Bringing Hope to Marginal Environments

CHICKPEA IMPROVEMENT AT ICRISAT

Science with a Human Face

International Crops Research Institute
for the Semi-Arid Tropics

Scientists champion drought-tolerant crops in India

May 2, 2000
Web posted at: 1:38 PM EDT (1738 GMT)

An Indian farmer displays a chickpea harvest

NEW DELHI, India (Reuters) -- An agricultural research group said on Tuesday it has pioneered two drought-tolerant chickpea crop varieties that have reversed the fortunes of poor farmers in one of five Indian states suffering from an acute water shortage.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), based in the southern Indian state of Andhra Pradesh, said alternative crops and the application of community-managed watersheds are solutions for the 800 million people living in low rainfall areas around the globe.

"In the semi-arid tropics, drought occurs two out of every five years. And even when there is rainfall, it is erratic, varying from year to year, and within seasons," the group said in a statement released at a news conference in New Delhi.

"Further, only 30-60 percent of this rainfall is used effectively for crop production; the remaining 40-70 percent of rainwater is lost as runoff, evaporation and deep drainage."

ICRISAT said that in Andhra Pradesh, one of several Indian states currently reeling under severe drought conditions, it had introduced short-duration chickpea varieties which mature in 85-100 days and therefore escape end of season drought.

For farmers near Guntur in Andhra Pradesh, 1999 was particularly harsh: there were no rains at all after October 21.

But those who grew the Swetha and Kranthi chickpea varieties harvested as much as 1.7 tonnes per hectare.

ICRISAT said Andhra Pradesh's "silent chickpea revolution" -- production of the pulse has grown sevenfold in the state over the past 10 years -- has been a boon to farmers previously struggling to make a living from cotton crops.

The chickpea requires less investment, labor and fertilizer than cotton crops, which have long been dogged by pests. In recent years dozens of [illegible] cotton farmers in central and southern India have committed suicide.

ICRISAT said that in conjunction with the Indian Council of Agricultural Research it had also released five varieties of groundnut in India, three of which are tolerant to end-of-season drought and two are tolerant to mid-season drought.

The institute also promotes the conservation of rainfall through community-managed watersheds, which it says increase crop productivity and reduce soil loss.

"It's a good approach to properly harvest the little rainfall we have," said ICRISAT Director General William Dar, who said that of the 800 million people living in semi-arid tropics, 300 million are the "poorest of the poor" and food-insecure.

Barry Shapiro, director of the group's natural resource management program, said that expansion of deserts is affecting 40 percent of Asia's land surface.

Advocating a long-term approach, he said scientists need to use remote sensing to identify areas of degradation, geographical information systems to locate ideal watershed areas and terrain modelling to capture rainwater efficiently.

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International Crops Research Institute for the Semi-Arid Tropics
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August 2000

Bringing Hope to Marginal Environments

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Executive Summary

The heartland of the CGIAR's renewed vision is to reduce poverty and food insecurity, particularly in the marginal environments that have largely been bypassed by previous research. The constraints of harsh environments and limited farm resources of the poor in many ways present a greater challenge than even the heroic achievements of the Green Revolution. But it is the most direct path to poverty reduction.

The accomplishments of ICRISAT's partnership-based chickpea research-for-development thrust over the past quarter century constitute a strong validation of this bold new direction. Over 100 improved varieties have been released, including a new type of adaptation that has enabled the crop to extend its range far south of its historical zone; adding a second crop – where previously only one crop per year was grown – through varieties that mature on residual soil moisture alone; resistance to the fusarium wilt disease; integrated control options for botrytis gray mold disease; enhanced root mass for drought resistance; an understanding of resistance mechanisms against an intractable pest, the helicoverpa pod borer insect; and molecular marker and gene transformation techniques to significantly accelerate breeding progress in the coming years. All these scientific and development accomplishments have been underpinned by intensive partnerships that have built national capacities that will enhance payoffs for decades to come.

Chickpea is by far the most important leguminous food grain, or pulse, in the diets of the peoples of South Asia. This is the world's most concentrated pocket of poverty, home to over half a billion desperately poor. Unable to afford (or restricting by choice) their intake of animal products, chickpea plays a vital dietary role in supplying proteins for these poor. And as a staple grown on more than eight million hectares, it is also a key income earner for millions of smallholder farmers in the region. Economic studies confirm the importance of this crop both for producers and consumers, and the significant impacts that productivity enhancements can play in reducing their poverty.

The impacts, and potential impacts of ICRISAT's contributions to partnership-based research are impressive for a rainfed crop grown in marginal environments. Annual losses owing to the main biotic and abiotic stresses affecting the chickpea crops have been estimated by ICRISAT and partners to exceed US$ 2 billion, lead by five major constraints: drought (over $1 billion), H*elicoverpa* pod borer insect damage ($0.5 billion), fusarium wilt ($250 million), ascochyta blight ($250 million), and botrytis gray mold ($100 million). The technical options described earlier are steadily chipping away at these losses.

Two new varieties in Andhra Pradesh State, India, have increased production of the crop *ninefold*, adding an estimated US$ 46 million annually in revenues to the State's income, roughly double ICRISAT's entire annual budget. One of these varieties garners a grain price triple that of its predecessor.

Tolerant to heat and maturing early to escape drought while resisting the fusarium wilt menace, these improved varieties have extended the reach of the crop into zones further south than ever before, helping farmers diversify their incomes in the impoverished semi-arid tropics. Promising even further genetic gains against drought in the future, high root mass has been shown to be an effective means of improving drought resistance, and has been transferred to advanced breeding lines. Progress in marker-assisted breeding techniques will greatly enhance breeder's ability to manipulate this valuable trait.

Scoring another major impact, lines were found that could adapt well to rice fallows, adding a second crop and doubling net incomes in the impoverished farming systems of northwestern Bangladesh. The chickpea area in that zone went from essentially zero to 10,000 hectares as a result, saving this ultra-poor country an estimated $3 million in imports annually. The potential for further expansion of this double-cropping niche across South and Southeast Asia is vast – approximately 14 million hectares.

And these are just the tip of the iceberg. Another 114 varieties with different combinations of resistances and adaptation characteristics are increasing productivity across South Asia, although the economic value of the gains, believed to be very substantial, still remain to be quantified in detail. ICRISAT helped Pakistan, South Asia's second leading chickpea producer, to establish a national breeding program and identify ascochyta blight resistant germplasm, contributing to recent productivity gains observed on a national scale. In Myanmar, newly-released chickpea cultivars derived from ICRISAT are grown on 20,000 ha and are expected to expand to about 100,000 ha over the coming years.

Nor are the gains limited to South Asia. In Ethiopia, the cultivar Mariye (derived from ICRISAT breeding material) spread rapidly from farmer-to-farmer in recent years and today most of the chickpea area in the Bechana province is sown to this cultivar.

Major spillover benefits have also been captured by farmers in Canada, Australia, and the USA. The ICRISAT-derived early-maturing, ascochyta blight resistant desi variety 'Myles' is now planted on nearly 100,000 ha in western Canada, or about 35% of the total chickpea area in the country,

Innovative biological control methods have added to the farmer's arsenal for disease and pest control, particularly against the helicoverpa pod borer and botrytis gray mold. The adoption of these eco-friendly practices is being enhanced through participatory on-farm research. The use of non-hazardous neem and nuclear polyhedrosis virus sprays instead of toxic insecticides to control the pod borer has been found to reduce crop protection costs by about US$ 100 per ha^{-1} in numerous on-farm trials across India.

A recent discovery of boron deficiency on acid-soil areas of Nepal and India is likely to deliver major productivity increases in the coming years. Studies of the nitrogen fixation process have identified synergies between variety-rhizobium strain combinations that have increased yields by about one-third in research trials. Non-nodulating chickpea variants were discovered which are being used by researchers around the world to uncover mechanisms and quantify the amounts of nitrogen fixation by the crop in different environments.

Solid science has underpinned all these discoveries. ICRISAT chickpea researchers have published prolifically, including approximately 200 refereed journal articles and book chapters. But the science has always been geared to practical outcomes.

Recognizing the long-term value of genetic resources, ICRISAT has vigorously partnered with national teams to enhance its world-

leading collection of chickpea to its present capacity of 17,115 accessions of cultivated species from 44 countries, and 135 accessions from 18 wild *Cicer* species. A core collection of 1,956 accessions has been identified spanning the range of diversity based on 13 quantitative traits assessed through cluster analysis.

These precious assets held in trust for humanity are provided freely to research and development specialists around the world. A total of 110,740 seed samples of germplasm accessions have been disseminated to requesting NARS. Fifteen gene bank accessions have been released as varieties by national authorities in 13 countries. Genes from the wild *Cicer* accessions have been transferred to cultivated chickpea though interspecific hybridization and embryo rescue, creating new genetic diversity for further long-term breeding progress.

The chickpea initiative has partnered with ARIs to stay at the forefront of applied genomics research. These partners and ICRISAT are together helping to overcome the technical bottleneck of low levels of polymorphism in the crop using RFLP, exploring other techniques to create a saturated marker map that will likely lead to more rapid progress against the intractable problems of drought and pod borer in the coming decade. Genetic transformation research is improving methodologies for wide gene transfer and making headway for some key traits such as insect resistance.

The chickpea initiative has always placed a strong emphasis on partnership, especially through networking. The dynamic CLAN network has been coordinated by ICRISAT at NARS' request. Constraint-focused joint working groups convened by the network continue to foster an international team approach with ICRISAT in a bridging role, bringing together scientists from leading advanced research institutions and NARS partners.

Training has been the second pillar of partnership, including advanced-degree guidance for research scholars; short-term and specialized skills training courses for NARS scientists upgrading their skills; and in-service apprenticeships to learn the latest techniques by working shoulder-to-shoulder with ICRISAT scientists. Approximately 400 national scientists have benefitted from these intensive assignments over the years.

Close collaboration with sister Centers has also been an elemental part of the strategy. Collaboration with ICARDA included joint scientist postings, with a focus on physiology, biotechnology and exchanging useful germplasm and characteristics between the kabuli and desi sub-genepools of cultivated chickpea. The gene banks of the two Centers serve as back-ups for each other. Joint initiatives for germplasm collection, characterization and utilization with IPGRI, and joint research on legumes in rice-based cropping systems with IRRI, also contributed importantly.

In sum, chickpea research-for-development by ICRISAT in partnership with NARS, NGOs, and farmer groups has created a wealth of technical options for increasing productivity in marginal areas for this vital, protein-rich foodstuff of the poor. The team faced imposing challenges head-on, demonstrating impact against the odds despite the harsh and limiting environments that the poor of the semi-arid tropics are confronted with. Much remains to be done, but the progress to date has proven that a science-based, long-term commitment to research-for-development can indeed help humankind triumph over poverty, even in marginal environments.

About Chickpea

Chickpea (*Cicer arietinum* L.) is called Bengal gram or or gram in South Asia and garbanzo bean in much of the developed world. It is the world's third most important food legume crop in terms of consumption, and by far the most important in South Asia. It is a protein-rich supplement to cereal-based diets, especially critical to the poor in the developing countries where people cannot afford animal proteins (or are vegetarians).

The versatility of chickpea in cuisine is legendary. It was the foodstuff of choice for the brilliant Mughal Emperor Shah Jehan of India (1628 to 1658), who conceived and built the wonderous Taj Mahal. After completing this masterpiece he was usurped and tragically imprisoned for the rest of his days by his cruel son Aurangzeb, who allowed him only one choice of food grain in captivity. Shah Jehan chose chickpea, because it could be used in preparing such a wide variety of dishes[1] (van der Maesen 1987, p. 14).

Chickpea originated in the temperate regions of southeastern Turkey. Subsequently, two distinct subtypes evolved. The small, dark-seeded *desi* variant is adapted to South Asia. The large, cream-seeded

type called *kabuli* (after Kabul, thought to be the point of dissemination of this type by humans during the late 17th century), predominates across West Asia and North Africa, and is also consumed in North America and Europe.

Chickpea is mainly eaten as whole boiled grains, de-husked split grains (*dhal*), mashed into a paste, or used as flour in baking various dough-like products. The leaves are also consumed as a nutritious green. Chickpea grain is relatively free from antinutritional factors, has high protein digestibility and is richer in phosphorus and calcium than other pulse crops. It is widely appreciated as a health food, used in salads and as sprouts. About 14% of the seed crop is used for animal feed, and the vegetative biomass is highly valued as a fodder in these dry areas where grazing vegetation is scarce. The leaf extract, rich in malic acid, is sometimes used for medicinal purposes.

[1] van der Maesen, L. J. G. 1987. Origin, history and taxonomy of chickpea. Pages 11–34 *in* The chickpea (Saxena, M.C., and Singh, K.B., eds.). Wallingford, Oxfordshire, UK: CAB International.

Kabuli and *Desi* Chickpeas

The *kabuli* (*garbanzo* bean) types (above left) are usually large seeded, with 'owls-head' shaped seeds having a smooth surface, and the seed coat is cream or beige coloured. These types are grown in the countries of the Mediterranean region, West Asia, North Africa, Australia, and American continent. D*esi* types (above right) are usually small seeded, with angular seeds, reticulated (rough) seed surface, and seed coat colour varying from yellow to black. D*esi* cultivars account for about 85% of the world's area and production of chickpea, and are grown mostly in the South Asia, Iran, Ethiopia and Mexico.

Healthy chickpeas are feeding children and older people worldwide

(Photo from: *The Chickpea Book – Agriculture Western Australia Bulletin 1326*)

Introduction

Chickpea: Cultivation, Consumption, Poverty, and Food Security

The distribution of chickpea cultivation and consumption coincides with the most concentrated pocket of poverty in the world, namely South Asia (Bangladesh, India, Nepal, Pakistan, Sri Lanka), home to 517 million people living on less than a dollar a day (TAC, 1996 database). South Asia accounts for about 90 percent of the crop's area and production. India, with 375 million poor, leads the world in production with a 66% share, followed by Pakistan, Turkey, and Iran. In subSaharan Africa, the crop is especially prominent in Ethiopia (2% of world production), with smaller amounts grown in Malawi and Tanzania.

As a ubiquitous staple of South Asian diets, reflected in a world-leading consumption rate of 4.0 kg per capita per year, chickpea plays a critical role as a protein source for these millions of poor families who cannot afford (and/or choose not to consume) meat.

Because i) the most detailed data and studies are available for India and ii) it dominates the crop's area and production, trends in this country can provide some insights into the relationship of the crop to poverty reduction and welfare of the poor. References used for the following discussion include Gopalan et al. 1999; Krishnaswamy et al. 2000; Murty, 1997; and National Sample Survey Organisation, Department of Statistics 1996.

In India the recommended daily intake of protein for rural men is 60 g/day. The poorest strata of society may be at risk of protein deficiency, since they only consume about 30 g/day, versus 90 g/day for the wealthier classes. With an average daily per capita availability of chickpea of 12.6 grams containing approximately 23% protein, it can be estimated that this crop contributes about 3 grams of protein per day to the average Indian diet, or about 10% of daily protein intake for the poor. This is a significant proportion, leading to the inference that increases in the affordability of chickpea could significantly enhance the nutritional security of the poorest in society.

Murthy (1997) conducted a detailed study of consumer response patterns for basic commodities in the 10 semi-arid tropical states of India. Within the poorest 30% of the population, chickpea exhibited a higher expenditure elasticity (his Table 26) than any major crop except rice (which it equaled). His data suggest that the poor would respond to a 10% increase in income with a 12.5% increase in purchases of chickpea, all other factors being constant. This indicates that it is a crop considered important by the poor, and that they would like to consume more of it if they could afford to.

Looking at the potential effects of price declines, the same study found that demand for chickpea was more inelastic in response to price declines than for other crops (ibid. Table 30). A 10% lowering of price would only increase purchases by 5.9%, freeing up nearly half of the savings for other purposes such as education, health care etc. This also implies that research achievements that increase the efficiency of production (thus enabling lower prices) would, in addition to benefitting rural smallholder farmers, deliver a sizeable share of those savings to poor consumers as well.

A Focus on Poverty Reduction in Marginal Areas

More than ever before, the renewed vision of the CGIAR emphasizes improving the livelihoods of the poorest peoples of the developing world. Many of those poor live and farm in areas termed as 'marginal', generally characterized by rainfed cultivation with harsh climates and poor soils.

In the past, major leaps in food production were achieved by 'homogenizing' the environment through irrigation, high fertilizer rates, and chemical crop protection. To a large extent, the major beneficiaries of this approach were those already relatively well-endowed because they had the land, water and capital resources to maximally exploit the high-yield technology.

But increasingly, the world is recognizing agro-ecosystem diversity as an asset rather than a

constraint – becoming concerned about the dangers of over-dependence on just a few crops and intensive production environments that may not be as sustainable as once thought.

Chickpea Cultivation and Production Trends

Area: Chickpea is currently grown on about 11.2 million ha worldwide, with 90% of the crop grown in South and West Asia. During 1980-98, the chickpea area expanded by 1.6 million ha, with an annual compound growth rate of 0.9%. Most of this growth (1 million ha) occurred during 1990-1998 in South Asia, and to a lesser extent in West Asia and Australia. Substantial area increases (in terms of percentages) also occurred in Ethiopia, Malawi, Tanzania and Spain.

Yield: Because chickpeas are generally grown in drought-prone, poor-soil environments, chickpea yield gains over the period trailed those of cereals and other pulses cultivated in more favorable areas. Between 1980 and 1998, the global average chickpea yield improved by 17%, from 0.6 to 0.7 t ha^{-1}.

Production: World chickpea production increased from 5.6 million t in 1980-1982 to 8.3 million t in 1996-1998. This is an annual growth rate of about 1.8%, attributable in roughly equal proportions to area increase and yield gains. Production increases in West Asia (Iran and Turkey) and Australia resulted from area expansion, while in South Asia (India, Pakistan) they were caused to an equal extent by yield increases.

Chickpea: Thriving on the Margin

Chickpea is a hardy crop well adapted to stress environments. It is a low input-requiring crop, deriving over 70% of its N requirement through symbiotic fixation, simultaneously improving soil fertility for subsequent crops.

In excess of 90% of tropical chickpeas are grown as a postrainy season crop, deriving most of their water requirement from stored soil moisture rather than from rainfall. This is a crucial niche in rainfed dryland farming systems, helping farmers make a fuller use of the limited cropping season and their variable land endowment. Because it is a legume, it is particularly important to farmers as a rotation or second crop after cereals, often maturing into the driest and hottest part of the annual season – providing food and income while improving the soil and breaking cereal pest/disease cycles.

Reflecting its adaptation to low-rainfall environments, water use efficiency (WUE) for chickpea is high (approximately 12 kg grain ha^{-1} mm^{-1} water used, depending on the growing environment). It is much more water-efficient than other crops, for example wheat (6.5), French bean (5.5), soybean (3.5), *Brassica* (3), or irrigated rice (3). With future predictions of greater water scarcity the high WUE of chickpea looms as an increasingly valuable asset.

Constraints and Opportunities

Productivity-enhancing chickpea technology, once adopted, directly benefits poor farmers and consumers through increased incomes, stabilized production, more secure food and fodder supplies, better family nutrition, and increased global competitiveness, an important factor in a world where trade barriers appear destined to weaken. ICRISAT research in close partnership with NARS, ARIs, and others has proven that major productivity increases are possible by improving adaptation, relieving disease and stress constraints, and enhancing yield potential *per se*. Many thousands of farmers have used these productivity-enhancing research outputs to achieve significant gains on-farm.

Although chickpea can yield up to 5 t ha^{-1} in research trials using improved varieties and management practices, the global average achieved by tropical farmers is a small fraction of that, typically 0.3 to 0.7 t ha^{-1}. Experienced chickpea scientists estimate that a doubling of current average yields is an achievable target for the coming decade if a strong international, national, and local research and development effort can be mounted. Such an accomplishment would be a dramatic upscaling from the past yield trend, and would deliver massive benefits to millions of poor including more than US $ 1.6 billion per annum in increased value of production.

Drought and heat combined are the main chickpea yield reducers in the tropics. Biotic stresses, especially *Helicoverpa* pod borer insect, *Fusarium* fungal wilt, *Ascochyta* blight, and *Botrytis* gray mold also detract significantly from the crop's potential productivity (elsewhere in this document, the names of these organisms will be used in nonitalicized lower-case). Soil nutrient imbalances are also important in localized areas.

Figure 1, derived from ICRISAT's medium-term planning process in 1994, estimates chickpea productivity losses due to these stresses.

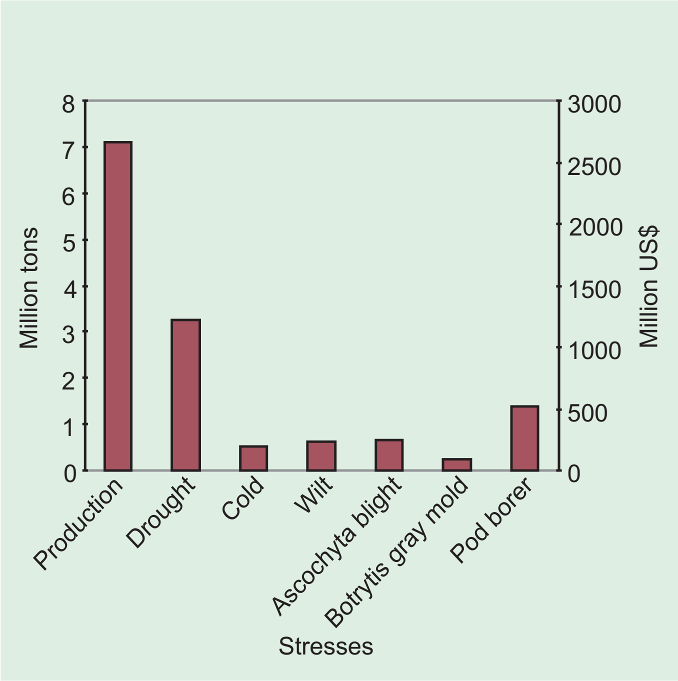


Figure 1. World chickpea production during 1989-91 (mean) and losses caused by major stresses (Ryan 1997).

Major Production Constraints

The economic value of the losses caused by drought and heat have been estimated at US$ 1.3 billion and cold at US$ 186 million. Losses due to helicoverpa pod borer cost farmers about US$ 542 million, ascochyta blight another US$ 260 million, fusarium wilt an estimated US$ 245 million, and botrytis gray mold, US$ 92 million. Losses caused by weeds and erratic plant stands are not estimated, but are sizable.

Field showing large patches of dry plants affected by ascochyta blight.

A farmer in Bangladesh sadly surveys his chickpea crop affected by gray mold.

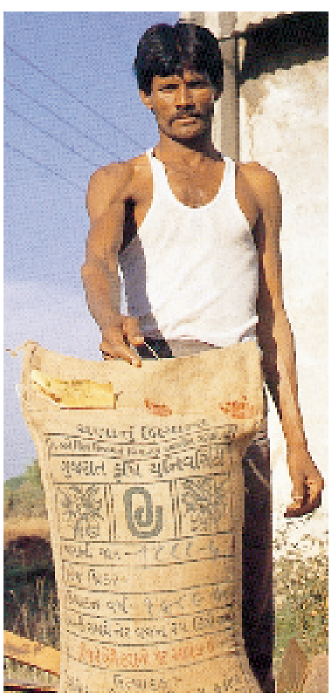
I. Major Adoption and Impacts of Improved Chickpea Technologies

Impact of Improved Varieties: Overview

The past quarter century of chickpea breeding has left an impressive legacy of varietal adoption across South Asia and parts of East Africa. Since 1980, over 100 improved cultivars have been released in 28 chickpea-growing countries, some of the most popular and recent of which are listed in Table 1. Year by year, these varieties are enhancing yields, protecting against diseases, discouraging insects, avoiding drought, delivering income sooner, and improving market prices received for the produce, among other benefits.

Impacts in India

The largest and most closely-studied impacts have been in the country of the largest area of chickpea cultivation, production, and consumption: India. For example, impact studies found that the net income from the new ICRISAT-derived cultivar ICCV 10 adopted in Gujarat State of India increased by 84% over the local variety, including a reduction of 23% in unit cost of production[1].



Farmers in Gujarat, India, are quick to adopt new chickpea varieties.

[1] ICRISAT (2000).Technologies for the semi-arid tropics: research and development, adoption and impact. A draft monograph by the Socioeconomics and Policy Program. Patancheru 502 324, AP, India: ICRISAT.

Extending kabuli cultivation into the tropical latitudes

Chickpea is traditionally a temperate crop, and has been introduced into the northern latitudes of South Asia only in recent centuries. These varieties matured far too late when planted in the tropics and succumbed to heat, drought, and disease pressure.

One of the most important achievements of ICRISAT and its partners was to breed types that could be grown below the tropic of Cancer in South Asia. The most successful line from this program was ICCV 2 or 'Swetha', the world's shortest-duration kabuli cultivar, bred from a cross between five desi and kabuli parents. It combines very early maturity (85-90 days, versus 110 days for previous cultivars that were often ravaged by drought) and resistance to fusarium wilt with the high-value kabuli grain type. It can produce a crop on residual soil moisture alone (e.g., following a main-season cereal crop), while fetching a price up to three times higher than the desi types. The desi line ICCC 37, known as 'Kranthi' in Andhra Pradesh, also bred for earliness, disease resistance, and adaptation to southern latitudes, is spreading rapidly in tandem with ICCV 2.

These varieties have been a boon to tropical chickpea farmers, providing them with a rewarding new cropping option for their marginal lands.

The high-value kabuli cultivar ICCV 2 or 'Swetha' (right) matures early, escaping drought in dry, hot tropical environments.

Table 1. Chickpea breeding material developed at ICRISAT and released as cultivars worldwide (selected examples).

Breeding line or ICRISAT code	Country of release	Release name	Year of release
ICCV 1	India	ICCC 4	1983
	Nepal	Sita	1987
Selection from F 378 x F 404	India	Anupam	1984
Selection from JG 62 x F 496	India	RSG 44	1984
Selection from L 550 x L 2	India	GNG 149	1985
Selection from K 850 x F 378	Myanmar	Schwe Kyehmon	1986
ICCL 83110	Kenya	ICCL 83110	1986
ICCL 81248	Bangladesh	Nabin	1987
Selection from K 850 x F 378	Ethiopia	Mariye	1988
ICCV 2	India	Swetha	1989
	Myanmar	ICCV 2	1992
	Sudan	Wad Hamid	1999
ICCC 37	India	Kranthi	1989
ICCL 82108	Nepal	Kalika	1990
ICCV 6	Nepal	Kosheli	1990
ICCV 10	India	Bharathi	1992
	Bangladesh	Barichhola – 2	1993
ICCL 83105	Bangladesh	Barichhola – 3	1993
ICCL 79096	Pakistan	DG 92	1993
ICCC 42	Myanmar	ICCC 42	1993
ICCL 82104	Ethiopia	Worku Golden	1993
ICCV 92809	USA	Myles	1994
ICCL 82106	Ethiopia	Akaki	1995
ICCL 85222	Bangladesh	Barichhola – 4	1996
ICCL 83149	Bangladesh	Barichhola – 6	1996
ICCV 88202	Australia	Sona	1998
ICCV 92311	India	KAK 2	1999
ICCV 93958	India	CO 4	1999
ICCV 93954	India	JG 11	1999
ICCV 93952	India	JAKI 9218	1999
ICCV 89509	Sudan	Atmor	1999
ICCV 91302	Sudan	Burgeig	1999
ICCV 92318	Sudan	Hawata	1999
ICCV 88003	Bangladesh	Barichhola – 8	1999
ICCX 810800	India	ICCX 810800	1999
Selections from [ICCC 32 x ICCX 780581-BH-10H-BH]	India	L 551	1999
	India	HPG 17	1999

Farmers Call it the Guaranteed Crop

This story of how ICRISAT, through partnerships, helped bring hope to a marginal environment in central India begins in the early 1990s when the cotton crop failed repeatedly in many districts of the state of Andhra Pradesh. Reports began flowing in of desperate, debt-ridden farmers driven to suicide. Chilli and tobacco – the two major cash crops – were plagued by heavy pest damage and rising fertilizer and pesticide prices, and falling prices for these crops. Farmers began to urgently seek alternatives.

It was then that some interested farmers with the help of A Satyanaryana, Senior Pulses Breeder at the Andhra Pradesh Agricultural University's Regional Agricultural Research Station, Lam, in Guntur, conducted pilot demonstrations in Gottipadu of the ICRISAT kabuli cultivar ICCV 2 (released by the Government of India as 'Swetha'), and the ICRISAT desi cultivar ICCC 37 (released as 'Kranthi'). During the demonstrations, farmers harvested up to 2 t ha^{-1} of chickpea and became instant leaders. In the following years the area planted to this crop increased to over 1,000 ha in Gottipadu village alone.

Most of the produce was sold as seed to the neighboring villages. This farmer-to-farmer exchange increased the area under chickpea rapidly – by 1998, the area under chickpea in Andhra Pradesh had more than doubled to 146,000 ha. Total chickpea production in the state during the same period increased nearly **nine-fold** (15,000 to 130,000 t) (Directorate of Economics & Statistics, Government of Andhra Pradesh, Hyderabad, India).

Following this example, many farmers adopted two new cropping patterns, soybean-chickpea and sesame-chickpea to replace cotton cultivation. Adopting chickpea helped farmers reduce costs of purchased inputs such as fertilizers, pesticides, and labor – chickpea requires just 100 kg DAP (diammonium phosphate) per hectare as opposed to fertilizer-hungry cotton and chilli (the latter sometimes recieves over a ton of fertilizer per hectare!). Farmers have increased their net incomes as chickpea prices have been relatively high and stable.

Moreover, extending kabuli cultivation to the tropics meant that the premium prices obtained by farmers in the subtropics are also now available to these farmers.

No wonder G Koteswara Rao and his fellow farmers of Gottipadu village said " Chickpea has come to us as a real boon. With cotton cultivation becoming a gamble, chickpea has come in as a savior. It is a guaranteed crop!"

A bumper crop of ICCV 2 *in India.*

It is transforming chickpea from a subsistence to a cash crop that rewards improved management.

Largely as a result of the new varieties, production in Andhra Pradesh has increased by about 16% per year and yields have tripled since 1989. The annual value of the additional production of chickpea is estimated at **US$ 46 million**, double ICRISAT's entire budget.

Success stories of short-duration tropical chickpea cultivars are also available from a number of other semi-arid Indian states, particularly Maharashtra, Karnataka, Gujarat, and Madhya Pradesh. The ICCV 2 breakthrough led to further recent advances such as the bolder-seeded kabuli cultivars ICCV 3 and KAK 2, which command an even higher premium in the marketplace. ICCV 2 has also now spread eastward to Myanmar and to the African continent (Ethiopia, Sudan, and Tanzania).

Impacts beyond India

While it has not been possible to track and document the impacts of each variety over their entire global range of adoption, some case studies are available that confirm that the adoption and impact of new varieties have been equally impressive elsewhere (see also Table 1).

Helping Pakistan overcome ascochyta blight and build a chickpea R&D capacity

Like in India, chickpea is the most important pulse crop in Pakistan, occupying 80% of the pulse area in the country. Through special support from the Asian Development Bank, an ICRISAT scientist was posted to Pakistan during the mid-'90s to assist the country in alleviating its most pressing biotic constraint: the devastating ascochyta blight disease. The project identified four distinct resistance sources, and developed four advanced breeding lines that reduced damage scores by about 50% over multilocational trials. It also trained national scientists and helped establish a viable national chickpea breeding program and facilities, all of which combined have contributed to recent increases in productivity observed in the country.

Screening chickpeas for ascochyta blight resistance in Pakistan.

Greening the drylands of the Barind

Most people think of Bangladesh as a water-drenched country, but it has a distinct dry season, particularly in the northwestern uplands merging into Nepal. This area, called the Barind, receives up to 1500 mm rainfall during the monsoon (June to September),

Growing chickpea on land that was previously left fallow in Barind, Bangladesh, provides farmers with a better livelihood.

enough for farmers to grow a good crop of *aman* (rainy season) rice. But most of the land remains fallow after rice harvest, during the dry, cool winter months.

Exploiting this opportunity, ICRISAT assisted the Bangladesh Agricultural Research Institute in identifying chickpea cultivars that could grow after rice in this area. Trials found that economic returns matched those from the irrigated crops, essentially doubling the farmer's income. Following hundreds of farmers' field demonstrations, the new crop was enthusiastically adopted, increasing from just 200 ha in 1984 to over 10,000 ha by 1998 (Musa et al. 1998).

This production of chickpea where previously the land lay idle now saves Bangladesh over US$ 3 million annually in pulse crop imports. The future potential of this system is vast: there are 14 million ha of winter rice fallows across South Asia which could grow a second crop of chickpea.

Chickpea in the Barind – Two Crops where Once there was One

After harvesting rice in the Barind (northwestern Bangladesh), farmers traditionally left their fields fallow, because after the rains cease the vertisol soils turn rock hard and cannot be cultivated. But Bangladeshi scientists working jointly with ICRISAT found that chickpeas sown into the stubble shortly after rice harvest can survive and mature on the residual moisture, yielding a valuable second crop. This low-labor, low-input technology greatly magnifies resource use efficiency for the extremely poor farmers of this area.

Chickpeas can be grown on residual moisture during the dry winter after harvesting rice.

Tailoring Technology to Marginal Environments – A Prime Example

To succeed in their race against receding soil moisture and hardening soils in rice fallows, the chickpea plants must establish quickly and drive their roots deep. New research has found that 'seed priming' can dramatically improve early establishment, resulting in yield gains as high as 46%! Seed priming is a simple, low-cost technique consisting of soaking chickpea seed overnight before seeding (Musa et al. 1999). Better emergence, early growth vigor, greater tolerance to disease, more biomass, more pods and earlier maturity contributed to the increased productivity. This startling intervention is being confirmed in over 100 on-farm trials during 1999/2000. This is a good example of how customized technology options can tailor cropping systems to better exploit niche diversity in marginal environments.

Wilt control triggers chickpea expansion in Myanmar

Chickpea is a major pulse crop in Myanmar and commands a premium price in the export market. But local cultivars and landraces were suffering heavy losses from fusarium wilt, drought and heat stresses. The introduction and release of fusarium-wilt resistant and early maturing cultivars are changing the situation. Four cultivars (ICCC 37, ICCC 42, ICCV 2 and ICCV 88002) were released in recent years, and now

Removing a Yield Constraint: Fusarium Wilt

Carefully-controlled trials have demonstrated large gains from controlling biotic factors such as the soil-borne fusarium wilt disease. In infected plots, the older chickpea cultivars JG 62 and COG 1 were killed, while the newly developed ICRISAT cultivars (Swetha and Kranthi) still produced good yields (see photo below).

Evaluation of cultivars released over different periods of time conducted at ICRISAT, Patancheru. Two of the fusarium wilt susceptible cultivars have been killed.

cover nearly 20,000 ha (1999 cropping season). National program scientists expected the crop to cover in excess of 100,000 ha within a few years.

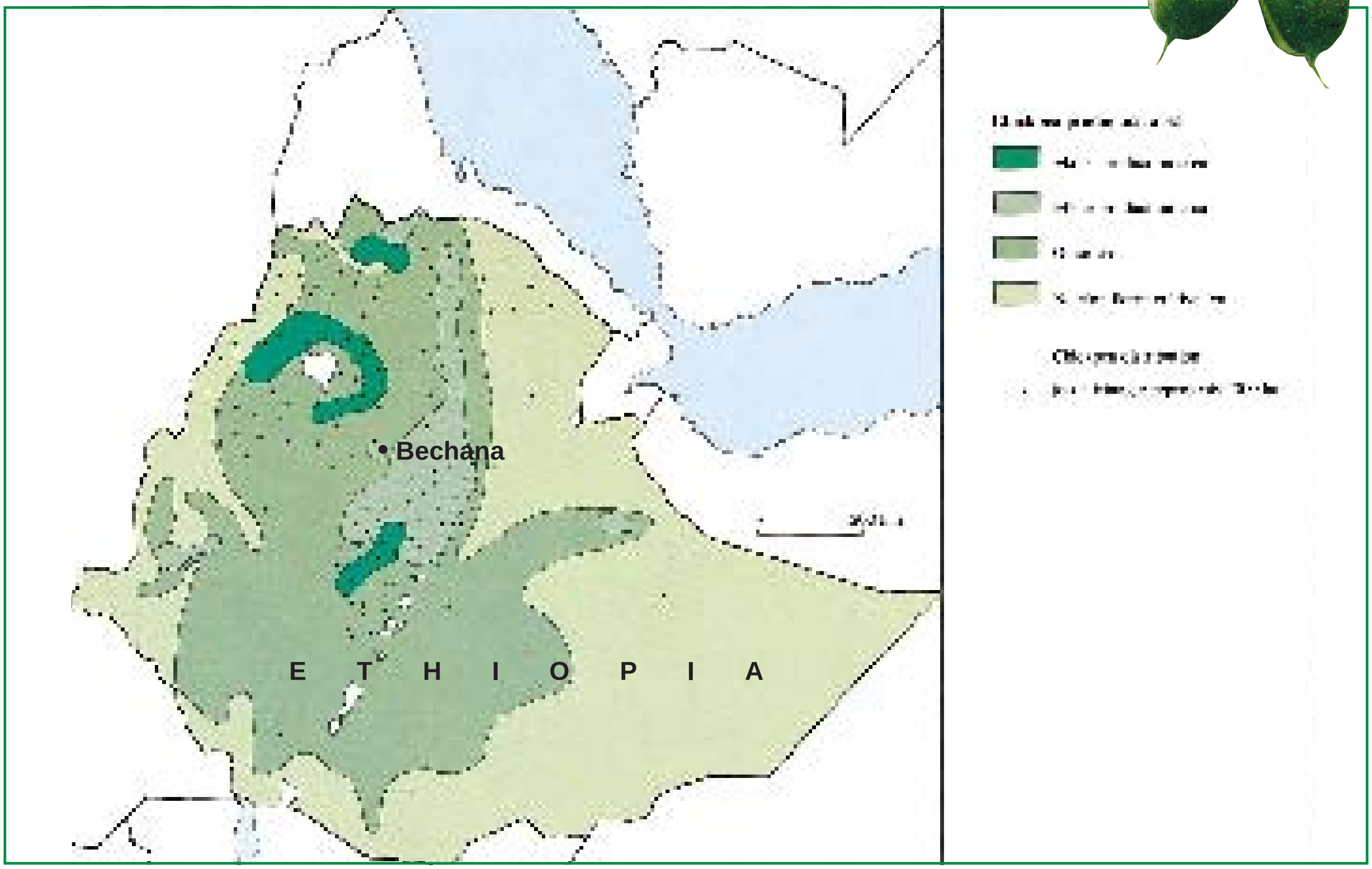
Winnowing chickpea in Myanmar.

New chickpea cultivars for Sudan

Chickpea is grown on 3,000 to 5,000 ha in Sudan. ICRISAT shared promising chickpea materials with its Sudanese partners for further testing and selection across environments. Four cultivars were released from this material, called Wad Hamid (ICCV 2), Hawata (ICCV 92318), Atmor (ICCV 89509), and Burgeig (ICCV 91302).

Widespread acceptance of ICRISAT chickpea in Ethiopia

Ethiopia, once an important chickpea exporting country (>10,000 t yearly) stopped exporting the crop due to reduction in chickpea production and greater internal demand for the crop. It is grown on 130,000 to 180,000 ha. The national program developed cultivars from breeding material provided by ICRISAT, which have proven to be well adapted. The spread of the cultivar 'Mariye' in the Bichena province provides a good example of this development. No seed agency was involved; reflecting enthusiastic farmer demand, the cultivar spread from



farm to farm. Almost the entire chickpea area in Bechana is now sown to Mariye. Other promising cultivars developed from ICRISAT-supplied materials are Worku Golden and Akaki, which are now becoming equally popular with farmers.

Spillover of ICRISAT's chickpea research benefits to developed countries

While benefits to developed countries are not a focus of ICRISAT's efforts, situations often arise wherein a research advance such as a particular breeding line turns out to have broad adaptation or to be a useful parent in breeding programs beyond the target zone.

In Australia, it is estimated that ICRISAT-developed chickpea lines will contribute 2.1% of the expected 5% yield growth for the 5 year-period ending in 2002 (Brennan and Bantilan 1999). This gain results in a cost reduction of A$39.18 per t for Western Australia and A$8.78 per t for the rest of Australia, or an annual cost saving of A$5.21 million for the country. The discounted gross benefits in 1996 values are predicted as A$ 39.3 million over the 25 year period (1999-2024), averaging A$ 1.64 million per year as spillover benefits from two cultivars – 'Heera' and 'Sona' (Brennan and Bantilan 1999).

Spillover benefits to the USA and Canada have also been significant. In the early 1990s, Washington State University released the early-maturing, ascochyta blight resistant desi variety 'Myles' identified from a breeding line supplied by ICRISAT, which has expanded dramatically in the last 2 years in Canada. Recent reports from Saskatoon indicate that Myles is planted on nearly 100,000 ha in western Canada, or about 35% of the total chickpea area in the country. Canada is expecting a record chickpea harvest this year, partly due to the blight resistance of this cultivar.

Additionally, the super-early chickpea line ICCV 96029 is being used in more than 50% chickpea crosses in Canada's breeding program. It matures about one week earlier than the earliest germplasm previously available. Earliness is often essential for escaping end-of season frost and cold damage in Canada.

II. How Chickpea Research is Enhancing the Sustainability of Production Systems

By fixing nitrogen, breaking continuous cereal cultivation cycles (to interrupt cereal disease cycles and nutrient drains), diversifying farm incomes, and adding protein to complement cereals in the farm household diet, chickpea is an important contributing factor to sustainable production systems. In spreading the range of adaptation of the crop (see previous section), ICRISAT and its partners have directly contributed to increasing system diversity, and in so doing have made a major contribution to enhancing the sustainability of farming systems in the semi-arid tropics of South Asia.

Additionally, ICRISAT and its partners have achieved a number of advances in integrated pest management of chickpea that enable farmers to reduce or eliminate pesticide and fungicide applications. This not only protects their health and the biodiversity of the agro-ecosystem, but also saves cash, improving the economic sustainability of crop cultivation. These are detailed below.

Soil Fertility Management

Enhancing biological nitrogen fixation

ICRISAT maintains a germplasm collection of nodulating, nitrogen-fixing bacteria specific to chickpea, recently named as *Mesorhizobium ciceri*. ICRISAT has been supplying samples of these upon request to researchers worldwide. More efficient R*hizobium* strains have also been isolated for use as inoculants based on greenhouse, on-station and on-farm evaluations in collaboration with partners (Rupela et al. 1997). On-farm evaluation of inoculant strains in at least four countries (Bangladesh, India, Nepal, and Vietnam) during 1990 to 1996 indicated increased grain yield (up to 30%) in most of the experiments over about 1500 location-year combinations.

Selection for high nodulation was successful. Tests in Bangladesh, Nepal, India, and Pakistan confirmed that the high-nodulating lines fixed much greater quantities of nitrogen than their parents and the low-nodulating selections (Dudeja et al. 1997). Selection for high nodulation within agronomically-acceptable cultivars was thus confirmed to be a viable approach to enhance the productivity and sustainability of chickpea cropping systems.

Doubling yields with boron application

Diagnosing and resolving systems constraints related to sustainability issues are complex and challenging tasks, but the payoffs can be great. A case in point is the resolution of a micronutrient problem – boron deficiency in Nepal – that baffled researchers for many years. This major yield constraint can now be solved at low cost, with a very dramatic response.

Flower drop had long been observed to be a serious yield reducer in chickpea-growing areas of the Terai zone of Nepal. It was initially thought to be due to botrytis gray mold infection. But acute observers from ICRISAT in partnership with national scientists gradually recognized that the problem was largely confined to areas with acidic soils. Following this lead, glasshouse and field research trials finally established that this problem was attributable to boron deficiency (Srivastava et al. 1997). In some locations molybdenum was also deficient.

These discoveries were quickly followed by farmer-participatory investigations in the field. Application of 1 kg ha^{-1} of boron (through boric acid) increased the grain yield of chickpea by 42% to 92% across a large number of on-farm trials (average yield without boron: about 500 kg ha^{-1}) (Fig. 2).

This technology is being actively disseminated in the affected area within Nepal. It is now thought that it may also explain yield losses in other important chickpea-growing areas of the Indo-Gangetic Plain, in India and Bangladesh. Because very small rates of inexpensive fertilizer can solve this problem, the return on investment for this research is expected to be extremely high over time.

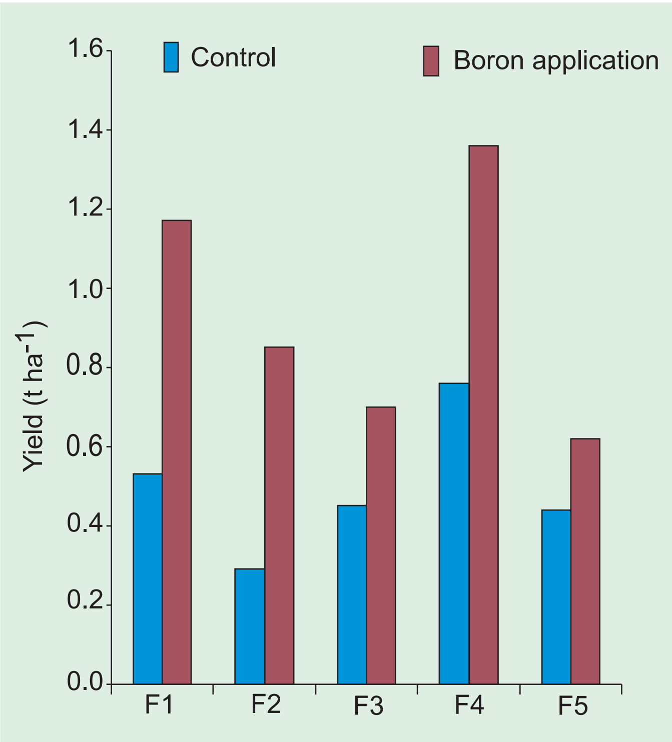


Figure 2. Increase in chickpea yields after boron application (1 kg ha-1). (Data from five replicated on-farm experiments in Nepal – F1 to F5, 1998/99.)

Integrated Disease Management

Integrated management of botrytis gray mold disease

Botrytis gray mold (BGM), caused by *Botrytis cinerea* is one of the major biotic constraints to chickpea production in Nepal. A BGM epidemic during the 1997/1998 season completely destroyed the chickpea crop and greatly discouraged farmers from cultivating the crop in rice fallows; 75% of these areas were not cultivated the following season, significantly damaging agricultural productivity in the country.

Responding to pleas for help, ICRISAT researchers helped Nepalese scientists evaluate the performance of integrated disease management (IDM) practices the next season, using a farmer-participatory approach to ensure the adoptability of any effective practices observed.

IDM technologies included an improved (BGM tolerant) cultivar, seed treatment with fungicide, wider row spacing, and need-based sprays of fungicide. The increase in seed yield attributable to IDM was 2 to 6 fold, and resulted in higher net incomes (Fig. 3) (Pande et al. 1998). This set of practices also holds great potential for India and Bangladesh in the near future.

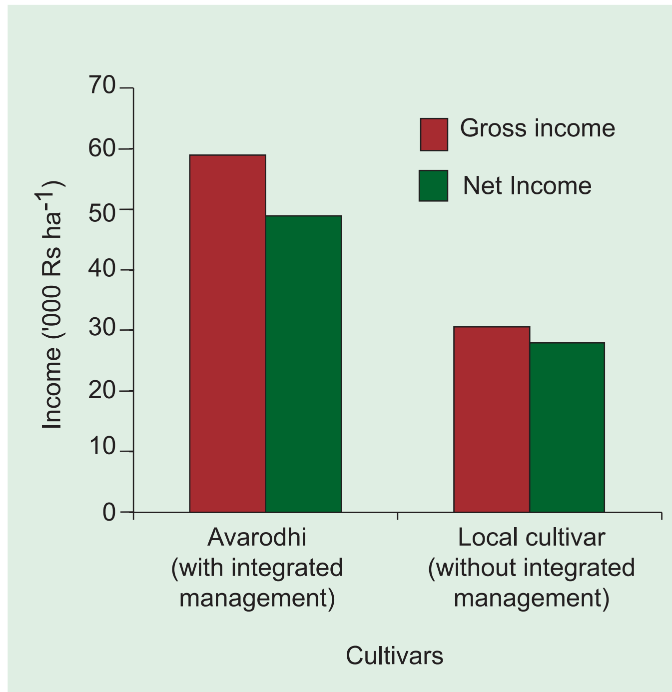


Figure 3. Gross and net income from improved cultivars "Avarodhi" with integrated management of botrytis gray mold compared with the income from local cultivars without integrated management of BGM. (Data from on-farm experiments in Nepal, 1998/99 postrainy season.)

Environment-Friendly, Integrated Control of Insects

Relatively few insect pests attack chickpea compared to other legume crops, partly due to the presence of glandular trichomes which secrete an acidic substance composed of mainly malic and oxalic acids. However, the pod borer (*Helicoverpa armigera*) in South Asia does still cause very significant losses, estimated at US$ 330 million annually.

Heavy dependency on chemical control over the past three decades led to failures in pest management due to development of insecticidal resistance, destruction of natural enemies, followed by

Over the past 3 decades, farmers have been indiscriminately using chemical pesticides against the pod borer without proper safeguards for their own health.

environmental degradation and erosion in profits. About 20% of the chickpea farmers in northern India used 5 to 6 sprays of insecticide to control helicoverpa, yet crop losses were still commonly in the 50% range (Wightman et al. 1995). In southern India farmers applied 2 to 3 chemical sprays.

This prompted researchers to seek IPM options for chickpea. To develop these options, ICRISAT and its partners made intensive efforts to understand the ecology of the crop as it interacted with the phenology and behavior of the pest, including studies of adult flight activity, length of the larval stage, the role of natural enemies, the relationship between insect density and yield loss, the influence of climatic factors, and related dynamics.

As a result of this sustained effort, the chickpea IPM arsenal now includes tolerant cultivars, intensive monitoring of pests using pheromones, application of bio-pesticides (neem products and nuclear polyhedrosis virus — NPV), encouraging natural enemies (bird perches), and reducing the frequency of sprays to a needs basis only.

The economics and farmer acceptability were also considered closely. For example, extensive field trials concluded that the cost of crop protection using NPV saved about \$100 ha^{-1} while providing the same degree of yield protection as costly and hazardous insecticidal control (IFAD Pulses IPM Progress Report 1999-2000).

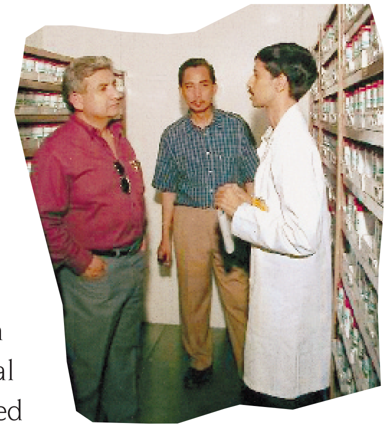
These IPM options against pod borer are now being shared with NARS in India, Nepal and Bangladesh — and farmers are embracing them. They have clearly seen that timely intervention to manage pests and diseases can improve chickpea yields and net returns. Across the set of on-farm sites in these countries, a 6% to 100% reduction in chemical pesticide usage has been successfully achieved (IFAD Pulses IPM Progress Report 1999-2000). This is a work in progress, and the results are exciting to watch as they unfold.

Use of IPM, including the application of biopesticides such as NPV, can help destroy the podborer and avoid spraying large volumes of insecticide.

III. Scientific Innovation in the Course of Chickpea Improvement at ICRISAT

Assembling, Conserving, and Utilizing Chickpea Genetic Resources

The genetic resources of chickpea held in trust for humanity by ICRISAT include landraces, cultivars, genetic and mutant stocks of cultivated species, and wild *Cicer* species. The collection includes 17,115 accessions of cultivated species from 44 countries, and 135 accessions of 18 (8 annual and 10 perennial) wild *Cicer* species. Of these, 4,153 accessions were obtained from 65 collection missions in 15 countries (Afghanistan, Bangladesh, Ethiopia, India, Kenya, Morocco, Malawi, Myanmar, Nepal, Pakistan, Syria, Turkey, Tanzania, Uganda, and former USSR). Sixty out of the 135 wild *Cicer* accessions were acquired by donations from six countries. The remaining wild *Cicer* accessions were collected from Afghanistan , Turkey, Syria, and Pakistan.



The accessions of wild and cultivated species have been characterized for a complete set of morphological descriptors. A publication entitled "Chickpea Descriptors" was published jointly by IBPGR, ICARDA, and ICRISAT in 1985 (IBPGR et al.1993).

Exemplifying collaboration among sister Centers, ICRISAT has deposited duplicate samples of 4,566 accessions in the genebank of ICARDA for safety backup, while the ICRISAT genebank holds duplicate samples of ICARDA's 5,914 accessions.

These accessions are distributed for research purposes to scientists around the world on request. Since 1974, ICRISAT has distributed 110,740 samples to scientists in 84 countries. ICRISAT scientists have themselves used 159,399 samples for various investigations and for breeding projects. Several germplasm lines have performed well in the evaluations, and 15 lines have been released as cultivars in 13 countries (Table 2).

Table 2. Chickpea germplasm from the ICRISAT collection released as cultivars in various countries.

Accession	Country of origin	Country of release	Released name	Year of release
ICC 552	India	Myanmar	Yezin 1	1986
ICC 4951	India	Myanmar	ICC 4951	-[1]
ICC 6098	India	Nepal	Radha	1987
ICC 8521	Italy	USA	Aztee	1980
ICC 8649	Afghanistan	Sudan	Shendi	1987
ICC 11879	Turkey	Turkey	-	1986
		Algeria	-	1988
		Morocco	-	1987
		Syria	Ghab 1	1982
ICC 13816	USSR (former)	Algeria	Yialousa	1984
		Italy	Sultano	1987
		Syria	Ghab 2	1986
ICC 14911	USSR (former)	Turkey	-	1986
		Morocco	-	1987
ICC 4923	India	India	Jyothi	1978
ICC 4998	India	Bangladesh	Bina Sola 2	1994
ICC 4880	India	Australia	Hira	1997
ICC 237	India	Oman	ICC 237	1988
ICC 14302	India	India	Anupam	1983
ICC 14559	Bangladesh	Bangladesh	Bari Chhola 5	1995
ICC 3274	Iran	Bangladesh	Bari Chhola 7	1999

1 = Not available.

Developing a core collection of chickpea

One of the main constraints to the optimal use of gene bank collections is their sheer size. One way to alleviate this difficulty is to create a 'core collection', a subset that samples the range of diversity of the entire collection. ICRISAT developed a core collection of chickpea using data standardized from 13 quantitative traits in a cluster analysis. From each cluster, accessions were randomly selected to form a core subset of 1,956 accessions. Statistical analyses confirmed that the core subset was representative of the entire collection (Upadhyaya et al. 2000).

This core collection will become a point of entry for chickpea scientists to cost-effectively explore the latitude of diversity available in the main collection, and identify subtypes for further investigation. It will enhance the utilization of the collection, and simplify the management of chickpea genetic resources. The list of entries in the core collection with the country of origin, ICC number, and cluster number can be found on ICRISAT's internet web site.

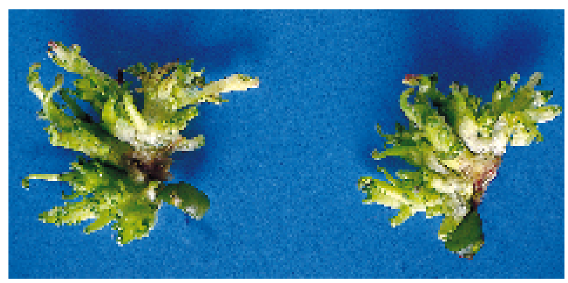
Progress in Biotechnology

Genomics: Genome mapping and marker-aided selection would be a major advance for chickpea breeding (Sharma and Ortiz 2000). Because it is a crop of less importance to the wealthy nations, chickpea biotechnology research has lagged behind the more glamorous crops that attract large research investments from multinational corporations. A lack of polymorphism in the cultivated species using typical RFLP analysis adds to the constraint. Consequently, only a few genetic linkage groups have been characterized for this crop so far. Recently, the first intraspecific genome map of chickpea was developed jointly by ICRISAT and Washington State University (USA) (unpublished).

In recent years isozymes, amplified fragment length polymorphism (AFLP), random amplified polymorphic DNA (RAPD) and sequence tagged micro-satellite (STMS) markers have helped to enhance the development of chickpea genome maps, with about 200 DNA markers. The identification of 300 well-distributed markers on the chickpea genome (estimated average separation of about 1000 cM) will make the map useful for practical breeding and map-based gene cloning.

Transgenics: For some of the major biotic constraints such as helicoverpa pod borer insect, fungal pathogens causing botrytis gray mold, ascochyta blight, and dry root rot, high levels of resistance are not available in existing germplasm. In these cases, there may be an opportunity to introduce resistance genes from related or distant genera.

For fungal resistance, ICRISAT is seeking genes with antifungal properties such as chitinases, glucanases and polygalacturinase-inhibiting proteins (PGIP). ICRISAT researchers are also aiming to identify and clone tissue-specific promoters for more controlled expression of these potential transgenes.



Regeneration from auxiliary buds in chickpea.

The effectiveness of alternative sources of insecticidal genes, including those derived from *Bacillus thuringiensis* (Bt), are currently being evaluated at ICRISAT. These investigations include the identification and cloning of protease inhibitors from pigeonpea and chickpea, and lectins from sweet pea and pigeonpea.

Rooting of transgenic chickpea.

In collaboration with its partners from both ARIs and NARS, ICRISAT is actively involved in developing genetic transformation technologies based on *Agrobacterium tumefaciens* and biolistics to enhance the efficiency of genetic transformation in chickpea.

Uncovering Genetic Mechanisms

To improve the efficiency, predictability, and effectiveness of chickpea breeding efforts, ICRISAT geneticists carried out many studies to understand the inheritance of important traits. Inheritance studies demonstrated the qualitative control of and provided the gene nomenclature for earliness (*efl*-1), fusarium wilt (*h*1, *h*2, and *h*3), double poddedness (*s*) and flower color (P, B and C). The first five genes have been used not only as genetic markers but are also utilized as selection aids in breeding, resulting in major gains (Table 3). Genetics of yield components (seed size, seed yield, number of branches), plant height, and pod number nodulation, iron deficiency, salinity tolerance, and other traits have also been investigated.

Table 3. Identification and nomenclature of genes and genetic stocks of chickpea (Jagdish Kumar and van Rheenen 2000).

Trait	Allele(s)	Genetic stock
Earliness	*efl*-1	ICCV 2
Fusarium wilt	*h*1H2*h*3	K 850
	H1*h*2*h*3	C 104
	H1H2H3	H 208
Double pods	*s*	JG 62
Flower color	C*b*P	P 9623
	CBP	RS 11
	CB*p*	T 39-1
	CBP	JG 62

ICRISAT breeders have developed many recombinant inbred lines for eventual use in chickpea genome mapping when that becomes practical. A saturated genome map will facilitate gene tagging, gene isolation, and DNA marker-assisted selection. QTL have been identified in genetic studies of plant height, seed size, resistance to chickpea stunt, and *Pythium ultimum* diseases, indicating that these traits may be polygenic.

Rapid generation turnover by extended daylength rainout shelter in off-season nursery

An innovative off-season nursery approach is used at ICRISAT, using field shelters to manipulate daylength to trigger early flowering, enabling four crop generations per year (Sethi et al. 1981). This enhances the efficiency of genetic studies as well as applied breeding work.

Using Wild Relatives for Chickpea Improvement

At least 13 wild *Cicer* species bear useful characteristics such as resistance to wilt, soilborne fungi, gray mold, blight, cyst nematode, leaf miner, and bruchid beetle; tolerance to cold and drought, high protein content, and multi-seeded or twin pods (Mallikarjuna 1999). ICRISAT collaborates closely with ICARDA to transfer genes for some of these wild species to chickpea.

Some of these species are perennial and not easy to propagate. Among the annual species, C. *reticulatum* belongs to the primary gene pool and fertile hybrids are obtained in crosses with chickpea. Likewise, high yielding lines were derived from C. *echinospermum* from the secondary gene pool, and hybrids between

Non-Nodulating Chickpeas Discovered

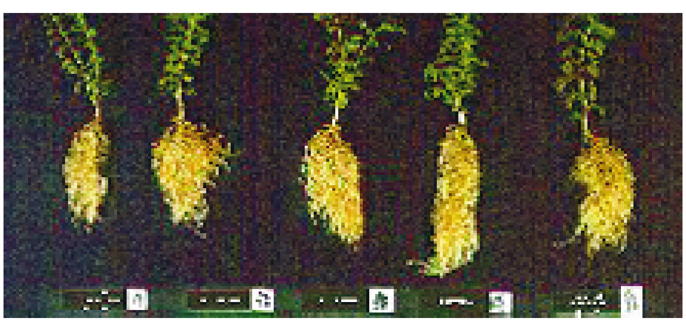
In the course of its nitrogen fixation research, ICRISAT identified non-nodulating lines (variants genetically unable to form nodules) for use as controls in quantifying the amount of nitrogen fixed by contrasting lines (Rupela 1992). Through these studies it was determined that chickpea acquires up to 80% of its N from the atmosphere. The non-nodulating and other nodulation variants developed at ICRISAT are important materials for basic research on nitrogen fixation processes in chickpea worldwide.

the blight resistant C. *pinnatifidum* and chickpea were obtained using embryo rescue. The other C*icer* annual species and all perennial species belong to the tertiary gene pool of chickpea.

Improving Drought Adaptation in Chickpea

Escaping terminal drought Chickpea matures as the rains end, risking drought damage during the critical yield-forming stage. ICRISAT has helped national partners achieve major impact by developing short-duration cultivars that mature before drought sets in, completing their growth cycle on residual soil moisture even if the rains fail (see success stories in section I). In cooler production systems, though, crop duration may be extended because cold injury slows the maturation process, thereby exposing the crop to terminal drought. ICRISAT breeders have therefore combined chilling tolerance with early maturity to provide 'double insurance' against terminal drought for cool-season production systems.

Enhancing drought tolerance After years of painstaking research to sort through genotype by environment interactions and identify drought tolerance traits, ICRISAT scientists were able to prove that high root mass can significantly enhance drought tolerance in chickpea (see photos below). This trait was incorporated into high-yielding cultivars through conventional breeding. In tests conducted by the Indian national system, one drought tolerant line has been found to exhibit 20-30% higher yield than the best local check.



Resistance to drought by combining larger root and few pinnules.

Variation in shoot and root mass in a cross between chickpea and Cicer reticulatum.

Breeding for this important trait is very difficult, though because of the laborious methods involved in digging and measuring roots. As molecular markers are developed in the coming years (see earlier), we will be able to use marker-assisted selection to greatly improve the efficiency of selection, accelerating progress dramatically.

Screening Techniques for Resistance to Diseases and Pests

The development of disease resistance screening techniques has contributed significantly to the success of the ICRISAT/NARS chickpea improvement effort. We developed reliable techniques for the identification of germplasm and breeding material resistant to wilt, blight, and gray mold. Screening for wilt resistance is conducted in wilt sick-plots. The sick-plot is developed by chopping wilt-infected chickpea plants into pieces and incorporating them into the soil. This is supplemented by sowing a known wilt-susceptible cultivar for 2 or 3 successive years, repeating the incorporation of the wilted plants into the soil each year. The susceptible cultivar exhibits more than 90% wilt incidence with this technique (Nene et al. 1981). In the greenhouse, screening is carried out by creating wilt infection in pots to validate the field results, and to breed for race-specific and multi-race resistance.

Using these techniques ICRISAT pathologists have screened about 16,000 accessions; about 500 of these showed high levels of wilt resistance (Nene et al. 1981). Many wilt resistant breeding lines are now available and these have been shared with NARS

Wilt damage

partners who have used them to develop resistant cultivars.

Screening for resistance to ascochyta blight and botrytis gray mold is conducted under controlled conditions in a growth chamber at seedling stage. Screening is done using an appropriate spore concentration and providing necessary temperature and humidity for the requisite time period. This technique allows screening of a large number of materials in a small space quickly, and is a precise and highly reliable technique (Haware et al. 1995).

All the proven techniques have been shared with interested NARS partners through training programs. Uniform rating scales have been developed and joint evaluations have been conducted at many locations. ICRISAT researchers routinely assist NARS that lack facilities, by providing the facilities and technical backstopping to screen their breeding materials.

Screening for resistance to wilt disease in chickpea. Susceptible checks are between resistant lines

Race identification in Fusarim oxysporum *f. sp* ciceri

The fusarium wilt pathogen is highly variable and race frequencies shift rapidly in populations in response to resistance challenges. To understand and manage this phenomenon, major efforts were made to identify variability in the pathogen using a set of 10 differential hosts. So far, seven distinct races of the pathogen have been identified in different parts of the world (Hervas et al. 1995). We have identified resistant sources against four races of fusarium wilt from India. With the cultivation of newer genotypes more new races of the pathogen are likely to emerge.

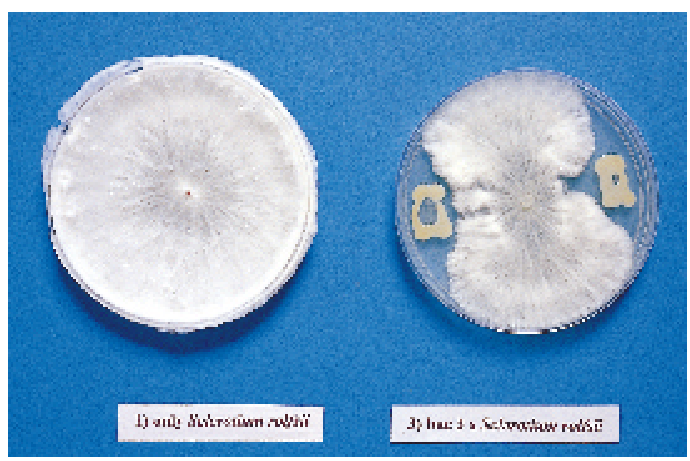
Molecular techniques are now being investigated to characterize the diversity in this pathogen.

ICCV 2 (left) with h1 and h2 alleles for fusarium wilt resistance.

Biocontrol of Diseases and Pests

Biocontrol of collar rot

Collar rot disease of chickpea is caused by a soil-borne pathogen (*Sclerotium rolfsii*) that grows well on non-decomposed organic matter and attacks over 100 crop species. The pathogen thrives at high soil moisture and high temperature (30°C). This disease is a major problem for seedling establishment in fields where chickpea follows rice. Since genetic resistance to the disease has not been identified,



In vitro inhibition of collar rot pathogen by* Pseudomonas *fluorescence.

ICRISAT researchers tested the efficacy of many antagonistic fungi and bacteria as potential seed treatments to control this disease.

Two bacterial cultures (*Pseudomonas fluorescence* and *Ochrabactrum anthropi*) showed significant antagonistic activity against this pathogen (Singh et al. 2000). The two cultures showed significant synergism with the fungicide tetramethyl thiuram disulphide. The bacteria-fungicide combination, applied as seed treatment, reduced collar rot disease by about 34% both in field and pot experiments. This clearly demonstrates the potential of antagonistic bacteria for the management of collar rot in farmers' fields.

Host-plant resistance to pod borer

Since 1976, more than 14,000 lines have been screened for tolerance to pod borer under field conditions at ICRISAT in India. Some lines were found to suffer significantly lower damage than others, and subsequent tests confirmed low levels of resistance or tolerance (Lateef 1985; Cowgill and Lateef 1996). In general, desi types are less susceptible to this pod borer than kabuli types.

The moderately tolerant lines have been supplied to collaborating scientists in India and elsewhere for systematic assessment of pod borer resistance and use in breeding programs. Breeding lines with combined resistance to fusarium wilt and tolerance to pod borer are now available.

Studies found that there was a significant negative correlation between pod damage and oxalic acid exudate levels on plant parts (Yoshida et al. 1995; Yoshida et al. 1997). Oxalic acid, which had been reported to have an antibiotic effect on helicoverpa armigera larvae, has an important role in resistance to this pest in chickpea. The length of the podding period was also a factor influencing the extent of pod damage; a longer podding period resulted in prolonged exposure to H. *armigera* attack and more pod damage.

Biocontrol of pod borer

Recent research at ICRISAT on natural enemies of helicoverpa indicated negligible role of egg parasitoid activity, which could be due to the deterrent effect of acidic exudates in the crop (Romeis and Shanower 1996). However, *Compoletis chloridae* was found to cause about 40% mortality of borer larvae (Pimbert and Srivastava 1990). It was also shown that the effectiveness of the larval parasite can be enhanced by the presence of coriander as a mixed crop with chickpea.

Lethal Attraction

Naturally-occurring chemicals in the host-plant and pest were isolated and then synthesized to help in studying the behaviour of helicoverpa moths and to monitor pest populations.

***Kairomone*:** Collaborative research with the Max Planck Institute, (Germany) identified the chickpea kairomone as an attractant for helicoverpa pod borer, indicating the involvement of four volatiles (pentan-1-ol, -Δ3 carene, myrene, and α- piene) as components (Rembold et al. 1990). The main components of the exudates are malate and oxalate, which are present in variable absolute and relative concentrations among chickpea plant parts.

***Pheromone*:** Identification and standardization of helicoverpa pheromone (sex hormone) technology was investigated with the collaboration of Natural Resources International Limited (UK) in the early 1980s (Pawar et al. 1988). The synthetic pheromone is now routinely used to monitor the pest population and buildup in different geographic regions. Pheromone trap data are used to predict pest damage, to enable farmers to take appropriate control measures.

IV. Partnerships for Chickpea Improvement

Many important scientific and development partners from around the world have contributed to chickpea improvement. Public, private, university, and NGO sector partners from Australia, Bangladesh, China, Ethiopia, India, Iran, Kenya, Mexico, Myanmar, Nepal, Pakistan, Sudan, Tanzania, Uganda and Zambia were especially active in these collaborations. A comprehensive list of partners is presented in Annex I.

Working together towards one vision – a world safe from hunger, poverty, and environmental degradation.

ICRISAT's partnerships with NARS for chickpea research began as informal linkages in the earlier years, but were soon molded into organized and effective mechanisms including a regional network for South Asia; bilateral funded projects; and multi-country collaborative research projects.

Some specific highlights of ICRISAT/NARS partnership can be noted in brief here. NARS from India, Iran, and Ethiopia have contributed extensively to the germplasm collection at ICRISAT, and others participated in joint collection expeditions. Together, all the partners have enriched the genebank for the common good of humanity, both now and in the future. NARS scientists have been active partners in joint in-country evaluation of advanced breeding lines generated at ICRISAT.

Farmers, of course are our ultimate partners in the adventure of chickpea research-for-development. They have been included in evaluations of new technologies, and have in some cases become the most active proponents in the dissemination of those innovations – for example, the spread of the variety 'Mariye' in Ethopia, highlighted earlier.

Networking

Research collaboration and technology exchange in Asia were formalized with the formation of the Asian Grain Legumes Network in 1986, which subsequently became the Cereals and Legumes Asia Network (CLAN) in 1992.

CLAN is a research and technology exchange network involving 13 countries: Bangladesh, China, India, Indonesia, Iran, Myanmar, Nepal, Pakistan,

NPV *production training course: participants practice bioassay techniques.*

Philippines, Sri Lanka, Thailand, Vietnam, and Yemen. These countries has been exchanging germplasm, breeding material, information and technology to increase knowledge and improve the production and productivity of chickpea, along with other major food crops of the region. At NARS members' request, ICRISAT has functioned as the coordinator of CLAN since its inception.

CLAN working groups to solve priority constraints

CLAN has constituted problem-focused *working groups* that bring together NARS, advanced research institutes, and international agricultural research centers. Membership is open to all scientists who commit time, facilities and resources and agree to share research responsibilities and results with their partners.

One example is the botrytis gray mold working group. The group brainstormed a collaborative strategy and partitioned duties according to complementary capacities of different partners. Gray mold resistance screening is carried out by Bangladesh, models for gray mold prediction are being developed by India, and experiments on integrated disease management are being undertaken in all participating countries. ARIs are also involved: the Scottish Crops Research Institute (UK) is carrying out frontier research examining the feasibility for transferring a resistance gene from Kiwi fruit to chickpea.

With ICRISAT serving as a bridge and facilitator of these working groups, it is likely that such international exchanges of skills and technology will lead to faster, more relevant results, tested more effectively in the field, resulting in impact sooner than would have otherwise been possible. The intangible benefits of building international bonds of partnership and collegiality while sharing skills, experiences, and ideas are equally important outcomes.

NARS Capacity-Building

Strengthening the skills of NARS research partners through individual and group training has been a major priority for ICRISAT over the last 25 years. The training program was customized for each participant. Participants over the past quarter century included Research Fellows (13), Visiting Scholars (110), Research Scholars (38), Apprentices (31), and In-service Trainees (183). In addition, 12 regional training courses and in-country training programs focused on chickpea were organized.

Technical Assistance to NARS Breeding Programs

The gene bank at ICRISAT has provided 110,740 germplasm accessions to national programs over the past 28 years. Since 1973, ICRISAT scientists have made thousands of crosses, generated a large number of segregating populations, and provided seed of promising lines to NARS scientists around the world. Early generation bulks, screened in disease and insect nurseries at ICRISAT, are supplied for selection in regional and national programs. Nurseries and trial sets of promising advanced breeding lines are distributed to interested researchers. Chickpea field days and workshops, exchange visits, and training events were provided to share knowledge and materials widely.

As a result, we estimate that 3-4 years on average have been shaved off the normal 10-12 year time frame of NARS breeding cycles.

Technology exchange in Bhutan. Local scientists examining chickpea in a trial supplied by ICRISAT

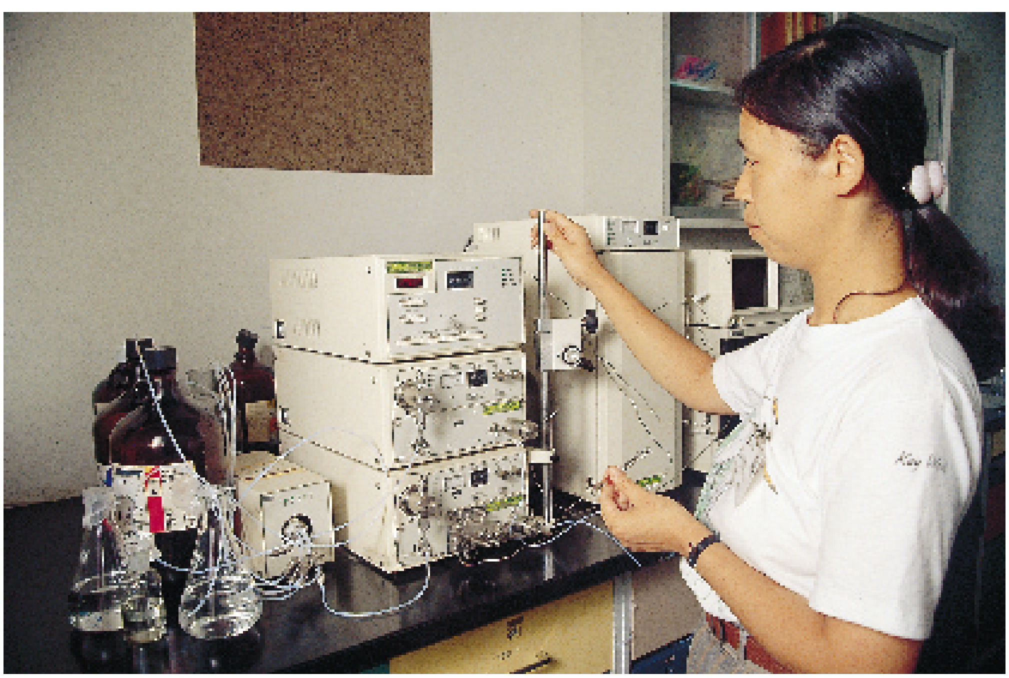
Farmer-Participatory On-Farm Research

Interaction with farmers has become integral to ICRISAT's chickpea improvement strategy. Interviews with farmers provide insights about their priority constraints and needs, and research is accordingly adjusted on an ongoing basis. For example, farmers in the Banke and Bardia districts in Nepal were able to increase production from 0.8 t ha^{-1} to 1.4 t ha^{-1} as a result of participatory research by joint teams of Nepalese and ICRISAT scientists with local extension experts.

Partnerships with Sister Centers and Advanced Research Institutions

ICRISAT shares its chickpea improvement mandate with ICARDA. ICRISAT focuses on tropical latitudes (South Asia and SubSaharan Africa) while ICARDA takes the lead in the temperate zone (West Asia and North Africa). The two Centers have worked closely in a number of areas, including genetic resources, biotechnology, and disease studies over the past quarter-century. As mentioned earlier, the two Institutes provide safety backups for each other's gene bank holdings. For many years an ICRISAT breeder was posted to ICARDA, working closely with the ICARDA legume pathologist. Scientific visits and collaborative projects have been continuous features of the relationship.

ICRISAT scientists have worked collaboratively with scientists of numerous advanced research institutes, maintaining a vigorous component of frontier science within the chickpea initiative. In the early days (late 1970s), studies of photoperiod and temperature interaction were carried out jointly with the University of Reading (UK). Characterization and detection of viruses have been carried out with the Scottish Crops Research Institute (UK), in addition to the joint project for transformation with the PGIP gene for resistance to botrytis gray mold mentioned earlier. Collaboration on molecular marker genome mapping is currently active jointly with Washington State University (USA) and the University of Saskatchewan (Canada). The roles of malic and oxalic acid as mechanisms of resistance to pod borer were investigated with researchers from the Max Plank Institute (Germany). ARIs from Australia, USA, and Thailand have also been involved with ICRISAT in R*hizobium* and nitrogen fixation research.

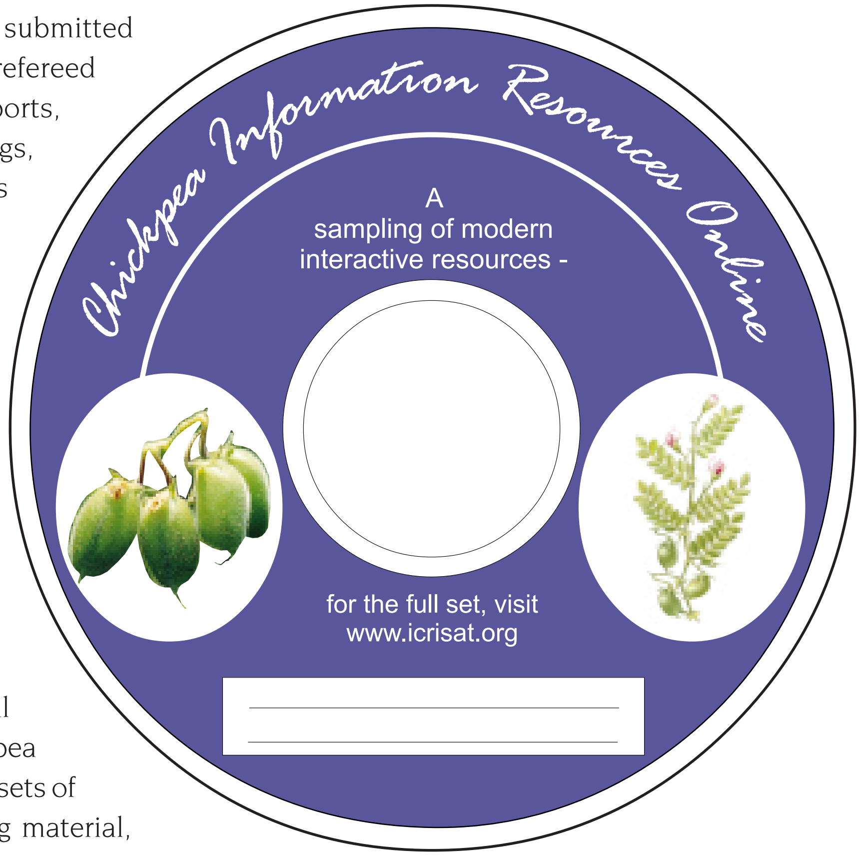


Analyzing chickpea leaf exudates, a Research Fellow from Japan helps in the fight against the helicoverpa pod borer.

Information and Knowledge Sharing

Information has been shared with partners and stakeholders through specialized publications and books on chickpea, an international newsletter coordinated by ICRISAT (including articles submitted by both partners and ICRISAT scientists), refereed journal publications, research progress reports, research papers, conference proceedings, practical bulletins, field problem diagnosis handbooks, and popular publications to disseminate new technologies. A list of major publications across these formats is provided in Annex II.

Knowledge sharing and information dissemination have undergone profound changes with the on-going developments in information technology. ICRISAT has invested major effort in using the World Wide Web as a medium to share information including crop specific information. This information covers diseases, insect pests, nutritional disorders, information on the chickpea germplasm held in trust by ICRISAT, core subsets of the germplasm, pedigree and elite breeding material, screening methods, and resistance sources against pests and diseases. CD-ROMs are provided to partners lacking internet access.



Internet and CD-ROM databases are a rich source of information helping partners worldwide to learn more about chickpea improvement at ICRISAT.

Conclusions

Since 1972 ICRISAT, working closely with a wide range of partners, has made remarkable progress in improving the adaptation of chickpea crops and cropping systems to the climatic, nutritional, pest, and disease variability of a wide range of marginal rainfed environments. The impacts have been impressive, including: large improvements in productivity and farm income; new cropping options to make farming systems more diverse and sustainable; value added to the harvested product; and reduction in crop protection-related expenses, losses, and human health risks – all, while improving national research-for-development capacities in some of the poorest, most densely-populated countries of the world.

This approach – adapting the crop and cropping system to the variability of the environment – is a difficult, time-consuming process, unlike the 'magic bullet' approach of homogenizing the environment through costly inputs (irrigation, fertilizer, etc.,) for high-yield agriculture. But the adaptation approach is more attuned to the realities facing the poorest farmers – their marginal land endowments and limited cash and labor resources – and therefore more directly targets their poverty. Enabling them to get more out of what they have builds their self-reliance, stabilizes their communities, and encourages them to invest in and enhance their rural environments towards a more sustainable future.

It is interesting to recall the early assumptions of the CGIAR as it contemplated entering the more difficult marginal environments during the 1970's: the System recognized that this would be a more difficult challenge than had ever been faced before. The achievements of chickpea research by ICRISAT and its partners, though, validates the decision to take on this challenge, because progress has truly made a difference in the lives of those living on the margin, in this case especially the half billion desperately poor of South Asia.

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Annex I. ICRISAT's Partners in Chickpea Research for Development

NARS partners in technology development and exchange

- **Bangladesh**
  Bangladesh Agricultural Research Institute (Joydebpur)
  Bangladesh Agricultural Research Council (Dhaka)
  Bangladesh Rice Research Institute (Joydebpur)
  CARITAS (Dhaka)
  Peoples Resource Oriented Voluntary Association (Rajshahi)

- **Chile**
  Estación Experimental Sociedad Nacional de Agricultura

- **China**
  China Academy of Agricultural Sciences (Beijing)
  Qinghai Academy of Agriculture and Forestry Sciences (Xining)

- **Ethiopia**
  Institute of Agricultural Research
  Ethopian Agricultural Research Organization (Addis Ababa)

- **India**
  Indian Council of Agricultural Research (New Delhi)
  Indian Agricultural Research Institute (New Delhi)
  Indian Institute of Pulses Research (Kanpur and AICPIP)
  National Bureau of Plant Genetics Resources (New Delhi)
  National Centre for Integrated Pest Management (New Delhi)
  Central Research Institute for Dryland Agriculture (Hyderabad)
  Commonwealth Institute of Biological Control (Bangalore)
  Jawaharlal Nehru University (New Delhi)
  National Chemical Laboratory (Pune)

State Agricultural Universities

Punjab Agricultural University (Ludhiana), **Haryana Agricultural University** (Hisar),**Banaras Hindu University** (Varanasi), **Acharya N G Ranga Agricultural University, Osmania University** (Hyderabad), **University of Hyderabad, Govind Ballabh Pant University of Agriculture & Technology** (Pantnagar), **Chandra Shekhar Azad University of Agriculture & Technology** (Kanpur), **Dr Punjabrao Deshmukh Krishi Vidyapeeth** (Akola), **Mahatma Phule Krishi Vidyapeeth** (Rahuri), **Marathwada Agricultural University** (Parbhani), **University of Agricultural Sciences** (Dharwad and Bangalore), **Gujarat Agricultural University** (Junagadh), **Rajasthan Agricultural University** (Durgapura, Sriganganagar), **Orissa University of Agriculture & Technology** (Bhubaneshwar), **Indira Gandhi Krishi Vishwa Vidyalaya** (Raipur), **Tamil Nadu Agricultural University** (Coimbatore), **Jawaharlal Nehru Krishi Vishwa Vidyalaya, Gwalior** (Indore), **Himachal Pradesh Krishi Vishwa Vidyalaya** (Dhaulakuan), **Sher-e-Kashmir University of Agriculture and Technology** (Jammu)

Non-Governmental Organizations

RIOD, KRIBHCO, Centre for World Solidarity, Community Action for Rural Development, Centre for Human Resource Development

- **Iran** — **Agricultural Research, Education and Extension Organization** (Tehran)
  Seed & Plant Improvement Institute (Karaj)
  Dryland Agricultural Research Institute (Maragheh)
- **Kenya** — **Kenya Agricultural Research Institute**
  National Dryland Farming Research Station
- **Mexico** — **Instituto Nacional de Investigaciones Forestales Agropecuarias**
- **Myanmar** — **Myanmar Agriculture Service** (Yangon)
- **Nepal** — **Nepal Agricultural Research Council** (Kathmandu)
  Department of Agricultural Development (Kathmandu)
- **Pakistan** — **National Agricultural Research Centre** (Islamabad)
  Pakistan Agricultural Research Council (Islamabad)
  Nuclear Institute of Agriculture and Biology (Faisalabad)
  Ayub Agricultural Research Institute (Faisalabad)
  Barani Agricultural Research Institute (Chakwal)
- **Sri Lanka** — **Field Crops Research and Development Institute** (Mahailluppallama)
- **Sudan** — **Hudeiba Research Station** (Eldamer)
- **Tanzania** — **Tanzanian Agriculture Research Organization**
  Karatu Development Association

International Centers

International Plant Genetic Resources Institute (Rome, Italy)
for germplasm collection, conservation, utilization

International Rice Research Institute (Los Baños, Philippines)
for legumes in rice-based systems

Asian Vegetable Research and Development Centre (Taiwan)
for training courses

International Center for Agricultural Research in the Dry Areas (Aleppo, Syria) *for collaborative research on kabuli chickpea*

Regional Organizations

Nitrogen-Fixation by Tropical Agricultural Legumes (Thailand and Hawaii)
for Rhizobium

Regional Cooperating Centre for Research and Development of Coarse Grains, Pulses, Roots and Tuber Crops in the Humid Tropics of Asia and the Pacific (Indonesia)
for price, markets and policy

Developed Country Partners

Australia

Agricultural Research Centre (Wagga Wagga) *for cultivar development*
Centre for Legumes in Mediterranean Agriculture (Perth) *for* investigations in cold and drought tolerance
Commonwealth Scientific and Industrial Research Organization (Canberra) and **New South Wales Agriculture (Tamworth)** *for* N *fixation*
University of Melbourne (Parkville) *for development of molecular markers*

Canada

University of Saskatoon, Saskatchewan f*or molecular markers*

Germany

Max Plank Institute of Biochemistry (Munich) *for pest resistance mechanisms*

United Kingdom

University of Reading f*or photo x thermal interaction studies*
NRI f*or integrated pest management, insecticide resistance management*
John Innes Centre f*or phenotyping of* Rhizobium, *molecular markers*
Scottish Crops Research Institute *for virus detection techniques, transformation for resistance to gray mold*
Commonwealth Mycological Institute f*or fungal identification*
Centre for Overseas Pest Research f*or resistance mechanisms in pod borer*
Cambridge University *for taxonomy of bacteria and fungi*
Centre for Agriculture and Biosciences International f*or information exchange*

USA

Washington State University (Pullman) f*or molecular markers and other genetic investigations*
Boyce Thompson Institute (Ithaca) *for viral control of pod borer*

Networks

Cereals and Legumes Asia Network
Asian Rice Farming Systems Network

Development Investors

Asian Development Bank
International Fund for Agricultural Development
United Nations Development Programme
Food and Agriculture Organization of the United Nations
Australian Centre for International Agricultural Research
Directorate General for International Cooperation, Belgium
Canadian International Development Agency
International Development Research Centre, Canada
Department for International Development, UK
German Agency for Technical Cooperation
United States Agency for International Development
Other core investors of the Consultative Group on International Agricultural Research

Annex II. Publications Related to Chickpea Improvement at ICRISAT

Scientific Journal Articles

Ananda Rao, P.K., and **Haware, M.P.** 1987. Inheritance of dry root rot (*Rhizoctonia bataticola*) resistance in chickpea (*Cicer arietinum*). Plant Breeding 98:349-352.

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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 and focus

To help developing countries apply science to increase crop productivity and food security, reduce poverty, and protect the environment. ICRISAT focuses on the farming systems of the semi-arid tropical areas of the developing world, where low rainfall is the major environmental constraint to agriculture. Special emphasis is placed on five crops that are particularly important in the diets of the poor: sorghum, millet, groundnut, chickpea, and pigeonpea.

ICRISAT's strategy

To form research partnerships with government, non-governmental, and private sector organizations in developing countries, and to link these partners to advanced research institutions worldwide. Each partner contributes its unique strengths 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 and services help partners enhance their capabilities to meet regional, national, and local development needs.

Where is ICRISAT?

Staff are based at eight locations across Africa and Asia. From these points, they travel extensively to work with partners across the semi-arid tropical world.

Acknowledgments

The core credit for more than two decades of chickpea improvement goes to the many dedicated scientists cited in the publications of Annex II. Rodomiro Ortiz, C.L.L. Gowda, and Jagdish Kumar assembled the facts and figures behind the story, based on source information derived from those publications and additional contributions from U.K. Deb, C.L.L. Gowda, Jagdish Kumar, N. Kameswara Rao, V. Mahalakshmi, Nalini Mallikarjuna, S. Pande, G.V. Ranga Rao, O.P. Rupela, N.P. Saxena, K.K. Sharma, S.D. Singh, H.D. Upahdhyaya, P. Parthasarathy Rao, and James G. Ryan. Mark Winslow synthesized the contributions for the final writeup. Savitri Mohapatra and A. Giridhar Rao carried out editing and proofreading. S Srinivas and the staff of the ICRISAT Library assisted in the bibliographic search. T. R. Kapoor supervised the pre-press, layout/design, and printing operations.

Citation: ICRISAT. 2000. Bringing hope to marginal environments: chickpea improvement at ICRISAT. (In En.) Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. ISBN 92-9066-422-3. Order code GAE 037.

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