Key fact
Through the gene pyramiding technique, breeders at AVRDC-The World Vegetable Center have developed tropical tomatoes with resistance to several whitefly-transmitted begomoviruses, including *Tomato yellow leaf curl virus* - a pathogen that can lead to 100 per cent crop loss.

Summary
Tomato yellow leaf curl disease (TYLCD) is caused by a diverse group of plant viruses called begomoviruses that are transmitted by the whitefly (*Bemisia tabaci*). *Tomato leaf curl virus* (ToLCV) and *Tomato yellow leaf curl virus* (TYLCV) can wipe out an entire tomato crop if the infection occurs at an early stage. Pesticides are often misused in the tropics and subtropics in an attempt to control whitefly. As a result *B. tabaci* has developed resistance to many insecticides.

By using gene pyramiding - combining multiple Ty genes into existing tomato lines - AVRDC breeders have produced tropical tomatoes with resistance to several whitefly-transmitted begomoviruses, allowing farmers to reduce pesticide use, thus reducing the costs of production, increasing net profit and protecting the health of farmers, consumers and the environment. From 2010 to date, AVRDC has sent 1,176 seed packets of the multiple Ty lines to 118 recipients in 46 countries around the world. AVRDC continues to develop and distribute new improved TYLCD-resistant lines today.

Facts & figures
- Tomato researchers in India, Israel, and the USA evaluated hundreds of tomato accessions for TYLCVD resistance.
- By 2007, approximately 1 million tomato farmers in India had adopted improved tomato varieties with resistance to ToLCV.
- The resistant lines reduced the number of pesticide applications, thus reducing the costs of production and increasing net profit. South Indian farmers reduced the use of pesticides by 20-25%, from 9-20 sprays to 7-15 sprays per crop.
- Farmers growing ToLCV-resistant varieties gained up to ten times the profit compared with ToLCV-susceptible varieties.
- Studies suggest that south Indian farmers adopting the improved varieties increase their profit by US$320 per crop, and see their incomes increase from US$768-US$2,195 to US$1,097-US$4,155 per hectare.
- South India’s smallscale farmers have land holdings ranging from 0.2 to 2 hectares. It is possible to grow three tomato crops per year in south India.
- ToLCV-resistant varieties yield between 1.9 to 4.5 times as many tomatoes as susceptible varieties, and on average, yield three times the total weight of fruit.
- The research-cost benefit ratio was estimated at 837:1.
European funding
The UK Department for International Development’s (DFID) Crop Protection Programme funded research to breed open-pollinated ToLCV-resistant genotypes at the University of Greenwich, University of Agricultural Sciences, Bangalore and AVRDC-The World Vegetable Center, Taiwan. Since 2004, DFID has provided US$6,721,020 in core funding, which has contributed to the work of developing Ty tomatoes. Between 2005 and 2008, an additional £103,849 was provided to support training, technology transfer, and impact assessment.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) contributed €1.2 million between 2004 and 2009 for molecular marker development and research on breeding resistant varieties, development of other integrated pest management strategies, tactics for TYLCD control, and basic work on virus and vector diversity studies. AVRDC has also received unrestricted support from France.

Project milestones
• Early 1990s: University of Agricultural Sciences in Bangalore, India initiates research programme to evaluate sources of ToLCV-resistance in tomato.
• 1995: AVRDC tomato breeding initiates crosses to develop tropically adapted inbred lines resistant to geminiviruses and bacterial wilt.
• 1998: AVRDC provides seed of improved lines to University of Agricultural Sciences in Bangalore, India to test for ToLCV disease resistance and adaptation to south India.
• 2003-2004: Development and release of three high yielding, open-pollinated ToLCV-resistant tomato varieties in India.
• 2003-2005: Eleven seed companies in India purchase breeders’ seed of the resistant varieties and begin breeding hybrids.
• 2007: Field days introduce 62 ToLCV-resistant hybrid tomatoes developed by 17 commercial seed companies and several public institutes to farmers in India.
• 2009: AVRDC distributes seed of ToLCV-resistant open-pollinated tomato varieties to public and private institutes in 13 countries in Asia and Africa.
• 2009: Through gene pyramiding, researchers at AVRDC breed tomato lines with multiple resistance to TYLCD.
• 2010 to date: AVRDC and national partners in India, Mali, and Tanzania continue research on durable, disease-resistant, open-pollinated tomato lines through gene pyramiding, and conduct multi-location trials and socio-economic surveys to evaluate the new lines.

Costs and benefits
Donors provided about US$1.3 million for the development and dissemination of the resistant tomato lines:
• By 2007, approximately 1 million farmers had adopted the resistant lines in India.
• Farmers growing ToLCV-resistant varieties gained up to ten times the profit compared with ToLCV-susceptible varieties. Average profit per crop was US$320.
• Farmer incomes increased from US$768-US$2,195 to US$1,097-US$4,155 per hectare.
• Research-cost benefit ratio was estimated at 837:1.
• The resistant lines reduced the number of pesticide applications, thus reducing the costs of production, increasing net profit and protecting the health of farmers, consumers and the environment.

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The great pyramid: Ty tomatoes resist pests and diseases

Producing a good crop of tomatoes in the tropics and subtropics challenges the best of farmers. Fighting pests and diseases is a never-ending battle as pathogens evolve and develop resistance, rendering once-effective pesticides useless. In some cases the pathogens have the upper hand: pathogen pressure from Tomato yellow leaf curl virus (TYLCV) is so intense in some ‘hotspots’ in India and West Africa that farmers have stopped producing tomatoes outside.

Tomato leaf curl viruses are caused by begomoviruses, transmitted by the whitefly (Bemisia tabaci). Adult whiteflies often hide on the undersides of leaves and look like tiny white moths (1-2 mm in length). Cucumbers, cotton, eggplants, tomato, sweet potato and some weeds are favourite whitefly hosts. Whiteflies feed on infected plants and then spread the virus to non-infected plants. Tomato plants infected in early growth stages (before flowering) are severely stunted with upright bushy shoots and yield less. Leaves are reduced in size and become curled and puckered. They may also become yellow between veins and around the edges.

Resistant tomato varieties are the cheapest, simplest and most effective way to control tomato virus diseases. Since the 1970s, breeders around the world have sought to develop tomato cultivars resistant to tomato yellow leaf curl virus disease (TYLCD) by breeding plants carrying resistant genes.

AVRDC-The World Vegetable Center, initiated a programme in the early 1990s to introduce ToLCV-resistance genes into tomatoes through conventional plant breeding techniques. AVRDC began distributing its own resistant tomato lines in 2000. With partners at the Natural Resources Institute, University of Greenwich, UK, and the University of Agricultural Sciences in Bangalore, India, three ToLCV-resistant open-pollinated tomato varieties (‘Sankranthi,’ ‘Nandi’ and ‘Vybhav’) were developed and officially released in India in 2003-2004.

Public institutions and private seed
companies in India obtained breeder’s seed of the high yielding, highly resistant varieties to multiply and distribute. By 2007, more than 1 million farmers in India had adopted the improved varieties, and AVRDC had distributed the improved seed to another 13 countries across Asia and Africa.

Resistant varieties reduced the need to use pesticides for whitefly control, making the entire production system more sustainable by reducing pesticide pressure on the environment and the health of farmers and consumers. To help farmers understand the connection between whiteflies and virus infection and the rationale for reducing pesticide applications, local public and private sector partners provided this information through CGIAR’s Tropical Whitefly Integrated Pest Management project.

Due to the widespread adoption of the resistant tomatoes, farmers reduced the number of pesticide sprays from 9-20 to 7-15 during the lifetime of a crop. In India, farmers that grew the resistant varieties realised an average profit per crop of US$320, and saw their incomes increase from US$768-US$2,195 to US$1,097-US$4,155 per hectare.

Farmers growing ToLCV-resistant varieties gained up to ten times the profit compared with ToLCV-susceptible varieties due to a combination of lower losses (because of less virus infection) and increased yield. Vybhav, in particular, is relatively heat tolerant and is able to produce more fruit at higher temperatures compared to other varieties.

“...an important example of public-private partnerships. The public sector has been doing a marvellous job and now the fruits of their research must reach the growers and the consumers. I extend all the support required for any future projects that will be done to meet your tastes and quality.”

Buta Singh Kanwal, marketing director, Namdhari Seeds, India

Gene pyramiding is a breeding technique used to introduce multiple genes into a plant, each of which imparts resistance to a specific pest or disease. Because a pest must overcome all of the resistance genes simultaneously to survive, it is more likely the vegetable line or variety will retain its resistance over a longer period - perhaps for several decades.

To find the Ty genes, breeders had to evaluate hundreds of tomato accessions. Researchers at the University of Florida, USA (Ty-1, Ty-3), Hebrew University in Israel (Ty-1), and Hisar University in India (Ty-2) found the genes in accessions of wild tomatoes - Solanum habrochaites, S. chilense, and S. peruvianum.
AVRDC obtained different lines with one or more Ty genes, and crossed its tomato lines with these sources. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) funding enabled AVRDC to add large-scale molecular marker-assisted selection activities for TYLCD resistance in 2008. Markers allow AVRDC breeders to efficiently identify and develop tomato lines with multiple TYLCD resistance genes. The improved lines carry various combinations of resistance to begomoviruses, bacterial wilt, fusarium wilt and early blight, as well as good tolerance to heat.

Interested farmers and partners can obtain seed of the improved fresh market and dual-purpose (fresh consumption and processing) lines through the AVRDC website. Most seed requests to AVRDC come from seed companies, universities, and scientists in national agricultural research and extension services (NARES). AVRDC lines are released directly, typically through public sector agencies, as inbred line varieties after national evaluation tests for yield, fruit quality, and disease resistance. AVRDC inbred lines are also used as parents to develop new hybrids.

Although resistance offers the best means to control TYLCV, providing resistance to 50 or more begomoviruses remains a challenge. The improved tomato lines are resistant to some, but not all, begomoviruses. Resistant varieties alone are not a permanent solution to TYLCD because new and potentially resistance-breaking forms of the virus exist or are likely to evolve.

The work of breeding disease-resistant vegetables is never really ‘finished’. There is a continuing need for plant breeding research and funding to develop improved lines that can help farmers stay ahead of evolving viruses and changing climates.

AVRDC’s disease-resistant lines coupled with good agricultural practices, such as the use of net houses or net shelters to exclude whitefly, help reduce exposure of resistant varieties to whiteflies and lowers chances of infection by new virus forms. The UK’s Department for International Development (DFID) provided support for this approach through its Tropical Whitefly Project.

Besides holding disease at bay, the new Ty resistant lines must also satisfy yield and fruit quality requirements of farmers and markets. Multi-location trials are ongoing in Central America, East Africa and India to solicit farmers’ impressions and comments about the resistant varieties, and to collect data on varietal preferences and characters for future breeding programmes. From 2010 to date, AVRDC has sent 1,176 seed packets of the multiple Ty lines to 118 recipients in 46 countries around the world.

The Ty resistance tomatoes are the latest in a very long line of improved tomato germplasm developed at AVRDC. Since 1978, 172 open-pollinated tomato varieties, based on the Center’s lines, have been released in 41 countries, offering farmers the opportunity to reduce their crop production costs by saving their own seed. AVRDC continues to develop and distribute new improved TYLCD-resistant lines today.

“We surveyed tomato farmers right at the start of the project to find out what solutions they would be willing to adopt to deal with Malle Roga, which is the local name for tomato leaf curl virus disease. One of the main reasons why this project has been successful has been the long period of funding that we’ve had which has lasted about ten years.”

John Colvin, project coordinator, Natural Resources Institute, University of Greenwich

Multi-location trials are ongoing in Central America, East Africa and India
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Multimedia material
Malle Roga: From Research to Impact

More information
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References


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