GENETIC IMPROVEMENT OF SELECTED VEGETABLES FOR THE TROPICS AND SUB-TROPICS

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ABSTRACT

Major biotic and abiotic stresses limit the productivity of vegetables in the humid tropics and sub-tropics. Prominent biotic factors include major pests and diseases which drastically reduce yield and quality. Abiotic stresses are high temperature, high rainfall, drought, and poor tropical soils. Research at the Asian Vegetable Research and Development Center (AVRDC) addresses the above constraints from two general perspectives-genetic manipulation to enhance crop adaptation (crop improvement) and reduction of production stresses through improved management (production systems). The crop improvement component is reviewed herewith from the context of enhancing the tropical adaptation of three selected vegetables-Chinese cabbage, tomato and sweet potato.

The goal of AVRDC's crop improvement research is tropical adaptation. General strategies that were adopted in quest of this goal are as follows : massive germplasm assembly, evaluation and utilization ; interdisciplinary research ; stepwise genetic improvement ; and, an adequate blend of strategic and applied research.

National programs worldwide have released a total of 84 improved AVRDC germplasm. The most advanced breeding lines combine desirable features such as heat tolerance, resistance to one or more major diseases and acceptable quality. Given these genetic gains, the prospects for further improvement of AVRDC's crops for the benefit of tropical vegetable farmers are discussed.

Introduction

Vegetables are good sources of essential proteins, vitamins and minerals, and complement well the starchy staple foods. They are also high value crops, providing a good source of income to the farmers (Selleck and Opeña, 1985).

Unfortunately, vegetable production in the tropics and sub-tropics is constrained by many problems. Consumption of vegetables in these areas is often lower than in the developed countries. For instance, FAO data reveal that the daily per capita consumption in Asia varies from a low of 43 g in Sri Lanka to as high as 270 g in South Korea[1]. A concerted effort to tackle the limiting factors of vegetable production and consumption is, therefore, necessary (Selleck and Opeña, 1985).

Vegetable research at the Asian Vegetable Research and Development Center, established in 1972 to deal with the production problems of six principal vegetables[2] in the tropics and sub-tropics, focuses on two general approaches. Altering the genetic make-up

1 Food and Agriculture Organization. 1988. FAO Production Yearbook. Vol. 41. FAO, Rome. 351 pp.

2 As vegetables are a complex and diverse group, initial research and development at the Center emphasized six vegetables-heading Chinese cabbage, mungbean, potato, soybean, sweet potato and tomato. Potato research was terminated in 1979. Pepper was added as a principal crop in 1986.

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of its crops to adjust their adaptation to the tropics constitutes one component that is collectively known as **crop improvement** research. Minimizing the abiotic stresses of the tropical environment through improved management is the complementary half of the Center's two-pronged solution to the problems of vegetable productivity in the tropics. This component is termed **production systems** research.

The present paper reviews mainly the crop improvement research at AVRDC, especially on the following crops-tomato, heading Chinese cabbage and sweet potato.

Constraints on vegetable production in the tropics

Tomato cultivation in the tropics is beset by many problems. These constraints may be classified as follows : **biotic** stresses, such as debilitating diseases[3] and insect pests[4] ; and, **abiotic** stresses, such as high temperature, high humidity, excessive rainfall, low light intensity, and poor soil fertility and structure. Both stresses exert drastic effects on productivity and quality of tomatoes.

In the tropics, heading Chinese cabbage is normally grown only in the high elevations because it requires low temperature for head formation. Major diseases, particularly soft rot (*Erwinia carotovora*), downy mildew (*Peronospora parasitica*), and turnip mosaic virus, further restrict its adaptation. Moreover, Chinese cabbage is sensitive to high soil moisture and flooding. The most serious insect attacking Chinese cabbage is diamond-back moth (*Plutella xylostella*), a pest of worldwide importance. Other major pests of Chinese cabbage in the tropics are imported cabbage worm (*Pieris rapae*) and webworm (*Hellula undalis*).

Biotic constraints to sweet potato production in the tropics include the sweet potato weevil (*Cylas formicarius*), its most destructive pest ; sweet potato vineborer (*Omphisa anastomasalis*), a common pest of sweet potato in Asia and the Pacific ; and, leaf scab (*Elsinoe batatas*), a common and serious disease in the tropics. Abiotic factors of the tropical environment which limit sweet potato productivity include flooding, excess soil moisture and drought.

Genetic enhancement of tropical adaptation

Successful production of tomato, Chinese cabbage and sweet potato in the hot and humid tropics demands several adaptation features-*heat tolerance* (particularly for tomato and Chinese cabbage), *tolerance of excess soil moisture* and *resistance to the major diseases and insect pests*. AVRDC's crop improvement research aims to equip its principal crops with the most essential prerequisites for tropical adaptation. In this paper, the breeding efforts on tolerance to high temperature and on resistance to the major diseases are particularly highlighted because of the significant advances that have been made in these areas.

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3 Some 9 or so of 51 tomato diseases are important in the humid tropics. These are bacterial wilt (*Pseudomonas solanacearum*), nematode (*Meloidogyne incognita*), tomato mosaic virus, leafmold (*Cladosporium fulvum*),grey leafspot (*Stemphylium solani*), Septoria leafspot (*Septoria lycopersici*) southern blight (*Sclerotium rolfsii*), early blight (*Alternaria solani*), late blight (*Phythopthora infestans*) and powdery mildew (*Leveillula taurica*). Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) has also become a severe problem in recent years.

4 Of the tomato insect pests, fruitworm (*Heliothis armigera*) has received the most attention. As vectors for virus diseases, some sap-sucking insects, such as aphids and white fly, are just as important. The green peach aphid (*Myzus persicae*) can transmit virus diseases such as yellow top and tomato aspermy ; and the white fly (*Bemisia tabaci*) serves as a vector for tomato leaf curl virus.

Assembly and evaluation of broad genetic diversity

Broad gene pools from which to derive the required genes for crop improvement are *sine qua non* to all breeding programs. Over the years, AVRDC scientists have endeavored to build sizeable germplasm collections to support the genetic enhancement programs of the Center's commodities. As of 1988, the collections which represent the basic foundation of the Center's breeding programs for the three crops reported in this paper add up to 8,042 accessions (Table 1).

Many of the genetic materials reported in Table 1 have been screened by AVRDC's crop improvement scientists for important traits such as tolerance to abiotic stresses (heat, flood, excess soil moisture, or drought), resistance to the major diseases and insect pests, nutritional potential, quality aspects, and others. Fig. 1 illustrates the typical flow of genetic materials among AVRDC's scientists working as interdisciplinary research teams.

High temperature tolerance-sources of genes and genetic control

AVRDC's crop improvement research has been focused sharply on heat tolerance from the outset because this trait is crucial for tropical adaptation, especially for tomato and Chinese cabbage. Heat tolerance in tomato is defined as "the ability to set fruits under night temperatures no lower than 21°C" (Villareal and Lai, 1979). In Chinese cabbage, heat tolerance refers to "the ability to produce compact heads under mean tempratures no lower than 25°C" (Opeña and Lo, 1979).

1 **Genetic resources for heat tolerance.** Thirty-nine tomato accessions, or about 1% of the 4,616 screened, were reported as heat-tolerant (Villareal and Lai, 1979). No significant additions to this list have been found from later evaluations. Some of the most important stocks that have been used in the AVRDC tomato breeding program are as follows : VC11-3-1-8 (Philippines), Tamu Chico III (USA), PI 289309 (USA), Divisoria -2 (Philippines), Nagcarlan (Philippines), and PI 289296 (Hungary).

About 15% or 79 of 540 accessions in the AVRDC's Chinese cabbage collection were heat-tolerant (Opeña and Lo, 1981). Additional heat-tolerant collections have been identified in later tests ; however, they were often derivatives of the local cultivars and do not represent entirely new genetic resources. With few exceptions, the elite heat-tolerant stocks came mostly from local collections in Taiwan and were very closely related genetically (Opeña and Lo, 1981). The implications of this constricted variability in breeding this crop for the tropics are further discussed below.

2 **Genetic basis of heat tolerance.** Heat tolerance in tomato reportedly gave strong indications of genetical complexity-variation was continuous and heritability values were low, with a range of only 5-19% (Villareal and Lai, 1978).

Further studies of a genetically diverse seven-parent diallel set showed that both additive and non-additive genes are important in regulating fruit set at high temperature (AVRDC, 1988a). A similar genetic behavior was noted for the splitting of the antheridial cone, a common reaction of tomato flowers to high temperature. Both conventional breeding methods, which take advantage of additively acting genes, and hybrid breeding, which relies primarily on genetic interactions, should thus be effective in breeding for heat tolerance. In support of the latter hypothesis, about 1/3 of the diallel hybrid progenies from the aforementioned study had better fruit set than the better heat-tolerant

Table 1 AVRDC germplasm collection for horticultural crops (as of 1988)

Commodity	Number of accessions
Chinese cabbage	856
Sweet potato	1,372
Tomato	5,814
Total	**8,042**

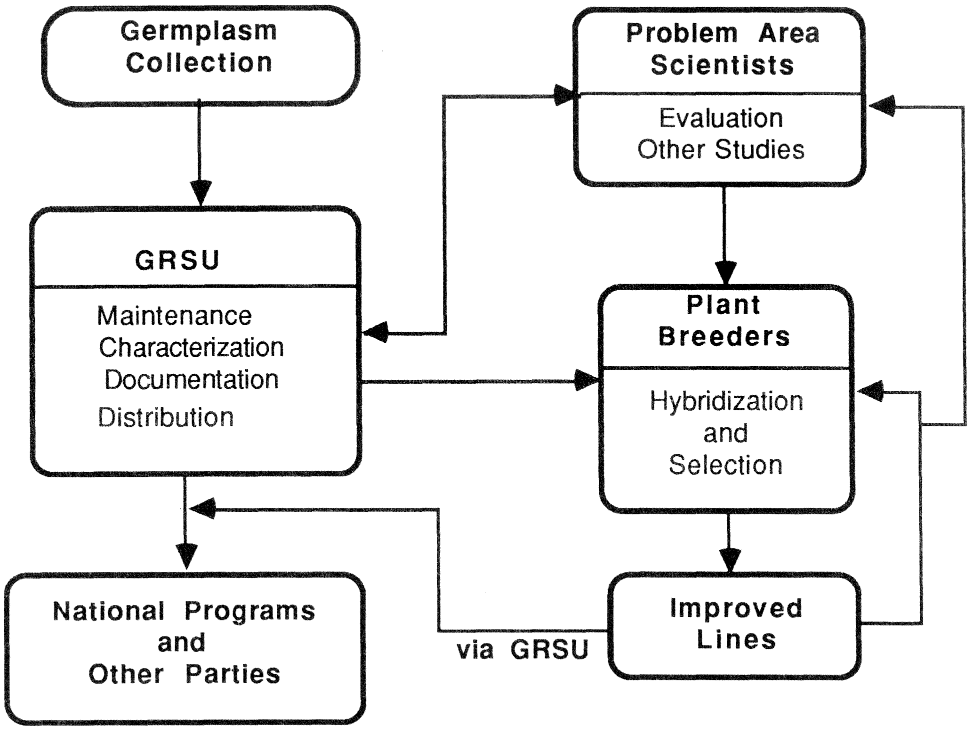

Fig. 1 **Diagrammatic sketch illustrating the flow of germplasm among various AVRDC research groups which form the crop-based interdisciplinary research teams**
Note : problem area scientists include pathologists, physiologists, entomologists, breeders, chemists, etc. in varying compositions depending upon the problems of each crop.

parents.

In a related study, crosses between heat-tolerant stocks were noted to have better fruit setting ability and yield than their crosses with heat-sensitive parents (Fig. 2). However, it was apparent from the range of F_1 means (Table 2) that some hybrids between heat-tolerant and heat-sensitive stocks could equal, if not surpass, the performance of heat tolerant x heat-tolerant stocks, further supporting the results from the diallel experiment (Opeña *et. al.*, 1987).

Heat tolerance in Chinese cabbage is inherited in monogenic fashion (Opeña and Lo, 1979 ; Yoon *et al.*, 1982). AVRDC breeders have met very little difficulty to fix this trait among breeding lines, further attesting to its simple inheritance.

Major tropical diseases-resistance sources and genetic control

A number of important diseases limit vegetable productivity in the tropics. AVRDC's research on the major diseases has traditionally emphasized the identification of resistance sources and their utilization in breeding resistant cultivars.

1 **Identification of disease-resistant stocks.** Bacterial wilt (BW), possibly the most important disease of tomato in the tropics, has received the highest priority in the breeding program (Opeña, Kuo and Yoon, 1987). Several BW resistance screening

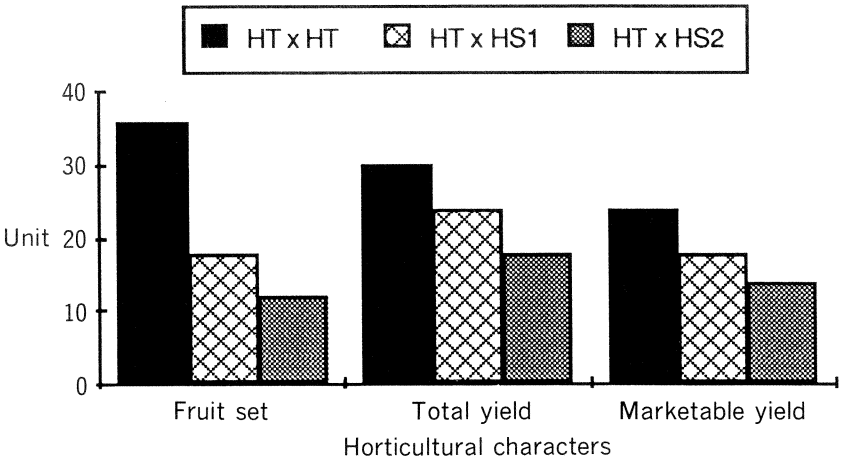

Fig. 2 Comparative fruit set and yield of hybrid progenies derived from crosses among parents with varying levels of heat tolerance (details on abbreviations are given in Table 2)

Table 2 Range of values for different characters among tomato hybrids with differing levels of heat tolerance

Type of Cross[z]	No. of crosses	Fruit set (%)	Yield (t/ha)		Fruit size (gm)
			total	marketable	
HT/HT	8	26-52	15.4-37.5	12.3-29.0	41-63
HT/HS1[y]	11	5-30	15.9-*28.8*	9.8-*23.2*	57-83
HT/HS2[x]	10	2-32	6.3-*33.2*	5.9-27.6	59-92

[z]HT=heat-tolerant parent.
[y]HS2=heat-sensitive parent (less than 10% fruit set).
[x]HS2=heat-sensitive parent (no fruit set).

methods were tested by pathologists, of which leaf clipping of young seedlings with a pair of scissors dipped in a mixture of highly infective BW inoculum became the standard screening method for many years (Opeña *et al.*, 1987). Field screening completely replaced leaf clipping since 1986 because of its relative accuracy (AVRDC 1985).

Some of the important BW-resistant stocks that have been used by the AVRDC tomato breeders are as follows : Venus (USA), Saturn (USA), L366 (unknown origin), VC11-3-1-8 (Philippines), VC48-1 (Philippines), PI406994 (Panama) and a few more, mostly coming from the tropical Southeast Asian countries.

AVRDC virologists have identified several stocks carrying resistance to tomato mosaic virus (Opeña *et al.*, 1988). Some of the tomato mosaic virus-resistant stocks that have been utilized in the AVRDC tomato breeding program are ah-Tm2a (USA), Ohio MR-12 (USA), Ohio MR-13 (USA), and a number of recently released commercial cultivars with superior characters.

The most important species causing root-knot in tomato is *Meloidogyne incognita*. The stocks that were used initially in the AVRDC tomato breeding program are Healani, Kewalo, Cal-Mart, and 72T6, obtained from various breeding programs in the United States. In recent years, several newly released nematode-resistant cultivars have found greater use in the AVRDC program because of their improved features such as large fruit size and better fruit firmness (Opeña *et al.*, 1988).

Although varietal differences in reaction to artificial soft rot infection have been observed, no resistance source has been reliably used in the breeding program.

The development of a concrete strain concept for turnip mosaic virus (TuMV) has helped greatly in identifying the important sources of resistance for breeding purposes (Green and Deng, 1985). AVRDC virologists identified a number of Chinese cabbage germplasm with resistance to strains TuMV-C1, TuMV-C2 and TuMV-C3 (AVRDC 1985). Resistance to TuMV-C4 and TuMV-C5 is rare, having been observed only in Accession B 730 (AVRDC 1985 ; AVRDC 1987). Another useful accession, B 708 (PI418957) carries immunity to strains TuMV-C1 and TuMV-C3 and resistance to TuMV-C2 and TuMV-C4 (AVRDC 1987).

Epiphytotic conditions of downy mildew, either natural, artificial, or both, enable the detection of resistant Chinese cabbage germplasm. An *in vitro* technique using sporangia production on detached cotyledons, inoculated and incubated for 12 hours at 14°C, promises to be a useful tool for screening a large number of seedlings (AVRDC, 1987). The most promising sources of downy mildew resistance were Korean introductions, particularly B742 (AVRDC 1985). B639 ('Hakuran'), a synthetic amphidiploid between *Brassica campestris* ssp. *pekinensis* and *B. oleracea*, also showed excellent downy mildew resistance (AVRDC, 1987).

Natural field screening for scab resistance in sweet potato was not feasible because this disease occurs infrequently at AVRDC. AVRDC plant pathologists developed a suitable method for *in vitro* propagation of the causal organism, rapid screening technique via artificial inoculation, and a suitable disease scoring method (AVRDC, 1988a ; AVRDC, 1988b). These techniques are now employed to identify resistant clones. Confirmed sources of resistance to scab are accessions I 75 (V2-30), I 1206 (GI 6), and I 1213 (GI 13) (AVRDC 1987 ; Opeña *et al.*, 1988).

2 **Genetic control of disease resistance.** Although there are contrasting theories on the genetics of BW resistance (Acosta, 1964 ; Bosch, 1985 ; S. K. Tikoo, personal communication), AVRDC breeders have proceeded through the years with the encompassing assumption that BW resistance is polygenic. Both Hawaii and North Carolina materials, for which polygenic inheritance was implicated, have been widely used in the AVRDC program, making this assumption circumstantially justified.

BW-resistant stocks vary in their ability to transmit resistance to their progenies (AVRDC, 1985). In a seven-parent diallel experiment, BW-resistant stocks such as L 96 (cv. Saturn from North Carolina) and L 285, a local collection from Taiwan, produced hybrid progenies with better average resistance than others. Some stocks, such as CL 1351-1-9-10, tended to show high BW resistance in some crosses but not in others. It seems that non-additive gene action may also be an important feature of the BW genetic system. The reactions of F_1 hybrids among parent stocks with differing BW resistance levels provide further proofs to this hypothesis (AVRDC, 1988b ; AVRDC, 1989).

Two dominant genes condition resistance to tomato mosaic virus. Gene **Tm-1** imparts resistance to ToMV strains 0, 2 and 2^2. On the other hand, gene **Tm-2** controls resistance to all strains except strain 2. Its allelic counterpart, gene **Tm-2**^{2}, also known as **Tm2**^{a}, imparts resistance to all strains except to strain 2^2. The most common strains found in Taiwan and other Southeast Asian countries are strains 0 and 1 (Green *et al.*, 1986). The AVRDC tomato breeders have thus bred gene **Tm-2**^{a} to all advanced breeding lines, imparting adequate protection to the common strains found in AVRDC's immediate region (AVRDC, 1985).

Resistance to common root-knot nematode is controlled by a single dominant gene, **Mi**. This gene is tightly linked to the gene **Aps-1**, an isozymic locus for acid phosphatase (Rick and Fobes, 1974) whose unique electrophoretic banding pattern can be used as a marker to screen tomato seedlings for nematode resistance. Unfortunately, the tight linkage appears to have been broken in some stocks, notably those from Hawaii (Medina-Filho and Stevens 1980) ; therefore, the nematode egg inoculation method is also used at

AVRDC as an alternative screening technique (Opeña *et al*., 1986).

There are five known strains of turnip mosaic virus (Green and Deng, 1985). Resistance to two strains, TuMV-C4 and TuMV-C5, is rare. So far, AVRDC breeders have found only one inbred line, O2, which carries resistance to both C2 and C5. Segregation ratios among the progenies of crosses between O2 and three susceptible inbred lines, scored by both visual reading and ELISA tests, indicate that two recessive genes condition resistance to both TuMV-C4 and TuMV-C5 (AVRDC, 1989).

The genetics of resistance to other major tropical diseases of tomato, Chinese cabbage and sweet potato, for which adequate information is not available in the literature, is studied as breeding for resistance to each becomes an integral component of the AVRDC's crop improvement research.

Breeding for improved tropical adaptation

As stated above, the two most important elements of tropical adaptation for AVRDC's horticultural crops are tolerance of adverse environmental factors and resistance to the major diseases of the humid tropics. The breeding strategies to combine these requisite traits are discussed below.

1 **Tomato.** The enormity of factors affecting the production of tomatoes in the humid tropics called for a stepwise approach to genetic improvement (Opeña *et al*., 1986). In the early years, the bringing together of heat tolerance and BW resistance among the advanced breeding lines was emphasized because these features are essential to grow a successful tomato crop in the tropics (Opeña *et al*., 1987).

In recent years, the AVRDC tomato breeders have further improved the tropical tomato by sequentially incorporating additional resistance to diseases and by enhancing fruit quality. The new traits that have been added are resistance to tomato mosaic virus (mainly gene $Tm\text{-}2^a$), resistance to root-knot nematode, resistance to fruit cracking, and improved fruit firmness and size (AVRDC, 1987 ; AVRDC, 1989). The stepwise improvement of tropical tomato, especially for disease resistance, is depicted in Fig. 3.

As more desirable genes are added to the tropical tomato, the valuable traits that they already possess may decrease in intensity with further genetic manipulations. Complex characters like BW resistance and heat tolerance are especially vulnerable. Thus, the AVRDC tomato breeders have increasingly resorted to the backcross (BC) method to recover adequate levels of the previous breeding gains while at the same time adding new traits. This method is finally combined with either the bulk, pedigree or single-seed descent method to handle the selfed BC populations (Opeña *et al*., 1987).

Selection for complex traits is also delayed now until selections have reached the family or line stage. Early generation selections are still made but they are limited to simple, highly heritable traits like monogenic disease resistances. In so doing, the hybrid progenies are screened beforehand for desirable horticultural types before selecting for complex traits, such as heat-tolerance and BW resistance.

Previous experiences indicated that the number of BC's needed to recover desirable levels of heattolerance from the heat-tolerant parents may not be that high (AVRDC, 1988a). On several occasions, many heat-tolerant segregants in the F_2 generation of the second backcross were already recoverable. This indirectly suggests that the genetics of heat tolerance may not be exceedingly complex, as previously supposed, and perhaps controlled only by a few major genetic factors with minor gene modifiers (AVRDC, 1988a).

2 **Chinese cabbage.** The simple genetic control of heat tolerance (Opeña and Lo, 1979 ; Yoon *et al*., 1982) assured that this trait could be easily handled in breeding. However, heat tolerance still needed to be combined with major traits like yield, disease resistance, and other desirable attributes.

The improvement of yield among heat-tolerant breeding populations was attempted through two breeding strategies-*population improvement* and *heterosis breeding* (Opeña

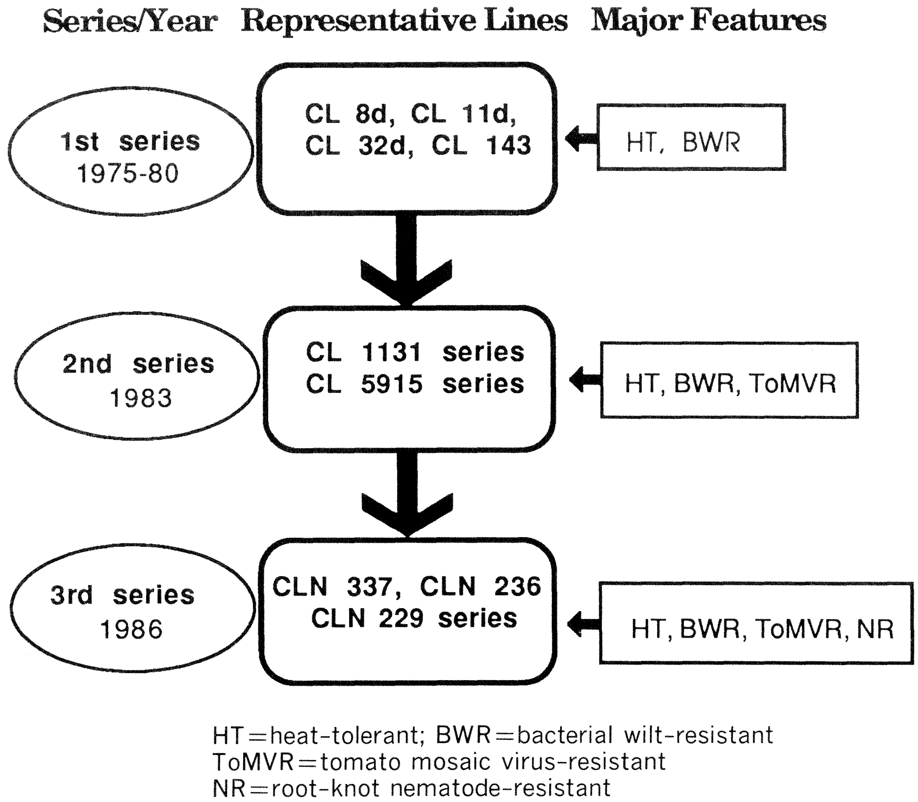

Fig. 3 Stepwise improvement of tropical tomato for heat tolerance and disease resistance

and Lo, 1981). Both recurrent selection and mass selection were effective in significantly increasing the mean head weights of some local heat-tolerant populations. However, the gains were small in practical terms (Table 3) ; therefore, a dramatic improvement of yield potential was sought through heterosis breeding.

The use of hybrid breeding to improve the yield potential of heat-tolerant Chinese cabbage was mitigated, however, by certain genetic principles. Heat tolerance is inherited in a recessive fashion ; thus, both parents of hybrids must possess the trait to obtain a good level of heat tolerance in the resulting F_1 progenies. However, finding two parents with enhanced heterotic interactions was difficult because the heat tolerance gene pool is considerably narrow (Opeña and Lo, 1981). The diversification of the heat tolerantce gene pool held the key, therefore, to maximizing heterosis for yield. To achieve this, local heat-tolerant populations were crossed with unrelated temperate cultivars and the resulting populations were mass-selected for two to three cycles for traits such as heat tolerance and disease resistance. New inbred lines with greater hybrid vigor than was previously possible were consequently derived from the broadened gene pools (Table 4). Several improved open-pollinated populations were also synthesized from intercrosses among the new inbred lines (Opeña and Lo, 1981).

5 Although genetic resistance is not available in the new breeding lines, their early and rapid maturation from the onset of heading to harvest enables them to escape severe soft rot incidence (Opeña, Kuo and Yoon 1988).

Table 3 **Results of two cycles of recurrent selection for yield in Chinese cabbage**[z]

Population	Yield (t/ha)	Mean head weight (g)
B129 C1	33.1	750
B129 C1	35.7	787
Gain over C2	2.6*	37*
Predicted gain	—	31

[z]Adopted from (Opeña and Lo, 1981).
[y]Calculated from variance component analysis of population C1.
Predicted gain (g) = KspH where :
K = selection differential = 1.76 (for 10% selection intensity) ;
sp = $\sqrt{\text{total phenotypic variance for head weight}} = \sqrt{19{,}157}$;
H = heritability of head weight = 0.126.
*significant at P = 0.05

Although resistance to soft rot[5] was not improved to the best possible degree, a number of the new hybrids and open-pollinated populations offered better resistance to downy mildew and turnip mosaic virus than the local varieties (AVRDC, 1987).

3 **Sweet potato.** Breeding of scab-resistant clones has been initiated since 1985. Scab-resistant accessions GI 6 and GI 13, and cultivar V2-30 have been incorporated into the AVRDC's polycross nurseries (Opeña *et al.*, 1988). Using semi-natural field test and greenhouse screening, 11 highly resistant clones were identified from the initial batch of AVRDC breeding lines (AVRDC, 1989). Intensified screening of polycross progenies is now underway to combine scab resistance with other desirable characters such as high yield, high dry matter content, and acceptable eating quality.

With respect to the abiotic stresses, sweet potato is vulnerable to damage due to flooding, excess soil moisture and drought. AVRDC's crop improvement research into these stresses is still at the exploratory stage. Current efforts are in the development of screening methods and identification of elite germplasm. U number of important genetic resources for the major stresses are as follows : flooding tolerance-I 103 (PI 318848), I 103 (PI 318855) and I 423 (Tainan 17) ; excess moisture tolerance-I 597 (NG 7570), I 444 (Kinmen), I 549 (Piksin) and I 435 (Nakamurasaki) ; drought tolerance-I 444 (Kinmen).

Table 4 **Comparative head weight of F_{13} among local heat-tolerant Chinese cabbage cultivars and among heat-tolerant inbreds derived from intercultivar crosses**[z]

No. of crosses	Material	Head weight mean	Head weight range
		(g)	
45	F_{13} from 10-parent local cultivar diallel	403	316-494
80	F_{13} among inbreds from intercultivar crosses	708	468-972

[z]Adopted from (Opeña and Lo, 1981).

Improved germplasm for the tropics

Genetic manipulations to combine the requisite traits for tropical adaptation led to the development of many breeding lines that were widely tested in Taiwan and in many tropical countries. A significant portion of the screening and utilization of AVRDC's

Table 5 Official germplasm releases by national programs of AVRDC's horticultural crops (as of May, 1989)

Commodity	Number of countries	Number of distinct lines released
Chinese cabbage	6	12
Sweet potato	3	11
Tomato	26	61

improved breeding lines was made possible through informal scientist-to-scientist collaborations. AVRDC has also entered into official bilateral agreements with several countries, notably Philippines, Thailand, Indonesia, Malaysia, and Korea, which provide a steady conduit for the transfer of AVRDC's enhanced technology.

National programs world wide have released a number of AVRDC's improved germplasm in several occasions (Table 5). For tomato alone, 61 distinct breeding lines and/or germplasm have been released to vegetable farmers in 26 countries. The most advanced of these tropically adapted lines already combine several desirable features such as heat tolerance, multiple resistances to bacterial wilt, tomato mosaic virus, and root-knot nematode, and improved fruit attributes such as firmness, crack resistance, and attractive smooth shape.

Potential developments in the future

AVRDC research has successfully brought its horticultural crops to adapt reasonably well to the humid lowland tropics. Advanced breeding lines of tomatoes, Chinese cabbage and sweet potatoes resist one or more major diseases, are tolerant to hot wet conditions, and bear acceptable quality. Given these features, what may be expected of AVRDC's breeding lines of the future ?

With increasingly pressured environments brought about by burgeoning population, global changes in climate and marked reduction of farm inputs, the AVRDC breeding lines of the future will have to carry tolerances to more stresses than ever before.

In tomato, marked advances in the levels of disease resistance and in the range of diseases that the future breeding lines would be resistant to are expected. Progress in resistance breeding for the following diseases are forthcoming : potato virus Y, leaf curl virus, bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), and certain fungal diseases such as black leaf mold (*Cercospora fuligena*). Even resistances to the unwieldy viruses, such as CMV, and equally important insects like fruitworm and aphids, may be unravelled as the potential of hitherto unexploited wild *Lycopersicon* and *Solanum* germplasm is widely explored.

Heat tolerance (specific for hot dry condition), drought tolerance, tolerance of excess soil moisture or flooding, and even tolerance of poor soil fertility may have to be added into the physiological arsenal of the future tropical tomatoes.

There will also be a need to upgrade the quality of future tropical tomatoes, especially in the visible parameters of acceptability such as absence of cracks, reduced blotchy ripening, improved color, and increased longevity in transit and storage through better fruit firmness and/or inherently long shelf-life properties.

The feasibility of growing Chinese cabbage in the humid tropics has already been realized through AVRDC's heat tolerance breeding. Resolving the problems of softrot, tipburn and internal rot would make the cultivation of Chinese cabbage in the lowland tropics truly stable and economical.

Seed production has been the most important bottleneck in making the AVRDC's tropical Chinese cabbage cultivars widely popular in the tropics. The tropical climate does pose stringent technical limits ; however, current techniques have proven useful for seed production in the tropical highlands (Opeña *et al.*, 1988). Continuing exploration of cytoplasmic male sterility as an alternative hybridity scheme to self-incompatibility may yield viable results.

Future sweet potato clones from the AVRDC breeding program will be resistant to leaf scab and witches' broom, two of the most important diseases in tropical Asia and the Pacific, and to one insect pest, the sweet potato vineborer, for which resistance is now being bred. Hitherto, AVRDC entomologists have yet to find a stable genetic resistance to the sweet potato weevil ; nonetheless, the wild species and other untapped germplasm will be continually explored for weevil resistance. In tandem, AVRDC's research on integrated weevil control will continue and possibly, may even be expanded. Ideally, the future clones should also possess more and better tolerances to abiotic stresses like excessive soil moisture or flooding, drought and poor soil conditions.

The potential of sweet potato to improve human nutrition is still largely unexploited. Asians generally prefer cooked sweet potato with dry texture. Unfortunately, the high ß-carotene clones often have wet post-cooking texture. AVRDC research will continue to find the ideal combination between good nutritional score and quality for the benefit of those who most need more ß-carotene.

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