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Disease resistance in protected crops and mushrooms

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Summary

Cultivars of tomatoes, cucumbers, lettuce and peppers have been bred for resistance to one or more pathogens. Some tomato and cucumber cultivars have resistance to a wide range of diseases. Resistance has been transient in many cases and a succession of cultivars with new genes or new combinations of resistance genes has been necessary to maintain control. There has been a number of notable exceptions and these have included durable resistance to such pathogens as *Fulvia fulva* and tomato mosaic virus. With lettuce the resistance situation is complicated by the occurrence of fungicide resistant pathotypes. There are no strains of *Agaricus bisporus* purposely bred for disease resistance.

In protected flower crops only resistance to Fusarium wilt in carnations has been purposely bred but differences in disease resistance are apparent in cultivars of many ornamental crops. This is particularly so in chrysanthemums where there are cultivars with resistance to many of the major pathogens. Similar situations occur with other flower crops and pot plants. Cultivars of some species have not been systematically investigated for resistance.

The need for genetic resistance will increase with the further reduction, in the limits on pesticide use and an increasing public awareness and importance of pesticide pollution.

Introduction

Production of crops in glasshouses and in mushroom sheds was well established in the UK at the beginning of the century. A great diversity of crops were grown including some vegetables, flowers and even fruits such as peaches and grapes. During the two world wars there was an emphasis on food production and many flower growers were compelled to grow tomatoes. In the 1960's plastic covered structures were developed and are now a substantial part of protected cropping in England and Wales. Throughout this entire period the tomato crop has been the most widely grown. The total area of commercial glasshouses and protected structures has remained more or less constant for some time, at around 2,200 ha. The total gross value of all protected crops at present is about £556 m which, put in the perspective of the more major crops grown, is about a third of the value of the wheat crop. Relative values and areas of the type of protection and of the individual crops (Tables 1, 2, 3) show that mushrooms have the largest gross value followed by tomatoes. Pot plants are the most valuable ornamental crop overall, but

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Table 1. Areas (ha) of protected crops in England and Wales 1991

Tomato		Chrysanthemum AYR+	72
heated	413	Pots	20
unheated	157	Other	150
Cucumber	213	Pinks	20
Lettuce	1455	Carnation	10
Celery	158	Alstroemeria	21
Sweet Pepper	70	Rose	12
Mushroom	549	Pot plants	173

+ All-year-round.

chrysanthemums have the highest value of the cut flowers.

This background gives some indication of the commercial relevance of protected cropping in relation to other crops and explains to a large extent why companies developing disease resistant cultivars or pesticides, cannot afford to embark on expensive research programmes for the UK industry alone. Even taken on a European or global scale it is financially debatable whether large expenditure can be justified on the development of disease resistance in cultivars of many protected crops.

It is therefore not surprising that there are relatively few cultivars that have been bred specifically for disease resistance that are available to growers of protected crops. The exception is the tomato, where there are many cultivars with resistance to a range of pathogens. Lettuce, cucumbers and peppers have been bred with resistance to one or more pathogens. Even where resistance has been introduced, it is not always present in acceptable cultivars. In protected ornamental crops, which include various cut flowers and pot plants, almost no cultivars have been bred especially for disease resistance. The exception is the carnation where resistance to Fusarium wilt (*Fusarium oxysporum* f. sp. *dianthi*) has been bred into cultivars which are now widely used.

Table 2. Area (ha) of types of protected cropping in England and Wales 1991

Glass	heated	1,451.7
	unheated	299.7
Plastic	heated	99.4
	unheated	320.5
Total		2,171.3

During the past twenty years there have also been major changes in methods of crop culture which have influenced the spectrum of diseases which occur in protected crops and therefore the grower's requirements. By far the biggest change has been the move out of the soil for crops such as tomatoes, cucumbers, peppers and pot plants into inert media such as rockwool or perlite, and in the case of pot plants into peat and peat/bark composts. The importance of some soil-borne diseases of protected vegetable crops has decreased as a result of this change and disease resistance requirements changed with it.

Fuel crises and the development of greater precision in the control of the environment have resulted in growers being able to control temperature and relative humidity more precisely. In this way some air-borne fungal pathogens have been successfully controlled without genetic resistance or fungicides. Conversely, other factors have increased the need for resistant cultivars, such as the development of fungicide resistant strains and the increasing restriction on the use of pesticides. Overall the size of the market for disease resistant cultivars will always determine the financial input into disease resistance breeding, which is likely to be concentrated on those crops which are grown world-wide and by the companies who have world wide sales of their propagation material.

Table 3. Gross values of protected crops in England and Wales 1990

Crops	Values in £M
Mushrooms	173.7
Tomato	90.4
Lettuce	36.2
Cucumber	43.7
Celery	5.0
Sweet pepper	2.6
ornamentals	199.9
Total	551.5

Tomato

In 1949 there were 1,380 ha of protected tomatoes in England and Wales, producing some 112,000 t of tomatoes (Hitchins, 1951), equivalent to about 81 t ha^{-1}. Maximum yield at this time would have been about 144 t ha^{-1}.

In 1990 there were 570 ha producing approximately 138,800 t equivalent to about 243 t ha^{-1}. Maximum yields are now near to 450 t ha^{-1}. Yield from the best crops and per hectare has more than trebled over the 43 year period and some of this increase is attributable to better disease control which is partly because of the development of disease resistant cultivars. Resistance is available to a range of pathogens as well as to root know nematodes (*Meloidogyne incognita*) and many cultivars have combined resistance to many of these (Table 4). The use of resistant cultivars has resulted in reduced fungicide use and some of the previously common diseases have become very uncommon, eg. Fusarium wilt (*F. oxysporum* f. sp. *lycopersici*) and Verticillium wilt (*V. albo-atrum, V. dahliae*), leaf mould (*Fulvia fulva*) and tomato mosaic. Root disease caused by *Pyrenochaeta lycopersici* is also less common, not because of resistance but because of the change in cultural practice away from the soil to the use of synthetic substrates or nutrient film. In 1973 it was estimated that 10–21% of the crop was lost annually due to tomato mosaic, leaf mould, Fusarium and Verticillium Wilt (Fletcher, 1973). In 1990 it is likely that losses from these diseases are insignificant and this is almost entirely due to the universal use of resistant cultivars. In addition to savings on lost yield, growers now spend no money on fungicides to control these diseases.

Tomato mosaic (Tomato mosaic virus, ToMV). The majority of tomato cultivars commercially cultivated are resistant to ToMV, once the most common and damaging disease of the crop (Fletcher, 1973). Resistance is largely dependent upon the gene *Tm*-2^2 which is the major source of resistance in the majority of cultivars. The first TMV resistant cultivars depended upon the gene *Tm*-1 alone but these remained resistant for a very short period, in some cases less than 6 months (Pelham, Fletcher & Hawkins, 1970). The use of *Tm*-2^2 either in combination with *Tm*-1 and *Tm*-2 or alone, has given durable resistance for more than 20 years. Although resistance breaking strains have been reported (Hall & Bowes, 1979) they have not become established in crops. There are only two records in the UK of such strains and both were from Sussex (1975 and 1976 respectively). At this time, resistant and susceptible cultivars were grown, often together. Cross protection of susceptible cultivars using an avirulent strain of the virus MII-16, was also practised (Rast, 1972). The predominant cultivar was Sonato (claimed to be homozygous for *Tm*-2^2) and the resistance breaking strain, although able to propagate in this cultivar, did so very poorly and spread within the affected crop was slow. By removing the diseased plants, the disease was totally arrested, a measure which would have had no noticeable effect on the rate of spread of the wild-type strain in susceptible cultivars. Similar resistance-breaking strains occurred at the same time in the Netherlands but since then there have been no further records. ToMV remains a problem and cross protection by mild strain inoculation is used where the susceptible cherry cultivar Gardeners Delight is grown.

Occasionally ToMV resistant cultivars have been grafted onto ToMV susceptible rootstocks which have become infected. The *Tm*-2^2 resistant scion cultivar develops severe distortion of the foliage and extensive necrosis of the fruit. ToMV resistant roodstocks (Hires and Signaal) are now available for graft combinations with *Tm*-2^2 resistant scions.

In early experiments with grafted plants it was shown that inoculation of a *Tm*-0 host with strain O, purified by single lesion transfer, grafted to cultivars with resistance genes *Tm*-1, *Tm*-2, *Tm*-1 + *Tm*-2 and *Tm*-2^2 with each genotype represented in a single graft combination, resulted in the recovery of strain 0 from the *Tm*-0 inoculated component, strain 1 from the *Tm*-1 component, strain 2 from *Tm*-2 and 1 : 2 from *Tm*-1 + *Tm*-2. No new strains were recovered from the *Tm*-2^2 component. The *Tm*-2^2 host showed necrosis and stunting which is considered to be a resistant reaction (McNeil & Fletcher, 1971; Hall & Bowes, 1979).

Table 4. Disease resistance in Tomato cultivars

Cultivar	Diseases						
	M	LM	FW	VW	FC & RR	B & CR	RK
2101	+	C5	F2	+	+	–	–
Abunda	+	C5	F2	+	–	–	–
Account	+	C5	F2	+	–	–	–
Angela	+	C3	F1	+	–	–	–
Arasta	–	C2	–	–	–	–	–
Astrid	+	C5	F2	+	+	–	–
Belcanto	+	C5	F2	+	–	–	+
Blizzard	+	C5	F2	+	–	–	–
Calypso	+	C5	F2	+	–	–	–
Cantatos	+	C5	F2	+	–	–	–
Carusa	+	C5	F2	+	–	–	–
Castel	+	C5	F2	–	–	–	+
Cheresita (FL52)	+	–	–	–	–	–	+
Choice	+	C5	F2	+	+	–	–
Concord	+	C5	F2	–	–	–	–
Concreto	+	C5	F2	–	–	–	–
Cossack	+	C5	F2	–	–	–	–
Counter	+	C5	F2	+	–	–	–
Criterion	+	C5	F2	+	–	–	–
Curabel	+	C5	F1	+	–	–	–
Dombella	+	C5	F2	+	–	–	+
Dombito	+	C2	F2	–	–	–	–
Duranto	+	C5	F2	–	–	–	–
Duro	+	C5	F1	+	–	–	+
Else	+	C5	F1	+	–	–	–
Estafette	+	C5	F1	+	–	–	+
Evita	+	–	–	–	–	–	+
Fianto	+	C5	F2	–	–	–	–
G's D'lit	–	–	–	–	–	–	–
Goldstar	+	C5	F2	+	–	–	–
Kontiki	+	C5	F2	+	–	–	–
Larganto	+	C2	–	–	–	–	–
Larma	+	C2	F2	–	–	–	–
Laura	+	C2	F2	+	–	–	–
Liberto	+	C5	F2	+	–	–	+
Libra	+	C5	F2	+	+	–	–
Lingano	+	C4	F2	–	–	–	–
Locanda	+	C4	F2	–	–	–	–
Lotus	+	–	F2	–	–	–	–
Mammoth	+	–	F2	–	–	–	–
Manhattan	+	–	F2	–	–	–	–
Marathon	+	C5	F2	+	–	–	–
Marcanto	+	C5	F2	–	–	–	–
Meltine	+	C2	F2	+	–	–	+
Mercator	+	C5	F2	+	–	–	–
Monza	+	C3	F1	–	–	–	–
Nomato	+	C5	F1	+	–	–	+
Ostona	+	C5	F1	–	–	–	–
Pannoy	+	C5	F2	+	–	–	–
Perfecto	+	C5	F2	–	–	–	–
Pinto	+	–	F1	+	–	–	–
Piranto	+	C5	F2	–	–	+	–
Portanto	+	C5	F2	–	–	–	+
Primato	+	C5	F2	+	–	–	–
Pronto	+	C5	F2	+	+	–	+
Rainbow	+	C5	F2	–	–	–	–
Red Ensign	–	C5	–	–	–	–	–
Restino	+	C5	F2	+	–	–	+
Rimini	+	C2	F2	+	–	–	+
Rocco	+	C5	F2	–	–	–	–
Samoa	+	C5	F2	+	+	–	–
Santana	+	C4	F2	–	–	–	–
Shirley	+	C3	F2	–	–	–	–
Sierra	+	C3	F1	–	–	–	–
Small Fry	–	–	F1	+	–	–	+
Sonatine	+	C5	F2	–	–	–	–
Sonato	+	C2	F1	–	–	–	–
Spectra	+	C5	F2	+	–	–	–
Supsweet 100	–	–	F1	+	–	–	–
Tahiti	+	C5	F2	+	–	–	–
Tipico 2055	+	C5	F2	+	+	–	–
Trend	+	C5	F2	+	+	–	–
Turbo	+	C5	F2	+	–	–	–
Typhoon	+	C5	F2	+	–	–	–
Vendettos	+	C5	F2	–	–	–	–
Virosa	+	C5	F2	–	–	–	–
Wiranto	+	C5	F2	–	–	–	–

M = Tomato Mosaic Virus; LM = Leaf mould (*Fulvia fulva*); C = Resistant to groups of races of *Fulvia fulva*; FW = Fusarium wilt (*F. oxysporum* f. sp. *lycopersici*); F = Resistance to races 1 or 2; VW = Verticillium wilt (*V. albo-atrum* & V. Dahliae); FC & RR = Fusarium crown and root rot (*F. oxysporum* f. sp. *radicis lycopersici*); B & CR = Brown and corky root (*Pyrenochaeta lycopersici*); RK = Root knot (*Meloidogyne incognita*); – = susceptible; + = resistant; G's D'lit = Gardener's Delight; Supsweet = Supersweet.

Similar necrosis had been reported by Cirulli & Alexander (1969) who found it to occur more commonly at high temperatures. Hall & Bowes (1979) showed that repeated transfer of ToMV (strain 0) through *Tm*-2^2 hosts increased the amount of systemic necrosis and they speculated that ToMV types could evolve which were capable of producing high levels of systemic necrosis in homozygous *Tm*-2^2 plants, at normal temperatures. They concluded that the strains from the two UK outbreaks on Sonato and similar strains from The Netherlands were not strictly strain 2^2 because they induced partial hypersensitive reactions and lacked the high transmissibility of ToMV on non resistant hosts.

The reactions of 52 cultivars, many with breeders numbers, to the two resistance breaking strains from Sussex, were tested by sap inoculation of the cotyledons. Three of the 52 cultivars showed typical ToMV symptoms, with mosaic and leaf narrowing. Two of these were known to be universally susceptible but the third, 1315/72, was claimed to have *Tm*-1 and *Tm*-2^2 resistance genes (Leo van den Berkmortel, Bruinsma Seeds, personal correspondence). Previous tests with strains 0, 1, 2 and 1.2 had shown 1315/72 to be resistant to these. Five cultivars showed no symptoms at all including Pagham and Kirdford Cross and all were claimed to have all three resistance genes. The remaining cultivars showed stunting and mottling of the leaves with pale green and dark green blotches. Leaves developing after inoculation were twisted and puckered but not reduced in width. Occasional necrotic flecks occurred in some of the youngest leaves. The plants grew only slowly but new leaves were less severely distorted, and developed a mild mosaic. Thus, with the exception of 1315/72, the cultivars tested which were claimed to have *Tm*-2^2 behaved in a somewhat resistant way to the two Sussex isolates obtained from a *Tm*-2^2 host. The behaviour of 1315/72 cannot be explained as it appeared to be resistant to strains with virulence for *Tm*-1 and *Tm*-2 but did not show the necrotic reaction when inoculated with the ToMV isolates from Sonato.

When typed on Pelham's isogenic differentials the Sussex isolates behaved as strain 1 (Pelham 1968) with the *Tm*-2^2 line showing some necrosis as it does with many isolates of strains 0 and 1. Fraser (1990) commented that the resistance breaking isolates of ToMV capable of overcoming the *Tm*-2^2 gene appear to be defective in their ability to establish on *Tm*-2^2 resistant plants. It is remarkable that resistance to such a virus as ToMV with its well known variation has remained effective for such a long time. The results of the earlier grafting experiments gave a clear indication of the ease of breakdown of *Tm*-1 and *Tm*-2 host resistance but also of the durability of the *Tm*-2^2 gene even when subjected to the extreme pressure of graft contact with an infected susceptible host.

Leaf mould. Many of the currently grown tomato cultivars have resistance to all five race-groups of *Fulvia fulva* (Hubbeling, 1971). These groups enable cultivars to be classified but may not give a clear indication of the resistance genes present, particularly if modifying genes are involved (Table 5). The early use of leaf mould resistance genes met with limited success and were fairly rapidly overcome. In Europe, cultivars with the combination of two genes (*Cf*-2 and *Cf*-4) became available in the 1960's and in spite of the fact that individually these genes were no longer useful, the combination remained effective for a number of years. From 1967 onwards effectiveness began to decline but the *Cf*-2 and *Cf*-4 gene combination continued to give good resistance in the UK up until the early 1980's. *Cf*-5 was introduced in 1975 and race-5 (group D) overcame this resistance in Belgium in 1976 and soon

Table 5. Race classification for *Fulvia fulva* on tomatoes

	Race groups				
	A	B	C	D	E
Virulence genes	1	4	2.4	5	2.3.4.5
	2	1.4	1.2.4		
	3	3.4	2.3.4		
	1.2	1.3.4	1.2.3.4		
	1.3				
	2.3				
	1.2.3				

(after Hubbeling, 1971).

afterwards a complex race R.2, 3, 4, 5 (group E) appeared in The Netherlands. Surveys of races in the UK indicated that virulence to *Cf*-5 lines was also present. But the resistance of the then commonly cultivated cultivar Sonatine remained effective against all races (Hall, Glasshouse Crops Research Institute, Littlehampton, personal communication).

Leaf mould in commercial tomato crops is now an unusual disease and is restricted to those crops that have no genetic resistance. Only cherry tomato growers and amateurs have a problem. Very few, if any, growers use fungicides to control this disease. The resistance genes in cv Sonatine and its successors, designated C5 by the seed suppliers, have therefore been very durable in spite of strains of the pathogen being recorded that can overcome the resistance genes individually. Perhaps, because of very low disease levels, cultivars have not been subjected to high selection pressure, and the use of fungicides to control other diseases especially in unheated crops may also have affected the development of epidemics of virulent strains of *F. fulva*. Recent analysis of the virulence patterns of strains has not been done and an explanation of the durability of leaf mould resistance has not been reported.

Vascular wilt pathogens. Many tomato cultivars are resistant to *Fusarium oxysporum* f. sp. *lycopersici* races 0 and 1 (American nomenclature races 1 and 2) (Gabe, 1975) to *Verticillium albo-atrum* and *V. dahliae* and more recently to *F. oxysporum* f. sp. *radicis lycopersici.* Since their use, Fusarium and Verticillium wilt diseases have been rare in the UK. There have been a number of reports of apparent breakdown of Fusarium resistance (Hall & Bowes, 1979) but none has been confirmed as due to resistance breaking strains. Infection has been attributed to incomplete resistance or exceptional cultural conditions which have allowed avirulent isolates to colonise the vascular system. Paternotte (1991) was able to infect two Verticillium resistant cultivars with a strain of *V. albo-atrum* found in Holland. This is the first report in Europe of a Verticillium resistance-breaking strain.

In 1988 *Fusarium oxysporum* f. sp. *radicis lycopersici* was found in the UK (Hartman & Fletcher, 1990) and is currently confined to the south of England. The use of new resistant cultivars in 1991 gave complete control and in 1992 growers had a choice of eight such cultivars.

Other tomato pathogens. Resistance is available to *Pyrenochaeta lycopersici* in a limited number of cultivars. But due to the development of soil-less systems the disease has become less important and because of their relatively poor yield these cultivars have never become well established in the UK. Even in soil, they have not yielded as well as susceptible cultivars grafted onto resistant rootstocks or grown in soil treated with dazomet or methyl bromide. However, it is likely that they would outyield susceptible cultivars growing in untreated, infested soil.

The two major diseases of the protected tomato crop where resistance is not available, are powdery mildew (*Erysiphe* sp.) and grey mould (*Botrytis cinerea*). At present powdery mildew is the one disease for which early season growers use fungicides, whereas *Botrytis* tends to be more of a problem in later unheated crops. It appears that there is little prospect at present of the development of cultivars resistant to either of these pathogens.

Disease resistance breeding of protected tomatoes has had considerable success and this has contributed to yield increases, and also to a reduction in the use of fungicides. Unfortunately, the occurrence of powdery mildew means that some growers must still use fungicides in order to obtain disease control.

Cucumber

Like tomatoes, cucumbers have been bred with resistance to a number of pathogens.

Leaf spot and gummosis. The earliest record of a disease resistant cultivar of any protected crop in the UK is that of Butcher's Disease Resister (BDR), a cucumber resistant to Cercospora Leaf Spot (*Corynespora cassiicola* syn. *Cercospora melonis*). This cultivar was selected by a grower, Mr

Butcher, from a crop which was affected by Cercospora Leaf Spot, a disease which threatened to eliminate the cucumber crop in the Lea Valley between 1896–1907. Following the introduction of BDR in 1907 Cercospora Leaf Spot declined and has been an insignificant problem since. There have been isolated outbreaks on susceptible cultivars (Green, 1932) but the disease has not been seen in commercial cucumber crops for many years. Most, if not all, modern cultivars are resistant to this disease and many may have the original BDR resistance. Little appears to be known about the genetics of resistance although it has been suggested that a single dominant gene is involved (Abdul-Hayja et al., 1978).

Although most modern cultivars are thought to be resistant to Cercospora Leaf Spot, only a relatively small number make claim for this resistance (Table 6). The same is also true for gummosis or scab (*Cladosporium cucumerinum*). Gummosis was occasionally a devastating disease in the 1960's but is now rare (van Steekelenburg, 1986). These two diseases, because of effective genetic resistance which is controlled by single dominant genes (Walker, 1950; Abdul-Hayja et al., 1978) have been uncommon in commercial crops for at least 25 years. There is the danger that they may be forgotten not only by the growers but also by the seed trade. It is to be hoped that plant breeders continue to include them in their screening trials.

Fusarium wilt. Fusarium wilt (*Fusarium oxysporum* f. sp. *cucumerinum*) has never been a serious problem in the UK in spite of the susceptibility of Butcher's Disease Resister. Fortunately the first occurrence of the disease in 1967 coincided with the

Table 6. Disease resistance in cucumber cultivars

Cultivar	Diseases							Cultivar	Diseases						
	LS	GorS	PM	DM	GM	BSR	V		LS	GorS	PM	DM	GM	BSR	V
468 Hazera	–	–	R	R	–	–	CMV	Femspot	R	R	–	–	–	–	–
472 Hazera	–	–	–	–	–	–	CMV	Fidelio	–	–	T	–	–	–	–
							MMV	Flamingo	–	–	T	–	–	–	–
492 Hazera	–	–	R	R	–	–	–								
								Girola	R	R	–	–	–	–	–
Aidas	R	R	–	–	–	–	–								
Allure	–	–	–	–	T	T	–	Jessica	–	–	–	–	–	–	–
Andora	R	R	–	–	–	–	–								
Aramon	–	–	T	–	T	–	–	Marana	–	R	–	–	–	–	–
								Marello	–	–	T	–	–	–	–
Bastion	R	R	–	–	–	–	–	Midistar	–	–	T	–	–	–	–
Bella	–	–	R	P	–	–	–	Mildana	–	–	P	P	–	–	–
Brucona	R	R	–	–	–	–	–								
Brudania	R	R	–	–	–	–	–	Pepita	–	–	R	–	–	–	CMV
Brustar	R	R	–	–	–	–	–	Prestige	–	–	–	–	–	–	CMV
								Pyralis	R	R	R	–	–	–	–
Carmen	–	R	P	P	–	–	–								
Cordito	–	–	T	–	–	–	–	Rebella	–	–	–	–	–	–	–
Corona	–	–	–	–	–	–	–								
								Separator	R	R	–	–	–	–	–
Euphya	–	–	R	–	–	–	–								
								Telstar	–	–	T	–	–	–	–
Farbiola	–	–	–	–	–	–	–	Type 7	–	–	R	–	–	–	–
Femdan	R	R	–	–	–	–	–								
								Vitalis	R	R	–	–	–	–	–

LS = Leaf Spot (*Corynespora cassiicola*); GorS = Gummosis or Scab (*Cladosporium cucumerinum*); PM = Powdery mildew (*Sphaerotheca fuliginea*); DM = Downy mildew (*Pseudoperonospora cubensis*); GM = Grey mould (*Botrytis cinerea*); BSR = Black stem rot (*Didymella bryoniae*); V = Virus; – = susceptible; T = tolerant; CMV = Cucumber mosaic resistance; R = resistant; P = Partial resistance; MMV = Melon mosaic resistance.

introduction of new Dutch cultivars which, by chance, were resistant. Wilt resistance is believed to be governed by a single dominant gene and quantitative differences in resistance have been recorded between homozygous and heterozygous lines. The same is true for Verticillium wilt (*V. albo-atrum* and *V. dahliae*). Resistance may be linked as cultivars resistant to one appear, in practice, to be resistant to both. But there have been no reports of systematic checks of cultivars for susceptibility to these pathogens apart from the initial work in the UK when a number were found to have marked resistance to Fusarium wilt (Fletcher & Kingham, 1966).

Root and stem diseases. The main root and stem pathogens of cucumbers in the UK are *Botrytis cinerea, Didymella bryoniae, Penicillium oxalicum* and *Phomopsis sclerotioides.* There are claims of reduced susceptibility in some cultivars to *Botrytis* and *Didymella* but these have not been substantiated in experimental work. Breeder's lines have been shown to have marked resistance to *Didymella* (van der Mear et al., 1978; Wyszogrodska et al., 1986). van Steekelenburg (1986) considers that breeding for resistance to gummosis and Cercospora Leaf Spot as well as bitter free fruits and all female cultivars, has resulted in greater susceptibility to stem and fruit rot diseases. *Phomopsis* can be controlled by steam treatment of the soil, by good hygiene and the use of rockwool or by grafting onto *Cucurbita ficifolia* rootstocks which are not only less susceptible to *Phomopsis* but also to Fusarium wilt and Fusarium basal rot (*F. solani* f. sp. *cucurbitae*). *Penicillium oxalicum* was first recorded in the UK in 1989 (O'Neill et al., 1991). Differences in the resistance of cultivars was demonstrated but nothing is known about the genetics of resistance.

Powdery mildew. Cucumber mildew (*Sphaerotheca fuliginea*) is a commonly occurring disease and is generally well controlled with fungicides although there are reports of resistance to dimethirimol and the triazoles (Bent et al., 1971; Schepers, 1985). A number of cultivars have resistance to this disease but have not found favour with the industry because of their poor yields and tendency to show leaf necrosis under low light conditions (van Steekelenburg, 1986). Breeders have variously described cultivars as tolerant, partially resistant or resistant but in a recent experiment at HRI Stockbridge House, little difference in resistance was seen between the cultivars compared (Table 7). Growers frequently make second crop plantings in July and it is these crops which are most likely to be affected by powdery mildew. A resistant cultivar is commonly chosen for such later planted crops. Cultivars resistant to powdery mildew also have some resistance to downy mildew (*Pseudoperonospora cubensis*), a disease which has occurred in the UK on a number of occasions during the past 5 years, but has rarely been epidemic. Although a wide spectrum of disease resistance is available in cucumber cultivars, most crops are sprayed, usually to control powdery mildew, *Botrytis* or *Didymella.*

Pepper

There are only 70 hectares of protected sweet peppers in the UK. Consumption considerably exceeds home production and the bulk of the retailed crop is imported. Pests and diseases are generally not important; pests are more common than diseases and are usually effectively controlled biologically. However, there are a number of pepper cultivars on the market with resistance to virus diseases. Various tobamoviruses have been isolated from sweet peppers. Some have been recognised as distinct viruses whilst others have been found to be identical to or related to tobamoviruses from other hosts (Boukema et al., 1980).

In order to convey the results of their resistance breeding programmes in a way which pepper growers can understand, some breeders have adopted a system of virus classification based upon the virus-host interactions in which pathogenicity of the tobamoviruses is expressed as a number which relates to the L-genes in the host *Capsicum* (Table 8). Others have not adopted this system. Rast (1988) suggests that this may lead to confusion because of the conflicting interests of breeders and virologists and has suggested a different system (Table 9). His classification involves representative strains or isolates of each tobamovirus which are known pathotypes on sweet peppers. Rast's concern is well illustrated in the seed catalogues where cultivar resistance to the tobamoviruses is expressed in various ways and is confusing (Table 10). It appears that the pathotypes P0, P1, P1.2 and P1.2.3 of Boukema et al. (1980) are referred to by the seedhouses as TM0, 1, 2 & 3 respectively.

Lettuce

Lettuce is both a field and protected crop in the UK which is significant in terms of disease inoculum. The protected crop is normally affected by *Botrytis cinerea, Bremia lactucae, Rhizoctonia solani* and occasionally lettuce mosaic virus and big vein. Control of these diseases is generally by chemical or environmental means. Lettuce downy mildew (*Bremia lactucae*) is the exception in that its control relies upon a combination of genetic resistance and fungicidal application (Crute, this volume). The situation is further complicated by the existence of phenylamide resistant strains and the control strategy has relied upon various combinations of the available fungicides and the current choice of resistant cultivars.

There has been confusion in the literature over the nomenclature of races of *Bremia*. All the protected lettuce cultivars grown in the UK are of Dutch origin and resistance is cited in terms of the Dutch NL nomenclature for strains of the pathogen. During the past 20 years there has been a succession of cultivars with various genes and combinations of genes for resistance. These have lasted a relatively short period particularly during the time when fungicidal control relied exclusively on the dithiocarbamates. Since the introduction of the phenylamide fungicide metalaxyl and also fosetyl-al, fungicidal control has been better and by reducing pathogen selection pressure, genetic resistance has lasted longer. The development of metalaxyl resistance in some of the virulent strains has further complicated the situation (Crute & Harrison, 1988). For a period the R11 resistance factor gave effective protection but recently a virulent strain, NL15 which is also metalaxyl resistant, has become widespread in the UK. In order to obtain mildew free crops growers are advised to choose cultivars resistant to NL15 but also resistant to those earlier strains which were metalaxyl resistant. In effect this means choosing cultivars with resistance genes R6 + R11 or R16 or R18 (O'Neill, ADAS Cambridge, personal communication). There is a range of such cultivars available to growers (Table 11) and by using these and combinations of fungicides with different modes of action downy mildew control is maximised.

Cultivars are also available that are resistant to lettuce mosaic virus eg., Oriana, Ermosa, Valuta, Vitana, Voluma but none of these are commonly grown under protection.

Table 7. A comparison of various cucumber cultivars with powdery mildew resistance

Cultivars	Resistance seedhouse category	Mean mildew score % leaf cover	Yield kg/m²
Jessica	S	78.0	10.2
Euphya	R	1.3	11.7
Flamingo	T	2.6	12.5
Carmen	P	0.6	10.4
Aramon	T	4.3	10.1
Millio	T	2.3	10.0

S = susceptible; R = resistant; P = partially resistant; T = tolerant.

Table 8. Pathotype-genotype interaction of tobamoviruses in Capsicum hosts (+ = susceptible; – = resistant)

Host	Genotype	Pathotype			
		P0	P1	P1.2	P1.2.3
C. annuum					
'Early California Wonder'	$L^+ L^+$	+	+	+	+
C. annuum					
'Bruinsma Wonder'	$L^1 L^1$	–	+	+	+
C. frutescens 'Tabasco'	$L^2 L^2$	–	–	+	+
C. chinense P.I. 159236	$L^3 L^3$	–	–	–	+
C. chacoense P.I. 260429	$L^4 L^4$	–	–	–	–

Adapted by Rast (1988) from Boukema et al. (1980).

Mushroom

Agaricus bisporus and *A. bitorquis* are widely cultivated throughout the world. The *A. bisporus* crop is the most valuable horticultural crop in the UK. There are numerous strains available varying from smooth whites to white with rough surface to creams and browns. Most growers now grow hybrid white strains which are not completely smooth, but give high yields of good quality mushrooms.

Very little work has been reported on a comparison of spawn strains and disease incidence and there are no strains marketed that claim to be resistant to any diseases. van Zaayen & van der Pol-Linton (1977) examined various strains of *A. bitorquis* in relation to false truffle disease (*Diehliomyces microsporus*). They found that of the five types examined, K26 and K32, were the least sensitive. Peng (1986) screened 42 strains of *A. bisporus* for resistance to *Verticillium fungicola*. He detected differences in strain susceptibility which he found to be consistent. Similarly, Peng screened eight strains for resistance to bacterial blotch (*Pseudomonas tolaasii*) and found strain variation in response to different levels of inoculum.

The incidence of virus diseases in *A. bisporus* varies with the strain but this is thought to be the result of incompatibility between strains preventing an anastamosis which is a major means of virus transmission (Fletcher et al., 1989).

Challen & Elliott (1987) took the unusual approach of breeding novel strains of *A. bisporus* which were resistant to four fungicides, thereby increasing the potential range of fungicides available for the control fungal diseases of the crop.

Ornamentals

There are a large number of plant species grown as protected ornamentals. They are sold as cut flowers, flowering pot plants, foliage plants and bedding plants.

Derbyshire & Ann (1986) described the most important diseases of 47 different species of pot plants in the UK and Chase (1987) described the diseases of 50 species whilst recognising that nearly 500 are grown as pot plants in Florida. Many are propagated from clonal material and others are produced from seeds. No cultivars have been bred for disease resistance although differences in susceptibility to pathogens have been observed in a number of species.

Internationally, chrysanthemums, carnations and roses are probably the most widely grown greenhouse flowers and in the UK begonias, pelargoniums, cyclamen, poinsettias and pot chrysanthemums are among the most commonly grown flowering pot plants. There are relatively few reports in the literature of screening the commonly grown cultivars for resistance to particular pathogens and even fewer where disease resistance breeding programmes have been developed.

Table 9. List of tobamoviruses and corresponding pepper pathotypes

Tobamovirus	Strain/isolate	Pathotype
Tobacco mosaic virus (TMV)	type or common strain, vulgare strain, U1	P0
Tomato mosaic virus (ToMV)	Dahlmense strain, Y-TAMV	P0
Bell pepper mottle virus (BePMV)	unusual pepper strain, FO, eggplant strain A1	P0
Tobacco mild green mosaic virus (TMGMV)	para-tobacco mosaic virus, T2MV, U2, South Carolina mild mottling strain, G-TAMV	P0 or P1
Unnamed	P11	P1
Tomato mosaic virus (ToMV)	Pepper strain Ob	P1 or P1.2
Pepper mild mottle virus (PMMV)	Samsun latent strain, SL-TMV, P8, P14, Capsicum mosaic virus	P1.2.3

After Rast (1988).

Carnation

There are numerous cultivars of this crop which is grown worldwide. In the UK it is now of minor importance, largely because of the imports of cheaply produced flowers from elsewhere. The crop is prone to a number of major diseases (Fletcher, 1984), in particular Fusarium wilt (*Fusarium oxysporum* f. sp. *dianthi*) which occurs wherever the crop is grown. An examination of various cultivars by Garibaldi (1975) showed that there were differences in susceptibility and although some of the Mediterranean and miniature cultivars showed resistance, the larger flowered American types were completely susceptible. Garibaldi initially recognised two forms of the pathogen which could be differentiated on these different cultivar types. Since then further work in various countries, (Garibaldi & Gullino, 1987; Blanc, 1983; Carrier, 1977; Matthews, 1979; Baayen et al., 1988; Demmink et al., 1989) has resulted in the production of resistant cultivars and some understanding of the host pathogen relationship. In 1983, Garibaldi recognised eight pathotypes. Garibaldi & Rossi (1987) reported pathotypes 1, 2, 4, 5, 6 and 8 to be commonly found in the Liguria area of Italy. Race 2 is believed to predominate in the UK and the Netherlands (Matthews, 1979). Garibaldi (1983) screened 112 cultivars using these pathotypes and although many were resistant to six or seven of them, only one, cv. Duca was resistant to all. Demmink et al. (1989) examined the virulence spectrum of three pathotypes, 1, 2 and 4 on nine carnation cultivars (Table 12). They concluded that resistance to pathotype 1 is monogenically inherited and is complete but resistance to pathotypes 2 and 4 is probably polygenically inherited.

Table 10. Pepper cultivars and tobamovirus resistance as listed by seedhouses

Cultivar	Resistance
Bell Boy	TMV
Belmont	TMV
Bianca	TM 0
Capri	TMV
Carlos	TMV race P0, PVY 0 & 1
Cubico	TM 2
Domina	TMV
Eagle	TM 2
Elea	TM2
Gloria	TMV
Gold Flame	TM 0 & PVY
Herpa	TMV
Jetta	TMV
Lambada	TM 0
Latina	PVY, TMV (tomato strains)
Locas	TM 0
Marraf	TM 2
Martel	TMV
Mazurka	TM 0
Medeo	TM 0
Pantser	TMV
Parma	TMV
Paula	TMV
Propa Rumba	TM 0
Ranger	TMV
Salsa	TM 0
Siraki	TM 0
Tasty	TM 3
Tenno	TMV race P0, PVY 0 & 1
Tequila	TM 0
Tonika	–
Valeta	TM 0
Zerto	TMV race P 0
Zico	TMV race P0, PVY 0 & 1

TMV = Tobacco mosaic virus; TM = Tomato mosaic virus; PVY = Potato virus Y.

Table 11. Lettuce cultivars resistant to all known metalaxyl resistant strains including NL15

Cultivar	Resistance gene(s)
Animo	R11 + R16
Banjo	R11 + R16
Berlo	R11 + R16
Clarisse	R6 + R11
Charlene	R3 + R11 + R16
Desso	R11
Disney	R11 + R16
Impala	R18
Liset	R6 + R11
Luxor	R2 + R16
Mirage	R6 + R11
Pantra	R3 + R11 + R16
Rosana	R16
Ricardo	R11 + R16
Titania	R16
Vicky	R11 + R16
Virginia	R16

Fusarium wilt in carnations is now well controlled by the use of resistant cultivars. A wide range of colours of high yielding cultivars is available and is widely used. Wilt resistance in carnations represents the main success in the breeding of cultivar resistance into protected ornamentals.

There are a few other reports of differences in the resistance of carnations to diseases. Rattink (1972) reported some differences in the susceptibility to *Phialophora cinerescens* in crosses made between cultivars William Sim and Royalette and breeding material. This vascular wilt was the most important disease of the crop until the appearance of Fusarium wilt in the 1960's. Its demise coincided with the increasing importance of Fusarium wilt and it had already become an insignificant disease before Fusarium wilt resistant cultivars were available. Various workers have noted differences in the susceptibility of cultivars to rust (*Uromyces dianthi*). Semina & Shestachenko (1981) reported 12 resistant cultivars in screening tests and Sezgin & Esentepe (1986) examined six cultivars and found one, Minirosa, to be resistant whilst Aliatta and Ernesto were highly and moderately susceptible respectively. In the UK, Spencer (1981) confirmed differences in cultivar reactions to rust.

Similar cultivar variability has been recorded to *Alternaria dianthi* by Strider (1978a). He inoculated a wide range of commercial cultivars and found them to be susceptible but Dusty, Imp, New Pink Sim, Light Pink Barbi, Maj Britt, Pink Ice and Red Gayety were significantly less susceptible than most.

Table 12. Virulence pattern of three pathotypes of *F. oxysporum* f. sp. *dianthi* on 9 cultivars

Cultivar	Pathotype of *F. oxysporum* f. sp. *dianthi*		
	Race 2	Race 4	Race 1
Sam's Pride	S	S	S
Alice, Sacha	S	S	R
Lena	S	MR	R
Pallas	MR	S	R
Niky, Elsy	MR	R	S
Revada, Novada	R	R	R

(after Demmink et al., 1989).

Chrysanthemum

This is probably the most widely grown protected ornamental. There are a vast number of cultivars and many pathogens have been recorded. In the UK the most serious diseases include Phoma root rot (*Phoma chrysanthemicola*), ray blight (*Didymella chrysanthemi*), Verticillium wilt (*V. dahliae*), petal blight (*Itersonilia perplexans*), grey mould (*Botrytis cinerea*), rusts (*Puccinia horiana* and *P. chrysanthemi*), and various virus diseases – most recently tomato spotted wilt. There are no cultivars marketed that claim resistance to any of these diseases but most growers know that different cultivars vary not only in their susceptibility to most diseases but also to pests. In the latter case, apparent differences in susceptibility to tomato spotted wilt virus reflects in part the preferential feeding of the vector, western flower thrips (*Frankinella occidentalis*), on some cultivars. There are various reports in the literature of differences in susceptibility to various pathogens and one company specialising in the development of new cultivars has recently begun a breeding programme to include disease resistance as one of its major aims (C. Scharfenberg, Yoder Bros., Florida, personal communication).

Englehard (1969) reported observations on 52 cultivars of commercial chrysanthemums in relation to Ascochyta blight (*Didymella chrysanthemi*) rust (*Puccinia chrysanthemi*) and flower spots caused by *Botrytis cinerea* or *Alternaria* sp. The results show a complete range of resistance for each of the diseases with the majority of the cultivars showing some resistance to one or more of the pathogens but with a minority being very susceptible. Englehard reports 'growers often disregard disease resistance or susceptibility when selecting cultivars to grow' and this is still the case in spite of resistance being present in some of the existing stocks. Recently Matteoni & Allen (1989) have reported on the sensitivity of cultivars to tomato spotted wilt virus which has spread internationally at alarming rates with the distribution of the vector, western flower thrips, probably on cuttings. They found considerable variation in the severity of symptom expression in a wide range of cultivars which they inoculated. Only one cultivar was symptomless but about a quarter of the inoculated plants of that cultivar were infected. This underlines the necessity to examine cultivars systematically in resistance tests particularly when screening for resistance to systemic pathogens.

Byrne et al. (1980) reported the results of screening 87 cultivars for resistance to *Verticillium dahliae* and *Puccinia chrysanthemi*. They found a wide range of resistance. Growers in the UK of all year round (AYR) crops recognise a range of susceptibility of cultivars to Verticillium wilt. For instance, cvs Hurricane, Rhino, Jaguar, Nikita, Mecca, Texas Improved, Garland and Princess Anne are known to be very susceptible whereas Rose Swan appears to be resistant. More extensive tests have been done on Fusarium wilt (*F. oxysporum* f. sp. *chrysanthemi* and *F. oxysporum* f. sp. *tracheiphilum*) not yet recorded in the UK. Strider (1985) reported the results of screening 183 cultivars and found a number with resistance to both species. Cultivars Airborne, Royal Trophy, Yellow Delaware were most susceptible and Jamboree, Puritan and Tune-up most resistant to *F. oxysporum* f. sp. *chrysanthemi*. None of the cultivars was highly susceptible to *F. oxysporum* f. sp. *tracheiphilum*.

In 1960 a root disease of chrysanthemums caused by *Phoma chrysanthemicola* was first recorded in England. Hawkins et al. (1963) found considerable variation in the susceptibility of cultivars and, in subsequent tests with a range of isolates of the pathogen, Wilcox (1963) showed that cvs Heyday, Supertop, Snowcap and Princess Anne had a high degree of resistance. Some cultivars varied in their reactions to some isolates suggesting that there could be a degree of specialisation in the pathogen.

Variations in the susceptibility of cultivars to other chrysanthemum pathogens have been recorded. Semina & Babkina (1981) showed considerable differences between cultivars in their resistance to powdery mildew. Water et al. (1984) found that of 10 cultivars tested, three, Carfour Album, Stateman and Coppa were resistant to *Puccinia horiana*. Similar reports were made by Rademaker & Jong (1985). Variation in resistance to *Septoria chrysanthemi* found by Zhang & Li (1986). Two of the 14 cultivars they tested had a degree of resistance to this leaf spot, whereas Strider & Jones (1986) found some resistance to bacterial leaf spot and bud blight (*Pseudomonas cichorii*) in eleven out of 131 cultivars tested.

Miller et al. (1975) examined 237 cultivars for susceptibility to *Agrobacterium tumefaciens*. They used the American culture collection type strain B6 and also an isolate from chrysanthemum which proved to be more virulent. Resistance to both strains was observed in 10% of the cultivars.

Although a large amount of variation in the resistance of chrysanthemum cultivars to various pathogens has been recorded, growers have not yet benefited. Fashions in cultivars change quickly and growers must grow what the market requires. This usually precludes the choice of disease resistant cultivars. There is clearly much scope for the development of disease resistant chrysanthemums but it is unlikely to happen unless the industry changes its policy and uses a more limited range of cultivars into which resistance could be bred.

Other ornamentals

The incidence of diseases and the resistance of cultivars of other protected crops are recorded in the literature. There are a number which refer to roses but these are concerned with field grown rather than protected crops. Differences in cultivar susceptibility were recorded to dieback (*Diplodina rosarum*) by Kove et al. (1977), to black spot (*Diplocarpon rosae*) by Palmer & Salac (1977); Svejola & Bolton (1980); Knight & Wheeler (1978); and to powdery mildew (*Sphaerotheca pannosa* var. *rosae*) by Semina & Timoshenko (1979), Deshpande et al. (1979) Bender & Coyier (1986). The latter authors found evidence for physiological specialisation in the pathogen in greenhouse crops.

Of the various pot plants, there are a number of records which relate to disease incidence in begonias. Strider (1978b) recorded the reactions of Rieger elatior begonias to powdery mildew (*Oidium* begoniae) and found cv. Aphrodite Red to be highly resistant and Stella, Ballerina and Hawaiian Punch to be resistant. O'Riordan (1979) in his tests on similar cultivars found that they were all susceptible with the exception of Aphrodite Red. Strider (1975) had previously reported on the resistance of begonias to bacterial blight (*Xanthomonas begoniae*). In contrast to the mildew reactions, the Aphrodite cultures were found to be susceptible whereas Goldachs and Bernstein Gelbe were only slightly affected. Later work (Strider, 1978) showed that the cultivars Ballerina, Nixie, Elfe and Stella also had some resistance. Differences between the resistance of the species of begonia in cultivation to *X. begoniae* were recorded by Harri et al. (1977). They tested elatior types and also fibrous and tuberous rooted begonias. All proved to be susceptible but all the Rex begonias were resistant when spray inoculated.

Begonias not only vary in their resistance to pathogens but also to damage by ozone. Reinert & Nelson (1979) tested twelve *Begonia* × *hiemalis* cultivars to 25 and 50 ppm ozone. They found distinct differences with Whisper O'Pink and Improved Krefeld Orange the most sensitive and Ballerina, Mikkell, Limelight and Turo the least.

Strider (1978c, 1980) studied the resistance of saintpaulia cultivars to *Phytophthora nicotianae* var. *parasitica* and also to powdery mildew (*Oidium* sp). He found great variation in the resistance of the Ballet and Rhapsodie series to Phytophthora root rot with cultivars Erica, Helga, Inge and Karth of the Ballet series and Barbara, Astrid and Ruby of the Rhapsodie series being the most resistant. Of the 48 cultivars tested for mildew resistance, in the Melodie and Ballet series he found differences between cultivars but also between the flowers and leaves of the same cultivar. Most resistant overall were cultivars Allison, Brilliant, Eva, Dolly, Mitzi, Pearl and Rachel.

Pelargonium rust. (*Puccinia pelargonii-zonalis*) has been investigated by various workers. McCoy (1975) examined the susceptibility of 17 species and cultivars. He found five cultivars of *Pelargonium hortorum* and one of *P. domesticum* to be highly susceptible, a high level of resistance in *P. radula* and *P. limoneum,* whilst all the other species were immune. Harwood & Raabe (1979) examined cultivars of *P. hortorum* and found variation in their resistance but also in the virulence of isolates of the pathogen, suggesting race specialisation. Similar variation in the resistance of pelargonium cultivars has been reported for virus diseases. Albouy et al. (1979) reported resistances to tobacco ring spot, tomato ring spot and tomato black ring in a red cultivar. Three other cultivars were susceptible.

Significant differences in the resistance of cyclamen cultivars to the relatively recently described anthracnose disease (*Crypocline cyclaminis*) were described by Brielmaier-Liebetanz & Buhmer (1988), although none were highly resistant.

Discussion

The range of plant species grown under protection is very wide, particularly of ornamentals. In some cases there are only a few growers in any one country with a particular type. In these circumstances it is not surprising that expensive breeding programmes have not been developed to provide resistant cultivars. The greatest use of resistance has been with tomatoes where breeding programmes can provide cultivars suitable for culture in the field as well as under protection. The estimated annual worldwide production of the tomato crop in 1985 was in the region of 60 million metric tonnes (Jones et al., 1991) making it a worthwhile market for breeders.

Some of the troublesome diseases of greenhouse vegetable crops are caused by pathogens which rot stems and leaves, in particular *Botrytis cinerea.* As a group, these diseases are not easily controlled by genetic resistance although it is interesting that there is now a number of cucumber cultivars which the breeders claim are less susceptible to some of them. Resistance to this type of pathogen appears to be more difficult to find and detection methods are not available for its quantification.

The durability of resistance has been variable, sometimes requiring a constant change of resistance genes or combinations as in the case of lettuce downy mildew and, for some years, tomato leaf mould and tomato mosaic virus diseases. Resistance to the latter two diseases has now been maintained for some years in spite of the plasticity of the pathogens involved. Single gene resistance in the case of tomato mosaic and Cercospora leaf spot of cucumbers has been extremely durable.

The need to include resistance to some of the major root rot pathogens of tomatoes and cucumbers has been largely overcome by the growth of these crops in a soil-free media. Such systems will become more sophisticated and in order to avoid pollution of the underlying soil with run-off fertilisers and pesticides, a change to recirculatory systems is likely. Recirculation could favour a different spectrum of root disease pathogens, in particular those which prefer the wet environment. The need to control such diseases by all available means is likely to increase in the next 5 years.

Flower producers, with the exception of carnation growers, have little to choose from if they are looking for disease resistance, although resistance is known to occur in many crops. Growers and plant raisers know from their observations that some cultivars are more susceptible to certain diseases than others; this information is never given in sales catalogues which usually concentrate on colour, form, season and keeping quality. New cultivars of such crops as chrysanthemums are numerous and fashions change. Although a grower with a particular disease problem, Verticillium wilt for instance, knows that there are some cultivars that will always be affected, he often has to grow some of them, perhaps in sterilised soil, in order to meet market demands. Soil sterilisation and fungicide use are expensive operations but so is plant breeding. Perhaps the time will come when public pressure will make breeding for disease resistance in flower crops worthwhile for the larger plant producers, and growers will benefit from a more economic means of disease control.

Pathologists, with some exceptions, have frequently not identified sources of resistance within existing cultivars. Such work, although mundane, is needed not only for immediate use but also to enable breeders to understand the possible interactions between their cultivars and pathotypes which may exist in various regions. Disease resistance in protected crops has had some notable successes, some at low cost (eg. cucumber, cv Butcher's Disease Resister).

The effect of disease resistance and the use of fungicides on protected crops is difficult to quantify. There can be no doubt that without the resistance available to tomato and cucumber growers, fungicides would be more extensively used. With the increased ability to control the protected environment, main crop tomato growers have little need to use fungicides. Unfortunately, the occurrence of the new powdery mildew disease has changed the situation for some of them. Cucumber growers, likewise, benefit from resistance to leaf spot and gummosis but still spray regularly to control mildew, grey mould and black stem rot. Lettuce growers spray mildew resistant cultivars to protect the resistance genes. Control of pests by biological means restricts the choice of fungicides that can be used on some crops but occasionally growers must resort to the use of fungicides that are disruptive of their biological pest control programmes. This pressure, together with a reduction in the availability of pesticides for horticultural crops and an increasing public awareness of pollution, makes the need to breed or identify good disease resistant cultivars very important for the future of the industry.

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