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Breeding Peppers to Resist Virus Diseases

Peppers (*Capsicum* spp. L.) are popular food items in our diet. Their rich flavor, aroma, spice, and pungency enhance hundreds of dishes and sauces of many ethnic groups. Peppers add color to food, help preserve food, have medicinal value, are an excellent source of vitamins A and C, and are low in caloric value.

Food Item of the New World

Peppers, members of the Solanaceae family, originated in South America in the region of southern Peru and Bolivia. *Capsicum annuum* may be found growing wild from the southern edge of the United States (Texas's chile piquin) to central Argentina. Peppers were cultivated by native peoples of America from Mexico through South America over 2,000 years ago.

Before Columbus's first voyage to the New World, peppers were unknown to the civilized world. One of the main purposes of the Columbus expedition in 1492 was to find new routes to spice-producing countries, such as India. The main spice commodity at that time was black pepper (*Piper nigrum*), which is not related to the American *Capsicum* spp. Black pepper, a valuable commodity, was used as a bartering item. Columbus's explorers felt great joy and amazement at their "discovery" of those small, very pungent, hot red "peppers" in the West Indies.

Later, many different types of sweet and hot peppers were discovered throughout Mexico and Central and South America. These were introduced into Spain, all of Europe, and eventually the Orient, where they became very popular, with each area developing its own type. Thus, peppers became the first New World food item commercially used in Europe (1,2,5,6). Pepper distribution throughout the United States followed a similar pattern. Some types were brought back from Europe but most traveled up from South and Central America and Mexico.

The most important cultivated pepper species of the Northern Hemisphere is *C. annuum*, with its center of domestication in Mexico (5,6). Another species grown commercially in the United States, Mexico, and Central America is *C. frutescens*. The world-famous Tabasco pepper is classified as *C. frutescens*. This small, pointed, extremely hot yellow pepper that turns red at maturity was imported from the Mexican state of Tabasco to Louisiana before the Civil War. About 16 other different pepper species have been identified (2). Five distinct species have been domesticated, and within these, the diversities of fruit shape, size, color, flavor, aroma, and pungency and of plant growth habit defy description. Some of these diversities are shown in Figures 1 and 2.

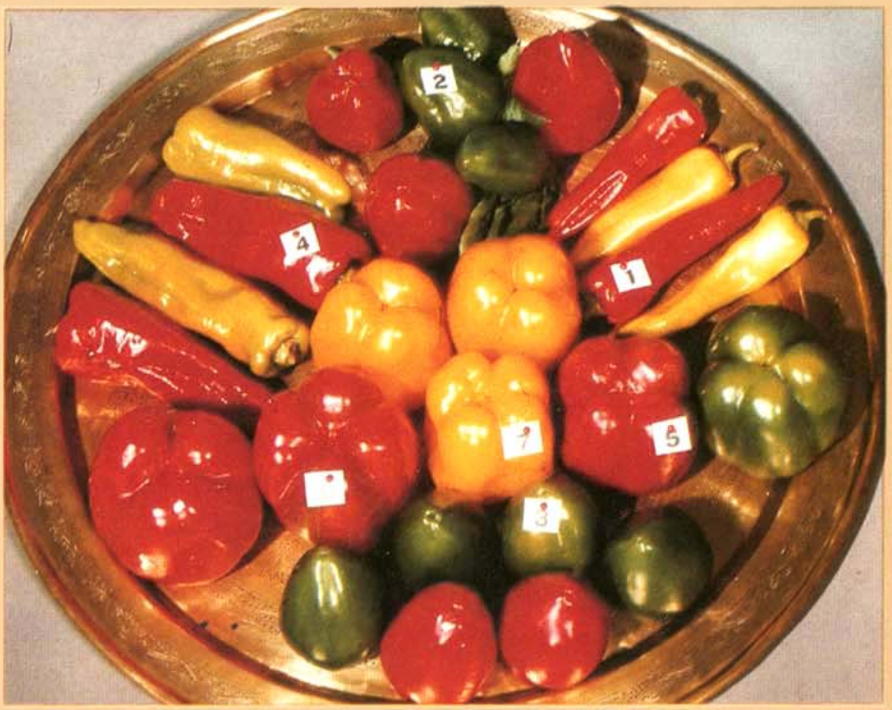

Fig. 1. Variations in size, shape, and color of fruit of sweet *Capsicum annuum* cultivars: (1) Sweet Banana, (2) Vinedale, (3) Pimiento, (4) Cubanelle, (5) California Wonder, (6) Keystone Resistant Giant, and (7) Golden Calwonder. (Courtesy Petoseed Co., Inc., Saticoy, CA)

Pepper Types and Names

Terminology in identifying pepper cultivars is confusing. The word "chile" or "chili" from the Mexican Indian Nahuatl tribe refers to any pepper and is used extensively in Mexico and Central America. The word "chile" in West Texas, New Mexico, Arizona, and California refers to a long (6–8 in.), mildly pungent green and/or red pepper pod. The term "chili peppers" or "chili" is used by most of the processing, dehydration, and seed industries. The product sold is chili powder. The words "chili," "chilli," and "chili pepper" are found in some European and U.S. literature and refer to any pungent pepper. In South America the term for peppers is "aji." "Pimiento" is Spanish for any pepper; "pimienton" is Spanish for ground red pepper powder. "Paprika" (Hungarian) is not a pepper cultivar but the dehydrated hot or sweet pepper that is powdered or crushed and used to add red to food (6). Peppers used for paprika contain high red pigment genes; pod shape varies considerably.

Knowledge of pepper types and names is important since multimillion dollar corporations depend on one or two specific types of pepper fruit. The Louisiana hot sauce industry thrives on

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Tabasco, Cayenne, and small yellow pickling types. The Texas "picante" (Spanish for hot) sauce and "escabeche" (pickling spiced juice) processing industry uses Jalapeno and Serrano peppers. The California and New Mexico chile industries use the long, mild green pod of the Anaheim Chile or New Mexico Chile for canning and the long red pod of the same cultivars for dehydrating into chili powder. The green and red sweet bell, Pimiento (heart-shaped), and Cherry peppers are used in the fresh market and processing industries for stuffing and pickling and in fresh salads, pizzas, meat loaves, and dehydrated processed meats.

Pungent peppers have gained international attention because of the heat chemical compound capsaicin formed in droplets in the placental tissues or scattered along the interlocular septa, or cross-wall portion, of the fruit (3). The pungent or heat effect on the touch receptors of the tongue and mouth is capsaicin's most outstanding property (12). Hot peppers, especially Jalapeno and chile, are the number one spice ingredient in Mexican-type cuisine. Mexican food is now the most popular ethnic food in the United States, partly because the Hispanic population is increasing but also because non-Hispanic segments of our population are using more spice and pungent peppers. This popularity has placed a heavy demand for Jalapeno, long green chile, Cayenne, and yellow pickling types, as well as for bell and Cherry types.

Economically, peppers are no longer considered a minor crop and have merited attention by the Texas Agricultural Experiment Station, California Agricultural Experiment Station, New Mexico State University, Louisiana State University, Florida Agricultural Experiment Station, Michigan State University, Auburn University, and many other public and private research agencies.

Table 1. Effects of four viruses on yield of six bell pepper cultivars

Cultivar breeding line	Source	Virus[y]	Tons/A	Percent yield reduction
7506	Texas Agricultural Experiment Station, Weslaco	Check	9.6 a[z]	...
		TEV	8.1 b	15.5
		TMV	7.0 c	27.7
		PMV	5.7 d	41.1
		PVY	4.8 d	50.5
Keystone Resistant Giant #3	Niagara Seeds, FMC Corporation, McAllen, TX	Check	7.7 a	...
		TEV	6.5 ab	14.5
		PMV	5.8 bc	23.9
		PVY	5.1 bc	33.5
		TMV	4.5 c	41.1
Lucky Green Giant	Eastern Seed Company, McAllen, TX	Check	8.4 a	...
		TEV	5.2 b	38.4
		TMV	4.2 bc	49.3
		PVY	3.7 c	55.7
		PMV	2.0 d	76.2
Delray Bell	University of Florida, Gainesville	PVY	6.7 a	+1.2
		Check	6.6 a	...
		TEV	6.3 a	4.6
		PMV	6.0 a	8.5
		TMV	3.5 b	46.7
VR-2	University of Florida, Gainesville	Check	6.4 a	...
		TEV	5.8 a	9.2
		PMV	3.3 b	48.0
		PVY	3.2 b	49.6
		TMV	2.9 b	54.3
Pip	Asgrow Seed Company, Weslaco, TX	Check	4.9 a	...
		PVY	3.6 b	27.1
		TMV	3.3 b	32.4
		TEV	3.3 b	33.6

[y]TEV = tobacco etch virus, TMV = tobacco mosaic virus, PMV = pepper mottle virus, PVY = potato virus Y.
[z]Figures followed by the same letter do not differ significantly according to Duncan's test at the 5% level of significance.

Table 2. Effects of four viruses on yield of Jalapeno M cultivar from two sources

Source	Virus[y]	Tons/A	Percent yield reduction
Petoseed Co., Inc., Saticoy, CA	Check	9.7 a[z]	...
	TEV	8.8 a	9.1
	TMV	5.6 b	42.3
	PMV	5.5 b	43.5
	PVY	4.8 b	50.4
Eastern Seed Company, McAllen, TX	Check	10.0 a	...
	TEV	6.5 b	35.2
	PVY	4.1 c	58.7
	PMV	4.1 c	59.1
	TMV	3.3 c	66.7

[y]TEV = tobacco etch virus, TMV = tobacco mosaic virus, PMV = pepper mottle virus, PVY = potato virus Y.
[z]Figures followed by the same letter do not differ significantly according to Duncan's test at the 5% level of significance.

The Problem of Virus Diseases

Virus diseases are an international problem of pepper production. Mosaic or viruslike symptoms on peppers were reported in the United States more than 55 years ago. Virus diseases damaging to peppers have been reported in Arizona, California, Florida, Hawaii, Iowa, Louisiana, New Jersey, and North Carolina and in several countries, including Brazil, Colombia, India, Israel, Japan, Korea, Mexico, and Puerto Rico (8,10,11).

There are approximately 36 different names for pepper virus diseases, but not all have been fully identified and characterized. Some are responsible for moderate to heavy losses annually in most pepper-growing areas; these include cucumber mosaic virus (CMV), pepper mottle virus (PMV) (Fig. 3), potato virus Y (PVY), tobacco etch virus (TEV) (Fig. 4), tobacco mosaic virus (TMV), and tobacco ringspot virus (TRSV). Occasionally, pepper crops are abandoned without harvesting in some of the major production areas in the southwestern United States.

Some pepper diseases caused by fungal or bacterial pathogens can be often controlled or prevented by use of chemicals, but no similar direct method for controlling pepper virus diseases is available. Evasive measures, such as using chemicals to control insect vectors, eliminating virus hosts, and changing cultural practices, have not been totally effective against pepper virus diseases. Overwintering host control has been economically effective in the Oxnard Plain and San Luis Rey Valley in California but has not been practiced elsewhere because pepper fields and host plants are so widely distributed. This is especially true in subtropic zones.

Resistance and immunity to pathogens can often be introduced into horticulturally acceptable cultivars from suitable wild types. Breeding for resistance provides the most feasible solution to controlling pepper virus diseases.

The Search for "New Genes"

Peppers, through the process of natural selection, probably originated thousands of years ago, but the greatest selection pressure by man originated over 485 years ago when Columbus took those small, hot red peppers back to Europe with him. The process of selection has been effective in the development of pepper types that no longer resemble their wild ancestors (5,6).

Genetic uniformity in pepper types has occurred through controlled breeding over the past 100 years. The attainment of fruit uniformity has, however, enhanced genetic recombinations in *C. annuum* that probably render it more susceptible than the wild types to insects and pathogenic organisms. Most cultivated pepper varieties developed under ideal conditions (chemical, insect, and disease control) for selection of desirable horticultural features only are unfortunately vulnerable when they lack sufficient genetic diversity to withstand stresses imposed by pests or unusual environmental conditions. The responses to these stresses may be expressed over a scale ranging from reduced productivity to complete loss. A case in point is the Lower Rio Grande Valley mosaic complex of bell pepper. These bell pepper cultivars were developed in and for other areas and are grown in South Texas. Yield losses of up to 100% are not uncommon (8–11). Tables 1, 2, and 3 show the effects of four viruses on yields of three pepper types. The Samsun latent strain of TMV was used in these experiments; most commercial bell peppers are not resistant to this strain.

About 16 distinct pepper species have been collected and studied. Eleven species are strictly wild, and the wild ancestral forms of most have been grown. Endless hours of hybridization studies at various research facilities revealed which species could be used for breeding purposes (1,2,5). Many pepper species have no recognizable commercial value.

Many "new genes" have been uncovered through screening procedures, but even in the popular species, the surface has just been scratched. The inventory of *Capsicum* germ plasm, maintained at the Southern Regional Plant Introduction Station at Experiment, Georgia, contains over 2,000 accessions representing most pepper species. This genetic material was obtained from over 50 countries. Most were introduced durng the past 30 years from Central and South America. European introductions are primarily cultivated *C. annuum* taken from this continent initially. Introductions from tropical America have the greatest diversity in species.

A vast array of both plant and fruit types can be found in this collection. Plant height ranges from 15 cm (extreme dwarf) to 130 cm. Maturity ranges from 65 to 180 days or longer. Fruits show myriad differences in size, shape, color, texture, flavor, aroma, and capsaicin level. The collection contains all commercial types, including bell, chile, paprika, Pimiento, Cherry, Cayenne,

Table 3. Effects of four viruses on yield of two chile cultivars from one source (Cal-Compack Foods, Inc., Santa Ana, CA)

Cultivar	Virus[y]	Tons/A	Percent yield reduction
New Mexico College 6-4	Check	8.5 a[z]	...
	TMV	4.6 b	45.4
	PMV	4.3 b	49.5
	PVY	4.1 b	51.8
	TEV	4.1 b	52.2
Anaheim Mild	Check	6.8 a	...
	TEV	3.9 b	43.6
	TMV	3.6 b	48.1
	PMV	2.9 b	58.0
	PVY	2.8 b	58.7

[y] TEV = tobacco etch virus, TMV = tobacco mosaic virus, PMV = pepper mottle virus, PVY = potato virus Y.
[z] Figures followed by the same letter do not differ significantly according to Duncan's test at the 5% level of significance.

Table 4. Eleven pepper meetings held since 1973

Date	Type[z]	Site	Coordinator	Attendance
May 1973	NPC	Weslaco, TX	B. Villalón, Texas Agricultural Experiment Station	120
January 1975	NPC	West Palm Beach, FL	T. A. Zitter, University of Florida	110
September 1976	NPC	Davis, CA	P. G. Smith, University of California	110
January 1977	ICGRC	Las Cruces, NM	J. Croft, New Mexico State University	250
June 1977	TPC	Weslaco, TX	B. Villalón, Texas Agricultural Experiment Station	130
January 1978	ICGRC	Las Cruces, NM	J. Croft, New Mexico State University	150
June 1978	TPC	Weslaco, TX	B. Villalón, Texas Agricultural Experiment Station	130
September 1978	NPC	Baton Rouge, LA	L. L. Black, Louisiana State University	105
January 1979	ICGRC	Las Cruces, NM	J. Croft, New Mexico State University	150
December 1979	TPC	Weslaco, TX	B. Villalón, Texas Agricultural Experiment Station	150
September 1980	NPC	Las Cruces, NM	R. Nakayama, New Mexico State University	200

[z] NPC = National Pepper Conference, ICGRC = International Connoisseurs of Green and Red Chile, TPC = Texas Pepper Conference.

Fig. 2. Variations in size, shape, and color of fruit of hot *Capsicum annuum* cultivars: (1) Anaheim Select, (2) Serrano, (3) Jalapeno, (4) Red Cherry Small, (5) Floral Grande, (6) Fresno Chili, (7) Cayenne, (8) Hungarian Hot Wax, (9) Red Chile, and (10) Roumanian Medium Hot. (Courtesy Petoseed Co., Inc. Saticoy, CA)

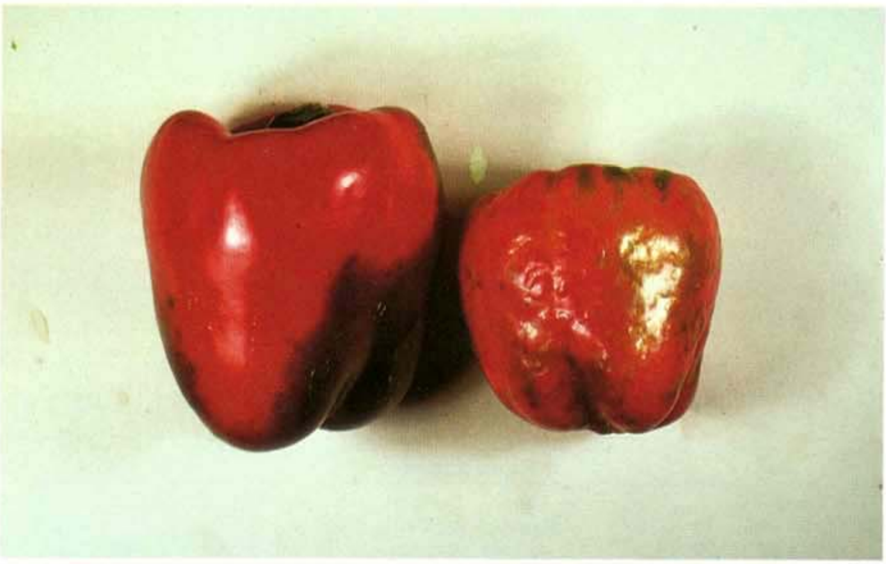

Fig. 3. Bell pepper fruit with typical symptoms of pepper mottle virus (right) compared with uninfected fruit.

piquin, yellow, Tabasco, Ancho, Jalapeno, and Serrano. Several introductions, because of their attractiveness, are classified simply as upright, small ornamentals. This collection of germ plasm provides a broad base of genetic material and is available to all pepper breeders. Sources of information with respect to other diseases can also be obtained from the PI Station.

Much effort has been directed toward locating genes conferring resistance to several diseases. Excellent sources of resistance to bacterial leaf spot have been found. Several collections from Mexico are resistant to Phytophthora root rot. Root-knot nematode (*Meloidogyne* spp.) resistance is also available. TMV was one of the first viral diseases for which natural genetic resistance was demonstrated in peppers. Resistance to virus diseases is very complex because of the different strains found for each virus. Nevertheless, high levels of resistance to TEV, PVY, PMV, and CMV have been discovered in *C. annuum*, *C. chinense*, *C. frutescens*, and several wild and primitive peppers from Texas and Mexico. These have been and are now being utilized in breeding programs by researchers (8,10,11).

Many other useful genetic traits have been observed but not utilized with complete success. These include deciduous calyx, male sterility, high capsaicin levels, high yields, early maturation, evergreen genes, easily removable pods for machine harvesting, and concentrated set of uniform maturity.

Communicating Research Data

Rapid dissemination of pepper research information was stimulated at the national level in 1973 by the National Pepper Conference at Weslaco, Texas, followed by the California Pepper Improvement Foundation at Davis, the International Connoisseurs of Green and Red Chile at Las Cruces, New Mexico, Texas Pepper Foundation conferences at Weslaco, and, in 1980, the New Mexico Chile Improvement Foundation, Las Cruces (Table 4). In 1975, Pickle Packers International organized the National Pepper Research Steering Committee to coordinate research efforts in all discipline areas and to serve as a check for these organizations. The committee notifies people interested in peppers of a particular meeting, conference, or latest research breakthrough.

A survey to coordinate pepper breeding aspects at a national level produced surprising results. Of the 21 replies, 14 were considered actual breeding programs and 7 were considered variety testing and evaluation efforts. The number one objective of 11 of the 14 breeding projects was to incorporate virus-resistant genes into commercial types; only five are currently working with known virus cultures. Of the 70 active pepper research projects in the United States listed in the Current Research Information Service (CRIS) report, only six were considered breeding programs; the list was incomplete and failed to identify several known active breeding programs.

The international picture is still very incomplete. About 10 research scientists in Mexico are working on peppers but not on virus diseases; two are considered breeders. The 2nd and 3rd Eucarpia Pepper conferences held in 1974 and 1977, respectively, drew many pepper researchers from throughout Europe. The 4th Eucarpia Conference was held in 1980 in Holland.

The Breeding Program at Weslaco

Peppers, one of the most profitable and most expensive to produce crops in Texas, are grown on 9,000–15,000 acres during the year and have a value of more than $25 million at the grower level. At present, estimated production costs per acre range from $300 in the high plains around Muleshoe to $900 in the Lower Rio Grande Valley; these figures do not include harvest and transportation costs. The acreage for sweet bell peppers has increased only slightly during the past 10 years. Pungent (hot) peppers (Jalapeno, Serrano, Cayenne, Tabasco, Cherry, Floral Gem, long green chile, and paprika types) have gained rapidly in popularity in Texas and throughout the United States. The rising cost of the Mexican imported product (due to decreased production in other countries) and the expanding U.S. market have stimulated interest in domestic production centered in Texas.

Production and yields vary considerably among areas and seasons because of adverse weather conditions, insects, and the effects of a complex of virus diseases. Yield losses may be total during severe virus epiphytotics in all major production areas. Virus epiphytotics in the Lower Rio Grande Valley may occur in the spring or fall and are highly unpredictable (8–11).

The virology-breeding program at Weslaco was initiated in January 1971. Specifically, initial steps were taken to readily identify virus diseases on sweet bell peppers. Field disease surveys throughout the pepper-growing areas, host range studies, phytoserological techniques, and diagnostic electron microscopic research indicated that TEV, PVY, TMV, CMV, TRSV, and PMV were involved in the Lower Rio Grande Valley mosaic complex of peppers. Over 100 commercial bell pepper varieties were found to be susceptible to local strains of all these viruses (8).

By the summer of 1971, we had received different pepper stocks known to possess a degree of resistance or tolerance to some of these viruses. Among those contributing lines for our virus screening program were: Paul G. Smith of the University of California at Davis; Hiroshi Nagai of São Paulo, Brazil; A. A. Cook of the University of Florida at Gainesville; Tom A. Zitter of the University of Florida at Belle Glade; Walter H. Greenleaf of Auburn University; Everett Wood of Cal-Compack Foods, Inc., Santa Ana, California; Andy Carrillo of Universal Foods, Salinas, California; Shigemi Honma of Michigan State University at East Lansing; and Grover Sowell, Jr., of the USDA-ARS Southern Regional Plant Introduction Station at Experiment, Georgia. The greatest diversity of genetic materials was obtained from the PI Station.

With a simple artist airbrush method, 30- to 40-day-old pepper seedlings were inoculated with local TEV isolates (8). Virus-resistant plants from 13 different exotic germ plasm stocks were selected for crossing to commercial bell pepper cultivars. F_1 hybrids were planted by February 1972, and F_2 populations were screened for virus resistance in the fall. It became readily apparent that high levels of resistance to TEV were being identified in the more pungent, pointed, primitive pepper types. A virus-resistant large, four-lobed sweet bell line was never recovered from the first cross, but virus-resistant sweet bell lines were developed by the backcross method. These lines are now being crossed with each other to obtain higher levels of resistance. The genes appear to act in an additive fashion. A spin-off of the hot virus-resistant segregates has been the development of other pepper types such as the Jalapeno with different pungency levels, long green and red chile, Serrano, Ancho, Pimiento, Cherry, yellow pickling, and paprika types.

Once homozygous resistance to TEV is established in F_3 lines, F_4 lines are screened for resistance to PMV, PVY, and TMV. F_5 lines with high levels of resistance to all four viruses are entered in observational yield tests. Advanced F_6 lines are included in replicated statewide tests. Promising lines are isolated for seed increase. The objective is to release adapted cultivars with resistance to multiple virus diseases and with desirable horticultural characteristics.

Three Important Releases

Research efforts have yielded many types. The most difficult part of the breeding effort is the total evaluation of a particular line. Attributes indigenous to processing quality and acceptance—color, texture, flavor, pungency, vitamins A and C, aroma, capsaicin level and distribution, extractability of red pigment, etc.—are rapidly being identified and quantified (3,4,7,12). We are using these data to delineate superior cultivars for increased commercial acreage in Texas.

Three important types of peppers were released to the industry in December 1979: bell 76004 (Fig. 5A), a sweet pepper on a short, compact plant; long green chile 76042 (Fig. 5B), a mildly pungent, high-color pepper; and mild Jalapeno 7585 (Fig. 5C), a mildly pungent, high-yielding

Fig. 4. Typical symptoms of tobacco etch virus on bell pepper foliage.

Benigno Villalón

Dr. Villalón is an associate professor of plant pathology at the Texas Agricultural Experiment Station, Weslaco. His interests are in vegetable virus diseases, with emphasis on development of multiple-virus-resistant hot and sweet pepper cultivars through screening and hybridization. He received a B.S. degree in agronomy in 1964, a master's degree in plant breeding in 1965, and a Ph.D. in plant pathology-virology in 1969—all from Texas A&M University. Before initiating the pepper virology-breeding program at Weslaco in 1971, he was responsible for tomato and strawberry breeding programs at the University of Florida in Homestead. He is also involved in research on virus diseases of sugarcane, sweet sorghum, grain sorghum, and corn in South Texas.

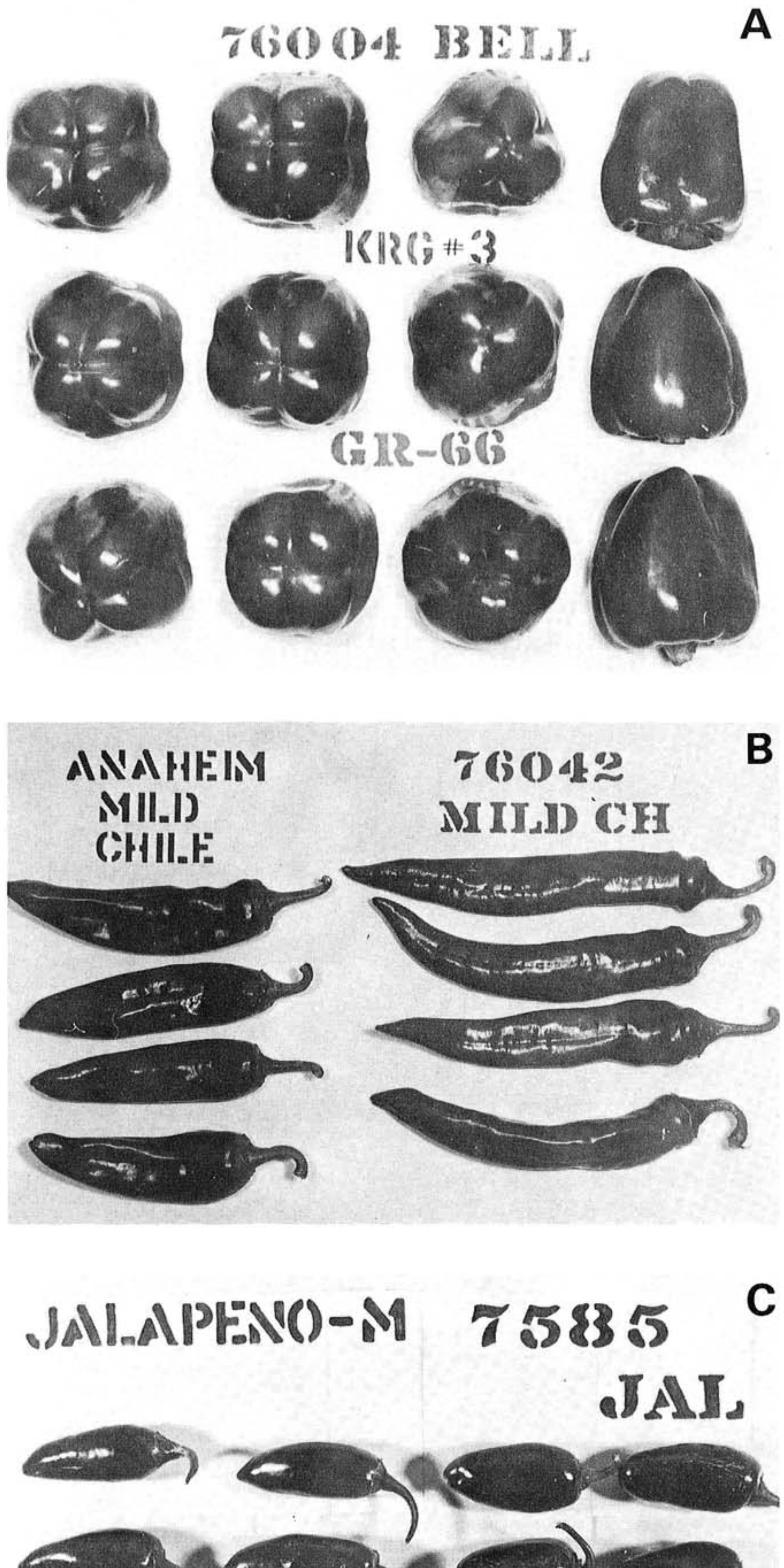

Fig. 5. Virus-resistant pepper lines released to the industry in December 1979 compared with commercial types: (A) bell 76004, (B) long green chile 76042, and (C) mild Jalapeno 7585.

pepper, now named Tam Mild Jalapeno-1. All possess resistance to South Texas strains of TEV, PMV, PVY, and TMV.

Our data indicate that these new peppers have good potential for future varieties for South Texas. As with any biological plant material, however, performance will vary from season to season and area to area in response to different weather, soil conditions, cultural practices, and virus strains; the existence of different strains of these viruses in various locations cannot be ignored. For these reasons, the new peppers should be tested under limited commercial conditions for several seasons. Before planting their entire acreage to one of these new peppers, growers should determine how the variety performs on their soils and with their cultural practices. The ultimate step—processor evaluation and consumer acceptance—must be taken by the industry itself.

Acknowledgments

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