# 2 Commercial Use of Fungi as Plant Disease Biological Control Agents: Status and Prospects

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## Introduction

Public concerns over the use of pesticides in agriculture and their effects on the environment are continuing to increase. These concerns, which are compounded by perceived risks associated with genetic modification of plants, have resulted in a desire for a more environmentally sustainable approach to agriculture, horticulture, forestry and related industries (including, for example, ornamental plants and turf grass). Globally, these views have resulted in greater restrictions on chemical pesticide use in the developed nations and a worldwide ban on the use of methyl bromide. Individual countries have been implementing their own initiatives in this area at a range of social levels. For example, in the Netherlands in 1991, the Dutch government instigated the Multiyear Crop Protection Plan, which aimed to reduce the use of pesticides by 50% by the year 2000. In the UK, major food retailers have introduced schemes for their contracted growers to minimize pesticide applications with the intention, in the long term, to dispense with their use altogether. Interestingly, these more 'natural' products are attracting a premium on price. In both the USA and the UK, there are organic farming certification standards, which severely restrict the use of chemicals of all forms (Lipson, 1997; Anon., 1999). As far as the control of plant disease is concerned, there are increasing trends for natural, non-chemical or organic approaches to disease control. This raises the question as to the role of disease biological control agents (BCAs) in modern agriculture and horticulture.

Some of the relative potential advantages and disadvantages for the development of BCAs over chemicals for control of plant diseases are listed in Table 2.1. What is clear is that the key determinants are influenced by public views and perceptions, scientific facts or observations, as well as commercial or financial considerations. Whether a property of a biocontrol agent is viewed as advantageous or not may be a matter of

 

**Table 2.1.** Perceived advantages and disadvantages of the commercial development of biological disease control agents relative to existing chemical control measures.

| Advantages | Disadvantages |
|---|---|
| Environmentally compatible; naturally occurring | Inconsistent and often low levels of control |
| Positive, 'green image' | Subject to environmental influences |
| Not persistent; low environmental impact | May lack persistence to give long-term control |
| Broad or narrow targets depending on organism | Chance of mutation and variation |
| Can be site-specific | Too specific or slow-acting |
| Less prone to resistance | Inoculum not robust: may have poor shelf-life |
| Cost-effective for specialized applications or where no chemical controls exist | Not cost-effective for certain existing markets |
| Application methods easily adaptable | Expensive and more difficult to use |
| Low cost of development | Needs novel fermentation facilities |
| Rapid and cheaper registration[a] | Costs of registration and toxicity testing excessive for niche markets |
| Small markets viable | Not practical for large-acreage agronomic crops |
| Integrated control possible, reducing chemical use | May not be compatible with accepted practices |

[a] The US Environmental Protection Agency (EPA) has a less expensive rapid registration process for biological in comparison with chemical fungicides. In the UK, fees charged by the Ministry of Agriculture, Fisheries and Food (MAFF) for assessment of a biopesticide package are only 25% of that charged for chemical pesticides.

opinion. On one hand, it may be considered that BCAs are ideal and environmentally acceptable for disease control and should be implemented irrespective of cost and relative efficacy, or on the other, BCAs may simply be considered unreliable, ineffective, or too costly. In practice, the truth probably lies somewhere between these extremes. This chapter considers the current and future status of commercial fungal BCAs with particular emphasis on products. Examples of specific products will be used to illustrate important relevant points rather than attempting an all-encompassing review.

## Products Available

The number of fungal products on the market used to control plant diseases is increasing, and nearly 40 have been reported in recent sources (Cook *et al.*, 1996; Whipps, 1997a; Fravel *et al.*, 1998; US Department of Agriculture/Agricultural Research Service/BPDL (USDA/ARS/BPDL) Biocontrol of Plant Diseases Laboratory webSite http://www.barc.usda.gov/psi/bpdl/bioprod.htm). However, many of these materials are not registered as BCAs (also termed biopesticides); rather, they are sold as some form of 'plant growth promoter' or 'stimulant', 'soil conditioner', 'plant strengthener' or 'wound protectant'. By not claiming fungicidal activity, producers of these materials avoid the need for registration and costs for obtaining efficacy, toxicology and environmental fate data. Although this speeds up entry of the product to the market-place, it also introduces an element of potential environmental and health risks in those cases where extensive experimental background information has not been accumulated. Making pesticidal claims for a product without formal registration and permission can lead to a ban on sales and the imposition of penalties (Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)).

**Table 2.2.** Fungi registered and commercially marketed as biological control agents (revised from Whipps, 1997a; Fravel *et al.*, 1998).

| Antagonist | Target pathogen(s)/activity | Disease/host | Product name and source |
|---|---|---|---|
| Soil and root microbiomes | | | |
| *Coniothyrium minitans* | *Sclerotinia minor*; *Sclerotinia sclerotiorum* | Protected vegetable and field crops | Contans WG (Prophyta Biologischer Pfanzenschutz GmbH, Germany) |
| | | Glasshouse crops and amenity areas | KONI (Bioved Ltd, Szigetszentmiklos, Hungary) |
| *Gliocladium* (*Trichoderma*) *virens* | *Pythium ultimum*; *Rhizoctonia solani* | Damping-off of bedding plants | SoilGard (GL-21), formerly GlioGard (Thermo Trilogy, Columbia, Maryland, USA) |
| *Trichoderma harzianum* | *Fusarium* spp; *P. ultimum*; *R. solani*; *Sclerotinia homeocarpa* | Range of crops, ornamentals and turf | T-22G, T-22 Planter Box, Bio-Trek and Root Shield (Bio-Works Inc., Geneva, New York, USA) |
| | Various fungi | | Supresivit (Borregaard and Reitzel, Denmark, or Fytovita, Czech Republic) |
| *T. harzianum* + *Trichoderma polysporum* | Various root-infecting fungi | Glasshouse crops | BINAB-T WP(Bio-Innovation Eftr AB, Bredholmen, Sweden; or Svenska Predator AB, Sweden; or Bayer, Sweden) |
| *Trichoderma viride* | *Fusarium* sp.; *Pythium* sp.; *Rhizoctonia* sp.; *Macrophomina phaseolina*; *Phytophthora* sp. | Cotton, legumes, sunflower, tobacco and vegetables | Ecofit (Hoechst Schering AgrEvo Ltd, Chakala, India) |
| Aerial microbiomes | | | |
| *Ampelomyces quisqualis* | Powdery mildew | Curcubits, grapes, ornamentals, strawberries, tomatoes | AQ10 Biofungicide (Ecogen Inc., Langhorne, Pennsylvania, USA) |
| *Peniophora* (*Phlebiopsis*) *gigantea* | *Heterobasidion annosum* | Stem and root rot of pine | Pg suspension (Omex Environmental Ltd UK) and Rotstop (Kemira Agro Oy, Helsinki, Finland) |
| *T. harzianum* | *Botrytis cinerea* and other foliar pathogens | Cucumber, grape, nectarine, soy-bean, strawberry, sunflower, tomato | Trichodex (Makhteshim Chemical Works Ltd, Israel) |
| *T. harzianum* + *T. polysporum* | *B. cinerea* | Strawberry | BINAB-T WP (Bio-Innovation Eftr AB, Bredholmen, Sweden; or Svenska Predator AB, Sweden; or Bayer, Sweden) |
| | *Chondrostereum purpureum*; *Eutypa* | Silver-leaf disease and chlorotic leaf curl in stone-fruit and grapes | |
| *T. harzianum* + *T. viride* (combinations) | *C. purpureum* | Silver-leaf disease in pip- and stone-fruit trees | Trichodowels, Trichoject and Trichoseal (Agrimm Technologies Ltd, New Zealand) |
| Postharvest microbiomes | | | |
| *Candida oleophila* | *Botrytis* spp.; *Penicillium* spp. | Storage rots of pome fruit | Aspire (Ecogen Inc., Pennsylvania, USA) |
| *Cryptococcus albidus* | *B. cinerea*; *Penicillium expansum* | Storage rots of apple and pear | Yield*Plus* (Anchor Yeast, Cape Town, South Africa) |

Surprisingly, only 20 products, made from nine species of fungi, are registered and sold commercially as BCAs or biopesticides (Table 2.2). Brief summaries of some of these products are given below. Where the information was provided by the manufacturers directly, they are not referenced further. Significantly, more than half of the products are *Trichoderma-* or *Gliocladium*-based preparations reflecting the widespread occurrence of these fungi, the relative ease of their production, their low toxicity and the huge volume of experimental data on these genera. Products are available for control of pathogens in soil and root, aerial and postharvest microbiomes (*sensu* Whipps *et al.*, 1988). These may be considered reasonably well-defined habitats that have distinct physicochemical properties containing characteristic microbial communities.

## *Soil and root microbiomes*

### Coniothyrium minitans

*Coniothyrium minitans* is a mycoparasite of sclerotia of *Sclerotinia sclerotiorum* and *Sclerotinia minor*. Two products containing this BCA are available: Contans WG, in Germany and Switzerland, and KONI, in Hungary. Both are granular formulations, but Contans WG is sprayed and incorporated into soil after dispersal in water whereas KONI is incorporated into soil directly. Application must be made several weeks prior to planting crops to allow time for the sclerotia to be destroyed. Currently, although use is restricted to glasshouses and polyethylene tunnels for a range of high-value crops, use on field crops and amenity areas is planned. *C. minitans* strain CON/M/91-08 in Contans WG is undergoing consideration for full European registration under the European Union (EU) Council Directive 91/414 and in spring 2001 received approval from the US-EPA and Austria.

### Gliocladium virens *(=* Trichoderma virens*)*

The BCA *Gliocladium virens* has appeared on the market in two formulations, GlioGard™, an alginate prill formulation, and SoilGard™, a granular fluid-bed formulation (Lumsden *et al.*, 1996). These products target damping-off diseases of vegetable and ornamental plant seedlings caused by *Rhizoctonia solani* and *Pythium* spp. Application was confined to greenhouse or interior container use (Lumsden *et al.*, 1996). Only the product SoilGard is now produced and is marketed by Thermo Trilogy Corp., Columbia, Maryland, USA.

### Trichoderma harzianum

A commercial formulation of *Trichoderma harzianum* strain 1295-22 (T-22) is manufactured by BioWorks, Inc., Geneva, New York, USA, and sold through several distributors as T-22 Planter Box™. This conidial formulation is designed for application to large-seeded crops such as maize, beans, cotton and soybeans, and in most cases can be applied to seeds already treated with fungicides (Harman and Björkman, 1998). The seed treatment delivers the *T. harzianum* inoculant to the growing seedling where it colonizes the spermosphere and also the developing root system, protecting crop plants from damping-off diseases.

Similar products using the same strain 1295-22 (T-22) include a granular formulation used as a greenhouse soil amendment, which is called RootShield™ and contains the entire thallus of *T. harzianum* colonized on clay particles. Another product, RootShield drench, consists of conidia and inert ingredients for use as a water-suspensible drench. In either case, the product is thought to colonize the root system of the crop to be protected (Harman and Björkman, 1998). This product is claimed to control root diseases caused by *Fusarium, Rhizoctonia* and *Pythium* spp., but not *Phytophthora* spp.

Another *T. harzianum* product available in the Czech Republic and Denmark for glasshouse use is Supresivit. This dispersible powder containing conidia of strain PV5736-89 is applied to soil or potting mixes to control disease complexes causing damping-off or root rots of ornamentals and forest-tree seedlings, and as a pea seed treatment to control damping-off.

### Trichoderma viride

*Trichoderma viride* is available as a BCA in India from Hoechst Schering AgrEvo Ltd in a product named Ecofit. It is a talc-based powder sold for the control of root rot, seedling rot, damping-off, collar rot and *Fusarium* wilt in cotton, chick-pea, pigeon-pea, Bengal gram, groundnut, sunflower, soybean, tobacco and vegetables. Depending on the plant and disease of interest, Ecofit can be applied before sowing as a dry powder or slurry seed treatment, before planting as a rhizome, tuber or set dip, or as a soil drench for soil incorporation following a preliminary scale-up procedure involving prior inoculation on to farmyard manure.

## *Aerial microbiomes*

### Ampelomyces quisqualis

*Ampelomyces quisqualis*, formulation AQ10, is the first biocontrol fungus developed specifically for controlling powdery mildew. AQ10 is water-dispersable and acts as a mycoparasite on powdery mildews affecting leaves, stems or fruits of plants. The range of plants protected includes strawberry, tomato, grape, tree fruit and ornamentals (Dik *et al.*, 1998). As with many other plant diseases, powdery mildews have developed resistance to commonly used chemical treatments, such as sulphur and demethylation-inhibiting fungicides. AQ10 is useful in powdery mildew management programmes to ward off resistance problems and can extend the usefulness of these chemical treatments for a reduced time and amount of application.

### Phlebiopsis (Peniophora) gigantea

*Phlebiopsis gigantea* is a common wood-rotting saprotroph that is applied to freshly cut stumps of pine to prevent their colonization by the root-rotting fungus *Heterobasidion annosum*. It is not a biocide that kills the target organism but rather it competes for the food base that the pathogen would otherwise use. Commercial products containing oidia are available in the UK from Omex Environmental Ltd and in Finland from Kemira Agro Oy as PG Suspension and Rotstop, respectively. *P.* gigantea is also available in other Scandinavian countries and Poland. Significantly, after 30 years of field use, PG Suspension has become the first fungal disease BCA approved in the UK under the Control of Pesticides Regulation (COPR) 1986 (Pratt *et al.*, 1999).

### Trichoderma harzianum

Strain T39 of *T. harzianum* has been used for greenhouse control of *Botrytis cinerea*. It is produced by Makhteshim Chemical Works and is marketed as Trichodex™ in Europe and Israel. The strategy for best control involves alternating chemical and biological control treatments (Elad *et al.*, 1994). This approach, as with *A. quisqualis*, reduced the use of chemicals and may also reduce the incidence of chemical resistance developed by *B. cinerea*.

### Trichoderma harzianum + Trichoderma polysporum

A combination of strains IMI 206040 and IMI 206039 of *T. harzianum* and *T. polysporum*, respectively, sold as BINAB-T, is one of the oldest commercial biopesticide preparations still available. Produced by Bio-Innovation Eftr AB in Sweden it has been used for over 20 years. Because of the long period of safe use it will continue to receive exemptions from the new pesticide regulations in Sweden (Kemikalieinspektionen) until a decision is made concerning a current application for registration made under the new regulations. BINAB-T has been registered and used in the past for control of numerous diseases, but currently, in Sweden and Denmark, is used largely for the control of grey mould (*B. cinerea*) on strawberries, with some minor use in glasshouse crops to control soil-borne pathogens. The other main market is Chile, where it is used for the suppression of silver-leaf disease (*Chondrostereum purpureum*) and chlorotic leaf curl (*Eutypa*) in stone fruit and grapes, respectively.

### Trichoderma harzianum + Trichoderma viride

Agrimm technologies in New Zealand have three registered products containing various combinations of *T. harzianum* and *T. viride* sold for the control of silver-leaf disease in pip- and stone-fruit trees. Trichodowels are small, *Trichoderma*-impregnated wooden dowels, inserted into the plant via a 6 mm hole drilled into the stem or trunk; Trichoject is a liquid preparation of *Trichoderma* injected into the stem or trunk; and Trichoseal is a wound paint for treating pruning wounds.

## *Postharvest microbiomes*

### Candida oleophila

Aspire™, a biocontrol product containing the yeast *Candida oleophila* as the BCA is registered in the USA and in Israel. The product is used to reduce rot diseases, green and blue mould, caused by *Penicillium digitatum* and *Penicillium italicum*, respectively. It is also efficacious against sour rot, caused by *Geotrichum candidum* (Wilson *et al.*, 1993; Droby *et al.*, 1998). Aspire works best in combination with reduced application rates of thiabendazole, and this treatment often reduces the incidence of decay as effectively as conventional, full-rate fungicide treatments (sodium O-phenyl phenate, thiabendazole, imazalil and metalaxyl). Aspire is marketed in the USA by Ecogen Corporation, Langhorn, Pennsylvania.

### Cryptococcus albidus

This yeast was developed for use on pome fruits, especially apples and pears, against grey and blue mould caused by *B. cinerea* and *Penicillium expansum*, respectively. A product, Yield*Plus*, is produced commercially by Anchor Yeast, Capetown, South Africa (de Koch, 1998; C.L. Wilson, personal communication).

## Long-term Developments

Both the commercial use and the acceptability of fungal BCAs are likely to depend on the perceived need for the products, the level of impetus for their development and the ability of the developers to overcome constraints or bottlenecks. Some of the relevant factors are discussed below.

### *Impetus for development of commercial disease biocontrol agents*

Legislation reflecting the need to reduce the use of chemical pesticides in the environment and the levels of pesticide residues in food has become one of the major driving forces for the development of commercial BCAs, either as direct substitutes for chemicals or in integrated management systems, where rates of chemical usage are reduced. However, a reduction in the use of agrochemicals may also influence the development of alternatives, especially if the chemical withdrawn was very effective at controlling diseases. For example, the loss of methyl bromide for the control of numerous soil-borne pathogens of ornamental and vegetable crops and of storage rots of fruits and vegetables is likely to have a significant impact (Ristaino and Thomas, 1997) since for many of these diseases there is no other economically viable means of control. Under these circumstances, BCAs may thus provide an option where no other control measures exist. Indeed, this may already be the case for diseases such as take-all (caused by *Gaemannomyces graminis* var. *tritici*) on wheat, chestnut blight (caused by *Cryphonectria parasitica*) and club-root (caused by *Plasmodiophora brassicae*) on brassicas, where no resistant cultivars or varieties exist and no chemical control products are available or effective. Here, crops are not grown where the pathogen is well established or a continual loss due to disease is accepted as normal.

### *Opportunities for future development of fungal-based biocontrol products*

Agricultural practice is changing as a result of demands to reduce the use of chemical pesticides, including fungicides, and to provide abundant feed, food and fibre using environmentally friendly, sustainable systems. Much of this change has been initiated and mandated or encouraged by national and international legislatures. The potential roles of biological methods in these evolving practices of pest control (in this sense including plant pathogens, weeds and insects as ‘pests’, as all are detrimental to agricultural production) are considered below.

### *Sustainable agriculture*

According to the US government 1990 Farm Bill, sustainable agriculture is:

> an integrated system of plant and animal production practices having a site specific application that will, over the long-term, satisfy human food and fiber needs; enhance environmental quality and the natural resource base, upon which the agricultural economy depends; make efficient use of non-renewable resources and on-farm resources, and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole.

The same concept of sustainable agricultural systems has been expounded by the Canadian government to address environmental health, economic profitability and social and economic equity (Acton and Gregorich, 1995). Fungal BCAs have not been used to a large extent in the development of sustainable systems, but they have the potential to do so by providing alternatives to chemical pesticides.

### *Pesticide control actions*

FIFRA has been a guiding force in the regulation of pesticides in the USA for many years. Similar guidelines are in place in the UK, such as COPR 1986, contained within the Food and Environment Protection Act (FEPA) 1985, and the Control of Substances Hazardous to Health (COSHH) Regulations 1988, made under the Health and Safety at Work Act 1974. Importantly, provisions of European legislation affecting all members of the European Community in the Plant Protection Products Directive 91/414/EEC are now being implemented in Britain by the Plant Protection Products Regulations (PPPR) 1995. In addition to the general regulations on the use of pesticides, several countries have implemented their own specific policies to reduce pesticide use. For example, Denmark, Sweden and the Netherlands have passed legislation requiring a reduction of 50% or more in the total use of agricultural pesticides by the year 2000 (Matteson, 1995). There are also similar US state and regional initiatives to reduce pesticide use (Matteson, 1995). Understandably, alternatives to chemical pesticides or products that allow reduced usage in terms of fewer or reduced rates of application are beginning to appear on the market in the form of fungal BCAs that can be used in integrated systems.

### *Integrated Pest Management (IPM)*

IPM is defined as a systems approach to pest management that combines multiple crop production practices with careful monitoring of pests (including plant pathogens) and their natural enemies (such as fungal antagonists). In 1977, the US Federal budget funded the USDA's IPM initiative to help agricultural producers implement IPM practices on 75% of total crop acreage by the year 2000. IPM as it relates to plant pathology was recently reviewed (Jacobsen, 1997). The concept of IPM was first introduced in relation to insect pest control through integrating the use of pesticides and biological control organisms. In practice, entomological applications of IPM are most advanced, but strides are being made to couple biocontrol of plant diseases with other disease control strategies. This is particularly important as often the current need to resort to chemical treatment for disease control disrupts an otherwise successful biological programme of pest control. For example, one strategy of IPM is to develop fungal BCAs with tolerance to fungicides or to incorporate fungicide resistance into antagonists (Locke *et al.*, 1985; Locke and Lumsden, 1989; O'Neill *et al.*, 1996). Combining resistant or tolerant fungal BCAs with fungicides can sometimes have twofold advantages in the treatment of seeds: a high level of seed protection is provided early on by the chemical component and then the biological component becomes active later in seedling development and can provide protection of root systems for improved plant health and function (Harman and Björkman, 1998). Integration of biocontrol may also be feasible in other systems, such as with disease forecasting for potato late blight control, in tandem with other strategies, or to substitute for the general biocidal properties of methyl bromide.

### *Methyl bromide replacement*

In November 1992, the Montreal Protocol, an international environmental treaty, was amended to include the agricultural fumigant methyl bromide on its official list of substances believed to harm the earth's protective ozone layer. The US Environmental Protection Agency (EPA) classifies methyl bromide as an acute toxin. The 1990 US Clean Air Act, as well as actions taken at a 1995 meeting in Vienna, Austria, determined a phase-out of the use of methyl bromide worldwide, to begin in 2001 and to be completely banned by 2010. The effect of this ban on agriculture, especially in the USA, and on the options for the control of soil-borne plant pathogens is significant (Ristaino and Thomas, 1997). The role that biological control may have in replacing methyl bromide (a potent biocide that kills everything it contacts) is unclear. However, the proposal itself has stimulated research for replacement materials, and significant progress has been made. For example, saprophytic strains of *Fusarium oxysporum* have been discovered which are antagonistic to *F. oxysporum* f. sp. *lycopersici*, the cause of *Fusarium* wilt of tomato (Larkin and Fravel, 1998). This may bode well for states such as Florida where large quantities of methyl bromide are currently used for the control of *Fusarium* wilt and other soil pests. Legislation similar to that which resulted in the methyl bromide ban is now beginning to be established for uses of other synthetic chemicals for disease control, illustrating the growing concern over the use of pesticides in general.

### *Food Quality Protection Act (FQPA)*

This act reforms US food safety laws and was made into law in 1996. It amends the two other laws involving pesticides, namely FIFRA (mentioned earlier) and the Federal Food, Drug and Cosmetic Act (FFDCA). FQPA potentially affects implementation of biocontrol in two ways. First, the law re-authorizes and increases user fees for the review of older pesticides to ensure they meet current standards. Many fungicides are likely to be dropped because of the review costs incurred, especially for those formulations involved in minor-use applications. The law affects all groups of pesticides that share a common mechanism of action, such as all organophosphates. Thus, when calculating the permitted amount of pesticide in the environment or as residues on food, all organophosphates used for both pathogen and pest control count together. This is expected to result in the loss of clearance for use on minor crops in order to get total exposure of all pesticides with the same mode of action under the tolerance set for that general class of pesticides. This is popularly called a 'risk cup'. The legislation may have the effect of opening up opportunities for fungal BCAs to be used in niche market applications on minor crops. Similar reregistration requirements are active in the UK. The second opportunity for biologicals in the USA is the provision in the law for a quick review of reduced-risk pesticides (under which BCAs would be considered) to enable them to reach the market sooner in order to replace older, potentially more risky chemicals. This 'advantage' remains to be proved, but may stimulate registrations, similar to the UK reduced-cost incentives. Other incentives for the increased use of BCAs may develop through organic certification initiatives.

### *Organic farming and organic food certification*

Countries around the world are developing national standards for organic farming and for the marketing of organic products. In Canada, the National Standard for Organic Agriculture operates with 47 self-administered organic certification bodies comprising the Canadian Organic Advisory Board (COAB). Israel has established the Israel Bio-organic Agricultural Association, which has defined all organic standards and regulations relating to growing, manufacturing and marketing bio-organic products. New Zealand has two certification systems – BIOGRO and Demeter – developed in the early 1980s, whose labels are issued by the Biodynamic Farming and Gardening Association and the NZ Biological Producers Council. In the UK, the Register of Organic Food Standards provides guidelines for certification for organic food production and maintains a register of approved producers. Chemical use is severely restricted but disease control using naturally occurring organisms against specific disease targets is permitted. Interest in organic farming is growing with the recent launch by the Ministry of Agriculture, Fisheries and Food (MAFF) of an organic farming initiative that includes research on plant disease control.

The US Organic Foods Production Act (OFPA) was enacted in 1990 as Title XXI of the Farm Bill. The USDA is currently developing standards for the use of the term 'organic' (Lipson, 1997). Agreement is now under negotiation to exclude such practices as utilizing municipal sludge compost and marketing produce derived from genetically modified plants. Significantly, biological control of weeds, insects and plant diseases is an integral component of the accepted practices for organic certification. However, distinct areas of uncertainty have developed in which, for example, a formulation process used in the manufacture of a BCA may not be compatible with perceived organic production standards. In addition, biologicals may not be acceptable if used routinely where the focus is on the inputs of biological pesticide and not on the understanding and management of agricultural ecological processes (Lipson, 1997: p. 63).

The intention of the OFPA is for the USDA to establish national standards for the production and handling of foods labelled 'organic'. Previously, private and state agencies have been certifying organic practices with no uniformity and therefore no guarantee from state to state or certifier to certifier. How differences in the development and interpretation of these standards are resolved remains to be seen.

All these legislative initiatives promote and encourage the use of fungal BCAs in agricultural production. However, the quantities that will be used in agriculture are unclear. The total number of applications available for immediate use are limited, and their future depends on the scientific community discovering and developing new BCAs, the industry adapting and marketing them, the end-users adopting biocontrol practices and the consumer accepting the technology. The future is bright but uncertain.

### Constraints on the development of commercial disease biocontrol agents

One of the major limitations with biological disease control is the inconsistency in efficacy which is often observed when useful antagonists reach the stage of large-scale glasshouse or field testing, and can arise from a variety of causes reflecting the biological nature of the control microorganism. Essentially the organism must first survive application and then retain activity in the environment of use throughout the period when active control is required, which may be several months for some soilborne pathogens. During this time, it must survive fluctuations in the physical environment and the action of the indigenous and competitive microbiota. In many cases, potential BCAs have been selected and tested in artificial *in vitro* systems that bear little resemblance to the environment of use. Consequently, failure at the scale-up stage is always likely to be high. In response to this problem, it has been suggested that all selection, screening and development processes should adopt an ecological approach that takes into account the features of the environment of use and should improve the number of active BCAs reaching the market (Deacon, 1991; Whipps, 1997a, b, c). The use of appropriate inoculum production, formulation and application technologies together with quality control checks should also help in this process. Nevertheless, even if reliable BCAs can be produced, they must still be easy to use and cost-effective, or they will either never reach the market-place or not be used by growers. At the moment, many chemical fungicides are cheap and effective and will not be substituted for by BCAs unless they are withdrawn from use. If they are withdrawn, market-driven forces will then dictate whether BCAs become commercially viable for use on the same crop or whether an alternative crop is grown, thereby avoiding the need for BCAs. Nevertheless, disease can be expected to build up in alternative crops over time, regardless of rotation, and some control measures will eventually be required. Appropriate BCAs need to be developed in advance of this situation, so as to be ready for the time when they become cost-effective for use. The situation in the glasshouse is somewhat different, as good hygiene can prevent or control many diseases. However, applications of BCAs may be cost-effective in this more controlled environment, where, in general, reproducibility is easier to achieve and profit margins are higher in comparison with field crops.

Another constraint concerns registration. Currently there are no fungal biocontrol products registered and sold worldwide. Some, such as those based on *P. gigantea*, are available in several countries while others, such as AQ10 and Aspire, are sold in two countries (Israel and the USA). Most of the others appear to be sold only in the country of development. This reflects the problems associated with registration requirements in different countries, and includes concerns about releasing non-indigenous microorganisms. There has always been a requirement for a registration package, generally including toxicology and efficacy data for each individual organism and formulated product, in every intended country of use. The high costs associated with this process have consequently stifled commercial development of BCAs for what are often small niche markets. In turn, this has led to a large number of products appearing on the market which actually work by controlling plant pathogens but which purport to be plant growth promoters, soil conditioners, biofertilizers, biological activators or similar microorganism-based materials that require no registration. Unfortunately, without the rigours of a registration package involving toxicological and efficacy data, safe use cannot be assured and consistent beneficial effects on disease control and crop growth are not always seen (Cook *et al.*, 1996). Regulatory authorities are now aware of this anomaly and are attempting to encourage legal registration and use in a variety of ways. For example, in the USA the EPA claims a more rapid and cheaper registration process for biological pesticides in comparison with chemical pesticides, and in the UK the fees charged by MAFF for assessment of a biopesticide package are only 25% of that charged for a chemical pesticide. Moreover, in the European Community, regulatory authorities in member countries are now beginning to implement the Plant Protection Product Directive 91/414/EEC, which paves the way for rapid pan-European registration once it is obtained in one of the member states (Klingauf, 1995). Authorities in Europe are also aware that legislation drafted essentially for chemical pesticides is not always applicable to biological pesticides, and the requirements for registration of biological pesticides are currently under discussion for appropriate review. The authorities in the USA have been aware of this situation for many years and use a realistic, case-by-case basis to interpret the existing legislation when considering BCAs. For discussion of this approach with regard to *G. virens* in GlioGard (now SoilGard), see Mintz and Walter (1993) and Lumsden and Walter (1995).

## Conclusions

It is now clear that the stage is set for fungal biological disease control agents to play a greater part in agriculture and horticulture. The need for alternatives to chemical fungicides, when viewed against a groundswell of feeling by the public for more natural or organic food production systems, makes this a priority. What is required to make this a reality is a long-term commitment from those involved in food production and environmental protection to collaborate. This would include researchers and extension scientists, government, producers, grower organizations and levy boards, retailers and agrochemical companies. The MAFF Horticulture LINK Scheme in the UK has several excellent examples of such consortia acting together. From such consortia, sufficient funding would need to be forthcoming to allow realistic screening, selection and efficacy testing to obtain antagonists with proved activity against specific target pathogens. At this stage the decision as to whether further characterization and development into a commercial product should take place has to be made. Cost–benefit analyses, toxicology and registration must be carried out. Importantly, providing that an appropriate collaboration agreement and royalty rights are agreed at the outset of each stage requiring funding, all those members of the consortia involved with developing the BCA will eventually benefit financially. This approach would undoubtedly encourage environmentally desirable products that are wanted by the public to reach the market-place rapidly.

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## Disclaimer

Mention of a trademark proprietary product does not constitute a guarantee or warranty by the USDA, MAFF or the BBSRC and does not imply approval by the exclusion of other products not mentioned that may also be suitable.

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