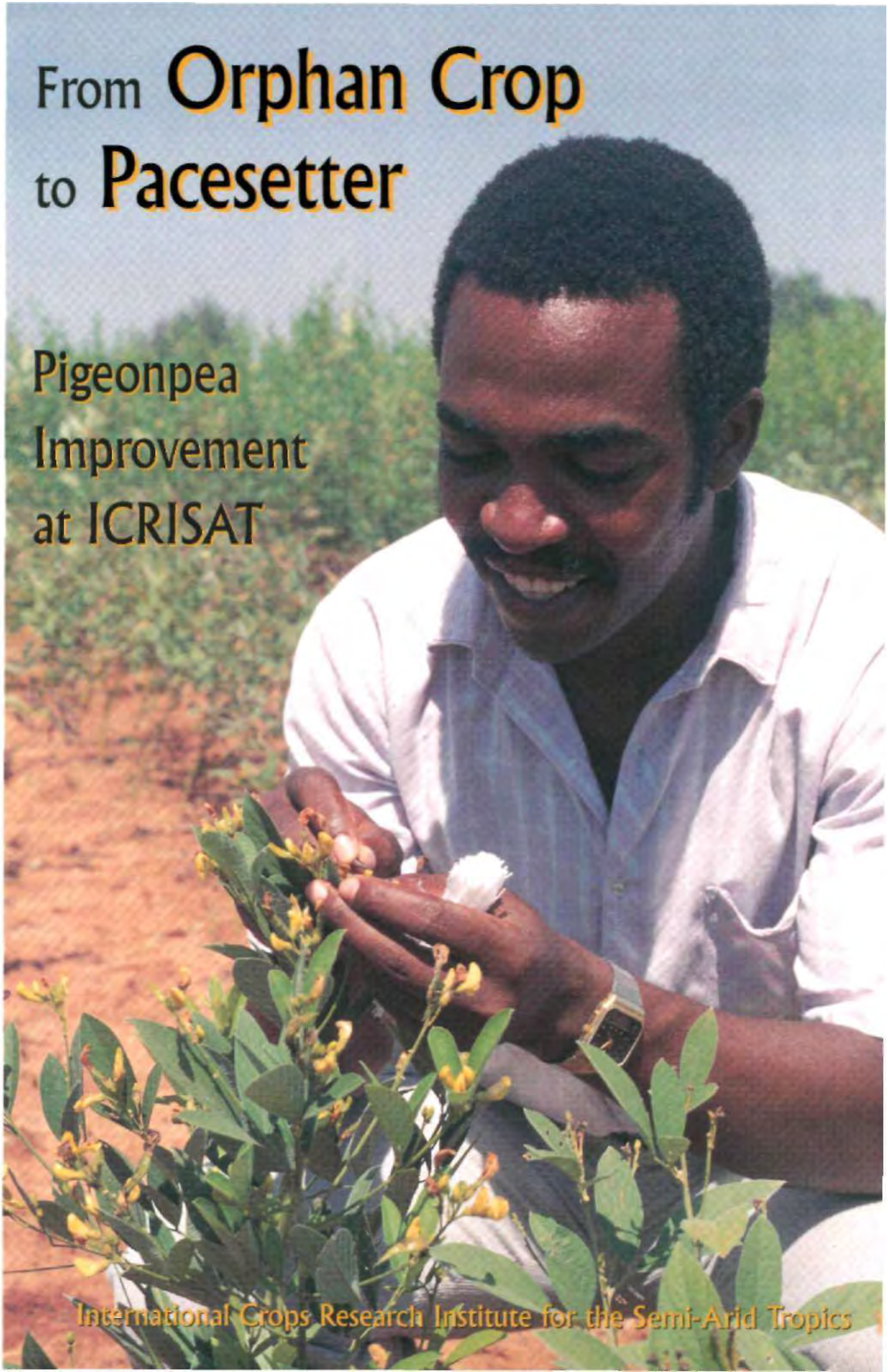
From Orphan Crop to Pacesetter

Pigeonpea Improvement at ICRISAT



Winner of the 1998 CGIAR King Baudouin Award

International Crops Research Institute for the Semi-Arid Tropics

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Cover photo: Dr Stephen Githiri Mwangi exemplifies the partnership and national capacity-building focus of ICRISAT's pigeonpea initiative. Supported by the International Development Research Centre (IDRC), Dr Mwangi studied pigeonpea disease screening techniques and data handling at Patancheru in 1990. He is currently a lecturer in the Department of Crop Science, at the University of Nairobi, where he is involved in teaching and pigeonpea breeding.

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The King Baudouin Award
of the Consultative Group on International
Agricultural Research

Presented to

The International Crops Research Institute
for The Semi-Arid Tropics
(ICRISAT)

October 29, 1998

In recognition of its development of high-yielding
and disease resistant pigeonpea varieties
and their contribution to agriculture and human welfare in
developing countries

DONALD WINKELMANN
CHAIR, TECHNICAL ADVISORY COMMITTEE

ISMAIL SERAGELDIN
CHAIRMAN, CGIAR

The CGIAR King Baudouin Award

When the Consultative Group on International Agricultural Research (CGIAR) was awarded the King Baudouin International Development Prize by Belgium in 1980, it decided to create a biennial award in recognition of exceptional achievement among its sixteen centers. The Technical Advisory Committee (TAC) of the CGIAR, consisting of renowned international agricultural scientists, judges submissions for the Award, which is presented during International Centers Week in Washington DC.

From Orphan Crop to Pacesetter : Pigeonpea Improvement at ICRISAT

Executive Summary

Until the mid-1970s, pigeonpea (*Cajanus cajan* L. Millsp.) was an orphan within the research and development establishment. Despite contributing protein to the diets of an estimated 1.1 billion people around the world, cultivated on some 5 million ha globally, it was thought to be a "poor person's meat," and attracted little attention from either public or private sector research and development (R&D) programs.

With the creation of ICRISAT in 1972, a commitment to improve the neglected food crops of the semi-arid tropical poor was established. Pigeonpea - a shrublike legume contributing as diverse a set of products as food, fuel, forage, and enhanced soil fertility - presented a fascinating range of opportunities for improvement not found in many crops of the CGIAR.

Over the past quarter-century, these opportunities have been systematically exploited through research jointly carried out with an array of partners. ICRISAT's contributions played a significant role in stimulating a near-doubling of the crop area in India, an achievement of which few rainfed crops can boast. This is a story of science in action, in which innovative thinking, applied to concrete objectives in concert with like-minded institutions, has delivered extensive benefits to millions of smallholder farmers and consumers.

The most significant achievements of this initiative are:

- Unique scientific contributions in the course of the conservation and characterization of an invaluable but neglected crop germplasm pool, including classic studies revising the taxonomy and center of origin of the crop;
- The application of disciplined science to take advantage of the germplasm collection to alleviate a major disease constraint, fusarium wilt, generating massive benefits to poor farmers;
- The innovative reconstruction of the plant into a short-duration, short-statured, high-yielding type, stimulating large productivity gains, diversifying existing cereal-dominated cropping systems by inserting a legume component, and triggering a major geographic extension of the crop;
- A scientific breakthrough: the world's first food legume hybrid to go into commercial production, demonstrating a 25% grain yield increase, plus additional stem and leaf biomass for fuel and forage, and improved drought, disease, and waterlogging tolerance; and
- An expansion of the scope and depth of partnerships, including NARS, NGOs, the private sector, and farmers groups (particularly women), in both Africa and Asia - amplifying future returns on R&D investments.

I. Building the Asset Base : Collection, Conservation, and Characterization

From its earliest years, ICRISAT placed great emphasis on collecting, conserving, and characterizing the genetic wealth underpinning its crop mandates. For pigeonpea, this core effort was complemented by excellent science in taxonomy and phytogeny.

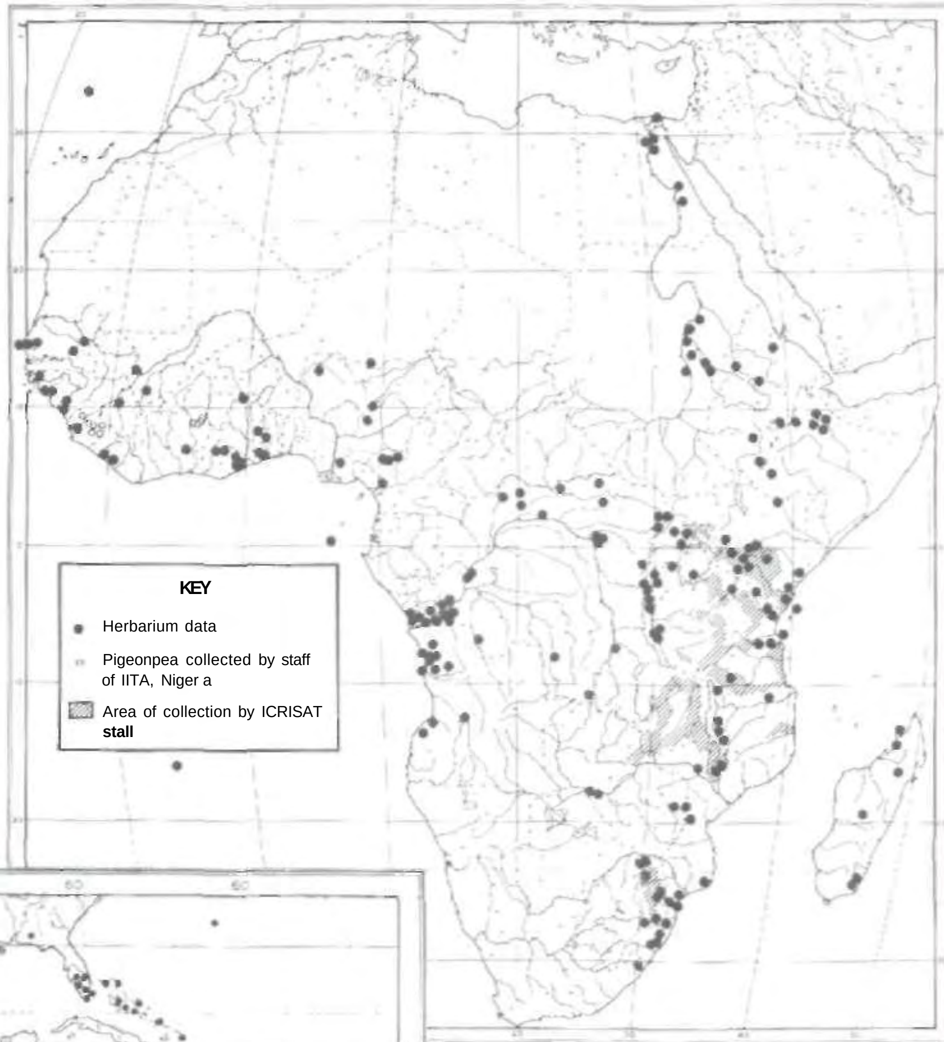
A global crop

When ICRISAT began, there was little documentation on the extent and diversity of pigeonpea. The generalization was often heard that pigeonpea was a crop of just one country, India. Detailed analysis by ICRISAT in the 1980s dispelled this notion. While the majority of *production* (circa 85%) is in India, the distribution of the crop is truly global.

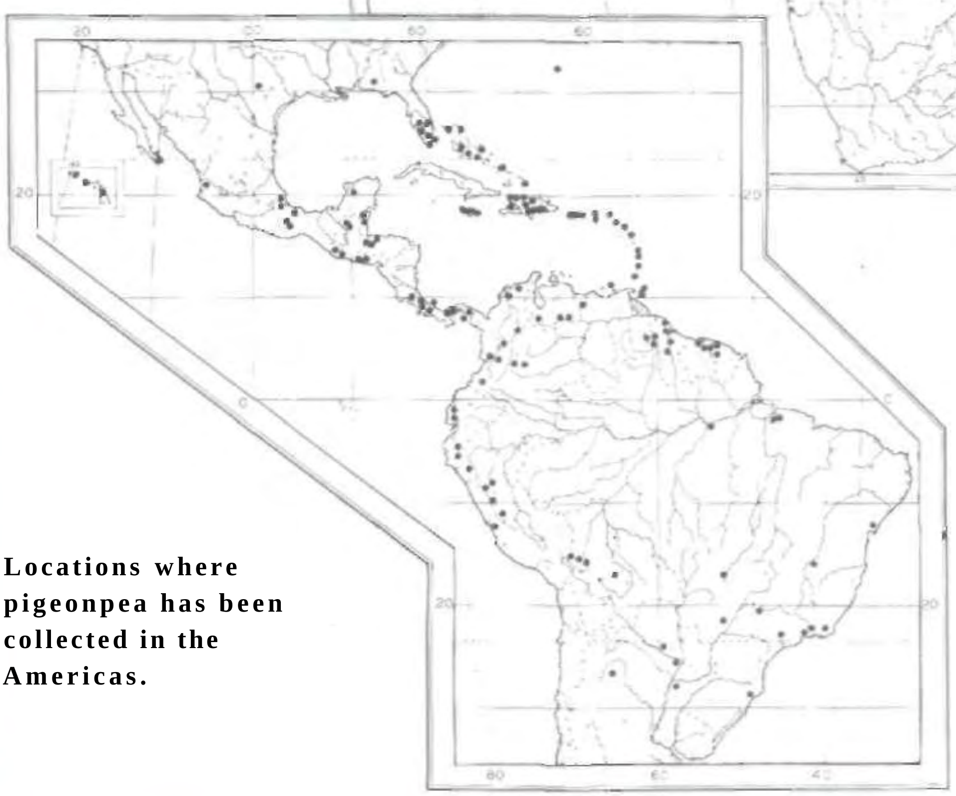
The study, which examined herbarium specimens available in other institutions together with data from ICRISAT/NARS collection trips, found pigeonpea in 37 countries of Africa, and across most of the countries of Central and South America and the Caribbean (see page 3) (van der Maesen 1983). Much of this is household production in compound gardens, that contributes importantly to poor smallholder family nutrition and food security, yet never reaches national production statistics.

The observation of a wide global distribution of pigeonpea held important ramifications for ICRISAT's research strategy. It demonstrated that the crop was accepted by rural populations across the tropics, so that research advances, if relevant and useful, would likely meet a receptive audience and lead to significant impact far beyond India. Experience has since confirmed this hunch, as described later in this publication.

Prepared and consumed in a wide variety of forms, pigeonpea is a protein source for a billion people.



Locations where pigeonpea has been collected in Africa.



Locations where pigeonpea has been collected in the Americas.

Source: van der Maesen 1983

Evolution and origin

As an orphan crop, the evolution of pigeonpea had received only limited study until the 1970s (van der Maesen 1990). Even the origin of the crop was in question - did it evolve in Asia, or Africa? In 1977, ICRISAT staff found *Atylosia cajanifolia*, a wild relative, in the jungles of the Bailadilla Hills in India. By studying the species closely, including its crossability with cultivated species, it became clear that it was very closely related to cultivated pigeonpea, being mainly separated by a single visible trait: a prominent strophiole, or raised ridge on the "eye" of the seed. This evidence, combined with available floristic, linguistic, and cytological data, argued strongly for an Asian origin for the cultivated species (van der Maesen 1980).

Another important germplasm achievement was an in-depth morphological, cytological, and chemo-taxonomical characterization which resulted in the revision of the subtribe Cajaninae. *Cajanus* now includes 32 species, and detailed botanical descriptions of each were jointly published by ICRISAT and the Agricultural University of Wageningen (van der Maesen 1985). These studies demonstrated close affinity between the genera *Atylosia* and *Cajanus*, and the former was consequently merged into the latter.

Collect, conserve, characterize

Strengthening this fundamental asset, ICRISAT has expanded initial holdings of about 4,000 lines to a current total of 13,015. These include accessions from 72 countries and 47 species belonging to 6 genera of Cajaninae. These collection and conservation activities could not have been as extensive without the steadfast support of the Asian Development Bank.

The collection has been exhaustively characterized for agronomic, morphological, and disease/pest resistance traits. A number of important traits have been found, and many of them have been utilized in the breeding program. These include resistances to the diseases fusarium wilt, alternaria leaf spot, cercospora leaf spot, phytophthora stem blight, sterility mosaic, and powdery mildew; and to the podfly insect, *Helicoverpa* and *Maruca* pod borers, and the *Clavigralla* pod-sucking bug.

To access traits residing in wild species, ICRISAT has developed procedures for rescuing embryos in wide crosses (Mallikarjuna et al. 1995). Wide crosses are also being successfully applied in the search for cytoplasmic male sterility for hybrid seed production (see page 15). Resistances to such important abiotic stresses as salinity, waterlogging, and drought have also been identified.

In a pioneering study supported by the Government of Japan and with direct involvement of seconded scientists from the Japan International Research Center for Agricultural Sciences (JIRCAS), it was found that pigeonpea could extract 2-7 times more iron-bound phosphorous (P) from typical Alfisol soils than could maize, millet, sorghum, or groundnut (Ae et al. 1990). This important

Intensive collections of pigeonpea landraces and wild species helped elucidate the crop's center of origin.

finding was published in the prestigious journal *Science* and has been widely cited. P is arguably the most limiting nutrient across the semi-arid tropics; and there are few solutions to deficiency other than to apply costly chemical fertilizer.

Not only did this study help explain why pigeonpea performs so well in poor soils under low-input management; it also suggested that pigeonpea enriches the P supply for subsequent crops, since organic forms of P will become available to other crops as pigeonpea residues break down. With continuing support from Japan, scientists are attempting to identify germplasm with the highest levels of expression for this trait, to further clarify the mechanisms involved, and to extend the scope of research to additional crops.

Impact of germplasm activities

Practical impacts of these studies and discoveries are spun out of the germplasm collection on a continuous basis, as breeders apply this information to incorporate new traits into breeding populations. Even direct usage of germplasm by farmers has paid off handsomely. NARS in five different countries have released varieties selected from landraces in the collection, including the wilt-resistant variety 'Maruthi', estimated to have delivered US$ 62 million in benefits to India to date (see Section II).

II. Rescuing Traditional Cultivation Systems by Controlling the Wilt Menace

The problem

With its arboreal habit, traditional pigeonpea requires 6 to 9 months to mature (a few landraces are even perennial). Long duration conveys important benefits in many situations, but it also provides an opportunity for the extended development of diseases, particularly fusarium wilt (causal organism *Fusarium udum* Butler).

Fusarium wilt devastates pigeonpea. A soil-borne fungus, it multiplies on the root surface and invades vascular tissues. Choking off the plant's water supply, it displays its harshest symptoms when the crop is fully grown and beginning to flower. This is when water demand peaks, causing the plants to wilt and die just as the crop begins to form grain. Yield losses on farms in India during the 1977/78 season cost the country an estimated US$ 36.4 million in foregone production (Bantilan and Joshi 1996).

The solution

ICRISAT's first major impact in pigeonpea was to help bring wilt under control for millions of smallholders across India. Since the poorest farmers cultivated the most susceptible, long-duration plant types, targeting wilt resistance was a way to deliver research benefits to the most needy smallholders.

The differences between wilt-susceptible (left) and resistant (right) plants are striking. 'Maruthi', the resistant variety shown here has been called a "blessing and a miracle" by Karnataka farmers.

The key to this success was a sustained (1977-86) and intensive breeding effort involving three main thrusts:

- The development of reliable, uniform sick-plot conditions for effective screening (Haware and Nene 1994);
- The exhaustive screening of 11,000 germplasm sources to identify just 33 exhibiting apparent resistance; and
- Extensive national (India) and international NARS/ICRISAT collaborative testing of resistant materials to identify durable resistance sources.

The impact

The impact of this research and development initiative in central India, the heart of the pigeonpea production zone (see page 8), was intensively studied in recent years by ICRISAT economists (Bantilan and Joshi 1996). The largest impact was generated by the line ICP 8863, released in 1986 as 'Maruthi' (Konda et al. 1986). Maruthi was selected from a landrace (P-l5-3-3, also known as ICP 7626) from Badnapur in Maharashtra state.

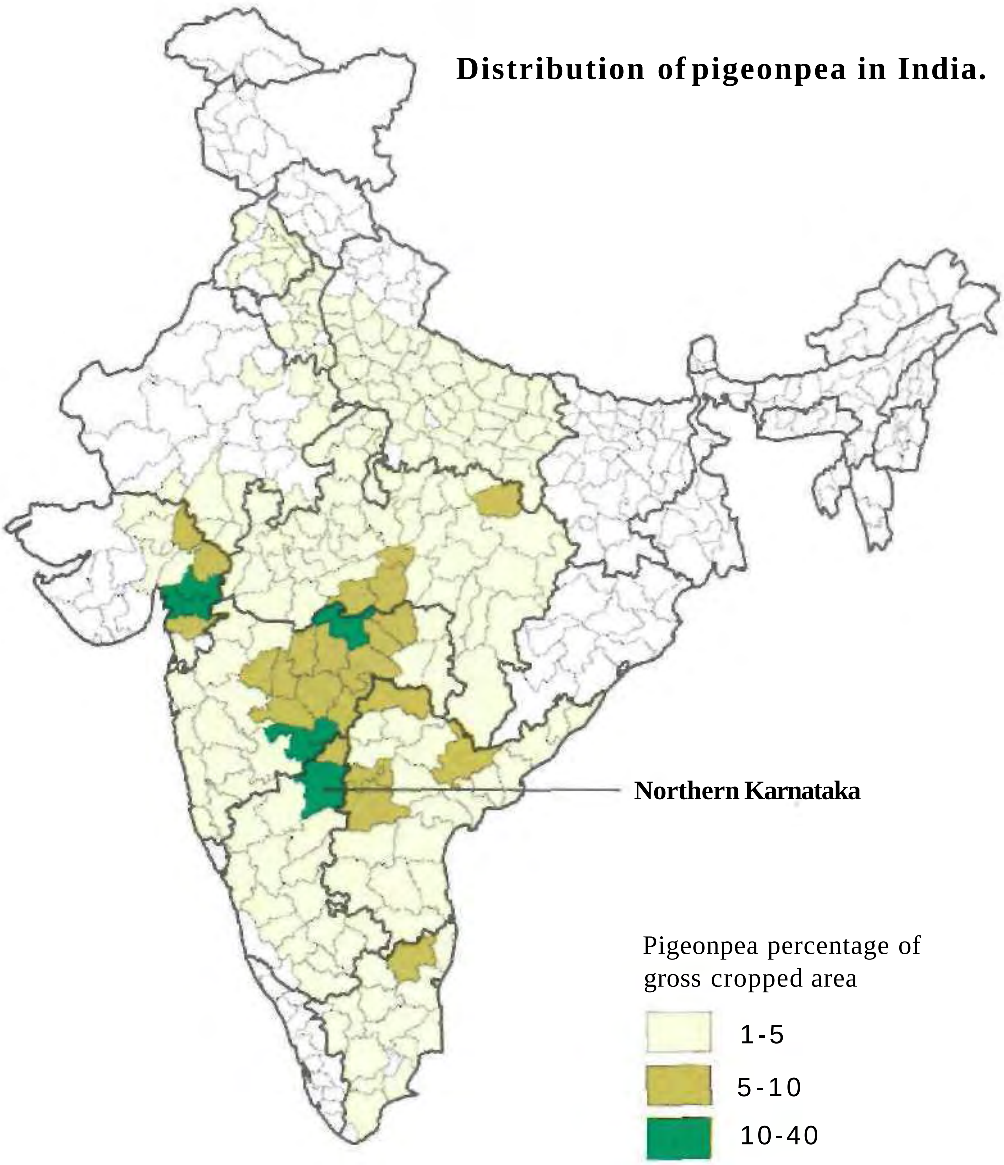
Maruthi (another name for the great hero Hanuman in the Hindu epic *Ramayana*) was an immediate hit. Its adoption in the northern part of Karnataka state, the primary target zone, increased from 5% in 1987 to almost 60% by 1992/93.

Gains included a stabilization of smallholder production, major expansion of crop area, and increased smallholder incomes. In on-farm trials, Maruthi's wilt resistance conveyed an impressive 57% advantage in yield performance. Failing smallholder enterprises became profitable once again, as unit costs of production fell by 42%, or US$ 1200 per ton. The net present value of benefits from the research effort have been estimated at US$62 million to date, representing an internal rate of return of 65% on the original research investment.

Remarkably, the Maruthi wilt resistance source has remained durable to this day. This is a classic example of the benefits of partnership, as the exhaustive multilocational testing that was needed to identify Maruthi would not have been possible without a carefully-planned program of collaboration between the Indian Council of Agricultural Research (ICAR) and ICRISAT (Amin et al. 1993).

ICRISAT actively pursues international spillovers of innovations. In the case of wilt, a major opportunity exists to extend these benefits to Africa. Enabled by the African Development Bank-sponsored Pigeonpea Improvement Project for Eastern and Southern Africa since 1992, ICRISAT and NARS are assessing the importance of wilt on the African continent, and farmers' needs in relation to it. Resistant germplasm and wilt screening methodology have been established within the Nairobi-based Project.

Distribution of pigeonpea in India.



Source: Bantilan and Joshi 1996

III. Reconstructing the Plant Type to Unleash Productivity and Cropping Systems Potential

The problem

Like many legumes, pigeonpea commands a relatively high price in the marketplace, and smallholder farmers benefit from it both *as* a cash generator and as a foodstuff. But yields of traditional pigeonpea were depressingly low for a crop that spent 6-9 months in the field, averaging about 700 kg ha^{-1}. The basic productivity of the system was insufficient to interest farmers in intensifying their crop management much beyond subsistence level.

The solution

With support from the Australian Centre for International Agricultural Research (ACIAR) and in collaboration with the University of Queensland, ICRISAT and ICAR scientists made a concerted effort to understand pigeonpea physiology and yield development processes, in the context of both existing and potential cultivation systems - and spotted opportunities for innovation (Chauhan et al. 1987).

They applied this understanding to breed more productive and adaptable, short-duration (4-month), "bush" plant types, which contrast sharply with the traditional, arboreal, asynchronous-flowering, photoperiod-sensitive, late-maturing (6-9 month) varieties. Crossing and selection for short duration combined with good agronomic type were carried out under long days in sub-tropical northern India, for yield at ICRISAT Patancheru, and for resistances to disease, pest, and other stresses at relevant hot spots across India, in close collaboration with ICAR.

Progeny fitting the desired "ideotype" grew to less than a meter in height in tropical environments, permitting much easier field operations. They were also more synchronous in flowering and grain maturation, opening the door to the possibility of mechanization.

However, it soon became clear that these bush types required substantially different crop management. Being less competitive, they were unsuited to traditional intercropping at low density. Monocropping with a fivefold increase over traditional sowing density was required (Chauhan et al. 1987).

In a sense, the traditional configuration of diversity in *space* (intercropping) was now supplemented by an additional varietal option that exploited system diversity in *time* (multiple cropping). This additional dimension could enhance total farm income substantially.

The old versus the new

Characteristic	Traditional varieties	Short-duration varieties
Adaptation	0 - 30°N and S	0 - 46° N and S
Duration	6-10 months	3-4 months
Plant type	Tall, treelike	Compact, short
Sowing time	Fixed	Flexible
Multiple cropping	Not possible	Possible
Mechanization	Not feasible	Feasible
Drought	Susceptible	Escape
Frost	Susceptible	Escape
Major diseases	Susceptible	Escape
Podfly	Susceptible	Escape

The impact

The timing of this breakthrough was fortuitous. By the mid-1980s, the Government of India had become very concerned that productivity increases in oilseeds and pulses were *lagging* far behind those of cereals, necessitating massive imports to meet basic food needs - estimated at US$ 2 billion during 1981-86 alone.

Responding to a special plea from the Government in 1987, ICRISAT partnered with ICAR and state extension organizations in a major on-farm testing and demonstration initiative across seven states, called LEGOFTEN (Legumes On-Farm Testing and Evaluation Nursery). From 1989-91, LEGOFTEN was generously supported by the International Fund for Agricultural Development (IFAD).

In collaboration with ICAR, ICRISAT's LEGOFTEN staff met with extension professionals from across the country to study local practices, identify constraints, and plan the trials. The results were impressive: in 67 trials over the period, the improved variety/management package demonstrated a mean yield increase of 58%, while maturing months sooner than crops grown in the traditional system. Public awareness activities spread the news throughout rural areas of central India. The technology was shared with NARS across Asia through special support from the Asian Development Bank for the Cereals and Legumes Asia Network (CLAN).

Farmers were quick to adopt these materials. ICPL 87, released as Pragati ('Progress' in Hindi) in central and southern India in 1986, immediately became popular in the drier regions of Maharashtra and Karnataka, and now covers over 150,000 ha in these states.

A detailed impact study (Bantilan and Parthasarathy 1998) found that the variety/management package resulted in an average 93% yield increase over the systems it replaced.

Another major reason for adoption was that it enabled double cropping: the pigeonpea matured early enough so that farmers could still sow their staple postrainy crops of sorghum, chickpea, and wheat. The bottom-line benefit to the overall enterprise was a 30% increase in net farm income. Interviews revealed that farmers also perceived, and valued, benefits to soil fertility and erosion control from adding pigeonpea to their rotations.

The impact of the short-duration pigeonpea research thrust in central India is under further study by an Australian economist (Ryan 1998). He assessed the costs of participation of all four institutions (ICRISAT, ICAR, ACIAR, and the University of Queensland) and the growing benefits from adoption in central India, and projected these to a point 30 years from the 1978 inception of the Project, i.e., to 2007. He estimates that the net present value of the investment in 1978 terms was US$ 117 million, generating *an* interna! rate *of return of more* than 27%.

Extra-short duration pigeonpea under collaborative testing in Sri Lanka.

Shorter shorts

Continuing to push the envelope, ICRISAT breeders are now testing even shorter-duration types, which mature in just 3 months. These would provide even greater cropping system flexibility. An exciting potential niche is within the rice-wheat systems of the Indo-Gangetic Plains.

Spanning four countries in south Asia, and home to approximately 260 million poor, this critical agro-ecosystem has been showing signs of instability apparently associated with the high-input, cereals-dominated cropping system introduced during the Green Revolution. The insertion of legumes into the rotation could help make it more sustainable, but traditional varieties take too long to mature - pushing the following crop (wheat) too far into the hot season.

Under the auspices of the CGIAR Systemwide Rice-Wheat Program, ICRISAT and NARS have found that an extra-early pigeonpea, ICPL 88039, has sufficiently short duration to be harvestable well in advance of the optimal wheat sowing date. Thus, it can be inserted into the warm-season rotation in place of rice when and where needed, e.g., where water shortages, price incentives, soil fertility constraints, etc., cause farmers to seek additional options. If this new niche proves successful, it could stimulate another major expansion of pigeonpea area and production into the area known as the "food basket" of south Asia.

Another niche for the extra-shorts is in the tropical latitudes, sown just after rice harvest. ICPL 179 has shown immense promise in this system in Sri Lanka. The potential area for this application is vast, encompassing the tropical rice belt of southeast Asia.

A special opportunity for women

Yet another interesting gain from the short-duration types is their suitability for green pea production (Faris et al. 1987). Immature (green) pigeonpea seeds are consumed as a fresh vegetable in many parts of India, the Caribbean, and southern and eastern Africa, where it attracts high prices and delivers a crop (and the ensuing profits) more quickly than dry peas. Since short-duration varieties are relatively photoperiod insensitive, they can be sown at different times of the year (under irrigation) to reap higher off-season prices for fresh produce. If pods are removed, repeated flushes of flowers can be stimulated and several pea crops harvested from the same plants.

Short-duration green pigeonpea creates a chance for the poor person's crop to become a springboard to prosperity. Women, who are often involved in the post harvest processing and marketing of pigeonpea, stand to especially gain from this opportunity.

The proud owner in front of her new granary explaining how she built it with profits from the sale of fresh green pigeonpeas in Kenya.

IV. Challenging Conventional Wisdom : Exploiting Hybrid Vigor

The problem

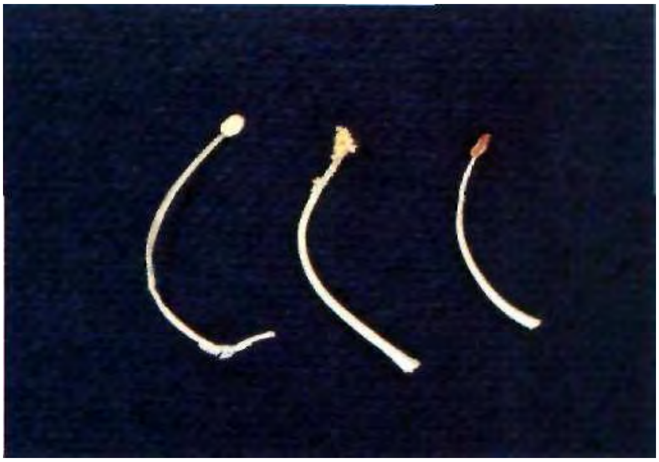
Despite the proven potential of hybrid cereals, few, if any leguminous food crops are grown as hybrids. This is not for lack of trying. Cross-pollination systems are usually difficult to develop in leguminous species, which tend to exhibit very limited natural outcrossing, and seed multiplication rates are low, resulting in un-economic costs of hybrid seed production. For example, although heterosis levels of 25% had been reported for pigeonpea since the 1950s on an experimental basis (Solomon 1957), this knowledge was not exploitable in the absence of a practical hybrid seed technology.

The solution

A major and innovative contribution of ICRISAT was to challenge the assumption that hybrid systems were not achievable for food legumes. It took 15 years of research and development to prove this dogma wrong - but the world's first pigeonpea hybrid variety, ICPH 8, finally reached farmers' fields in 1991 (ICRISAT 1993, Saxena et al. 1996).

By challenging conventional wisdom, ICRISAT had opened up a whole new vista for pigeonpea improvement. The orphan crop had become the pacesetter. How was it done?

First, studies were carried out to understand the dynamics of pollination in pigeonpea (Saxena et al. 1990). Insects actively distribute pigeonpea pollen, but this only occasionally results in outcrossing, because the anthers dehisce a day before the flower opens, in most cases self-pollinating the stigma before exsertion. ICRISAT gambled that with male sterility, this self-pollination could be prevented, making 100% outcrossing achievable.



Anthers of (left to right) translucent male-sterile ms_1, normal, and brown arrow-head male-sterile ms_2 pigeonpea variants.

In 1974, an extensive search for sterility sources was carried out on a trial of 7,216 accessions from the ICRISAT germplasm collection, and 124 lines derived from crosses with wild relative species. Seventy-two plants with aberrant floral characteristics were found, and grouped into five types.

The "translucent anther" type (found within accessions ICP 1555 and ICP 1596) appeared most promising, because it was devoid of functional pollen grains and it was easy to visually recognize in the field, which is critical when rogueing offtypes. A second genetic source was later identified in Australia, and dubbed "brown arrow-head" for the appearance of its anthers. Genetic analyses found that the two sources (*ms_1* and *ms_2*) are non-allelic, and both are under single-gene recessive control.

Once these key traits had been identified, much work was needed to place them in genetic backgrounds that were heterotic in combination, synchronous in flowering, and agronomically desirable. Since 1977, over 1200 experimental hybrids have been tested, and the best have been shared with NARS and the private sector. Diverse male-sterile lines have also been made available for NARS and seed companies to incorporate into their own breeding programs.

Ready for sale: sacks filled with ICPH 8 hybrid pigeonpea seeds produced by the National Seed Corporation of India.

The impact

The first major impact was on partnerships. The creation of a hybrid pigeonpea technology stimulated excitement among partner institutions — and they rushed to join in.

The hybrid technology was shared with ICAR and 14 public and private seed companies in India in the late 1980s/early 90s. In 1989, a comprehensive hybrid pigeonpea development initiative was launched by ICAR involving nine of its centers. In short order, leading Indian agricultural universities and ICAR developed two additional hybrids, PPH 4 (Verma et al. 1994) and CoH 1 (Rathnaswamy et al. 1994).

The private sector also became involved. Annually since 1992, the Maharashtra Hybrid Seed Company (MAHYCO) has been marketing sufficient pigeonpea hybrid seed to cover an estimated 2,000 ha. The demand far exceeds supply.

Supply has been constrained by the technical difficulties inherent in the seed production system, which demands diligent rogueing labor, and requires contract growers to forego the large potential seed yields of the rogued plants. Seed companies must test seed lots using grow-outs, which defers growers' compensation. These difficulties should ease as more experience is gained, and operations are streamlined.

The hybrids demonstrated a consistent grain yield advantage of 25-35% over non-hybrid varieties of similar plant type and duration (Table 1).

Table 1. Seed yield advantage of pigeonpea hybrid ICPH 8 versus non-hybrid varieties UPAS 120 and Manak in different zones in India, 1981-89. All entries are short-duration (4 months).

			Hybrid (ICPH 8) increase (%) over:	
Zone	Years	Number of trials	UPAS 120	Manak
Northwest plains	6	36	35.0	31.0
Central	\	30	32.9	52.5
Southern	4	30	23.6	27.3
Northwest hills	1	2	4.3	31.0
Northeast hills	1	1	45.6	-
Western	1	1	45.6	29.5
Mean			30.5	34.2

A number of additional benefits due to hybridity were observed. The early vigor of hybrids allows them to establish well and produce more and deeper roots, thus enhancing drought resistance. Hybrids have also performed much better than non-hybrids under fusarium wilt pressure, even though only wilt-resistant varieties were compared (Table 2). It appears that hybrid vigor conveys an extra degree of resilience (i.e., in addition to specific anti-fungal mechanisms per se) that enables plants to tolerate and produce under severe disease pressure to a greater extent than non-hybrids.

Another benefit of hybrid vigor is increased productivity of vegetative matter (Chauhan et al. 1995). Typically, about two-thirds of pigeonpeas' above-ground biomass is non-grain, i.e., leaves for grazing or litter (which improves soil fertility), plus stems which are highly valued for fuel (because fuel materials are particularly scarce in the semi-arid tropics). Studies have shown that hybrids produce about 10-15% more vegetative matter than non-hybrids (Table 3).

Table 2. Interaction of hybrid advantage with wilt disease pressure. Means of three hybrid and two non-hybrid pigeonpea varieties over two seasons at Patancheru, 1993/94. All genotypes were classified as wilt-resistant.

Varietal type	Disease-free field (t ha^{-1})	Wilt-sick field (t ha^{-1})
Hybrids[1]	2.31	1.68
Non-hybrids[2]	1.93	1.00
Hybrid advantage (%)	+20	+68

1. Hybrids: IPH 1326, IPH 1395, IPH 1327.
2. Non-hybrids: ICPL 87119, ICPL 87051.

Women are the primary collectors of fuel supplies both in India and Africa, so these hybrids provide additional benefits to them.

Table 3. Above-ground vegetative dry matter (VDM) at harvest, and crop growth rate (C) of hybrid and non-hybrid pigeonpea varieties of similar duration. Means of 7 trials at three locations over 2 years[1].

Factor	VDM (t ha^{-1})	C (kg ha^{-1} ^{o}Cd^{-1})	Days to maturity
Non-hybrids[2]	8.29	4.55	132
Hybrid (ICPH 8)	9.31	5.21	131
SE	±0.34	±0.190	±1.02
Hybrid advantage (%)	12	14	

1. From Chauhan et al. (1995).
   Years: 1986, 1988.
   Locations: Patancheru, Gwalior, Hisar.
2. Mean of three well-adapted, non-hybrid varieties: UPAS 120, ICPL 87, ICPL 161.

Greater seedling vigor in hybrids (center), versus parents translates into better stands and higher tolerance of different stresses.

A new wave of hybrid research is launched

The consortium of interested institutions brought together by the initial hybrid success has now turned its energies towards developing a cytoplasmic male sterility (CMS) system. A CMS will bypass many of the operational difficulties of the nuclear male sterility approach, particularly the high labor requirement for rogueing (and seed yield reduction that entails). The consortium embarked upon a large-scale program of crossing cultivated pigeonpea with wild species, in hopes of identifying genetic incompatibilities between wild cytoplasm and the cultivated nucleus. Convened by ICRISAT, this consortium has partitioned out the crossing and progeny selection assignments thus:

Interspecific hybrid plant grown from a rescued embryo.

Divide and conquer: partnership in CMS hybrid research

Institution[1]	Species
ICRISAT, BARC	*Cajanus sericeus*
IARI	*C. platycarpus, C. voliibilis, Rhynchosia bracteata*
IIPR	*C. albicans, C. cajanifolius*
NDUAT	*C. scarabaoides, R. minima*
PKV	*C. voliibilis*
GSFC	Will use material developed at ICRISAT

1. BARC Bhabha Atomic Research Centre
IARI Indian Agricultural Research Institute
IIPR Indian Institute of Pulses Research
NDUAT Narendra Dev University of Agriculture and Technology
PKV Punjabrao Krishi Vidhyapeet
GSFC Gujarat State Fertilizer Company

ICRISAT also provides training and technical backstopping to the consortium. For example, ICRISAT has carried out embryo rescue operations to help complete some of the crosses. The consortium has been working so well that, beginning in 1998, the major private-sector partner (MAHYCO) began to contribute funds to ensure ICRISAT's continued capacity to participate.

Rapid progress has been achieved since the initiative began in 1990 (Ariyanayagam et al. 1995). Levels of male sterility approaching 100% have been obtained from *Cajanus sericeus* (wild) x *C. cajan* (cultivated) progeny following 6 generations of backcrossing to the cultivated parent. Effective maintainer and restorer lines have been identified.

V. Broadening Partnerships, Amplifying Benefits

The achievements described in Sections I-IV created exciting new technology options, that provoked wide interest in partnership-based efforts to intensify the global cultivation of the crop, address a broad spectrum of production system issues, and tackle some of the most intractable problems. In a sense, it was first necessary to prove what pigeonpea was capable of, and to communicate those findings widely (Nene et al. 1990), in order to attract additional partners to help fulfill the crop's true global potential.

Calling all NGOs: ecofriendly ways to control Helicoverpa

Circles of partnership in pigeonpea improvement have expanded to include NGOs in recent years. With their close ties to village and farmer organizations, these groups are highly effective in the testing and adoption of such knowledge-rich technologies as integrated pest management. This comparative advantage is being applied to test and disseminate practical methods for controlling the *Helicoverpa* pod borer.

The* Helicoverpa *pod borer is the most dreaded pest of pigeonpea.

Helicoverpa, a relative of the cotton boll weevil and other well-known Heliothine pests, is unquestionably the most important biological constraint in pigeonpea cultivation, causing annual losses estimated at a stunning US$ 317 million. It lays eggs in newly-formed floral buds; emerging larvae feed on the floral organs, and later instars bore into green pods to feed on the seeds. Chemical control, while hazardous, is the only effective option for farmers at present.

A voracious feeder, many have assumed that resistance to *Helicoverpa* is unattainable. (Nevertheless, ICRISAT is currently studying whether progress might be made against this intractable problem through biotechnology.)

The International Fund for Agricultural Development is helping ICRISAT engage 19 NGOs, together with Indian NARS, to test practical methods for controlling this scourge in Andhra Pradesh, India. The use of natural and biological control alternatives, such as neem and the NPV virus, threshold-based spray schedules, and other ecofriendly alternatives to agrochemicals are being tried. If successful, this alliance could catalyze additional partnerships with NGOs.

Partnering across continents to solve postharvest constraints

Growing improved varieties is of little use if there is no way to process the produce. Take Sri Lanka. Earlier efforts to introduce pigeonpea—a crop ideally suited to dry, eroded lands in this country—failed because there was no processing technology available.

A small-scale pulse dehuller developed in Sri Lanka with support from the Asian Development Bank.

With support from the Asian Development Bank, ICRISAT scientists have been able to work with Sri Lankan NARS to design and manufacture a small, portable, medium-volume (40 kg h^{-1}) dehulling mill (Nimal Jayantha and Saxena 1998). (Dehulling removes the seed coat, and splits the grains into fragments known as *dhal* for faster cooking). A high-quality video was locally produced to spread awareness of this Project.

Since it is smallholder-oriented, African partners have suggested that modifications of this same technology could hold considerable promise for their continent. Under the auspices of the African Development Bank-sponsored Pigeonpea Improvement Project described later, ICRISAT is sharing the technology with partners in southern and eastern Africa, including the development of local manufacturing sources. Trans-continental sharing of the traditional Indian household pulse-dehulling implement, known as the *chakki,* is also being sponsored by the Project.

Given the important role of women in processing and marketing of pigeonpea, ICRISAT developed participatory methods for eliciting women's preferences in the grain quality of new varieties in Andhra Pradesh, India in the late 1980s. A video program entitled "Participatory Research with Women Farmers", was produced from the experience. The video, widely praised for quality and content, has raised awareness within the R&D and stakeholder community of the importance of women farmers, and the value of participatory research methodology.

In rural India, women traditionally use a grinding stone **(chakki)** *to dehull pigeonpea.*

As part of a participatory research program, women farmers were asked to evaluate varietal differences in pigeonpea grain quality using their own criteria.

The promise of Africa

The conventional view of pigeonpea has been that it is only an Indian crop. This narrow view precludes the enormous contribution this plant could make—and increasingly is making—across the developing world.

After South Asia, southern and eastern Africa (SEA) is the next most important pigeonpea-growing area in the world, accounting for an estimated 12% of global production. (As explained in Section I, this figure may underestimate the real amount because much of the household production across the African continent is not reported through the official channels). Exercising its comparative advantage as a catalyst for global R&D spillovers, ICRISAT has been actively engaged with regional institutions and NARS to help them enhance their pigeonpea production systems.

Pigeonpea conveys sustainability benefits to cropping systems that are particularly valuable and appropriate for Africa. In recent decades, the continent has seen a major expansion of maize cultivation, stimulated by various direct and indirect subsidies that included inexpensive, widely available fertilizers.

As economic restructuring has taken increasing hold since the mid-1980s, subsidies are being removed and effective costs for fertilizer are increasing substantially, cutting directly into the profitability of these systems. Farmers are urgently (some might say desperately) seeking additional cropping options that require less fertilizer, and better still—can also help improve soil fertility—so they can reduce purchased fertilizer inputs.

Pigeonpea fits this bill exceptionally well. It has long been grown as an intercrop in SEA, and farmers are well aware of the soil fertility benefits of this system. Responding to these forces, pigeonpea production increased by 46% from 1980 to 1997 in Kenya, Malawi, Tanzania, and Uganda, with a strong annual growth rate of 3%.

Help from a key donor

ICRISAT's fledgling efforts in Africa were greatly strengthened in 1992, when the African Development Bank decided to launch a major Pigeonpea Improvement Project for Eastern and Southern Africa. Coordinated by ICRISAT, the Project is a true partnership: NARS work jointly with ICRISAT in setting the priorities and in the execution of workplans.

A rising profile

Before 1992, pigeonpea was not given high priority by regional governments. Today, in part due to the public awareness efforts of the Pigeonpea Improvement Project, policy makers are far more aware of the many benefits pigeonpea can provide.

Kenya now lists pigeonpea as the highest priority grain legume for dry areas. Tanzania considers it the country's second most important grain legume, and Uganda ranks it as the most important grain legume in its northern region. Malawi is focusing on its grain and soil fertility improvement aspects. Such NGOs as World Vision, Care International, and Action Aid have recently launched several pigeonpea-based development programs which link closely with the Pigeonpea Improvement Project.

The expanding circle of partnerships also extends to sister CGIAR Centers. ICRISAT has supplied ICRAF with germplasm for testing in agroforestry systems. CIMMYT, through its participation in the Soil Fertility Network, has been testing the ICRISAT wilt-resistant variety ICP 9145 in Malawi. In Kenya, CIMMYT has been investigating the use of short-duration pigeonpea in rotation with maize to control the pernicious witchweed *Striga.*

Building regional capacity

The Pigeonpea Improvement Project has not simply assumed the same priorities as in Asia - it has put much effort into assessing Africa-specific needs, within both the socio-economic and biophysical realms. It quickly became clear that building scientific and technical capacities within the region was a first priority.

The Project has contributed strongly to meeting this need. It has sponsored four scientists from the region for PhD degrees, and 17 technicians have undergone intensive training in pigeonpea production and agronomy. The number of NARS scientist-years devoted to pigeonpea research in the region has increased fivefold, to 10.6 per annum, since the Project began.

Processing and postharvest practices in African pigeonpea production are major bottlenecks for increased commercialization of the crop. These stages of production are often carried out by women, so they form a strategic entry point for achieving gender-related impact. Training courses in processing and utilization have been highly effective, with strong participation of women.

The first, at ICRISAT-Patancheru involved scientists, processors, fabricators of equipment, and members of women's organizations. In the second set of in-country courses on on-farm processing and utilization, 130 women farmers were trained in Kenya, Malawi, Tanzania, and Uganda.

As they are in India, green peas are popular in Africa - and are an especially important income opportunity for women, who are predominantly involved in postharvest and processing activities. Export markets, if developed, would ensure stable high prices for this commodity.

ICRISAT scientists are working with the Kenya-based Horticultural Exporting Company to develop the export of fresh and frozen pigeonpeas. Samples of fresh green pigeonpeas (ICRISAT short-duration variety ICPL 87091) were recently shipped to the UK and quality tested, with favorable results.

The impact

While most of the effort of the Pigeonpea Improvement Project to date has focused on capacity building, impacts on farm productivity are imminent. Within the short span of 5 years, three improved varieties have been released: KAT 60/8 and ICPL 87091 in Kenya, and ICP 9145 in Malawi. Two more varieties ICEAP 0068 and ICP 6927 are in farmers fields in Kenya, as is KAT 60/8 in Uganda. Seed is quickly spreading from farmer to farmer. Some farmers are even establishing themselves as seed entrepreneurs to capitalize on this demand.

Vegetable pigeonpea is fast emerging as a cash crop for women farmers in Africa.

Conclusions

Throughout history, legumes have proven to be especially difficult targets for crop improvement. ICRISAT's partnership-based pigeonpea research initiative is a demonstrable exception as it continues to generate substantial impact in farmers' fields, in national production statistics, and in smallholder household welfare — particularly for women.

The transformation of this crop, from orphan to pacesetter, required exceptional scientific creativity, commitment to difficult long-term goals, and vigorous partnerships in research for development. It is a case of success building on success — an ascending spiral in which initial accomplishments catalyzed a broadening of partnerships, that in turn increased the size and sophistication of the collective toolkit for further progress.

Heralding this achievement, in 1998 the CGIAR crowned ICRISAT with its highest accolade —— ——the King Baudouin Award.

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What is ICRISAT?

A nonprofit, apolitical, international organization for science-based agricultural development. Established in 1972, it is one of 16 Centers supported by more than 50 donor governments, foundations, and development banks, through membership in the Consultative Group for International Agricultural Research (CGIAR). ICRISAT has approximately 1,300 staff, and an annual budget of about US$ 26 million.

ICRISAT's Mission

To help developing countries increase food security, reduce poverty, and protect the environment in the semi-arid tropics (SAT).

ICRISAT's Strategy

To form research partnerships with government, non-governmental, and private sector organizations in developing countries, and to help link these partners to advanced research institutions worldwide. Each partner contributes its unique comparative advantages to make the whole greater than the sum of its parts. ICRISAT excels in strategic research on global issues, and on international exchanges of knowledge, technologies, and skills. These products are tailored by partners to suit regional, national, and local development needs.

Where does ICRISAT work?

Within the semi-arid tropics SAT, where low rainfall is the major environmental constraint to agriculture, ICRISAT works to improve agricultural systems with special emphasis on five crops that are particularly important in the diets of the poor: sorghum, millet, groundnut, chickpea, and pigeonpea. ICRISAT staff work from eight locations in some of the poorest countries of the African and Asian SAT.

ICRISAT

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