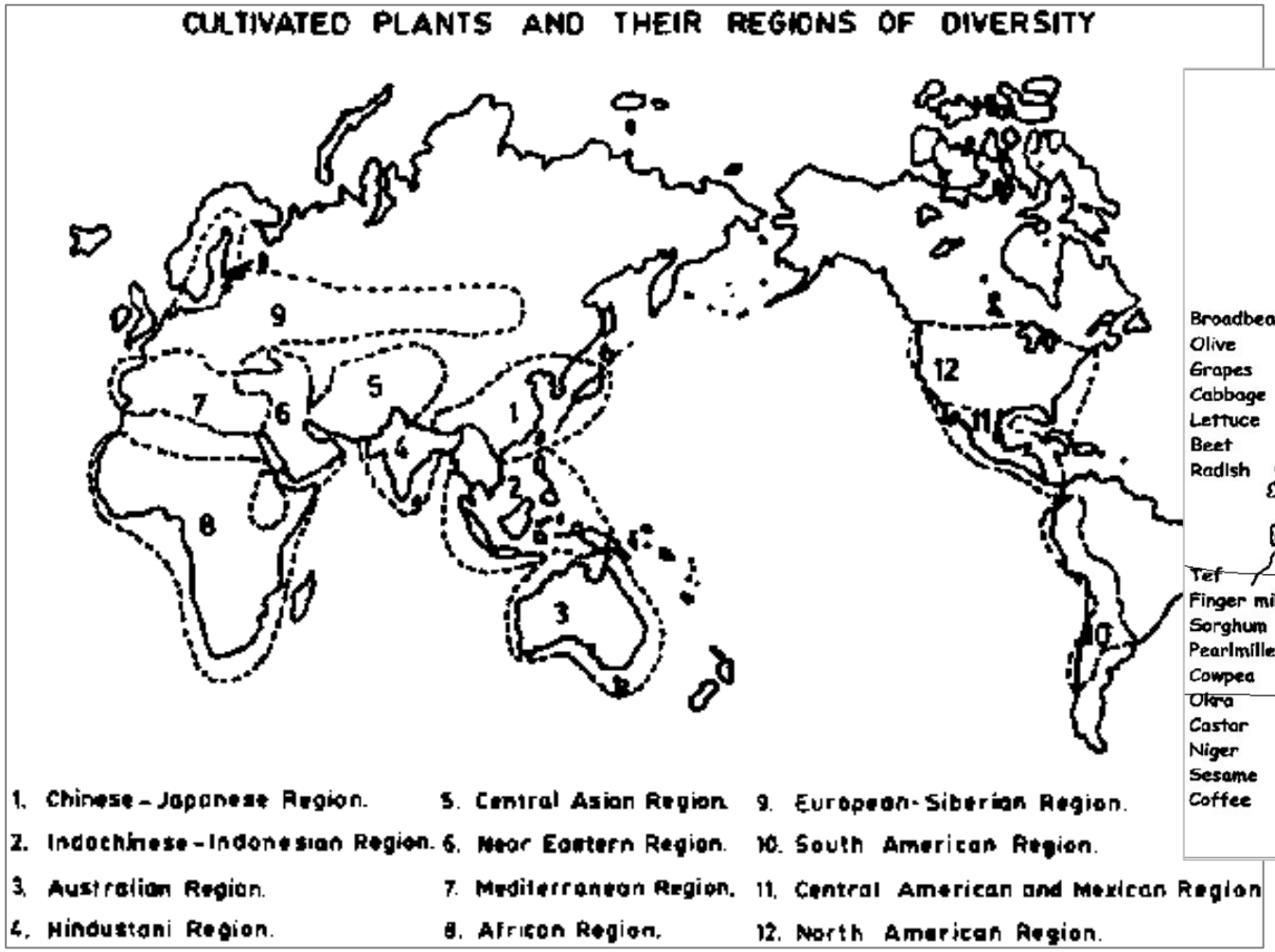
Centres of origin and diversity in crop plants- importance in management of PGR

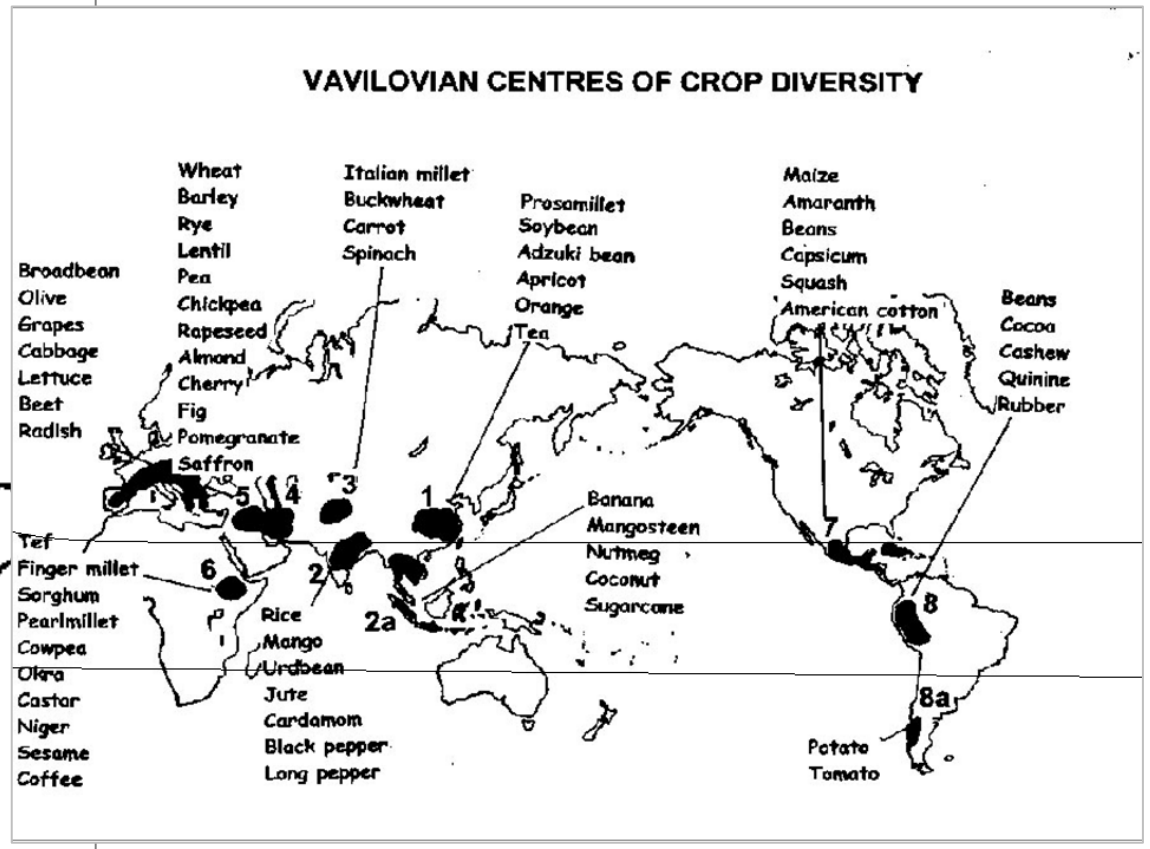
E. Roshini Nayar

ex-NBPGR, New Delhi

Zhukovsky, 1965, ‘68

Vavilov, 1935





Paroda & Arora, 1997: Plant Genetic Resources: Conservation and Management

Vavilov, 1926. Centres of Origin of Cultivated Plants. Dedicated to A. de Candolle.

Three significant theories- the law of homologous variation, the centers of origin for crop plants, and concept of genetic erosion

Centres of origin of major food crops- originated from a central point, from which they successfully dispersed- exploration & evaluation to prove it.

predictions of unknown forms and species, diseases and pests coevolved at centers of origin for cultivated crops

The Bureau of Plant Industry- 1890s and early 1900s- the first long-term ex situ plant conservation genebank

specific genetic resources in locations for use in breeding programs in Russia viz. wheat and barley- working collections

>100 plant expeditions between 1920 and 1940
>250,000 accessions- >10,000 species from 5 continents represented in the All-Union Institute of Plant Industry
- subsequent plant evaluation
Evaluation & identification of 19 sites of homologous variation
40 international explorations from 1940 through 1993

Hummer & Hancock, 2015: HORTSCIENCE VOL. 50(6) JUNE 2015

Nuclear centres and regions of diversity of domesticated plants (Hawkes, 1983)

Nuclear centres	Regions of diversity	Outlying minor centres
A. Northern China	I China	1 Japan
	II India	2 New Guinea
	III South-East Asia	3 Solomon Islands, Fiji and South Pacific
B. The Near East	IV Central Asia	4 Northwestern Europe
	V The Near East	
	VI The Mediterranean	
	VII Ethiopia	
	VIII West Africa	
C. Southern Mexico	IX Meso-America	5 United States, Canada
		6 The Caribbean
D. Central toSouthern Peru	X Northern Andes	7 Southern Chile
	(Venezuela to Bolivia)	8 Brazil

Saccharum

Musa

Harlan's centres and non-centres (Harlan, 1971)

Centre	Non-centre
North Chinese Centre - B1	South-East Asian and South Pacific non-centre - B2
North East Centre - A1	African non-centre - A2
Meso American Centre - C1	South American non-centre - C2

Vavilovian centres - of diversity
Micro centres‘- small areas viz. Turkey & Africa (Harlan, 1975)- varietal diversity of several crops; disappearing with changing agricultural practices; ‘‘genetic vulnerability’’ and ‘‘genetic wipeout.’’

CO/ CD in relation to PGR- providing the 'Best-practices' guidelines for PGR

1. CO/ CD as a working hypothesis of the geobotanical diversity- improved as we know more about crop diversity/ genepool
2. A vast amount of referable material- in herbaria, and as seed samples collected and evaluated
3. Foundations of PGR- collection, evaluation of variation/ estimating diversity, conservation and use

Aim for CP	Crop plants (CP)	Floristic diversity (FD)	Aim for FD
CD/ CO of crop plants	Von Humboldt, 1807; de Candolle, 1885; Vavilov, 1926, '35; Harlan, 1951, '71	Bentham & Hooker, 1862, '83; Engler/ & Prantl/ & Diels, 1897, '36; Hutchinson, 1934; Rendle, 1904, '25; Bessey, 1893, '15 Cronquist, 1960('88), '81; Takhtajan, 1969	'Natural' classification; Origin of flowering plants; Phylogeny
Genetic basis of diversity	"ecological passport" for crops- 19 sites where different crops show similar shared characters- Vavilov, '35; Genepools of crop plants- GP1, 2 & 3, Harlan & de Wet, 1971	Genecology- Turesson, 1922; Hall/ Clausen, Keck & Heisey, 1940; Ford, 1940s; Stebbins, 1950; Heslop-Harrison, 1964; Dobzhansky, 1968; Biosystematics- Stebbins, 1950; Anderson, 1930s~	Genetic diversity and adaptation; 'taking genetics to the field'- Ford, '80; delineating the evolutionary unit & evolutionary theory.

Indian region

"..more varied than that of any other country of equal area in the Eastern Hemisphere, if not on the globe." (Hooker, 1904)

Indo-Myanmar region & adjacent areas, a cradle of flowering plants (Takhtajan, 1969)

- Hindustani centre of origin (Vavilov, 1926); Megacentre of agro-diversity (Zhukovskii, 1968)
- Crops in India represent "a world synthesis" (Singh & Hardas, 1970, NBPGR)
- Two 'hot-spot' regions- > 0.5% of total endemics/lost 70% of original habitat (Myers, 2000)

Major aspects of study of Indian plants

- Phytogeographic analysis of native diversity: endemics, floristic regions, 'hot spots'
- Floristic diversity
- Documentation & inventorisation of economic plants
- Ethnobotanical findings, ethnic uses
- Forestry wealth and documentation
- Genetic diversity of crop plants, wild relatives, its distribution & PGR management

Arora, Nayar & Pandey, 2006

Indian centre of diversity-

>166 crop plants with native diversity

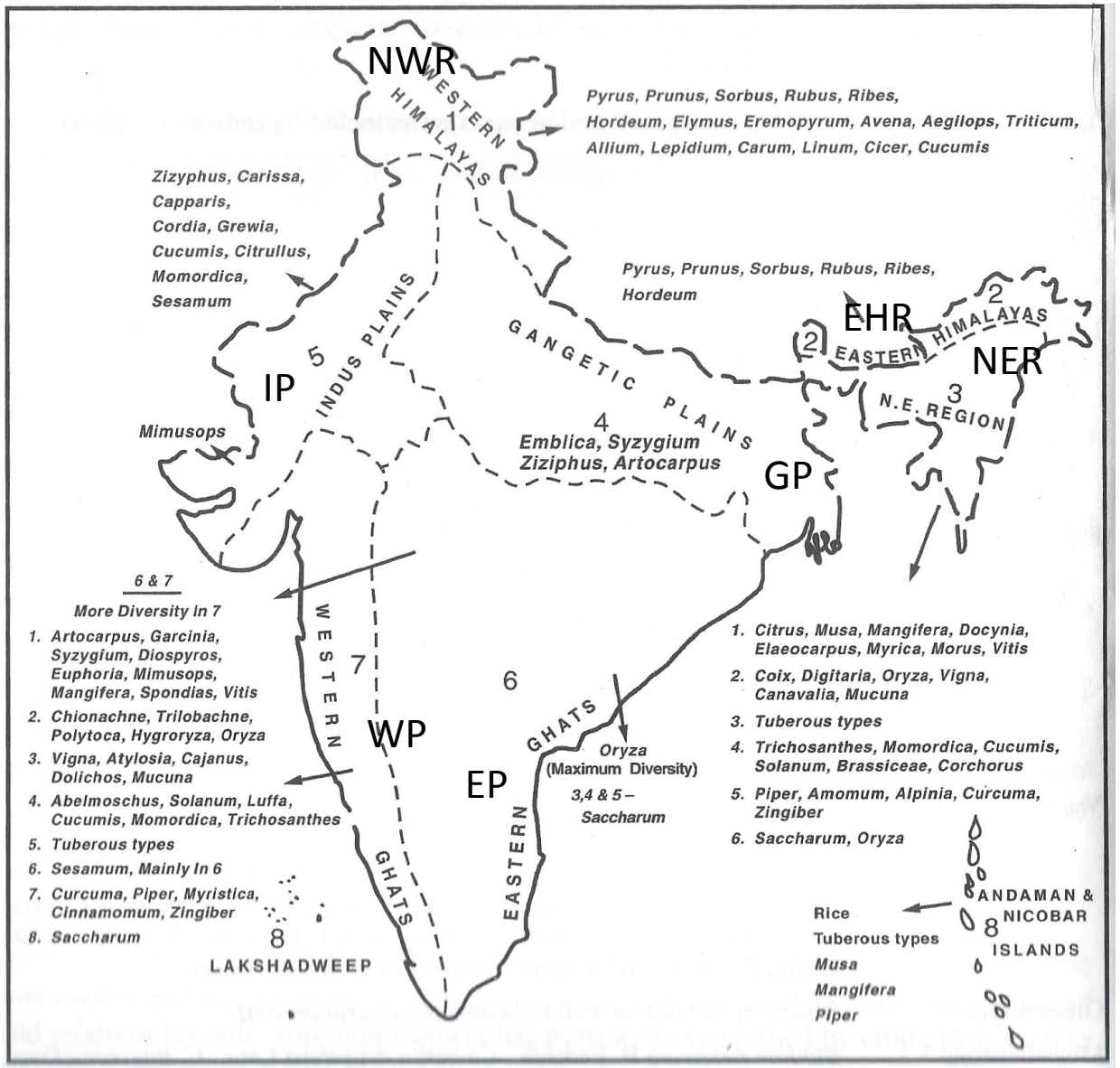
>326 wild relatives of crops- WP 145> NEI 132> NWR 125> EP 91> EHR 82> GP 66> IP 45

Indian flora- SE Asian- 35%, Mediterranean- 5%, African- 3%

Western Himalayas: Cold/ & drought tolerance. Barley, bluish/black grain types (>3300 m) like local Tibetan types. Wheat, Lahaul and Spiti- resistance/tolerance to rust.

North-eastern region/ Eastern Himalayas: Tribal dominated belts- legumes; *Brassica*, *Perilla*; tree cotton; taro/yam and tuberous/ rhizomatous/bulbous types; *Citrus*, *Musa* and bamboos.

Western peninsular region/ Eastern peninsular region: tuber crops/ rhizomatous types- *Curcuma* & ginger, pepper. East- tribal-dominated tract of Orissa and the Chotanagpur plateau; *Central tribal region:* Madhya Pradesh and adjoining tracts of Maharashtra



Arora, 1997; Arora et al., 2006; Arora & Nayar, 1984; Arora & Pandey, 1996

Crops of the Indian region

primary centre of diversity-

rice, black gram, moth bean, pigeon pea, cucurbits like smooth gourd, ridge gourd and pointed gourd, tree cotton, *capsularis* jute, jack fruit, banana, mango, *Syzygium cumini*/jamun, large cardamom, black pepper and several minor millets and medicinal plants like *Rauvolfia serpentina* and *Saussurea lappa.*

secondary centre of diversity-

for African crops, such as finger millet, sorghum, cowpea, cluster bean, okra, sesame, niger and safflower; tropical American crops, maize, tomato, pumpkin/*Cucurbita* spp., chayote or chou chou, chillies and *Amaranthus;*

regional (Asiatic) diversity-

barley, amaranth, buckwheat, prosomillet, foxtail millet, mung bean/green gram, chickpea, cucumber, bitter gourd, bottle gourd, snake gourd and Brassicae, sugarcane.

Categories	Species diversity (50 %) in India#
Cereals and Millets	Millets, *Oryza*
Grain legumes	*Cajanus*
Edible tubers	*Flemingia*
Vegetables	*Abelmoschus*
Miscellaneous-	
	Saccharum

Species less than 50% diversity in India
Millets, *Oryza*, *Sesamum*, *Vigna*

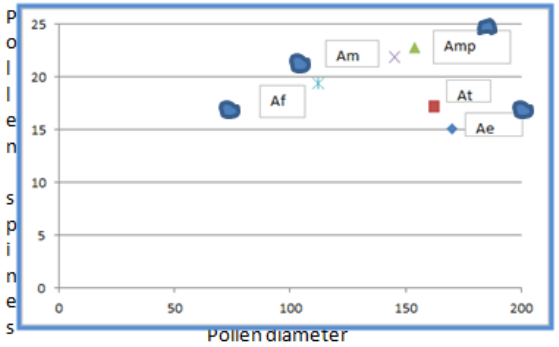
Arora, 1997; Nayar *et al*., 2013

Abelmoschus esculentus- a native crop

A. tuberculatus: closest relative of okra

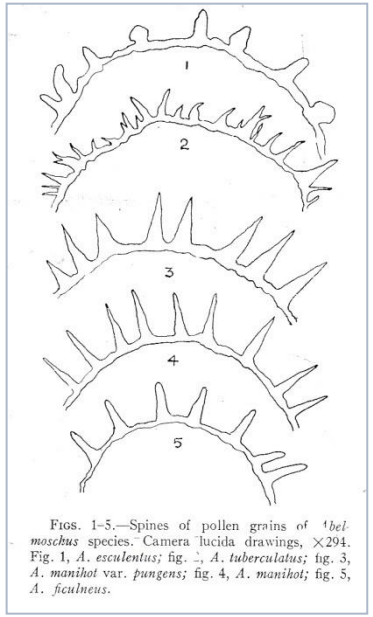
Species described: 1952 (Bot. Gaz., 455-463)
Comparative studies:
- Morphological characters of plant
- Pollen and seed characters
- Cytology Ae, 2n=130, At, 58
- Crossability studies

Taxonomic status:
- Variety of Ae (BSI)/ New species (Kew)

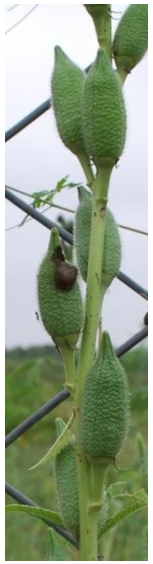


Abelmoschus tuberculatus Pal & Singh
HS5277 [NHCP], NBPGR, New Delhi

M ↓ / F →	Ae	At	Am	Af
Ae		34	34	3
At	89		13	X
Am	97	35		0
Af	0	X	0	



FIGS. 1–5.—Spines of pollen grains of *Abelmoschus* species. Camera lucida drawings, ×294. Fig. 1, *A. esculentus*; fig. 2, *A. tuberculatus*; fig. 3, *A. manihot* var. *pungens*; fig. 4, *A. manihot*; fig. 5, *A. ficulneus*.

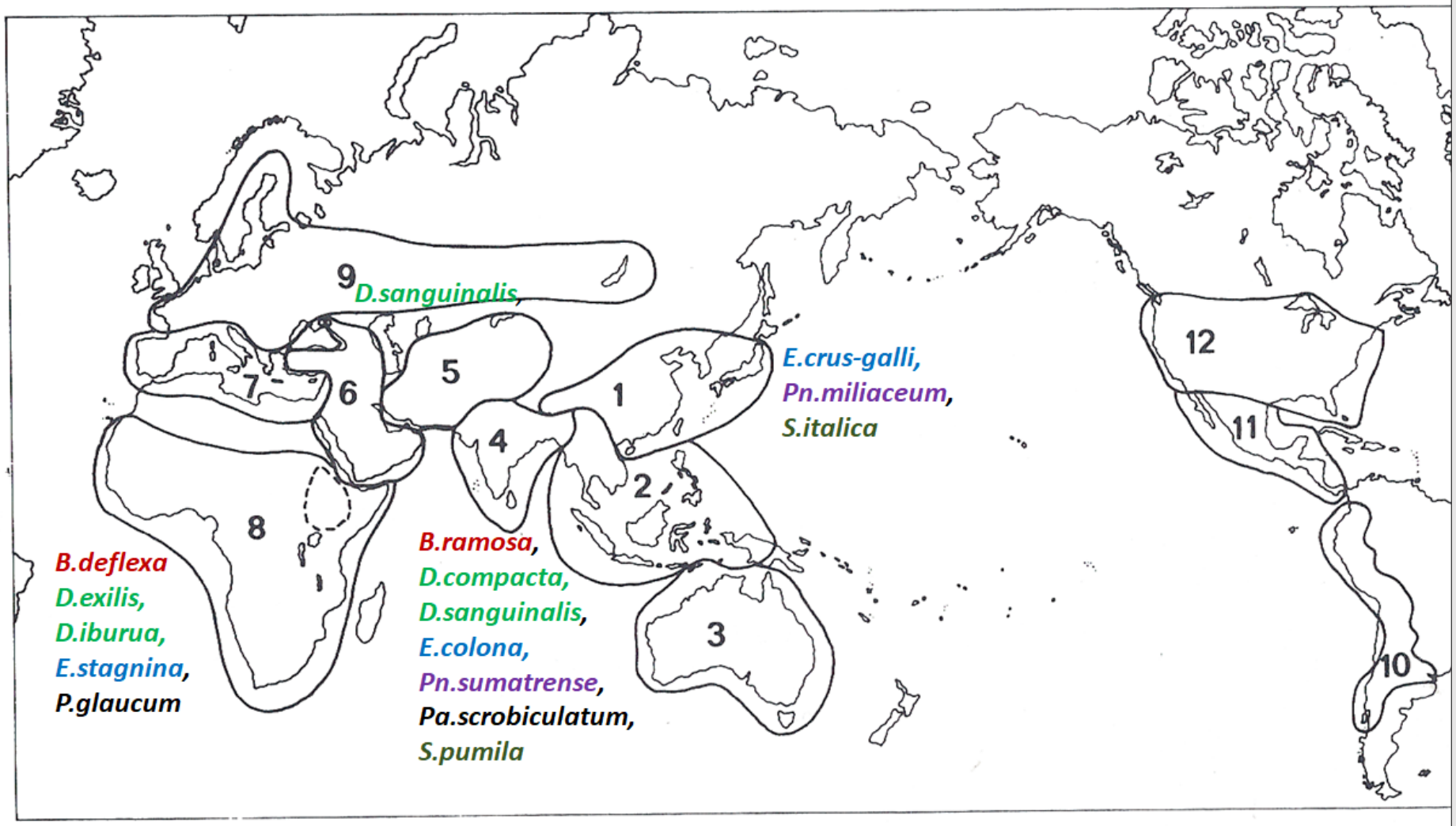


Wild species related to *Abelmoschus esculentus* (Bhindi) collected during search for material for breeding programme

Locality: Collected from Saharanpur, Uttar Pradesh (IW 130)
Plants raised in Plant Introduction fields of IARI, New Delhi on 15/12/1946; Collector: HB Singh

Abelmoschus caillei, West African okra
Hybrid (Ae X Am) with YVMV resistance

Crop species- their Centres of domestication



- Predominantly Asian:

  Echinochloa [distinct genepools]

  Setaria [Genome D (India), genome A (China)]

  Panicum [*P.repens*, common relative]

- African- Asian:

  Brachiaria [Grp IB]

  Digitaria [Sect. Digitaria (India), Verrucipilae/ Clavipilae (Afr)]

- African:

  Pennisetum

- Asian domesticate:

  Paspalum

African/Asian (widespread) - Asian - endemic components:

B.ramosa/B.deflexa - *B.kurzii/B.remota* (EI/PI) - *B. semiverticillata* (PI)
B.reptans - *B.villosa* (NE/PI) - *B.nilagirica* (SI)
D.ciliata - *D.sanguinalis/cruciata complex* (widespread)- *D.duthieana* (EI)

Species relationships- elucidating relationships between crop and CWR

Crop genus	Taxonomic/ biosystematic study	Reference
Brachiaria	Biology, agronomy & improvement- emphasising fodder species	Miles *et al*., 1996
Digitaria	Study of spp- N America, SW Europe, Mexico, Pakistan; morphology of spikelet, morphology-based cladistics analysis	Vega & Agrasar,2001; Vega *et al*.,2009
Echinochloa	Study of weed complexes, biosystematics with emphasis on Japanese species	Yabuno,1966; Yamaguchi *et al*.,2005
Panicum	Crops and weeds, phylogeny	Aliscioni *et al*.,2003; Ellstrand,2010
Paspalum	Diversity within crop	de Wet *et al*.,1983
Pennisetum	Crossability, domestication and evolution	Dujardin & Hanna,1989; Remigereau *et al*.,2011;
Setaria	Diversity and distribution, genome identification in domesticated species in North America and Europe to Chinese regions	Dekkar,2003; Zhao *et al*.,2013; Nani *et al*.,2015; Jia *et al*.,2013; Huang *et al*.,2014,2016

Sesamum

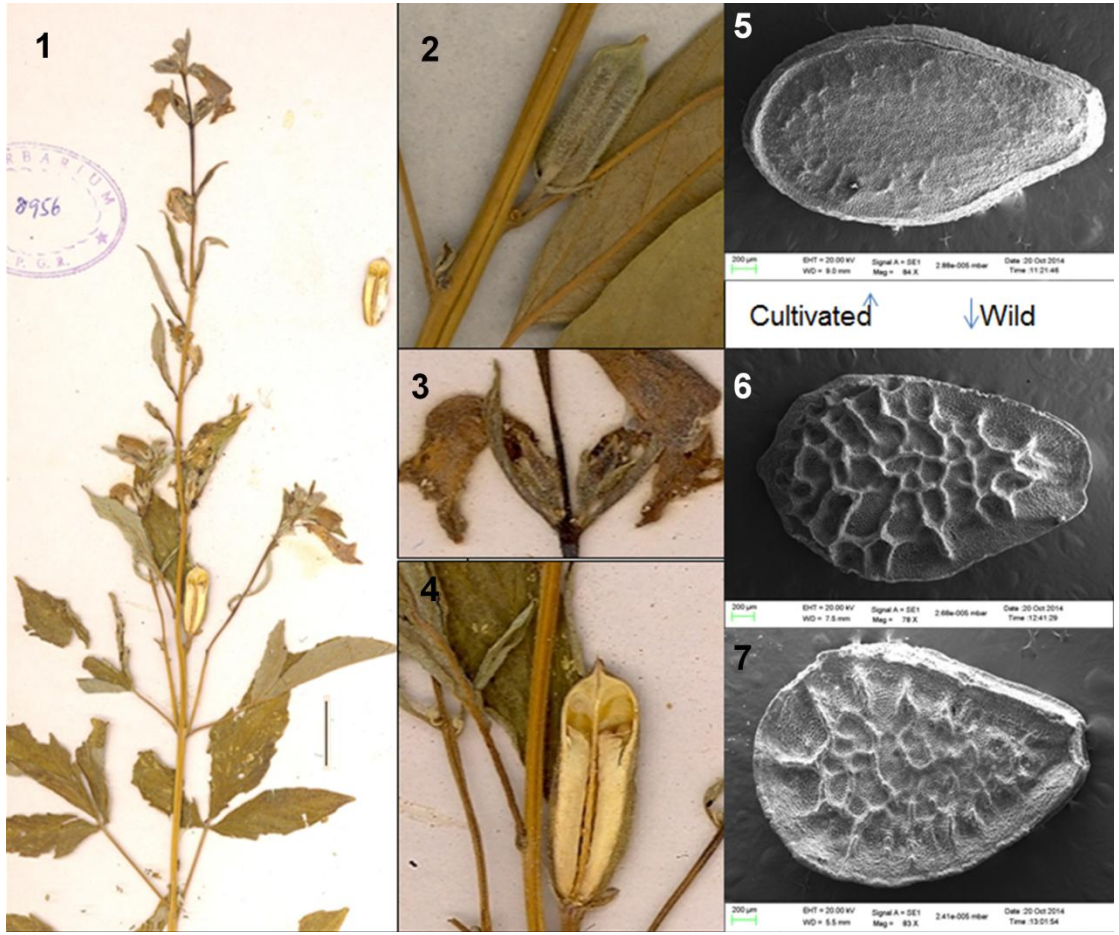
21 spp.- Africa; 8 in Asia

Sesamum spp. in NHCP

Native diversity
(Genepool I)

Crop species: *Sesamum indicum* L.; related wild & weedy forms *S. mulayanum* & *S. malabaricum*

Erect, annual herbs; leaves highly variable, lower ones lobed or digitate, opposite or alternate; flower white or pinkish-mauve, inferior lip not prominent, extrafloral nectaries prominent; seeds not winged but with a conspicuous double fringe, testa smooth or somewhat venous, black, brown or white at maturity.

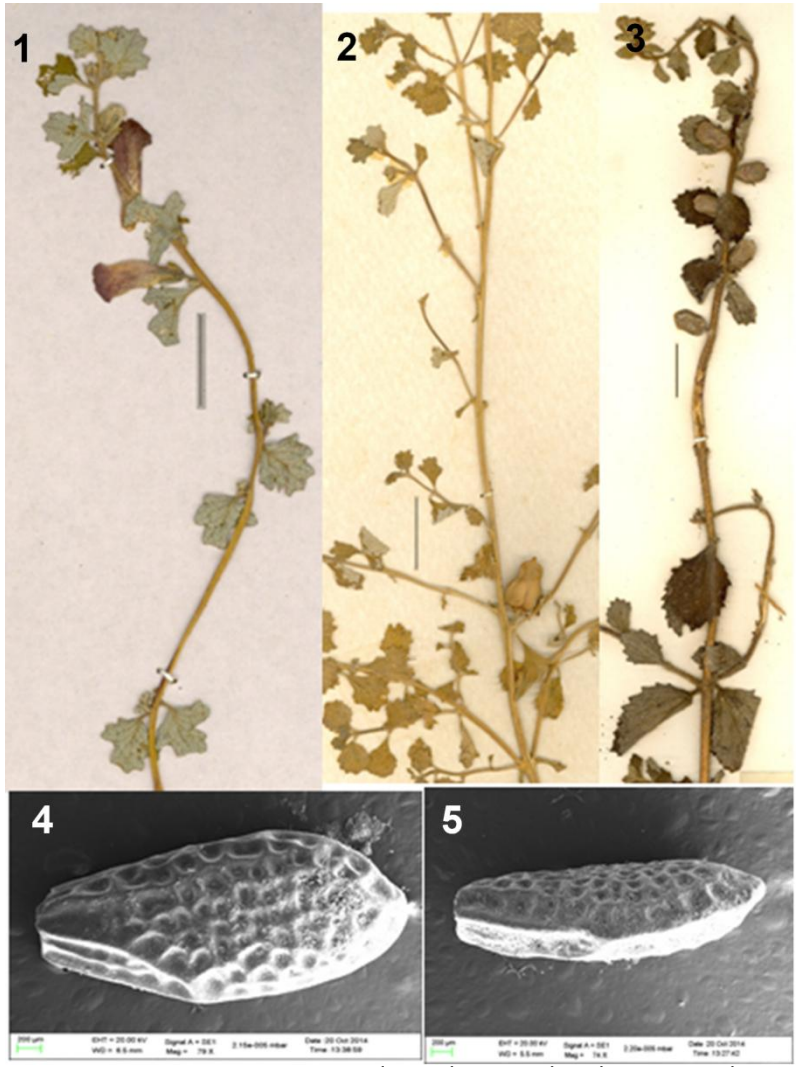


1. S. indicum: HS8956, MS, VD Verma, 7/10/1991
2. S. indicum wild pod, HS10371, Delhi, A Pandey et al., 15/7/1999
3. S. indicum: HS8956, flower
4. S. indicum: HS8956, LS of mature pod
5. S. indicum cultivated: SEM of seed
6. S. malabaricum: seed
7. S. indicum wild: seed

Native diversity (Genepool III)

Wild species- *S. prostratum, S. laciniatum*

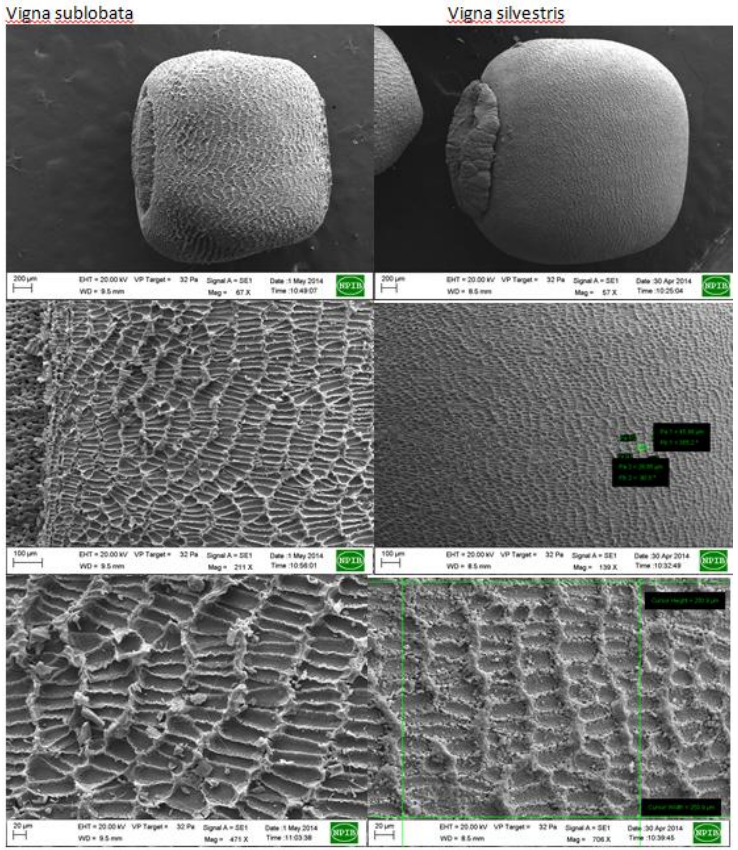
Prostrate habit, leaves short petioled, rounded with crenate margin; flowers solitary in axils (no rudimentary structures), pedicellate, bracteate, with purple corolla; capsule ovoid compressed with tough pericarp, opening loculicidally from top to a short distance below. Seeds few, deeply reticulate with thick testa.



1. S. prostratum: HS13418, Karur, Tamil Nadu, Z. Abraham et al., 26/10/1999
2. S. prostratum: HS5296, Botany Division, IARI, S. Singh, 772, 15/10/1951 [voucher for crossability with sesame]
3. S. laciniatum: HS9487, Palghat, Kerala, Z. Abraham et al., 18/10/1992
4. & 5. S. prostratum: SEM of seeds, surface and side view

Vigna sublobata and *V. silvestris*- wild related species of mung and urid

	Domesticated form	Wild form
Habit	Trailing to erect	Trailing/ climbing
Flower		
Pod partitions between seeds	**Absent**	**Present**
Pod at maturity	Less dehiscent	Dehiscent
Seed size*	Larger (5-fold approx.)	Small
Seed surface	**Generally smooth**	**With periderm deposits**
Seed coat hardness	Less	More; resistance to insect attack
Seed colour	Variously coloured	Brown to black
*Gigantism in plant, leaf, flower, seed		



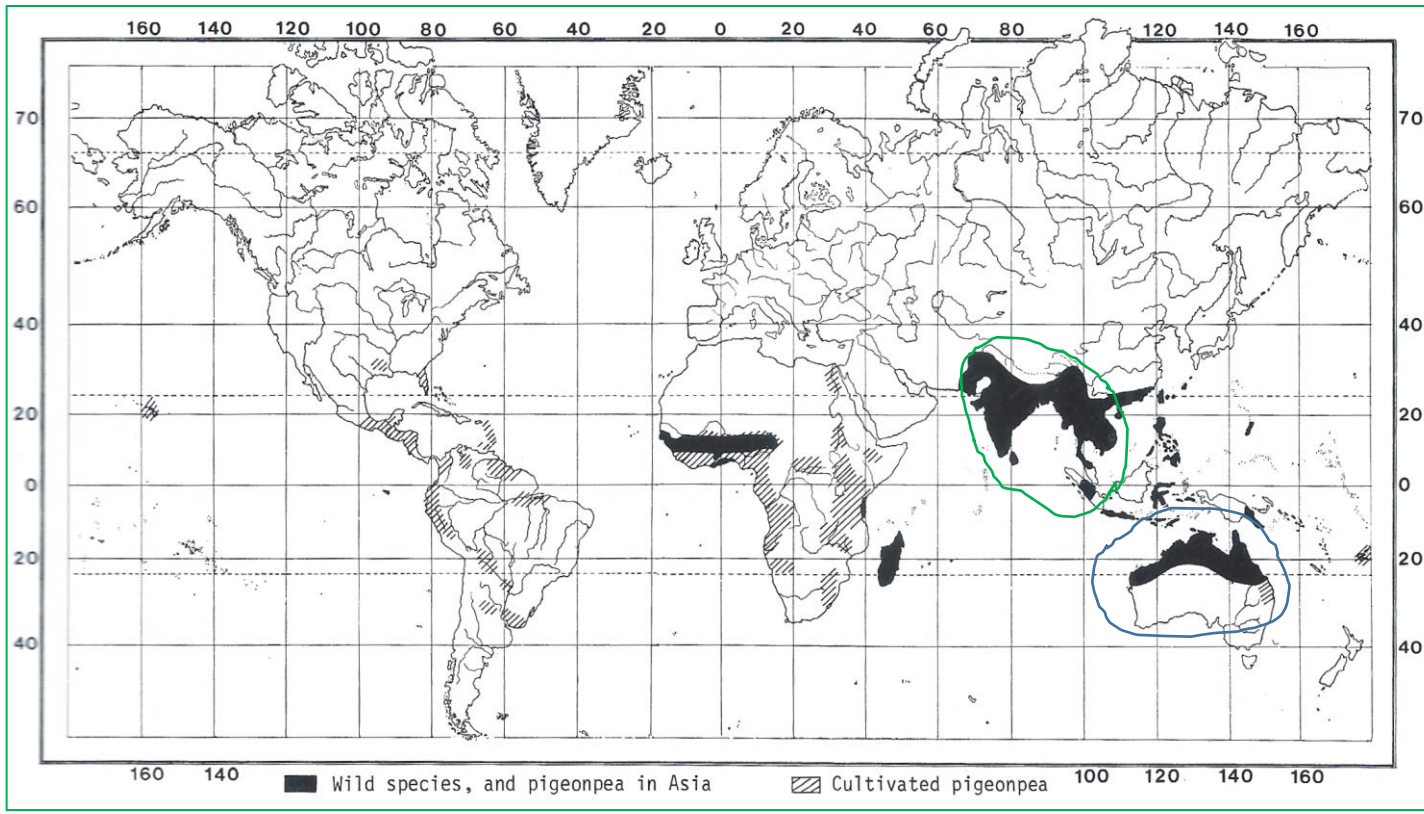
Similar aminoacid profile, crossability studies

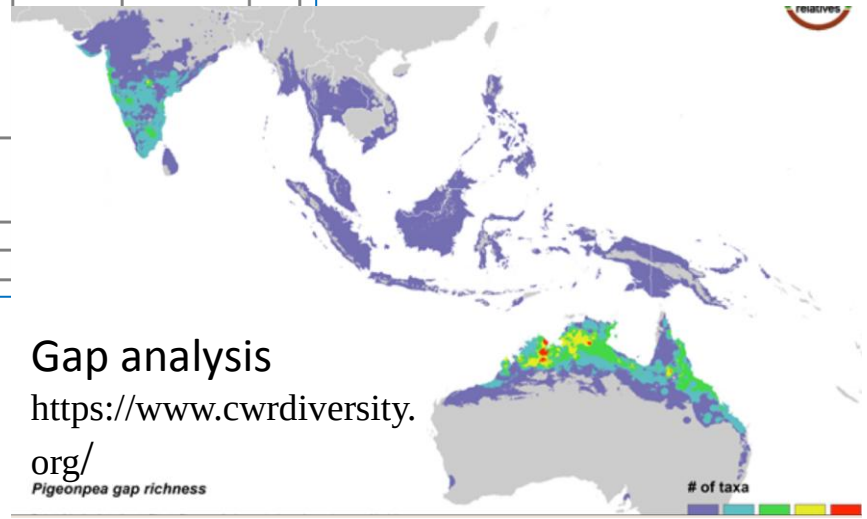
V.sahyadriana- seed with rough surface, with well developed aril, very hairy long pods, and horizontal position

Cajanus cajan: Native crop

Sections	Habit	Australia	India, Myanmar, Sri Lanka, Java	Phil., Indonesia	Africa
Atylia	Erect	C. emerus, C. confertiflorus, C. lanuginosus, C. reticulatus var. grandifolius, C. reticulatus var. reticulatus, C. reticulatus var. maritimus	C. lineatus*, C. sericeus*, C. trinervius*		
Cajanus			C. cajan*, C. cajanifolia*		
Cantharospermum	Climbing	C. scarabaeoides var. pedunculatus C. scarabaeoides var. scarabaeoides	C. albicans*, C. elongatus, C. goensis**, C. rugosus**, C. scarabaeoides* var. scarabaeoides		
Fruticosa	Erect	C. pubescens var. mollis C. acutifolius C. aromaticus C. crassicaulis C. laceolatus C. latisepalus C. pubescens var. pubescens C. viscidus	C. niveus		C. kerstingii
Rhynchosoides	Trailing	C. mareebensis C. marmoratus	C. platycarpus**		
Volubilis	Climbing		C. grandiflorus C.heynei** C. mollis** C. villosus C. volubilis** var. volubilis C. volubilis var. burmanicus		
?					
Total species		15	17		
Endemics		13	8		

*Closely related taxa; ** Tertiary genepool





Gap analysis

https://www.cwrdiversity.org/

- *Cajanus cajan* (Arhar, tur/ pigeon pea) native to India
- Semi-wild and naturalized plants in Asia and Africa
- Primary genepool (Sec. Cajanus), Secondary genepool (Sec. Volubilis) and tertiary genepool represented in Asia/ Australia
- Endemic species in S/ SE Asia
- Majority of species in Australia endemics – centre of speciation

Monograph: van der Maesen, 1985. *Cajanus* DC. and *Atylosia*

	India	China	Australia	Rest of Oceania	Africa	Americas	Eur
Saccharum	16	9	1	2	6	9	3
Miscanthus	3	8	-	1	3	-	-
Saccharum-Miscanthus	19	17	1	3	9	9	3

Saccharum and related genus _Miscanthus_:

Species distribution- global: Nearly 40 species, extending from probable centre of origin in New Guinea to the Asian region.

Crop species/ useful species: Species under cultivation- *S. robustum*, *S. officinarum* and *S. sinense*/ *S. barberi*.

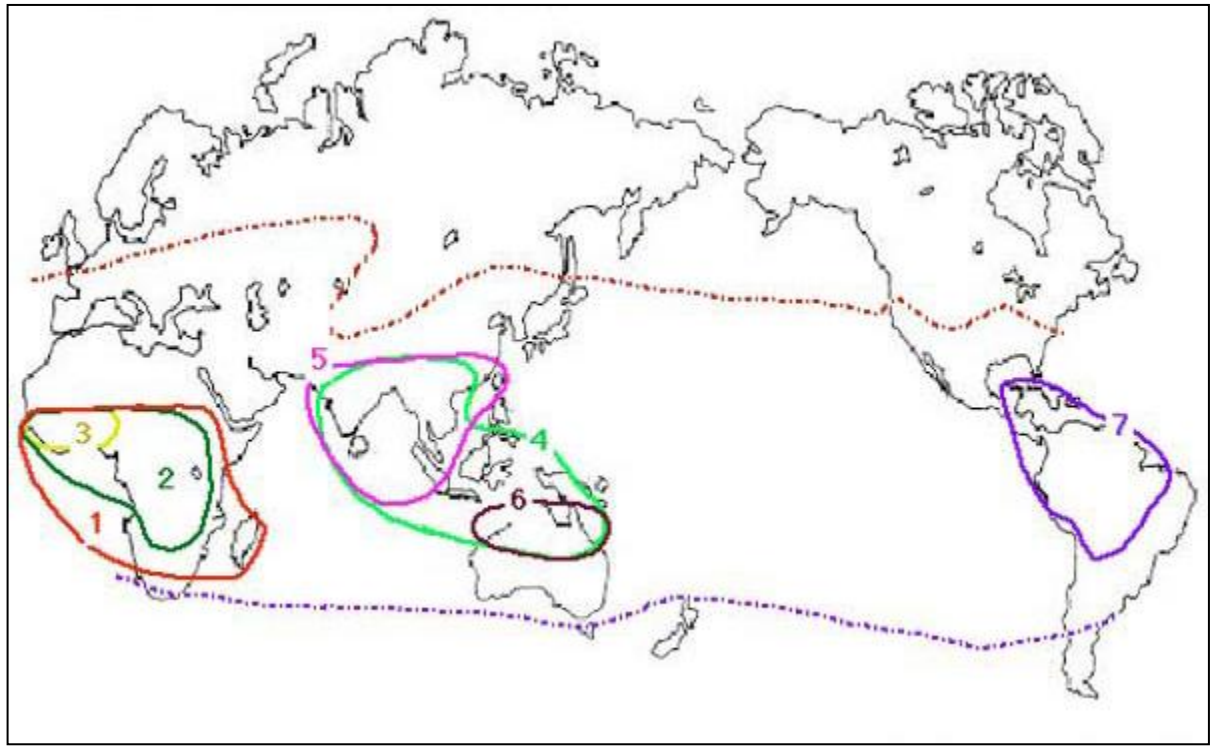
Indian region: 17 species. Species diversity in north eastern and north western parts of India.

- Species endemic to the Indian subcontinent occurred in north western hills (*S. stewartii*), or the Himalayas and eastern plains (*S. sikkimense*).
- Maximum build-up of species widespread over the Indian subcontinent, China, Indo-China and Malesia (*Saccharum*, 5, *Miscanthus*, 2); within the Indian region these occurred north-eastern region and Eastern Himalaya, most extending to the north-western hills and plains, only one extending to peninsular India.
- As per past collections, north eastern areas were areas of availability of the natural introgressed materials.

Stresses: Peninsular and eastern India, followed by north western plains and hills maximum incidence of disease. Widespread species, *S. spontaneum* and *S. arundinaceum*, sources of resistance for several diseases; abiotic stresses, drought and waterlogging tolerance (*S. spontaneum* and *S. arundinaceum*) and salinity (*S. spontaneum*), cold tolerance (*S. longisetosum* and *S. rufipilum*).

Oryza in the Indian subcontinent

Oryza sativa complex (AA genome) H. Morishima and M. Akimoto



1. *Oryza longistaminata*	2. *O. barthii*	3. *O. glaberrima*	
4. *O. rufipogon*,perennial type	5. *O. rufipogon*,annual type	6. *O. meridionalis*	
7. *O. glumaepatula*			

0. granulata complex (Deciduous forests/ primary and secondary forests; complete shade)

0. granulata Nees et Arn. ex Watt	24	GG	Asia
0. meyeriana (Zoll. et Mor.ex Steud.)Baill.	24	GG	Asia

0. officinalis complex (Forest/forest edges; seasonally wet, full sun/partial shade)

0. officinalis Wall ex Watt	24	CC	Asia
0. minuta J.S. Presl. ex C.B. Presl.	48	BBCC	Philippines
0. rhizomatis Vaughan	24	CC	Sri Lanka
0. eichingeri Peter	24	CC	Africa, Sri Lanka
0. punctata Kotschy ex Steud.	24,48	BB,BBCC	Africa
0. latifolia Desv.	48	CCDD	Central & South America
0. alta Swallen	48	CCDD	Central & South America
0. grandiglumis (Doell) Prod.	48	CCDD	South America
0. australiensis Domin	24	EE	Australia

Wild economic/ underutilised species, local domesticates

	India	China	Australia	Oceania	Africa	Americas	Eur
Cajanus	15	7	14	1	1	-	-
Flemingia	18	15	4	-	1	-	-

Flemingia prostrata (syn. *Moghania vestita*)
Fam. Fabaceae
Local names:
Soh-phlong (market sample), Singh & Arora, '73
Khey (edible tubers sold with perilla seed chutney), K. Pradheep, '11
Wild plants plentiful (NW Himalaya), roots eaten by herd boys (Watt, 1890); "if systematically cultivated ..a useful new vegetable"
Domesticate probably of jhum areas of Khasi & Jaintia hills (Hooker, 1878; Gait, 1896; Agric. Bull. 1898; Singh & Arora, '73)
Cultivation done on slopes (45°); promoted by KVK, W. Khasi Hills (K. Pradheep, Nov., '11)

Herbarium specimens
Uttarakhand: 3116 ('68), 6769 ('83), 8682 ('88), 18404 ('87)
Meghalaya: 9453 ('89)
HP: 16804 ('04), 17525 ('04)

Seed samples
Uttarakhand: IC201905 (1996)
Meghalaya: IC20314 (1973); IC330063/ 65 (2001)

Singh & Arora, 1973

Khey: tubers with perilla seed chutney, sold in NEH (K.Pradheep, W Khasi Hills, 20/11/'11; KC Bhatt, 2011)

Plukenetia corniculata, Meetha Patta/ Borneo pea [Euphorbiaceae]

Pradheep *et al*., 2015

KP/SC-1585, IC614466, HS21667 (cult), 21668 (market)

Leafy vegetable (cultivated last 10 years, Assam; gathered from the wild/ grown in homesteads (Nagaland, Assam)
Cultivated (~70-1200m), wild (50-800m)

Medicinal use in AP

SE Asian region, upto Philippines; Sumatra max., elsewhere scattered. significant among tribes of SE Asia

Plukenetia (Forest peanut)
No latex in sap
21 spp.: 20, S. America; 6, Africa; 1, Asia.
N. Peru 'C-D'

Other edible spp.:
P. conophora: Nigeria
P. volubilis (Inca nut),
P. huayllabambana 2008 &
P. carolis-vegae 2013, N. Peru

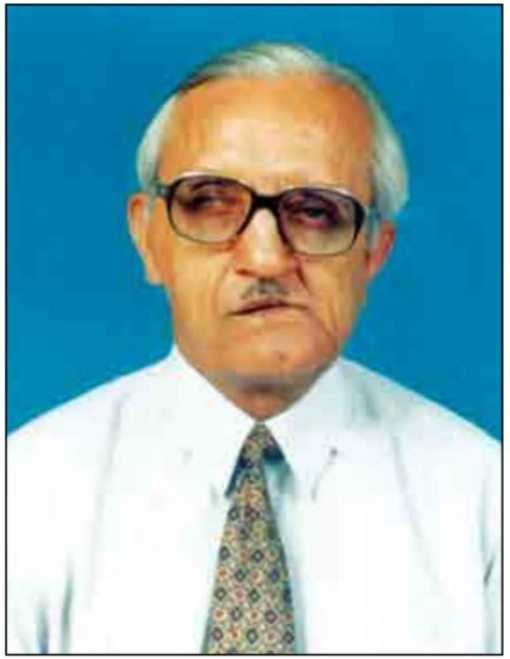
Fig. 2 "Meetha patta" **a** 5-month old young plants in field; **b** 3-year old plantation; **c** young shoots ready for hand-plucking (note the sign of earlier harvests at the base of shoot); **d** inflorescence (leaf-opposed, with one female flower at base); **e** seeds; **f** bundle of leafy shoots in vegetable market at Dimapur

Dr. Harbhajan Singh

Breeder- mainly vegetable crops

Collection and introduction-

Botanist-
Set up a herbarium- got it recognized (PI)
Common weeds of crops (with Mr. Khanna)



Dr. R. K. Arora

Head, Exploration

Collection in Western Ghats, cold arid tracts, north eastern India, especially tribal tracts

Wild relatives of crop plants in India (Arora & Nayar, 1984)

Wild edible plants of India (Arora & Pandey, 1996)

Diversity in underutilised plant species- Asia-Pacific (2014)

PGR Activities

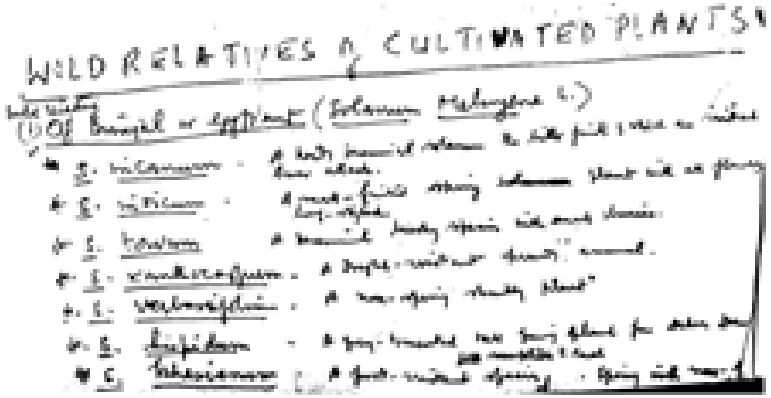
- Collection
- Introduction & Exchange
- Quarantine
- Evaluation
- Conservation
- Documentation
- Management- national and global
- Utilisation

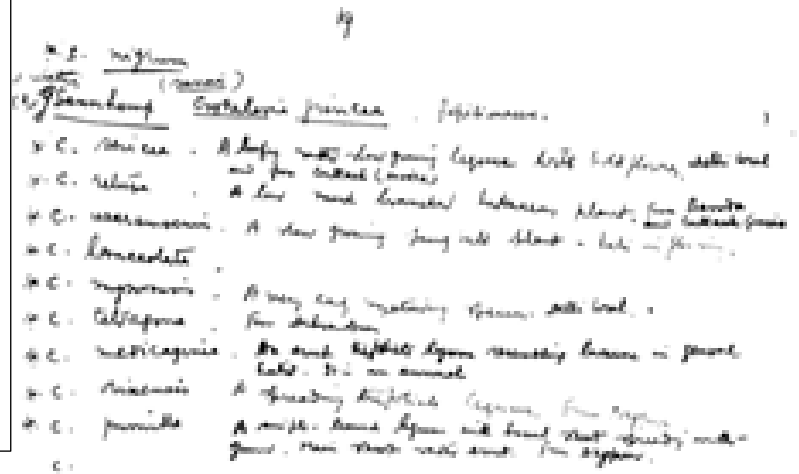
Wild relatives of crop plants in India- Documentation

Search for new genes
(BP Pal, 1937 Agriculture and Livestock in India, 7: 573-578)

Wild relatives of crop plants in India
(Arora and Nayar, 1984, NBPGR, New Delhi)

Wild relatives of cultivated plants in India
(Pradheep, Bhandari and Bansal, 2014, NBPGR, New Delhi)





Search for YMV-resistant & collection of *Abelmoschus tuberculatus* (IW 130), Saharanpur, raised in Plant Introduction Plots, HS5277, 15/12/1946, HB Singh.

Collection of diversity in wild forms of brinjal, *Solanum melongena* var. *insanum* identified by the place of their collection- Potangi type from Koraput, Odisha, also used in crosses
Pal & Singh, 1943, ‘46

Sesamum prostratum and *S. laciniatum* Chromosome numbers and cytogenetical studies.
Ramanujam, 1941, ’42; Ramanujam & Joshi, 1947; Ragavan & Krishnamurti, 1945, ‘47.

Collection of *Vigna sublobata*, progenitor species of mung, from Western Ghats: Arora & Singh, 1974

Delineating wild relatives:

1. Species related to the crop genus (also related genera)
2. Work out areas of concentration of species
3. Grouped on the basis of differences in morphology and distributional patterns

4. Crossability patterns used to delineate- primary genepool, secondary genepool and tertiary genepool (with reducing success of crosses, techniques such as embryo rescue needed for obtaining hybrids)

5. Quantitative and qualitative differences and trends in growth, reproductive patterns, response to biotic and abiotic stresses and nutritional parameters
6. Tissue compatibility in vegetatively propagated plants

>320/1270 species, priority species related to major crops (1984)

Wild relatives of crops: Issues

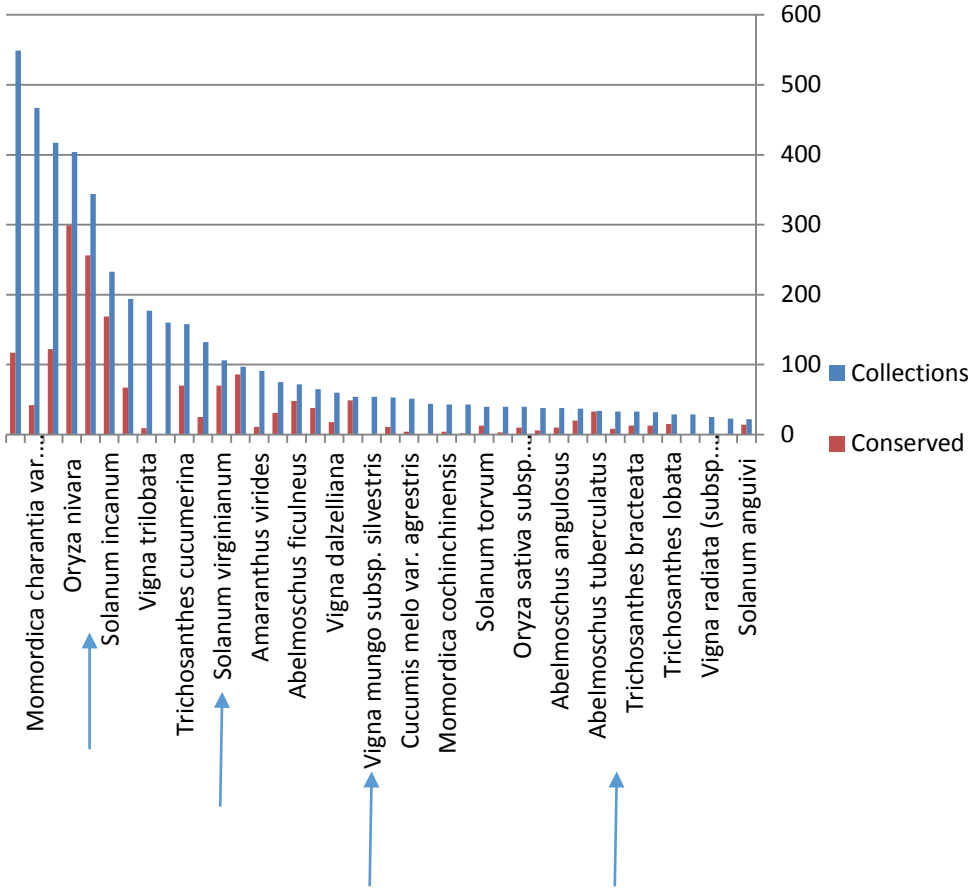
- **Wild relatives account for 7% of total wild species diversity**
- **Priority given for diversity collection and conservation of species of wild related species of crop plants at the NBPGR**

Diversity collected by NBPGR: 2409 accessions of wild relatives out of 23243 accessions of wild species collected (10.47%)

Diversity conserved by NBPGR: 1125 accessions of wild relatives out of 13583 accessions of wild species conserved (8.25%)

83 species of wild relatives out of 580 wild species conserved at the NBPGR (14.26%):

Genebank (GB): 564 accessions (43 species)
Cryobank (CB): 504 accessions (69 species)
In vitro (IV): 48 accessions (16 species)
140 species represented as herbarium specimens in NHCP
AKMU database
>3100 accessions cultivated/wild status unknown;



F W Went, (1903-1990); Desert Research Institute, University of Nevada, USA- **pioneer in establishing the idea of a seed vault and the need for preservation** under safer and more controlled conditions

Fritz Went and Philip Munz long-term seed longevity experiment- 100 different native species from a wide range of families and habitats, 20 sets seeds to run for 360 years/ until 2307; dried down to very low moisture content, and placed into glass tubes sealed under vacuum.

Went and Munz Test Species	1947	1967	1997
Asteraceae, Achillea millefolium	98	98	62
Chenopodiaceae, Allenrolfea occidentalis	5	40	60
Chenopodiaceae, Atriplex hymenolytra	0	10	20
Onagraceae, Clarkia elegans	100	95	88
Asteraceae, Coreopsis bigelovii	58	63	8
Asteraceae, Encelia actoni	13	7	0
Loasaceae, Mentzelia lindleyi	4	62	10
Platanaceae, Platanus racemosa	45	63	4
Iridaceae, Sisyrinchium bellum	23	49	0*

Exotic specimens in the NHCP, NBPGR- record of germplasm under global exchange, as seed or planting material !946-2006

	Crop category	Spp	Intrd	Conserv (GB/ FGB)
1	Cereals/ millets (a)	38	71	13
2	Grain legumes (b)	19	43	9
3	Fruits (c)	13	14	10
4	Vegetables (d)	14	38	11
5	Oilseeds (e)	13	21	8
6	Pseudocereals (f)	3	6	3
7	Spices/ condiments (g)	5	5	-
8	Fodder/ forage grasses (h)	35	53	2
9	Fodder/ forage legumes (h)	124	190	7
10	Ornamentals (i)	11	11	8
11	Medicinal/ aromatic plants (j)	23	31	5
	Total	298	482	22

Wild Relatives: Major Taxa Collected & Conserved

Accessions/sp.	Species conserved		Species collected		
			Species no.		Diversity/ States where collected
>100	2		3		4-11
>50-100	4	**25.3%**	7	**24.6%**	3-11
>25-50	9		5		3-8
>12-25	6		13		2-8
>6-12	14		12		1-5
>3-6	12		20		1-4
>1-3	19		22		1-3
=1	17		32		1

Global priority genetic reserve locations for wild relatives of 12 food crops