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Biological and integrated protection in the Mediterranean greenhouse: is disease management the weak link?

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Abstract: While biocontrol is commonly used for the protection of greenhouse crops against arthropods, continued reliance on chemical control against diseases is often considered as a hindrance to integrated protection. This paper presents a review of currently available biocontrol products and other alternatives to pesticides for use against plant diseases in the Mediterranean greenhouse. At least 12 biological active substances (micro-organism or plant extract) are commercially available for the control of soilborne pathogens and 14 against foliar diseases, in one country or more in the Mediterranean Basin. Future prospects and challenges are presented.

Key words: biological control, plant diseases, commercial products

Introduction

Greenhouse production systems are often cited among the most successful and the most advanced for the implementation of integrated protection schemes. Indeed, tools for biocontrol of pests in the greenhouse have long been available (van Lenteren, 2000, 2012) and natural enemies are successfully used against major pests in an ever increasing proportion of greenhouse acreage (Pilkington *et al.*, 2010). In contrast, development of biological control methods against plant pathogens is a more recent endeavour (van Lenteren, 2000) and continued reliance on chemical control against diseases is considered to be a hindrance to integrated protection, as many products have harmful effects on natural enemies. Is disease management really the weak link of IPM in the Mediterranean greenhouse?

This paper presents a review of currently available biocontrol methods for use against plant diseases in the Mediterranean greenhouse and proposes perspectives on short term evolution of the situation.

Major diseases of Mediterranean greenhouse crops

The main diseases present on greenhouse crops were comprehensively reviewed in the landmark book edited by Albajes *et al* (1999). While new pests have emerged in the Mediterranean greenhouses since the turn of the millennium, often associated with emerging plant viruses they can transmit, the key bacterial and fungal pathogens have overall remained the same. Much of the use of fungicides in the greenhouse targets either powdery mildews or airborne diseases fostered by excessive humidity such as *Botrytis* diseases, downy mildews (and late blight of tomato) and various leaf moulds, scabs and blights or stem rots. More recently, the effective phasing out of methyl bromide in the European Union (EU) and other countries around the Mediterranean has marked an increase in the importance paid to soilborne plant pathogenic fungi and nematodes.

Biological and integrated protection against diseases of greenhouse crops

Although research on biological control of diseases has been a very dynamic field, with an estimate of over 12 000 papers published in international journals between 1973 and 2008, only a trickle of commercial products have reached the market (Fravel, 2005; Nicot, 2011). In 2010, only 14 microbial biocontrol agents were included in the EU list of active substances (Annex I of Directive 91/414) against plant pathogens (Nicot *et al.*, 2012). Various analyses have provided clues to explain this situation, including technical, regulatory and commercial difficulties encountered in the production, registration and use of biopesticides (Kabaluk *et al.*, 2010; Nicot, 2011; Nicot *et al.*, 2012; Ravensberg, 2012).

To identify currently available commercial products in countries of the Mediterranean Basin, several sources of online information were accessed in addition to simple Google searches with appropriate key words. Key, publicly accessible resources used in this study included the "EU Pesticide Database" (http://ec.europa.eu/sanco_pesticides/) and national databases on registered plant protection products in several countries of the European and Mediterranean Plant Protection Organization (www.eppo.int), the "Bio-Pesticides Data Base" of the University of Hertfordshire (www.herts.ac.uk) and the "Directory of Biopesticides in Organization for Economic Cooperation and Development Countries" developed by Agriculture and Agri-Food Canada (www.agr.gc.ca). Collected data were cross-checked among several databases and, whenever possible, validated directly with representatives of the companies.

Currently available commercial biocontrol products for the Mediterranean greenhouse

At least 12 microbial preparations, six of which are based on species of *Trichoderma*, are commercially available for the control of soilborne pathogens of greenhouse crops in one country or more of the Mediterranean region (Table 1). Their application range encompasses a variety of fruit, vegetable and ornamental crops. Their recommended use is most often as soil drench, but several products may be mixed into greenhouse substrates, used to dip transplants or cuttings or as seed dressing. This represents a substantial increase over the situation observed only a few years ago. Several products initially registered by companies based in northern latitudes are now distributed in the Mediterranean region.

Another striking improvement is that many products are now available for biocontrol of key airborne diseases (such as *Botrytis* and the powdery mildews) of a variety of greenhouse crops (Table 1). Particularly interesting among them, are several micro-organisms (such as *Bacillus* sp.) with a wide range of action, covering a variety of pathogens on many different crops.

However, the availability of biocontrol products against diseases is not evenly distributed within the Mediterranean region. Greenhouse growers in Italy, Spain and Turkey have the widest choice (with at least 6 to 9 products targeting soilborne and airborne pathogens), while there seems to be no product on the market in several countries (Table 1).

Other alternatives to chemical control of diseases in the greenhouse

Besides biocontrol, a variety of cultural practices may be used by growers to reduce the impact of diseases in the greenhouse (see excellent reviews in Albajes *et al.*, 1999; van Lenteren, 2000, for example). Over the years the arsenal of such methods has widened, including the availability of less susceptible varieties, avoidance of excess humidity and the use of grafted transplants with resistance to soilborne pathogens. Increasingly, more systemic approaches are considered, including for example the impact of fertilization or water stress on plant susceptibility to diseases (and pests) and on the efficacy of biocontrol agents.

Table 1: Examples of commercially available biocontrol products against diseases of Mediterranean greenhouse crops

Active substance	Commercial name	Company	Current usage			
			Crops	Mode of application	Target diseases or pathogens	Country of registration*
<i>Ampelomyces quisqualis</i>	AQ10	Intrachem www.intrachem.com	several fruit, vegetable and ornamental crops	foliar spray	powdery mildew	BG, CY, FR, GR, IT, SI, ES
<i>Bacillus amylolique-faciens</i> D747	Amylo-X	Intrachem Italia www.intrachem.it	several fruit and vegetable crops	foliar spray	various foliar fungi	IT
<i>Bacillus megaterium</i>	Bio Arc	Organic for Bio Technology	several fruit & vegetable crops	foliar spray	various foliar fungi	EG
<i>Bacillus subtilis</i>	Baubak	Biontek Inc.	cucumber	foliar spray	downy mildew	EG
<i>Bacillus subtilis</i> GB03	Companion	Growth Products www.growthproducts.com	several fruit, vegetable and ornamental crops	soil drench / foliar spray	various soilborne & foliar fungi	GR, IT, TR
<i>Bacillus subtilis</i> QST 713	Serenade	Agraquest http://agraquest.com BASF Agro www.basf.com	several fruit and vegetable crops	foliar spray	various foliar fungi and bacteria	FR, IT, IL, MA, PT, TR
<i>Bacillus subtilis</i> Y1336	Biobac	Atlantik Tarim http://www.atlantiktarim.com/en/Urunler.aspx	tomato	foliar spray	<i>Botrytis cinerea</i>	TR
citric acid + mint oil	Fungastop	Agriprotec www.agriprotec.com.tn	several fruit and vegetable crops	foliar spray	various foliar & soilborne diseases	TN
<i>Coniothyrium minitans</i>	Contans	Prophyta www.prophyta.de/en	several fruit, vegetable and ornamental crops	mix into substrate or soil drench	<i>Sclerotinia</i> diseases	FR,GR, IT, PT, ES
<i>Fusarium oxysporum</i> F047	Fusaclean	Arysta Lifescience	cucumber	mix into substrate or soil drench	soilborne fungi	BG
neem oil	Agrimor Stop	Agrimor IL Ltd www.agrimor.co.il	pepper	foliar spray	powdery mildew	IL
neem oil	Nimgard	Agron Agrochemicals www.agron.co.il	several fruit, vegetable and ornamental crops	foliar spray	powdery mildew + mites	IL

Active substance	Commercial name	Company	Current usage			
			Crops	Mode of application	Target diseases or pathogens	Country of registration*
neem oil extract	Trilogy	Certis www.certisusa.com	several fruit and vegetable crops	foliar spray	various foliar fungi + various arthropods	EG, IL, MA, TR
potassium bicarbonate	Armicarb	DE SANGOSSE www.desangosse.fr	strawberry	foliar spray	powdery mildew	FR
<i>Pseudomonas</i> sp Proradix DSMZ 13134	Proradix	Sourcon Padena	various vegetables	drench or spray	soilborne fungi	IT, TR
soybean oil	Bionatrol	Univers Horticole www.univershorticole.ma	tomato	foliar spray	<i>Botrytis cinerea</i>	MA
<i>Streptomyces</i> K61	Mycostop	Verdera www.verdera.fi/en	vegetables, herbs & ornamentals	seed dressing, drench or spray at planting; soak or dip before planting	soilborne fungi + <i>Botrytis cinerea</i>	CY, GR, IT, ES
<i>Streptomyces lydicus</i> WYCD108	Actinovate	Natural Industries Inc. http://naturalindustries.com	several fruit and vegetable crops	soil drench / foliar spray	various soilborne & foliar fungi	TR
<i>Trichoderma album</i>	Bio Zeid	Organic for Biotechnology	several fruit & vegetable crops	foliar spray	various foliar fungi	EG
<i>Trichoderma asperellum</i> (ex <i>T. viride</i>) strain TV1	Xedasper / Xedadrim	Xeda International http://xeda.com	several fruit and vegetable crops	mix into substrate or soil drench	soilborne fungi	IT
<i>Trichoderma asperellum</i> ICC 012 + <i>T. gamsii</i> ICC 080	Bioten / Radix / Remedier / Tenet	Isagro www.isagro.com/en/biological-fungicides.html	several fruit, vegetable and ornamental crops	mix into substrate or soil drench	soilborne fungi	IT, MA, SI, ES, TR
<i>Trichoderma atroviride</i> IMI 206040 + <i>T. parapiluliferum</i> (pomy-sporum) IMI 206039	Binab TF	Binab Bio-Innovation www.algonet.se/~binab/index2.html	several fruit, vegetable and ornamental crops	mix into substrate or drench + foliar spray + delivery via bees (<i>Botrytis</i>)	soilborne fungi + <i>Botrytis cinerea</i>	ES?
<i>Trichoderma harzianum</i> + <i>T. viride</i>	Tusal	Certis www.certiseurope.es	several fruit, vegetable and ornamental crops	mix into substrate or soil drench	soilborne fungi	ES

Active substance	Commercial name	Company	Current usage			
			Crops	Mode of application	Target diseases or pathogens	Country of registration*
<i>Trichoderma harzianum</i>	Plant Guard	Biotech for Biofertilizers and Biopesticides	strawberry	foliar spray	fruit rot	EG
<i>Trichoderma harzianum</i> T-22	Trianum	Koppert www.trianum.com	several fruit, vegetable and ornamental crops	mix into substrate or soil drench	soilborne fungi	FR, ES, GR, IT, MA, RO
<i>Trichoderma virens</i> CL-21 (formerly called <i>Gliocladium virens</i>)	SoilGard	Certis www.certisusa.com	several fruit, vegetable and ornamental crops	soil drench, irrigation water or spray	soilborne diseases	TR

* ISO 3166 country code

Future prospects and challenges

Based on the recent evolution we have observed, it appears likely that further extension of the geographical range of registration will be sought for some of the existing products, as well as an increase in the numbers of crops and possibly diseases targeted by those products. More products, currently under development or registered for the protection of vegetable, fruit or ornamental crops in other parts of the world may also be suitable for use in the Mediterranean region. Among an example of 15 such products (Table 2), it is striking that most are directed at the control of foliar pathogens (including key fungi such as powdery and downy mildews) and several have a wide range of use that includes soilborne diseases. There may be others on the way as well, as the EU Pesticide Database presents several new microbial strains with a "pending" status for inclusion in Annex 1.

Intense research and tremendous progress in the comprehension of the interactions between the plant, its environment, the pathogens and the biocontrol agents show promise for the selection of better microorganisms or plant defence enhancing compounds and for the design of more efficient formulations and tactics of application.

Finally, biocontrol is generally considered as unlikely to result in the selection of resistant pathogens. However, past experience with microbial biocontrol against arthropods suggests that caution should be applied lest durability would become an issue when biocontrol is increasingly used against certain plant pathogens. Other future challenges may result from the increasing cost of energy (with consequences for example on humidity reduction measures in the greenhouse), shortage of water in certain regions and various effects of climate change.

Conclusions

The recent evolution in the availability of biocontrol products against diseases of greenhouse crops in the Mediterranean greenhouse is highly positive. Clearly, the trickle has now become a stream and future evolution could be even faster as several leading plant protection

companies are becoming players in this domain. There is a general consensus among various sources that the global market for biopesticides is set to increase steadily over the coming years. A 2.5-fold increase is expected in 6 years by Markets and Markets (2012), for example, to reach \$3.2 billions in 2017. The question about disease management being the weak link of IPM in the Mediterranean greenhouse could thus be soon part of the past.

Table 2. Examples of prospective biocontrol products against diseases of Mediterranean greenhouse crops

Active substance	Commercial name	Company	Target diseases or pathogens	Country (ISO 3166)
<i>Aureobasidium pullulans</i> DSM 14940 + 14941	BoniProtect forte	Bio-ferm www.bio-ferm.com	<i>Botrytis cinerea</i>	DE
<i>Bacillus subtilis</i> FZB24	Rhizoctol (FZB24)	Agron Agrochemicals www.agron.co.il	<i>Rhizoctonia solani</i>	IL
extract from <i>Equisetum arvense</i>	Equisetum Plus	Biofa Bio-farming systems www.biofa-farming.com	powdery mildew	DE
extract from garlic	Influence	AEF Global www.aefglobal.com	powdery mildew	CA
extract from <i>Reynoutria sachalinensis</i>	Milsana	Biofa Bio-farming systems www.biofa-farming.com	powdery mildew + other foliar fungi	DE
extract from <i>Reynoutria sachalinensis</i>	Regalia	Marrone Bio Innovations http://marronebioinnovations.com	powdery mildew + other foliar fungi	US
<i>Gliocladium catenulatum</i> J1446	Prestop	Verdera www.verdera.fi/en	various soilborne & foliar fungi	US, CA
potassium bicarbonate	Milstop	BioWorks / Koppert Canada www.bioworksinc.com / www.koppertonline.ca	powdery mildew	US, CA
potassium bicarbonate	VitiSan	Biofa Bio-farming systems www.biofa-farming.com	powdery mildew	DE
potassium iodide + potassium thiocyanate + lactoperoxidase	Enzicur	Koppert www.enzicur.com	powdery mildew	NL
paraffinic oil	SuffOil-X	BioWorks www.bioworksinc.com	foliar fungi	US
<i>Pythium oligandrum</i> DV74	Polyversum	Biopreparaty www.biopreparaty.eu	various soilborne & foliar fungi	CZ
sodium bicarbonate	Steinhauer's Mehltauschreck	Biofa Bio-farming systems www.biofa-farming.com	powdery mildew	DE
soluble silica	Sil-MATRIX	PQ Corporation www.pqcorp.com	powdery mildew	US
<i>Streptomyces lydicus</i> WYEC 108	Microplus	Sustainable Ventures Pty Limited www.sustainableventures.com.au	various soilborne & foliar fungi	NZ
<i>Trichoderma atroviride</i> LC52	Sentinel	AgriMm Technologies Limited www.vinevax.com	<i>Botrytis</i> stem rot	NZ
<i>Trichoderma hamatum</i> LU593	Lettucemate	AgriMm Technologies Limited www.vinevax.com	lettuce drop	NZ

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