Phytopathol. Mediterr. (2007) 46, 135–149

REVIEW

Critical aspects in management of fungal diseases of ornamental plants and directions in research

Maria Lodovica GULLINO and Angelo GARIBALDI

Center of Competence for the Innovation in the Agro-Environmental Sector, University of Torino,
Via Leonardo da Vinci 44, 10095 Grugliasco, Italy

Summary. The production of ornamental plants is a thriving and expanding industry, which is economically important in the United States of America, Canada, South America, Australia, and Europe as well as in many developing countries. During the last few decades significant changes have occurred, with many new crops being introduced, new products such as pot plants replacing cut flowers, and improved techniques for growing, treating and handling plants being introduced. Such changes have had a profound influence on disease development and management. This review focuses on critical aspects of the disease management of ornamental crops, considering the role of breeding strategies, cultural practices, chemical and biological control, natural products, regulatory control and diagnostic tools. Finally, the research needs in this sector are critically analysed.

Key words: breeding, chemical and biological control, natural products, regulatory control, diagnostics.

Introduction

The production of ornamental plants is a thriving and expanding industry, which is economically important in the United States of America, Canada, South America, Australia, and Europe as well as in many developing countries. It stands out in the agricultural scenario because of the frequency and rapidity with which the product changes, the technology adopted, as well as the production areas. Ornamental plants include deciduous and evergreen trees, woody ornamentals, shrubs, nursery crops, foliage plants, cut flowers, flowering potted plants, bedding/garden plants, potted bedding and garden plants, herbaceous perennials, cut cultivated greens and propagation material.

The world floricultural export market is almost 20 billion Euros: of which 50% consists of cut flowers, 35% of foliage potted and bedding plants, 8.5% of bulbs, 8.5% of cut cultivated green (Heinrichs, 2005). Over 50% of ornamental exports originates from the Netherlands. This country ranks first in many production sectors, such as cut flowers, potted plants, and bulbs. The per capita consumption of cut flower and potted plants varies in the different geographical areas, and is higher in the industrialized countries (Tables 1 and 2).

Corresponding author: M.L. Gullino
Fax: + 39 011 6709307
E-mail: marialodovica.gullino@unito.it

Table 1. Market value of cut flowers and plants and per capita consumption in selected countries. Values in Euros referred to 2002.

Geographical area	Estimated market value (millions Euro)	Per capita consumption Euro
Europe	24,433	40
USA	7,286	26
Japan	3,850	31
China	840	1

Although Europe remains the leading area for ornamental plant production, the past few years have seen a decrease in the cut flower and bulb production of most European countries (with the exception of Germany and Hungary for cut flowers and the Czech Republic for bulbs). The trend for potted plants and nursery stock has been more stable (Heinrichs, 2005). The main reasons for the lower production are higher energy costs, increasing competition, higher production costs, stagnating consumer demand, low prices and over supply.

Table 2. Per capita consumption in European countries. Values are expressed in Euro and referred to 2002.

Country	Per capita consumption Euro
Austria	78
Belgium	70
Croatia	14
Czech Republic	14
Denmark	83
Finland	62
France	52
Germany	83
Greece	23
Hungary	19
Ireland	41
Italy	43
Netherlands	93
Norway	114
Poland	10
Portugal	23
Russia	4
Slovakia	10
Slovenia	41
Spain	30
Sweden	77
Switzerland	136
United Kingdom	52
Average	40

Over the last decades significant changes have occurred, with many new crops being introduced, new products such as potted plants partly replacing cut flowers, improved techniques for growing, treating and handling plants and flowers being introduced, and new production areas emerging. Such changes have had a profound influence on disease development as well as on their management.

Ornamental plants differ from other crops in a number of ways: the unique features of the ornamental industry have been reviewed by several authors (Baker and Linderman, 1979; Niedbalski-Cline *et al*., 1988; Garibaldi and Gullino, 1990; Gullino and Wardlow, 1999; Daughtrey and Benson, 2005; Gullino and Garibaldi, 2005). These peculiar characteristics strongly affect the phytopathological picture and the management of pests and diseases (Daughtrey and Benson, 2005; Gullino and Garibaldi, 2005 and 2006). Novelty is an important component of the ornamental industry and the search for new crops as well as the production of new cultivars of already familiar species have always been part of research in this field. Many genera and species, new to horticulture, with a potential for becoming economically important crops, have been exploited and there is a rich flora waiting to be tapped. Diversity of crops and varieties, and the constant turnover in consumer demand multiplies the number of potential pests and diseases and complicates the development of resistant varieties and of plant novelties. New production areas are quickly developing and the widespread interregional and international transport of living plants has a tremendous impact on the spread of pests and pathogens. The increased demand for potted plants from the consumer has led to great changes in the production and transport sectors. Diverse and sophisticated greenhouse production techniques have led to a variety of environmental and cultural conditions in which different pests and pathogens may thrive in turn. A high capital investment and a high crop value may justify expensive methods of disease eradication, such as by means of chemical pesticides. Chemical pesticides from the 1960s to the early 1980s made it possible to obtain high yields of good-quality, blemish-free plants. This has set a standard not easy to maintain without severe pesticide pressure, also in view of current limitations imposed on the use of chemicals.

Not only must growers face many old diseases that complicate IPM, but they also continuously have to face new diseases on old and new crops. New pests and diseases can suddenly arise in planting material or they can be a consequence of the introduction of new cultivars.

This review will focus on the most crucial aspects in the management of diseases of ornamental plants.

Critical aspects in disease management

As already mentioned, the unique features of the ornamental industry also strongly influence disease management strategies. From a general point of view, it must be emphasized that any disease is managed by relying on any one particular practice. Diseases are managed, prevented or controlled by sets of practices loosely held together under the concept of integrated health management. A holistic approach is necessary, and the entire group of applicable management practices must be implemented as a whole for success.

Breeding strategies

Breeding resistance is an effective strategy for managing or avoiding outbreaks of damaging diseases. At a time of increasing environmental awareness among agricultural workers and the public, along with stricter standards for exposure of workers to pesticides, the production of disease-resistant cultivars offers the means to reduce pesticide use and possibly labour costs without sacrificing crop quality. In certain situations, such as with ornamental shrubs and trees, and turf grass for commercial and residential situations, disease-resistant plant material also reduces maintenance costs (Hagan, 2001).

Although the development of resistant cultivars should be the best means to control many diseases, it is difficult to adopt this approach because in floricultural programmes the maintenance of quality is a priority. Any selections not meeting the rigorous standards of plant and flower quality are always eliminated. The development and detection of resistant varieties and clones is an expensive and time-consuming process, and is also, in most cases, a waste of effort. A negative aspect of breeding programmes is that new improved cultivars can be more susceptible to some diseases; for instance, ranunculus F1 hybrids are more susceptible to Fusarium wilt than the old varieties, and the new Paris daisy varieties with yellow flowers are severely attacked by a rust (Gullino and Garibaldi, 2005).

Moreover, even if a breeder succeeds in developing a resistant line, the floricultural characteristics must equal or exceed those of existing cultivars. This is extremely difficult even for breeders not selecting for resistance. Nevertheless, it is becoming more important to use resistance as a control strategy against wilt. Commercially acceptable cultivars of carnations resistant to several pathotypes of *Fusarium oxysporum* f. sp. *dianthi* are available (Garibaldi and Gullino, 1990). Among the varieties of the Paris daisy (*Argyranthemum frutescens*), the African daisy (*Osteospermum* sp.), chrysanthemum and gerbera, many have recently been shown resistant to the Fusarium wilt caused by *F. oxysporum* f. sp. *chrysanthem*i (Minuto *et al*., 2006 and 2007a). Most azalea cultivars also have interesting levels of resistance to *Colletotrichum acutatum*, the causal agent of anthracnose (Bertetti *et al*., 2007).

In the case of roses, breeders are interested in developing cultivars with a high resistance to *Diplocarpon rosae*. Because of limited genetic diversity among rose cultivars, most of which are highly susceptible to this pathogen, the search for new resistant genes has focused on wild rose species. A recent study carried out on 34 rose genotypes found some partial forms of resistance and different resistance mechanisms (Blechert and Debener, 2005).

There is a need for varieties resistant to several major diseases of ornamental crops, because the identification, selection and development of disease resistant cultivars by conventional and *in vitro* techniques could significantly reduce the impact of these diseases. Genetic engineering approaches may help (Loffler and Florak, 1997; Hammond *et al*., 2006). For instance, transgenic chrysanthemum (*Dendranthema grandiflorum*) expressing a rice chitinase gene and showing enhanced resistance to *Botrytis cinerea* has been obtained (Takatsu *et al*., 1999).

However, disease resistance is not always complete and under conditions very favourable to disease development, it can easily be overcome by the appearance of new races of the pathogen involved.

Cultural practices

Modern techniques have given growers some powerful tools for production, many of which could significantly affect the epidemiology or severity of diseases. Major changes in cultural techniques include the use of hydroponic and soilless cultures, artificial substrates and the use of computerized systems. Although these changes are ultimately intended to reduce production costs and maximize profits, precise environmental and nutrition controls pushing plants to new limits of growth and productivity can generate chronic stress conditions, difficult to measure, but apparently conducive to diseases from pathogens such as *Penicillium* spp. or *Pythium* spp. (Jarvis, 1992; Stanghellini and Rasmussen, 1994). The recently observed wilt of gerbera, caused by *F. oxysporum* f. sp. *chrysanthemi*, is more severe on plants grown in soilless systems than on plants grown in soil (Minuto *et al*., 2007 b).

During the past two decades various composted organic wastes have partly replaced peat in container media used for the production of ornamentals. Recycling of these wastes has been adopted for economic and production reasons. The cost of compost can be lower than that of peat. Production costs can also be decreased because some of the compost-amended media, particularly those amended with composted bark, suppress the main soil-borne plant pathogens, thus reducing plant losses (Hoitink and Bohem, 1999). The use of compost and other organic amendments for disease suppression has the potential of reducing the need for fungicides. Although compost may not control diseases to the point where it can replace fungicides altogether, its integration into disease management may reduce fungicide use. This has been shown for instance in the suppression of dollar spot (*Sclerotinia homeocarpa*) on turfgrass (Boulter *et al*., 2002).

Plant production under glass makes it possible to control climatic factors, both for optimisation of plant growth and for the integrated control of pathogens. In a closed system such as a greenhouse, simple management practices can be adopted that are more difficult in an open field. Plants with *Pythium* root rot or *Fusarium* stem rot can, for instance, be saved from total destruction. Because these diseases are favoured by cool and wet soils, serious consequences of the disease can be avoided by mounding over the first few stem internodes with a peaty soil mix. A frequent plant response to root rot is the production of adventitious roots. This mound is drained better and warms up faster, encouraging the formation of new roots that usually remain disease-free (Jarvis, 1992). Moreover, microbial optimisation of the nutrient solution, through the addition of beneficial microorganisms has been successfully attempted in the case of gerbera (Garibaldi *et al*., 2003), and is already established practice in the case of vegetable crops (Postma *et al*., 2000).

Greenhouses and benches can be designed to improve air movement, reducing the risk of diseases. Bottom heat, a traditional means of avoiding root rots caused by species of *Phytophthora*, *Pythium* and *Rhizoctonia*, is enhanced in cutting and seedling trays by an upward air movement between the young plants. Through-the-bench air movement is, perhaps, the most neglected and simplest means of reducing seedling rots in tangled plant masses.

A modest amount of spatial isolation, such as maintaining a distance of at least 10 m from fields where lilies had been grown the previous year, reduced Botrytis leaf blight in lily. Such a simple practice was more effective than other cultural practices aimed at reducing survival of the sclerotia (such as removal of crop residues, crop rotation) and was particularly effective when combined with the use of a relatively resistant cultivar (De Kraker *et al*., 2005).

Fusarium root and crown rot, caused by *Fusarium hostae* in container-grown hostas was affected by the type of wounding caused during propagation, by the container mix content, and by the watering schedule and temperature: a peat or peat-bark container mix reduced disease incidence, while a dry-container mix at moderate (20–25°C) temperatures raised it (Wang and Jeffers, 2002).

Disease control by climate management is most promising for pathogens which have critical climatic requirements at specific stages of their development. Monitoring the environment and controlling it to keep plants disease-free has become a fundamental part of greenhouse management. Once the environmental parameters that influence pathogens and biocontrol organisms are understood, they can be more precisely regulated. Disease management is greatly enhanced by computer monitoring and control of temperature, light, humidity, water, ventilation, carbon dioxide, and by crop nutrition. Of these factors, manipulating the interaction of temperature and humidity is probably the most important in the control of foliar diseases, while rhizosphere moisture and temperature are the most important for root diseases. In high humidity, guttation can occur from leaves and pruning wounds. A repeated cycle of guttation and drying can lead to a buildup of phytotoxic salt levels that serve as infection points for necrotrophic pathogens. Dew deposition, which favours downy mildews, rusts, and *Botrytis* blight, is common in greenhouses on cool nights following warm, humid days. Regulating day and night atmospheres is important for disease control and helps to reduce the total amount of chemical pesticides that need be sprayed (Hausbeck and Moorman, 2002). Growers concerned about energy costs should consult Ausburger and Powell (1986) who provide data on the cost of humidity management.

Specific climate and/or ventilation management has proved to be effective to control *Botrytis cinerea* on fuchsia. Particularly, a humidity/temperature based management consisting in controlled dehumidification combined with a drop of temperature in the morning, with supplementary direct ventilation to decrease air humidity within the canopy, reduced stem blight to one-third and sporulation on nectrotic leaves to half that of the control (Friederich *et al*., 2005). Cultural control, and particularly the avoidance of temperatures conducive to *Phytophthora infestans,* and reducing moisture levels, reduced late blight on petunia (Becktell *et al*., 2005b) and can be effectively combined with a lower use of fungicides (Becktell *et al*., 2005a).

Because of differences in the weather, some of these strategies can be more easily and effectively applied in countries such as the Netherlands than in southern Europe. Air humidity and lighting are important in affecting powdery mildew development and the vase life of roses. Maintaining a constant 90% RH in greenhouses in northern Europe eliminated powdery mildew in roses and increased the vase life of cut flowers (Mortensen and Gislerød, 2005). Maintaining temperatures higher than 21°C, the optimum for the disease, reduced powdery mildew severity in poinsettia (Byrne *et a*l., 2000). In the case of Rhododendron, it has been observed that proper management of RH, light intensity and photoperiod has a significant impact on powdery mildew. RH was particularly important both during spore germination and later during colony development, with disease development being adversely affected when the RH was reduced from 100 to 70 or to 85%. Light intensity and photoperiod both had a considerable effect on the induced resistance response of the host (Kenyon *et al*., 2002).

Chemical control

Fungicides will probably remain a major tool to control many foliar as well as root pathogens. However, in recent years the number of chemical pesticides approved for use on ornamentals has strongly decreased, forcing growers to look for alternative means of control (Gullino and Garibaldi, 2005). At present the cost of obtaining effectiveness and phytotoxicity data for the many plant species under cultivation discourages pesticide companies from expanding the suitability indications on their new product labels to make them include ornamental crops (Niedbalski Cline *et al*., 1988), which are all included as minor crops (Gullino and Kuijipers, 1994). Moreover, even when chemical pesticides are available, their efficacy is often only partial, because the plants have developed resistance. Fungicide resistance is quite widespread, especially under greenhouse conditions, due to the high number of sprays often needed to combat some pathogens. Moreover, under protected conditions, resistant strains are concentrated, not diluted, and easily spread; eventually causing complete loss of control. Resistant populations are a major problem in the case of pathogens such as *Botrytis* spp.:

strains of *B. cinerea* resistant to the benzimidazoles, dicarboximides and anilinopyrimidines (multiple resistance) are widespread in a number of crops (Gullino, 1992; Gullino and Garibaldi, 2005).

Fungicide resistance complicates the control of many other pathogens. Control of severe attacks of leaf curl on anemone and anthracnose on cyclamen was complicated by the fact that the causal agent, *Colletotrichum gloeosporioides,* proved resistant to the benzimidazoles. Resistance to the benzimidazoles is also widespread in *Penicillium* spp. and *Fusarium*, the causal agents of bulb rots. This loss of effectiveness in protecting bulbs and corms has caused problems because other effective fungicides are not always so selective (Gullino and Wardlow, 1999). Resistance to propamocarb and mefenoxam now occurs in species of *Pythium* (*Pythium aphanidermatum*, *P. irregulare* and *P. ultimum*) isolated from geranium in commercial greenhouses in Pennsylvania (Moorman and Kim, 2004) and on *Phytophthora* spp. from gerbera, aster, dusty miller, pansy, and African violet in the USA (Hwang and Benson, 2005).

Due to the great number of cultivated species and varieties, selectivity remains a major problem for many of the chemical pesticides used to protect ornamental crops. Visible pesticide residues on florist crops diminish their retail value, and frequent use of pesticides often hardens, marks or stunts the plants. Because of their potential plant growth-modifying effects, many of the EBIs can be applied on a new variety only after specific evaluation. These fungicides are structurally related to some growth regulators, and inappropriate use can lead to shorter stems, which is generally a negative feature for ornamental crops. Sometimes, even innocuous pesticides can damage crops if they are used too frequently and/or in combination with other products. Mixtures of pesticides can be particularly hazardous. Quite often only certain cultivars of plants are affected: chrysanthemums and carnations are a good example. It is also generally accepted that pesticides which are safe to crops in some nurseries, may not be so in others; this is due to differing cultural conditions which can be even greater because of climatic differences in various parts of the world (Gullino and Kuijipers, 1994).

A critical aspect is represented by soil disinfestation, after methyl bromide was banned in 2005 in industrialized countries. This forced growers to rely more on other fumigants, often less effective, or on steam or soil solarization (Gullino *et al.*, 2003 and 2007; Rosskopf *et al.*, 2005). In Florida, soil solarization was effective against Rhizoctonia crown and root blight and damping-off caused by *Pythium* spp. on impatiens (McGovern *et al.*, 2002) as well as against *Phytophthora nicotianae* on Madagascar periwinkle (*Catharanthus roseus*) (McGovern *et al.*, 2000).

Natural products

Salts, plant extracts and oils are increasingly being used to control fungal diseases, particularly diseases of the leaves, in gardens and even under commercial conditions. They tend to be more active against foliar diseases.

Interesting and promising results have been obtained against powdery mildews using potassium salts, mineral oils, vinegar, and plant extracts (Horst *et al.*, 1992; Pasini *et al.*, 1997). Commercial formulations containing potassium bicarbonate as well as neem oil are available in the USA and are applied against rose powdery mildew. In the case of roses in home gardens, sodium bicarbonate in combination with horticultural oils has been successfully applied against powdery mildew. However, sodium bicarbonate is deleterious to soil pH and soil structure and may leave white foliar deposits: so numerous applications with resulting runoff should be avoided. This treatment may not be approved for commercial use (Karlik and Flint, 2002).

Silicon provided at least partial control of powdery mildew of greenhouse crops, as well as of brown patch (*Rhizoctonia solani*), dollar spot (*Sclerotinia homeocarpa*) and gray leaf spot (*Magnaporthe grisea*) on turfgrass (Bélanger *et al.*, 1995; Bretch *et al.*, 2004; Uriarte *et al.*, 2004). Trials with various plant extracts (Bowers and Locke, 2000) and with sodium chloride (Elmer, 2000) to control Fusarium wilts of greenhouse crops achieved only a marginal effect. Among these extracts, those of *Reynoutria sachalinensis* (commercial product Milsana) gave satisfactory control, of powdery mildew on a number of ornamental crops, including roses, under commercial conditions.

Although natural compounds cannot provide the level of control offered by chemical pesticides, their use is interesting, particularly in the case of public parks, gardens and in low maintenance situations. Moreover, they are very useful for organically grown crops, which represent an increasing sector in many countries.

Biological control

Although several mechanisms of biological control have been successfully exploited in a number of ornamental crops, there are as yet insufficient practical demonstrations of its reliability. The chances of biological control may be greater with greenhouse crops such as ornamentals because the environment can be controlled. At present the controlled environment of greenhouses, the high value of the crops, and the limited number of approved fungicides offer a unique niche for the biological control of plant diseases (Paulitz and Bélanger, 2001). However, the enormous importance of aesthetics complicates the practical application of biocontrol agents (BCAs) which also, in most cases, provide only partial disease control (Gullino and Wardlow, 1999).

There are conspicuous failures in the process of transferring laboratory-observed antagonisms to crop production systems. In general, preliminary experimental work is done in a laboratory or greenhouse setting with only two or three components, including the parasite and its antagonists, or a hyperparasite and the host plant, which may be in a non-productive condition. In nature, however, biocontrol agents have their own antagonists; and moreover, compromises have to be made when choosíng between environmental conditions that are optimal for biocontrol activity, or those that are optimal and economical for production. For example, in the biological control of powdery mildew, organisms that act as hyperparasites may require periods of free water which, however, are then conducive to other diseases such as downy mildew or Botrytis blight.

There are, however, situations where biological control can indeed represent a breakthrough, particularly for the management of soilborne pathogens: a list of biocontrol agents used in some countries is shown in Table 3. It is well known that certain soil-borne diseases do not occur or are less severe in some soils, which are referred to as suppressive. In contrast, conducive soils support rapid disease development (Tousson, 1975). Soils suppressive of *Fusarium oxysporum* f. sp. *dianthi* have been described in the USA, France and Italy (Tramier *et al*., 1983; Garibaldi *et al*., 1989). In all cases suppressiveness had a microbiological origin that was destroyed by steaming. Certain bacteria and/or fungi indigenous to these soils have been shown to be responsible for the suppression of the Fusarium wilt pathogens. The most effective were *Pseudomonas* and *Alcaligene*s in the USA and *Fusaria* in France and Italy. Antagonistic *Fusaria* isolated from the rhizosphere of carnation plants grown in suppressive soils showed high rhizosphere competence as compared with saprophytic, non-antagonistic *Fusaria* from the same soils (Garibaldi *et al*., 1989); when applied to soil and substrates these bacteria and/or fungi controlled Fusarium wilt on crops such as carnation, cyclamen and bulb crops (Garibaldi and Gullino, 1990; Minuto *et al*., 1995). Strains of *Trichoderma viride* showed good antagonistic activity against Fusarium wilts and have been used in chrysanthemum (Gullino and Wardlow, 1999). Soils that suppressed *Rhizoctonia solani* also contained large amounts of *Trichoderma* spp. (Chet, 1987).

Some substrates used in floriculture may also have suppressive effects. When hardwood bark (composted or not) is used, plant growth is generally improved, especially in potted plants. The suppressive effect on the pathogens and the improved vigour of plants in such bark substrates derive from the physical characteristics of the bark composts and from the higher levels of antagonists supported by these composts (Hoitink and Bohem, 1999). Although composted materials have mostly been used in container media, particularly as peat alternatives and substitutes (De Ceuster and Hoitink, 1999; Hoitink *et al*., 2001), there are also several references in the literature on the use of composted materials to suppress soil-borne plant diseases of turf-grass (Noble and Coventry, 2005). To improve the consistency of disease control when using composts, BCAs have been added; composts provide a food base for BCAs of soilborne pathogens (Ramona and Line, 2002). Results indicate that mixtures of bacterial and fungal BCAs are more effective than single BCAs in inducing suppression of *Rhizoctonia* and *Pythium* (Ryckeboer, 2001). This approach is relatively recent and has not yet been widely investigated (Noble and Coventry, 2005).

Antagonists such as *Trichoderma virens* (= *Glio-*

Table 3. Biocontrol agents commercially applied on ornamental crops against soil-borne pathogens in some countries.

Microorganism	Commercial formulation	Target pathogen(s)
Bacteria		
Agrobacterium radiobacter	Galltrol-A, Nogall, Diegall, Norbac 84C	*Agrobacterium tumefaciens*
Bacillus subtilis	Epic, Kodiak, System 3, Rhizo-plus, Serenade	*Rhizoctonia solani, Fusarium* spp., *Alternaria* spp., *Aspergillus* spp.
Burkholderia cepacia (Pseudomonas)	Blu Circle, Deny, Intercept	*Fusarium, Pythium, Rhizoctonia,*
Streptomyces griseoviriridis	Mycostop	*Fusarium* spp., *Pythium* spp., *Phytophthora* spp.
Streptomyces lydicus	Actinovate	Soilborne pathogens
Fungi		
Coniothyrium minitans	Contans, Koni	*Sclerotinia sclerotiorum, S. minor*
Fusarium oxysporum	F.O. 215/2, Fusaclean	*Fusarium oxysporum*
Gliocladium virens	SoilGard (previously GlioGard)	*Rhizoctonia solani*, *Pythium* spp.
Gliocladium catenulatum	Primastop	*Pythium* spp., *Rhizoctonia* spp., *Phytophthora* spp.
Pythium oligandrum	Polygandron, Polyversum	*Pythium ultimum*
Talaromices flavus	Protus WG	*Verticllium* spp., *Rhizoctonia solani*
Trichoderma harzianum and other species	RootShield, T-22G, T-22 Planter Box, (Bio-Trek), Bio-fungus, Binab T, Promote, Suppresivit, Trichodex, Trichopel, Tricoject, Trichodowels, Trichoseal, Trichoderma 2000	*Sclerotinia, Phytophthora, Rhizoctonia solani, Pythium* spp., *Fusarium, Verticillium*

cladium virens), *Trichoderma* spp., and *Streptomyces griseoviridis* have been successfully applied in the growing mix or as seed treatment against root rots (Paulitz and Bélanger, 2001). *T. virens* was effective when applied to potting mix against damping-off caused by *Pythium ultimum* on *Catharanthus roseus* (Burns and Benson, 2000).

Binucleate *Rhizoctonia* spp., applied as wheat flour kaolin granules (Pesta) or as a rice flour formulation to the potting mix, was comparable to the benzimidazoles in controlling pre-emergence damping-off caused by *Rhizoctonia solani* of impatiens (Honeycutt and Benson, 2001).

Strain B2 of *Serratia marcescens*, which produces chitinolytic enzymes, under experimental conditions suppressed damping-off of cyclamen caused by *R. solani* (Someya *et al*., 2000).

Closed recirculating soilless systems represent an interesting environment for exploiting biological control, through the microbial optimisation of soilless systems by applying microrganisms that colonise the root systems of plants grown under a strictly controlled environment (Van Os and Postma, 2000). A slow sand filtration technique combined with the application of different antagonistic strains of *Fusarium* spp. and *Trichoderma* spp. proved effective against *Phytophthora cryptogea* of gerbera (Garibadi *et al*., 2003).

The application of biocontrol agents against foliar diseases, on the contrary, offers less promising results at this time. The biological control of geranium rust (*Puccinia pelargonii-zonalis*) with *Bacillus subtilis* has been attempted under greenhouse conditions, and good results have been obtained with some strains. A commercial formulation of strain QST713 of *B. subtilis* is available in some countries: it is advertised as active against a wide range of diseases, including grey mould and powdery mildew (Paulitz and Bélanger, 2001). Due to the zero tolerance for geranium rust, *B. subtilis* could be alternated with fungicides (Rytter *et al.*, 1989). The biological control of carnation rust (*Uromyces caryophyllinus*) has been achieved under experimental conditions using *Verticillium lecanii*. This fungus infested the uredia of carnation rust. As a consequence, under the experimental conditions and depending on the time of application, the rust infection was prevented or the formation of uredospores arrested.

Strain T-39 of *Trichoderma harzianum*, registered in several countries as Trichodex (Makhteshim Chemical Works, Beer-Sheva, Israel) (Elad *et al.*, 1999) as well as other strains of *Trichoderma* spp. partially control grey mould also on ornamental crops: its efficacy was improved when it was applied as part of IPM, in alternation with chemical pesticides (Gullino and Wardlow, 1999).

Ulocladium atrum is effective against grey mould on greenhouse crops such as cyclamen, geranium and roses (Kohl *et al.*, 2000; Gerlagh *et al.*, 2001): the antagonism of *U. atrum* against *Botrytis* spp. appears to involve competition in necrotic tissues. This antagonist has a high ecological competence for the habitat of above-ground necrotic plant tissues (Kohl *et al.*, 1999).

Several studies have shown the effectiveness of selected strains of *Clonostachys rosea*, a cosmopolitan soil-inhabiting saprophyte, in controlling *Botrytis cinera* on roses (Morandi *et al.*, 2000 and 2003; Noble *et al.*, 2005): these strains colonise rose leaves even following a 16-h-dry period after application (Morandi *et al.*, 2003), reduce sporulation of *B. cinerea* on rose debris and establish themselves as endophytes (Morandi *et al.*, 2000).

Two biocontrol agents, the yeast *Exophiala ieanselmei* and a coryneform-type bacterium, controlled *B. cinerea* infection on cut roses during storage at 2.5°C: the level of disease control achieved with these biocontrol agents during storage was comparable to that offered by vinchlozolin, but they were less effective in controlling post-storage infection (Hammer and Marois, 1989). The fungus *Ampelomyces quisqualis*, a hyperparasite of powdery mildew, provided good control of rose powdery mildew, even under severe disease pressure (Pasini *et al.*, 1997).

The basidiomycetous yeast *Pseudozyma flocculosa* is a very effective natural antagonist of powdery mildew (Paulitz and Bélanger, 2001). It controls rose powdery mildew quite as effectively as the commonly used fungicide dodemorph. It improves the flower quality of some cultivars by eliminating the phytotoxicity caused by fungicides (Bélanger *et al.*, 1994).

Biocontrol agents are expected to play a major role in disease management in the future, through a better integration into production systems (Fravel, 2005).

Regulatory control

State, regional and international laws and regulations govern the production, sale and transport of ornamental plants. Measures to control the introduction of foreign pests are routine in several countries. Domestic and international quarantines restrict the movement of plant materials that may carry pests in order to prevent or delay the introduction of these pests. These quarantines often require particular cultural practices or chemical treatments before the material is permitted to enter the country. Quarantine-regulated pest lists are available for several regions (Stebbins and Johnson, 2001; Ebbels, 2003; Gullino *et al.*, 2004).

Quarantine restrictions and eradication measures are sometimes necessary to avoid the spread of pathogens that severely affect the production of certain economically important crops (Ebbels, 2003). In several countries, for instance, quarantines are imposed in order to prevent or limit the import of the rust pathogens of geranium, chrysanthemum, daylily and gladiolus. Quarantines have proved successful in the USA as well as in Australia in the case of chrysanthemum white rust caused by *Puccinia horiana* (Bonde and Rizvi, 1995), and gladiolus rust caused by *Uromyces transversalis* (Beilharz *et al.*, 2001). Quarantines have also been effective in Colombia, where in the early 1980s a strict eradication and control campaign was started to keep all chrysanthemum exports free of *P. horiana* (Ortega, 1999). If any white rust were now detected on plant material imported from Colombia, the USA would halt its imports from that country.

In other cases, quarantine measures have however been ineffective. For instance it proved impossible to prevent *Puccinia hemerocallis,* the causal agent of daylily rust, from entering the USA because of the widespread movement of plants caused by hobbyists and nurseries (Williams-Woodward *et al*., 2001). Quarantine restrictions and the destruction of infected plants also could not prevent geranium rust, caused by *Puccinia pelargonii-zonalis*, from becoming endemic in Europe and the USA (Wise *et al*., 2004).

A considerable number of pathogens has in recent years become endemic in Italy despite quarantine regulations being in force. They include *F. oxysporum* f. sp. *chrysanthemi* on gerbera, *F. oxysporum* f. sp. *hebae* on hebe, powdery mildew on Euphorbia, *Colletotrichum acutatum* on anemone, and *Phytophthora ramorum* on azalea (Gullino *et al*., 2004).

Quarantine restriction and eradication efforts can be costly, and may have a significant economic impact on flower production. Even so, however, they are not always effective, as has been shown.

Diagnostic tools

It is a realistic assumption that the international trade in ornamental products will increase, driven as it is by free trade and consumer demand. Inspectors will increasingly encounter fungus-infected material to refer to the laboratory for diagnosis, and the identification given will increasingly be for organisms with scientific names not in the quarantine-pest lists they rely on. Only a few centres have a strong expertise in the field of pest identification. Most plant pathogens are currently known by the diseases they cause, and by their general morphological characteristics. Only a few have been characterised by examining living cultures, DNA and DNA sequences. Phytosanitary diagnostics must keep abreast of new developments, and strategic decisions are needed now, at an international level, to determine how this can be funded and achieved (Schaad *et al*., 2003; Crous, 2005).

With a greater investment in international biosecurity and biodefence, it is expected that the intensive development of new technologies will provide new, more effective, faster and less labour-intensive methods both for validating the origin and tracing the movements of plant consignments and for detecting and identifying diseases. Advances in molecular-based diagnostics already have a strong impact on plant disease management (Martin *et al*., 2000).

There will be a continued drive to provide rapid diagnostic methods for use at points of entry and inspection (Baker *et al*., 2005). As already mentioned, for many important pathogens such as *Fusarium* spp., *Phytophthora* spp., *Pythium* spp. (Mes *et al*., 1994; Ferguson and Jeffers, 1999; Jung *et al*., 1999; Cooke *et al*., 2000; Moorman *et al*., 2002; Pasquali *et al*., 2003, 2004a, 2004b; Ivors *et al*., 2004; Garzòn *et al*., 2005) diagnostic methods now exist and should be made available to extension services. Although PCR was discovered 20 years ago, PCR technology is not yet applied for routine plant diagnosis and portable real-time PCR instruments have only recently become available (Schaad *et al*., 2003). They should be very useful in the ornamental plant industry and the extension services should be trained in using them.

Research needs and outlook

Many important problems of the ornamental industry are still unresolved and new ones are emerging as the ornamental industry undergoes ever more changes in production, marketing and shipping procedures. The major changes will include more widely-adopted mechanization and automation systems for improved crop management and the use of biotechnology in plant production. Some of these changes will exacerbate the severity of diseases, thus challenging plant pathologists working with ornamentals.

The pathology of ornamental plants includes a wide range of diseases on a variety of crops, with great opportunities for imaginative research and the exploitation of new methods of disease control. The energy crisis, increasing restrictions on the use of pesticides as well as the exploitation of new crops, represent new challenges to researchers.

Plant pathologists will have to work more closely with horticulturists to ensure that new management practices have beneficial, or at least neutral effects on plant health. New methods to improve the accuracy and speed of field and laboratory diagnosis are urgently needed. Better and more widely used monitoring and diagnostic systems to determine the populations and economic thresholds of pathogens will make more rational management decisions possible. A high priority should be placed on the production of pathogen-free propagating material by scrupulous sanitary practices. Clean growing media, pots, containers, and benches, disinfected mostly with steam, will continue to be important in the management of soil-borne diseases. Further attention will have to be paid to developing new techniques and technologies for soil and substrate disinfestation, after the banning of methyl bromide, which was widely used in the ornamental industry (Rosskopf *et al*., 2005). Surveys recently carried out in Italy have shown that the ornamental industry has been one of the most successful in adapting to this ban (Gullino *et al*., 2007). There is also a demand for more effective disease control agents (biological and chemical). More research in biological control is certainly needed to expand its present range of application. A common drawback in biocontrol research is the inconsistency of its results, which can be partly attributed to pathogen variability (Buck and Jeffers, 2004). When tested against a single strain of a pathogen, single-strain biocontrol agents are often efficient, but when they have to cope with a variable pathogen population in the field they become much less effective. Future research should address the selection of potential biocontrol agents based on their colonization efficiency in plant tissues. New approaches monitoring how microbial community structures in the soil change as a result of compost amendment may lead to a better understanding of which changes in microbial communities are responsible for the disease suppressing effects of compost. This may eventually lead to improved and more reliable disease control resulting from compost amendment of soil, sand or peat, both in container crops in greenhouses and in the field (Noble and Coventry, 2005). Research on the aetiology of resistance, and on monitoring, modelling and breeding for resistance is also needed.

As organically produced flowers and plants are gaining in importance, the development of disease management strategies for organic production is becoming an interesting field of research.

Some sectors require specific research. The foliage plant industry which is growing demands high quality, durable plants with greater disease resistance (Chen *et al*., 2005). This need also exists for container grown and landscape plants.

Important but untested assumptions and promising outcomes should be tested under field conditions, which should include economic aspects, before recommendations are made to growers.

Finally, there is a strong need to improve the information flow between researchers, extension people and growers, to maintain the close links between the production and the marketing sectors of the industry, and to devote more attention to consumer education.

Unfortunately, only a few research programmes are tailored specifically for research on ornamental pathology and most funding agencies still consider research in this field as a kind of hobby for researchers. For instance, the VII Framework Programme recently launched by the European commission did not give this sector due weight, despite its economic importance. This is very unfortunate, because in this way the Programme failed to realise that a number of techniques developed specifically for the ornamental industry (culture-indexing of cuttings, apical meristem culture, improvements in tissue culture methods, virus indexing by grafting on indicator plants, soil steaming, soilless cultivation,…) have also proved useful for controlling diseases in other crop plants (Baker and Linderman, 1979; Gullino and Garibaldi, 2005).

Despite a general pressure to concentrate research on food crops, the vanishing beauty of much of the world today will probably push up the demand for ornamentals around the home. The high aesthetic value of ornamental crops to a large portion of the population means that they deserve more attention from plant pathologists and from researchers generally. As a result, diseases of ornamental plants will continue to provide a fruitful and stimulating field of study for plant pathologists.

Acknowledgements

This work was supported by grants from University of Torino and Regione Liguria, Project REV-FLOR.

Literature cited

Ausburger N.D. and C.G. Powell, 1986. Correct greenhouse ventilation: Basis of excessive humidity control. *Ohio Florist Association Bullettin* 675, 6–8.

Baker K.F. and R.G. Linderman, 1979. Unique features of the pathology of ornamental plants. *Annual Review of Phytopathology* 17, 253–277.

Baker R., R. Cannon, P. Bartlett and I. Barker, 2005. Novel strategies for assessing and managing the risks posed by invasive alien species to global crop production and biodiversity. *Annals of Applied Biology* 146, 177–191.

Becktell M.C., M.L. Daughtrey and W.E. Fry, 2005a. Epidemiology and management of petunia and tomato late blight in the greenhouse. *Plant Disease* 89, 1000–1008.

Becktell M.C., M.L. Daughtrey and W.E. Fry, 2005b. Temperature and leaf wetness requirements for pathogen establishment, incubation period, and sporulation of *Phytophthora infestans* on *Petunia × hybrida*. *Plant Disease* 89, 975–979.

Beilharz V., D.G. Parberry and I.G. Pascoe, 2001. Gladiolus rust (caused by *Uromyces transversalis*) in eastern Australia. *Australian Plant Pathology* 30, 267–270.

Bélanger R.R., P.A. Bowen, D.L. Ehret and J.G. Menzies, 1995. Soluble silicon: its role in crop and disease management of greenhouse crops. *Plant Disease* 79, 329–336.

Bélanger R.R., C. Labbé and W.R. Jarwis, 1994. Commercial-scale control of rose powdery mildew with a fungal antagonist. *Plant Disease* 78, 420–424.

Bertetti D., M.L. Gullino and A. Garibaldi, 2007. Susceptibility of evergreen azaleas to anthracnose caused by *Colletotrichum acutatum*. *HortTechnology*, in press.

Blechert O. and T. Debener, 2005. Morphological characterization of the interaction between *Diplocarpon rosae* and various rose species. *Plant Pathology* 54, 82–90.

Bonde M.R. and S.A. Rizvi, 1995. Myclobutanil as a curative agent for chrysanthemum white rust. *Plant Disease* 79, 500–505.

Boulter J.I., G.J. Boland and J.T. Trevors, 2002. Evaluation of composts for suppression of dollar spot (*Sclerotinia homeocarpa*) of turfgrass. *Plant Disease* 86, 405–410.

Bowers J.H. and J.C. Locke, 2000. Effect of botanical extracts on the population density of *Fusarium oxysporum* in soil and control of Fusarium wilt in the greenhouse. *Plant Disease* 84, 300–305.

Brecht M.O., L.E. Datnoff., T.A. Kucharek. and R.T. Nagata, 2004. Influence of silicon and chlorothalonil on the suppression of grass leaf spot and increase plant growth in St. Augustine grass. *Plant Disease* 88, 338–344.

Buck J.W. and S.N. Jeffers, 2004. Effect of pathogen aggressiveness and vinclozolin on efficacy of *Rhodotorula glutinis* PM4 against *Botrytis cinerea* on geranium leaf disks and seedlings. *Plant Disease* 88, 1262–1268.

Burns J.R. and D.M. Benson, 2000. Biocontrol of damping-off of *Catharanthus roseus* caused by *Pythium ultimum* with *Trichoderma virens* and binucleate *Rhizoctonia* fungi. *Plant Disease* 84, 644–648.

Byrne J.M., M.K. Hausbeck and B.D. Shaw, 2000. Factors affecting concentrations of airborne conidia of *Oidium* sp. among poinsettias in a greenhouse. *Plant Disease* 84, 1089–1095.

Chen I., D.B. Mc Connel, D.J. Norman and R.J. Henry, 2005. The foliage plant industry. *Horticulture Review* 31, 47–112.

Chet I., 1987. *Trichoderma* - Application, mode of action, and potential as a biocontrol agent of soilborne plant pathogenic fungi. In: *Innovative approaches to plant disease control* (I. Chet, ed.) John Wiley & Sons, 137–160.

Cooke D.E.L., A. Drent, J.M. Duncan, G. Wagels and C.M. Brasier, 2000. A molecular phylogeny of *Phytophthora* and related *Oomycetes*. *Fungal genetics and Biology* 30, 17–32.

Crous P.W., 2005. Impact of molecular phylogenetics on the taxonomy and diagnostics of fungi. *EPPO Bulletin* 35, 47–51.

Daughtrey M.L. and D.M. Benson, 2005. Principles of plant health management for ornamental plants. *Annual Review of Phytopathology* 43, 141–169.

De Ceuster T.J.J. and H.A.J. Hoitink, 1999. Prospects for composts and biocontrol agents as substitutes for methyl bromide in biological control of plant diseases. *Compost Science and Utilization* 7, 6–15.

De Kraker J., J.E. Van den Ende and WA.H. Rossing, 2005. Control strategies with reduced fungicide input for Botrytis leaf blight in lily – a simulation analysis. *Crop Protection* 24, 157–165.

Ebbels D.I., 2003. *Principles of Plant Health and Quarantine*. CAB International, Wallingford, UK, 302 pp.

Elad Y., R.R. Bélanger and J. Kohl, 1999. Biological control of diseases in the phyllosphere. In: *Integrated Pest and Disease Management in Greenhouse Crops*. (R. Albajes, M.L. Gullino, J.C. van Lenteren, Y. Elad, ed.) Kluwer Academic Publishers, Dordrecht, The Netherlands, 338–352.

Elmer W.H., 2002. Influence of inoculum density of *Fusarium oxysporum* f. sp. *cyclaminis* and sodium chloride and the development of Fusarium wilt. *Plant Disease* 86, 389–393.

Ferguson A.J. and S.N. Jeffers, 1999. Detecting multiple species of *Phytophthora* in container mixes from ornamental crop nurseries. *Plant Disease* 83, 1129–1136.

Fravel D.R., 2005. Commercialization and implementation of biocontrol. *Annual Review Phytopathology* 43, 337–359.

Friedrich S., D. Gebelein and C. Boyle, 2005. Control of *Botrytis cinerea* in glasshouse fuchsia by specific climate management. *European Journal of Plant Pathology* 111, 249–262.

Garibaldi A., L. Guglielmone and M.L. Gullino, 1989. Rhizosphere competence of antagonistic *Fusaria* isolated from suppressive soils. *Symbiosis* 9, 401–404

Garibaldi A. and M.L. Gullino, 1990. Disease management of ornamental plants: a never ending challenge. *Med. Fac. Landbouww. Rijksuniv. Gent* 55, 189 –201.

Garibaldi A., A. Minuto, V. Grasso and M.L. Gullino, 2003. Application of selected antagonistic strains against *Phytophthora cryptogea* on gerbera in closed soilless systems with disinfection by slow sand filtration. *Crop Protection* 22, 1053–1061.

Garzòn C.D., D.M. Geiser and G.W. Moorman, 2005. Diagnosis and population analysis of *Pythium* species using AFLP fingerprinting. *Plant Disease* 89, 81–89.

Gerlagh M., J.J. Amsing, W.M.L. Molhoek, A.L. Bosken-van Zessen, C.H. Lombaers van der Plas and J. Kohl, 2001. The effect of treatment with *Ulocladium atrum* on *Botrytis cinerea* attack of geranium (*Pelargonium zonale)* stock plants and cuttings. *European Journal Plant Pathology* 107, 377–386.

Gullino M.L., 1992. Chemical control of *Botrytis* spp. In: *Recent Advances of* Botrytis *Research*. (K. Verhoeff, N.E.Malathrakis, B. Williamson, ed.) Pudoc, Wageningen, The Netherlands, 218–222.

Gullino M.L., A. Camponogara, G. Gasparrini, V. Rizzo, C. Clini and A. Garibaldi, 2003. Replacing methyl bromide for soil disinfestation: the Italian experience and the implication for other countries. *Plant Disease* 87, 1012–1021.

Gullino M.L. and A. Garibaldi, 2005. Evolution of fungal diseases of ornamental plants and their management. In: *Biodiversity of Fungi. Their Role in Human Life. (*S.K. Deshmukh and M.K. Rai, ed.) Science Publishers, Inc. Enfield, NH, USA, 357–374.

Gullino M.L. and A. Garibaldi, 2006. Evolution of fungal diseases of ornamental plants and main implications for their management. In: *Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues*. 1st Edition, (J.A. Teixeira da Silva, ed.), Global Science Books, London, UK, 464–471.

Gullino M.L. and L.A.M. Kuijpers, 1994. Social and political implications of managing plant diseases with restricted fungicides in Europe. *Annual Review of Phytopathology* 32, 559–579.

Gullino M.L., G. Magnano di San Lio and A. Garibaldi, 2004. Funghi. In: *Parassiti e Patogeni a Rischio di Introduzione e di Quarantena*. *Georgofili, Quaderni 2004* IV, 43–63.

Gullino M.L., R. Savigliano, G. Gasparrini and C. Clini, 2007. Critical use exemption for methyl bromide for soil disinfestation: Italy's experience with the European Union process. *Phytoparasitica,* 35, 321–329.

Gullino M.L. and L. Wardlow, 1999. Ornamentals. In: *Integrated Pest and Disease Management in Greenhouse Crops*. (R. Albajes, M.L. Gullino, J.C. van Lenteren, Y. Elad, ed.) Kluwer Academic Publishers, Dordrecht, The Netherlands, 486–505.

Hagan A.K., 2001. Disease resistance. in: *Diseases of Woody Ornamentals and Trees in Nurseries*.(R.K. Jones, D.M.Benson, ed.) APS Press, St Paul, MN, USA, 431–432

Hammer P.E. and J.J. Marois, 1989. Nonchemical methods for postharvest control of *Botrytis cinerea* on cut roses. *Journal of the American Society of Horticultural Science* 114, 100–106.

Hammond J., H.T. Hsu, Q. Huang, R. Jordan, K. Kamo and M. Pooler, 2006. Transgenic approaches to disease resistance in ornamental crops. *Journal of Crop Improvement* 17, 155–220.

Hausbeck M.K. and G.W. Moorman, 1996. Managing *Botrytis* in greenhouse-grown flower crops. *Plant Disease* 80, 1212–1219.

Heinrichs F., 2005. *International Statistics. Flowers and Plants. Institut fur Gartenbauokonomie der Universitat Hannover* 53, 133 pp.

Hoitink H.A.J. and M.J. Bohem, 1999. Biocontrol within the context of soil microbial communities: a substrate dependent phenomenon. *Annual Review of Phytopathology* 37, 427–446.

Hoitink H.A.J., M.S. Krause and D.Y. Han, 2001. Spectrum and mechanisms of plant disease control with composts. In: *Compost Utilization in Horticultural Cropping Systems*. (P.J. Stofella, B.A. Kahn, ed.). Lewis Publishers, Boca Raton, USA, 263–274.

Honeycutt E.W. and D.M. Benson, 2001. Formulation of binucleate *Rhizoctonia* spp. and biocontrol of *Rhizoctonia solani* on Impatiens. *Plant Disease* 85, 1241–1248.

Horst R.K., S.O. Kawamoto and L.L. Porter, 1992. Effect of sodium bicarbonate and oils on the control of powdery mildew and black spot of roses. *Plant Disease* 76, 347–351.

Hwang J. and D.M. Benson, 2005. Identification, mefenoxam sensitivity, and compatibility type of *Phytophthora* spp. attacking floriculture crops in North Carolina. *Plant Disease* 89, 185–190.

Ivors K.I., K.J. Hayden, P.J.M. Bonants, D.M. Rizzo and M. Garbelotto, 2004. AFLP and phylogenetic analyses of North American and European populations of *Phytophthora ramorum*. *Mycological Research* 108, 376–392.

Jarvis W.R., 1992. *Managing Diseases in Greenhouse Crops*. American Phytopathological Society Press, St Paul, MN, USA, 288 pp.

Jung T., D.G.L. Cooke, H. Blashke, J.M. Duncan and W. Oswald, 1999. *Phytophthora quercina* sp. nov., causing root rot of European oaks. *Mycological Research* 103, 785–798.

Karlik J.F. and M.L. Flint,. 2002. Diseases and abiotic disorders of outdoor roses. APSnet Feature, www.apsnet.org, 6 pp.

Kenyon D.M., G.R. Dixon and S. Helfer, 2002. Effects of relative humidity, light intensity and photoperiod on the colony development of *Erysiphe* sp. on *Rhododendron. Plant Pathology* 51, 103–108.

Kohl J., M. Gerlagh and G. Grit, 2000. Biocontrol of *Botrytis cinerea* by *Ulocladium atrum* in different production systems of cyclamen. *Plant Disease* 84, 569–573.

Kohl J., C.H. Lombaers-van der Plaas, W.M.L. Molhoek, G.J. Kessel and H.M. Goosen-van de Gejn, 1999. Competitive ability of the antagonists *Ulocladium atrum* and *Gliocladium roseum* at temperatures favourable for *Botrytis* spp. development. *BioControl* 44, 329–346.

Loffler H.J.M. and D.E.A. Florack, 1997. Engineering for bacterial and fungal disease resistance. In: *Biotechnology of Ornamental Plants*. (R.I. Geneve., J.E. Preece, S.A.Merkle, ed.) CAB International, Willingford, UK, 313–333.

Martin R.R., D. James and A. Lévesque, 2000. Impacts of molecular diagnostic technologies on plant disease management. *Annual Review of Phytopathology* 38, 207–239.

McGovern R.J., R. McSorley and M.L. Bell, 2002. Reduction of landscape pathogens in Florida by soil solarization. *Plant Disease* 86, 1388–1395.

McGovern R.J., R. McSorley and R.R. Urs, 2000. Reduction of Phytophthora blight of Madagascar Periwinkle in Florida by soil solarization in autumn. *Plant Disease* 84, 185–191.

Mes J.J., J. Van Doorn, E.J.A. Roebroeck and P.M. Boonekamp, 1994. Detection and identification of *Fusarium oxysporum* f. sp. *gladioli* by RFLP and RAPD analysis. In: *Modern Assays for Plant Pathogenic Fungi*. (A. Schots, F.M. Dewey, R. Oliver, ed.). CAB International, Willingford, UK, 63–68.

Minuto A., D. Bertetti, M.L. Gullino and A. Garibaldi, 2006. Evaluation of susceptibility of varieties of *Gerbera jamesonii* to Fusarium wilt. *IOBC/wprs* 29, 269–274.

Minuto A., A. Garibaldi and M.L. Gullino, 2007a. Resistance of varieties of chrysanthemum and gerbera to Fusarium wilt incited by *Fusarium oxysporum* f. sp. *chrysanthemi*. *Communications in Agricultural and Applied Biological Sciences* 72, in press.

Minuto A., ML. Gullino and A. Garibaldi, 2007b. *Gerbera jamesonii*, *Osteospermum* sp. and *Argyranthemum frutescens*: new hosts of *Fusarium oxysporum* f. sp. *chrysanthemi*. *J. Phytopathology* 155, 373–376.

Minuto A., Q. Migheli and A. Garibaldi, 1995. Evaluation of antagonistic strains of *Fusarium* spp. in the biological and integrated control of Fusarium wilt of cyclamen. *Crop Protection* 14, 221–226.

Moorman G.W., S. Kang, D.M. Geiser and S.H. Kim, 2002. Identification and characterisation of *Pythium* species associated with greenhouse floral crops in Pennsylvania. *Plant Disease* 86, 1227–1231.

Moorman G.W. and S.H. Kim, 2004. Species of *Pythium* from greenhouses in Pennsylvania exhibit resistance to propamocarb and mefenoxam. *Plant Disease* 88, 630–632.

Morandi M.A.B., L.A. Maffia, E.S.G. Mizubuti, A.C. Alfenas and J.C. Barbosa, 2003. Suppression of *Botrytis cinerea* sporulation by *Clonostachys rosea* on rose debris: a valuable component in Botrytis blight management in commercial greenhouse. *Biological Control* 26, 311–317.

Morandi M.A.B., J.C. Sutton and L.A. Maffia, 2000. Effects of host and microbial factors on development of *Clonostachys rosea* and control of *Botrytis cinerea*. *European Journal of Plant Patholology* 106, 439–448.

Mortensen L.M. and H.R. Gislerød, 2005. Effect of air humidity variation on powdery mildew and keeping quality of cut roses. *Scientia Horticulturae* 104, 49–55.

Niedbalski Cline M., G.A. Castagner, M. Aragaki, R. Baker, M.L. Daughtrey, R.H. Lawson, J.D. MacDonald, J.F. Tammen and G.L. Worf, 1988. Current and future research directions of ornamental pathology. *Plant Disease* 72, 926–934.

Noble R and E. Coventry, 2005. Suppression of soil-borne plant diseases with composts: a review. *Biocontrol Science and Technology* 15, 3–20.

Noble S.A.M., L.A. Maffia, E.S.G. Mizubuti., L.V. Cota and A.P.S. Dias, 2005. Selection of *Clonotachys rosea* isolates from Brazilian ecosystems effective in controlling *Botrytis cinerea*. *Biological Control* 34, 132–143.

Ortega L., 1999. Prevention and eradication of white rust (*Puccinia horiana*) in Colombia. *Acta Horticulturae* 482, 187–195.

Pasini C., F. D'Aquila, P. Curir and M.L. Gullino, 1997. Effectiveness of antifungal compounds against rose powdery mildew (*Sphaerotheca pannosa* var. *rosae*) in glasshouses. *Crop Protection* 16, 251–256.

Pasquali M., A. Acquadro, V. Balmas, Q. Migheli, A. Garibaldi and M.L Gullino, 2003. RAPD characterization of *Fusarium oxysporum* isolates pathogenic on *Argyranthemum frutescens*. *Journal of Phytopathology* 151, 30–35.

Pasquali M., A. Acquadro, V. Balmas, Q. Migheli, M.L. Gullino and A. Garibaldi, 2004. Development of PCR primers for a new *Fusarium oxysporum* pathogenic on *Argyranthemum frutescens*. *European Journal of Plant Pathology* 110, 7–11.

Pasquali M., L. Marena, M. Fiora, M.L Gullino and A. Garibaldi, 2004. Real-time polymerase chain reaction for identification of a highly pathogenic group of *Fusarium oxysporum* f. sp. *chrysanthemi* on *Argyranthemum frutescens*. *Journal of Plant Pathology* 86, 153–159.

Paulitz T.C. and R.R. Belanger, 2001. Biological control in greenhouse systems. *Annual Review of Phytopatholology* 39, 103–133.

Postma J., M.J.E. Willemsen-De Klein and J.D. Van Elsas, 2000. Effect of indigenous microflora on the development of crown and root rot caused by *Pythium aphanidermatum* in cucumber grown on rockwool. *Phytopathology* 90, 125–133.

Ramona Y. and M.A. Line, 2002. Potential for the large-scale production of a biocontrol fungus in raw and composted paper mille waste. *Compost Science & Utilization* 10, 57–62.

Rosskopf E. N., D.O. Chellemi, N. Kokalis-Burelle and G.T. Church, 2005. Alternatives to methyl bromide: a Florida perspective. APSnet Feature www.apsnet.org, 37 pp.

Ryckeboer J., 2001. Biowaste and yard waste composts: microbiological and hygienic aspects – suppressiveness to plant diseases. PhD Thesis, Katholike Universiteit Leuven, Belgium, 245 pp.

Rytter J.L., F.L. Lukezic, R. Craig and G.W. Moorman, 1989. Biological control of geranium rust by *Bacillus subtilis*. *Phytopathology* 79, 367–370.

Schaad N.W., R.D. Frederick, J. Shaw, W.L. Schneider, R. Hickson, M.D. Petrillo and D.G. Luster, 2003. Advances in molecular-based diagnostic in meeting crop biosecurity and phytosanitary issues. *Annual Review of Phytopathology* 41, 305–324.

Someya N., N. Kataoka, K. Hirayae, T. Hibi and K. Akutsu, 2000. Biological control of cyclamen soilborne diseases by *Serratia marcescens* strain B 2. *Plant Disease* 84, 334–340.

Stanghellini M.E. and S.L Rasmussen, 1994. Hydroponics: a solution for zoosporic pathogens. *Plant Disease* 78, 1130–1138.

Stebbins T. and D. Johnson, 2001. Regulatory control. In: *Diseases of Woody Ornamentals and Trees in Nurseries*. (R.K. Jones and D.M. Benson, ed.), APS Press, St Paul, MN, USA, 457–458.

Takatsu Y., Y. Nishizawa, T. Hibi and K. Akutsu, 1999.

Transgenic chrysanthemum (*Dendranthema grandiflorum* [Ramat] Kitamura) expressing a rice chitinase gene shows enhanced resistance to gray mold (*Botrytis cinerea*). *Scientia Horticulturae* 82, 113–123.

Toussoun T.A., 1975 Fusarium-suppressive soils. In: *Biology and Control of Soil-borne Plant Pathogens*. (W. Bruehl, ed.) APS, St Paul, MN, USA, 145–151.

Tramier R., C. Antonini, A. Bettacchini and C. Metay, 1983. Studies on Fusarium wilt resistance in carnation. *Acta Horticulturae* 141, 89–94.

Uriarte R.F., H.D. Shew and D.C. Bowman, 2004. Effect of soluble silica on brown patch and dollar spot of creeping bentgrass. *Journal of Plant Nutrition* 27, 325–339.

Van Os E. and J. Postma, 2000. Prevention of root diseases in closed soilless growing systems by microbial optimisation and slow sand filtration. *Acta Horticulturae* 532, 97–102.

Wang B. and S.N. Jeffers, 2002. Effects of cultural practices and temperature on Fusarium root and crown rot of container-grown hostas. *Plant Disease* 86, 225–231.

Williams-Woodward J.L., J.F. Hennen, K.W. Parda and J.M. Fowler, 2001. First report of daylily rust in the United States. *Plant Disease* 85, 1121.

Wise K.A., D.S. Mueller and J.W. Buck, 2004. Quarantines and ornamental rusts. APSnet Feature, www.apsnet.org, 8 pp.

Accepted for publication: July 2, 2007