Potential biological control agents for fumitory (*Fumaria* spp.) in Australia

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**Summary**

*Fumaria* species are increasingly problematic in the cropping regions of southern Australia, and one fumitory, *Fumaria densiflora* DC, has developed populations with herbicide resistance. Consequently, the potential for biological control was assessed. Nine species of fungi were found associated with *Fumaria* spp. in a survey of 33 sites in southern France. According to the literature, species potentially host specific to fumitory include *Cladosporium brachormium* Berk. and Broome, *Entyloma fumariae* J. Schröt. and *Peronospora affinis* Rossmann. Of the insects detected on *Fumaria* spp. in France, the stem weevil, *Sirocalodes mixtus* Mulsant and Rey has potential as a biological control agent because it is thought to be host specific. None of these species were detected amongst the six pathogen species found during surveys of 64 locations in southeastern and southwestern Australia. The absence of pathogens and insects associated with *Fumaria* species in Australia, the lack of *Fumaria* spp. native to Australia, and few closely related crops or ornamental species, indicate that there are opportunities for research into the development of natural enemies for the biological control of fumitory.

**Keywords:** *Fumaria* species, biological control, field surveys, fungal pathogens, arthropods.

**Introduction**

Fumitory species are weeds of many parts of the world, mainly in cereal and legume cultivation, vineyards, wastelands and gardens, but have not been considered as a target for biological control. In Australia, fumitory is a problem in canola and pulse crops (particularly peas and lupins; Holding and Bowcher, 2004). Lemerle *et al.* (1996) found *Fumaria* species in 37% of 86 cereal crops in southern New South Wales during a survey of weeds conducted in spring 1993. Agronomists and farmers from this region ranked fumitory in the top ten of 50 species in terms of potential threat. *Fumaria densiflora* DC first evolved resistance to group K1/3 herbicides (Ditroanilines and others) in New South Wales (NSW) (Heap, 2007), underlining that this species is the most important weed of the genus in Australia (Norton *et al.*, 2004). In Australia, all *Fumaria* species (seven species and two subspecies: *Fumaria bastardii* Boreau, *Fumaria capreolata* L., *Fumaria capreolata* L. subsp. *capreolata*, *F. densiflora*, *Fumaria indica* (Hausskn.) Pugsley, *Fumaria muralis* Sond. ex W.D.J.Koch, *Fumaria muralis* Sond. ex W.D.J.Koch subsp. *muralis*, *Fumaria officinalis* L., *Fumaria purpurea* Lamarck) are introduced, mostly from Europe (Australian National Botanical Garden, 2007 a, b; Norton, 2003). *Fumaria* species were found in all States of Australia and are abundant only in southern regions, mostly in New South Wales, Victoria, South Australia and Western Australia. The increasing importance of *Fumaria* spp. and the rise of herbicide resistance point to the need to investigate alternative means of control. This paper reports on preliminary surveys in France and Australia to find potential biological control agents.

**Methods**

**Surveys in France**

Surveys were conducted in France from April 2004 to May 2005. Populations of *Fumaria* were found at 33 sites out of 79 inspected, either in vegetable culture or vineyards or on areas of freshly disturbed soil. The sites were distributed along five transects covering the Riviera between Hyères, St Tropez and Lake Ste Croix.
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(circa 270 km), the Cévennes between Mount Aigoual and Montpellier (ca. 110 km), the Pyrénées between The Boulou and Prades (ca. 130 km), the Atlantic coast between Tarbes and St Jean de Luz (ca. 200 km) and Bordeaux to Agen (ca. 150 km) and one longer transect through agricultural regions (ca. 1580 km).

At each site, plants were searched visually for evidence of disease. Samples of diseased tissue were collected and examined in the laboratory. When a pathogen was found associated with a symptom, after its fructification in a humid chamber, a single spore was collected with a sterile needle under a stereomicroscope, deposited on a potato dextrose agar (PDA; Difco) Petri dish and placed in a controlled environment (20°C and 12 h photoperiod). Fungi were identified morphologically by microscopic observations.

Plants were searched for evidence of insects at each site, and from four to ten entire plants were collected then taken back to the laboratory in transparent plastic bags for dissection. Plants with evidence of insect damage were cut up and put in Petri dishes, on wet paper, to allow eggs or larvae to develop to the adult.

**Surveys in Australia**

Transects were made through grain-growing regions in southeastern Australia (NSW and Victoria) and southwestern Australia between April and October 2005. The transects were made through districts where *Fumaria* species have been previously recorded, and crops and other roadside habitats were briefly searched for the presence of fumitory at intervals of approximately 25 km along the length of each transect. The transect distance travelled was approximately 1200 km in each of NSW and Victoria and 1800 km in southwestern Australia. At sites where fumitory was detected, at least 20 plants from that site were examined closely over a 20- to 30-min period for symptoms of disease and insect attack. Where arthropods were detected or signs of arthropod attack were observed, this was noted. When fruits were present, these were examined from at least 20 plants using a 10× hand lens for evidence of insect-caused galls.

Representative samples from each disease category were collected from each site, placed into polyethylene bags and stored in an insulated cool box with ice until they were brought to the laboratory. Leaf symptoms were recorded, and pathogens were isolated and identified as described below.

**Fungal isolation and species identification:** Subsamples of diseased material were placed into humid chambers for up to 14 days at 15°C and 20°C under a 12 h near-UV light: 12 h dark photoperiod to encourage fungal sporulation. The humid chambers consisted of two to three layers of moistened sterile filter paper in sterile 90 mm Petri dishes or plastic ‘take-away’ containers (150 mm × 80 mm × 50 mm) sealed with Parafilm wrap or plastic cling film (Gladwrap). In addition, diseased shoot and root material was surface disinfested by soaking in 2.5% sodium hypochlorite (v/v) for 1 min, rinsed in three changes of sterile tap water, blotted dry and plated onto 2% malt extract agar (MEA; Difco) or water agar (20 g Difco agar made up to l 1 with deionised water). Pure fungal cultures were obtained by transferring single spores or single hyphal tips onto fresh media and maintained on MEA, PDA or V8 juice agar (200 ml Campbell’s V8 juice, 3 g CaCO3, 15 g Difco agar made up to l 1 with deionised water). Cultures were grown under white fluorescent and near-UV light in a 12 h light:12 h dark photoperiod at 20°C in order to induce fruiting structures to facilitate species identification.

Small pieces of culture were mounted under acidified glycerol blue [0.05 % aniline blue (Gurr) in lactoglycerol] and investigated under the light microscope for the formation of fructifications. Fungal structures were investigated on normal or phase-contrast settings (100–1000×), and 30 measurements were made of conidial dimensions. Fungi were identified according to standard mycological texts, and original descriptions where indicated.

**Results**

Twelve genera including 15 identified species of fungal pathogens have been reported in the literature as associated with *Fumaria* spp. (results not shown). Three species are considered to be potentially host specific at the level of the plant family and genus (*Cladosporium brachormium* Berk. and Broome (anamorphic Mycosphaerellaceae), *Entyloma fumariae* J. Schrot. (Entylomataceae) and *Peronospora affinis* Rossmann (Peronosporaceae)).

**Surveys in France**

Pathogens: Nine species of fungi were found associated with *Fumaria* species. Diseased leaves of *Fumaria* sp. with symptoms of leaf smut, *E. fumariae*, were collected from six sites in November, January and April. Symptoms of leaf smut appear as whitish spots on both sides of *Fumaria* leaves and occasionally petioles. Lesions become dark brown and entire leaves shrivel and eventually die. The three kinds of spores were observed, two external: primary sporidia (filiformes) and secondary sporidia on sterigma (ballistospores). Microscopic examination of internal leaf tissues revealed masses of round, double-walled, pale green-to-yellow spores typical of the usitospores of *Entyloma*. *E. fumariae* was grown on artificial culture medium (PDA) and formed ballistospores that...
have a similar structure and form to those produced on plants. 

*P. affinis* was found on *Fumaria* spp. in ten sites of the 33 sites surveyed in France. The first symptoms observed were small faint yellow spots on the upper foliage. As they matured, fungus fruiting structures were visible on the lower leaf surface as conidiophores bearing conidia. Two kinds of spores were observed in field material: conidia on conidiophores and oospores in infected leaves.

Diseased plants of *Fumaria* spp. with symptoms of a *Cladosporium* species were collected from 13 sites. Extensive sporeulation on leaves, inflorescences and stems were observed.

Two *Alternaria* spp. (anamorphic Pleosporaceae), a *Botrytis* sp. (anamorphic Sclerotiniaceae), a *Colletotrichum* sp. (anamorphic Phyllachoraceae), an *Oidium* sp. (anamorphic Erysiphaceae) and *Phomopsis leptostromiformis* (J.G. Kühn) Bubák (Valssceae) were also found associated with diseased plants of *Fumaria* spp.

**Arthropods:** The only two polyphagous aphid species cited in the literature on *Fumaria* spp. were observed at three sites in France, *Aphis fabae* Scopoli and *Macrostephus euphorbiace* (Thomas). A polyphagous lepidoptera, *Plusia* sp. (Noctuidae), was also observed at five sites. Otherwise, *Sirocalodes mixtus* Mulsant and Rey (Curculionidae), with stem-mining larvae, was the most common insect, being found at 13 of 33 sites.

**Surveys in Australia**

**Pathogens:** The survey found fumitory at 64 of the 160 sites visited throughout the grain-growing districts of southern Australia. Six fungal species were identified from diseased fumitory plants: *Alternaria alternata* (Fr.) Keissl. (anamorphic Pleosporaceae), *Alternaria dauci* (J.G. Kühn) J.W. Groves and Skolko (anamorphic Pleosporaceae), *Davidiella tassiana* (De Not.) Crous and U. Braun (Mycosphaerellaceae), *Phoma* sp. (anamorphic Pleosporaceae), *Pleospora* sp. (Pleosporaceae) and *Sclerotinia* sp. (Sclerotiniaceae). In addition, several saprophytic and unidentified fungi that failed to sporulate were isolated from diseased material (data not shown). *Olpidium brassicae* (Woronin) P.A. Dang. (Olpidiaceae), previously recorded on fumitory in Western Australia (WA), was not recorded in the current survey. No pathogenic bacteria or nematodes were detected on fumitory.

The fungi were identified from six different fumitory species. *F. muralis* and *F. capreolata* were the only two species present in the WA surveys. In addition to these two species, *F. bastardii*, *F. densiflora*, *F. officinalis* and *F. parviflora* were observed in the surveys of eastern Australia. The plants were not identified to subspecies rank. *F. indica* was not detected in the current survey.

**Arthropods:** No arthropods were found on *Fumaria* in Australia during the surveys. There was evidence of possible sap-feeding insects on some plants at a few sites; however, no causative insects were present on the plants. No arthropods associated with fumitory have been reported from Australia in the literature.

**Discussion**

The genus *Fumaria* is placed in the Subfamily Fumarioideae in the Family Papaveraceae (Lidén, 1986; Stevens, 2007). In earlier taxonomic treatments, the subfamily is treated as the Family, Fumariaceae. *Fumaria* is chiefly a Mediterranean group of 55 species with few species reaching India and east Africa (Lidén, 1986). There are no native Australian species in the Family Papaveraceae; the only genera of this family in Australia apart from *Fumaria* are introduced species of *Argemone* (three species), *Dicentra* (one species), *Eschscholzia* (one species), *Glaucium* (two species), *Hypecoum* (one species), *Papaver* (six species), *Platycapsus* (one species), *Pseudofumaria* (one species), *Roemeria* (one species) and *Romneya* (two species) (Australian National Botanical Gardens, 2007a,b). The only closely related crop to *Fumaria* is *Papaver somniferum* L. (poppy) which is grown in Tasmania for production of pharmaceutical chemicals (Laughlin et al., 1998). *Fumaria* species are also weeds in this crop (Baldwin, 1977). Related ornamentals grown in Australia include species of *Chelidonium*, *Corydalis*, *Dicentra*, *Eschscholzia*, *Glaucium*, *Macleaya*, *Meconopsis*, *Romneya* and *Pseudofumaria* (Spencer, 1997). Thus the absence of related native species and few related commercial species indicates that weedy *Fumaria* species could be ideal targets for biological control.

**Surveys**

The identification of pathogens is provisional, and further work is needed to confirm identifications with molecular techniques or by appropriate experts. The sampling was carried out in France during an exceptionally dry year (2005). Even so, up to five pathogens were found per site, and what appeared to be sites with damaging infestations were found for *P. affinis*, *E. fumariae* and *P. leptostromiformis*. A more complete picture of the number of pathogens could be obtained by extending the survey to other western and southern European areas where there is an abundance of *Fumaria* species (Tutin et al. 1993). However, based on the literature, the survey in France has found most organisms of interest. This is also the first report of presence of *E. fumariae* in France. The sampling in Australia shows that this fungus and the other potential agents are highly likely to be absent.
Pathogens

*F. fumariae* appears to be the most promising potential agent especially as it attacks several *Fumaria* species and is not present in Australia. *F. fumariae* has been found on *F. muralis* in Madeira Islands, *Fumaria rostellata* Knaf in Romania and *Fumaria vaillantii* Loisel. in Germany and Sweden (Vanky, 1994) and on *F. parviflora* in India (Zundel, 1953). Vanky (1994) noted about *F. fumariae* in Europe ‘Rarely reported, almost certainly because *F. fumariae* is very inconspicuous’.

Despite this, recent experience shows that *Entyloma* species can be successful agents. Barton et al. (2007) report that *Entyloma ageratinae* R.W. Barreto and H.C. Evans was introduced in 1998 with success for the biological control of mist flower, *Ageratina riparia* (Regel) R.M. King and H.Robinson, in New Zealand. By 2004, the proportion of leaves infected by the fungus increased to 60%. The estimated cover of *A. riparia* in heavily infested plots decreased from 81% to 1.5% with a corresponding recovery of the diversity of native vegetation (Barton et al., 2007).

*P. affinis*, an obligate plant parasite, was abundant at three sites in France and not reported from Australia. It is associated with *Fumaria* species making it a candidate for further consideration for biological control. However, there is a report in Farr et al. (2007) of a 1902 herbarium specimen from Italy with *P. affinis* on the leaves of *Chenopodium album* L. (Chenopodiaceae). Host range tests are needed to establish if this is a valid host.

The third species that could be considered is *C. brachycormium* since it is only known from *F. officinalis*. It has not been reported from Australia. *Cladosporium* species are known generally as saprophytes, but they can be also pathogens. Otherwise, there appears to be very little known about this fungus.

Insects

Few insect species were found during the surveys and most of them are polyphagous. Little information on fumitory and insects is available in the literature. Three curculionids are cited on *Fumaria* (Hoffmann, 1954). *Sirocalodes quercicola* Paykull is a gall former developing in crown of *F. officinalis* and *F. capreolata*. This species is found in Europe but is not common. *Sirocalodes nigrinus* Marsham is common in France particularly in the southeast coastal region. The larvae develop in stems on *F. officinalis* and *F. parviflora*. The adult was also recorded on *F. vaillantii*, *F. capreolata*, *Platycapons spicata* (L.) Bernh. (Hoffmann, 1954) and *Papaver rhoesas* L. (Campobasso et al., 1999).

During our surveys, we only found the third species, *S. mixtus*. It occurs throughout France, but it is more common in the Mediterranean region (Hoffmann, 1954). This species could be considered as a potential agent, and further studies are needed to define the host-plant specificity of this insect. It has only been associated with *F. officinalis* and *F. parviflora* in France (Hoffmann, 1954). Adults have been found on *Papaver hybridum* L. in Portugal (Campobasso et al., 1999).

A second arthropod that is a potential agent is the cynipid wasp, *Neaylas versicolor* (Nieves-Aldrey). The larvae of this wasp form galls in the fruits of *Fumaria* species. It is the only cynipid found in *Fumaria* spp. (Nieves-Aldrey, 2003; Askew and Nieves-Aldrey, 2005) and has a distribution including southern France, Greece and Spain. We did not find it in our survey as most of the plants were just flowering, and the few green fruits did not show any obvious wasp damage.

Conclusions

We have identified suitable organisms to be considered for a biological control project in Australia. Any future project will require relevant authorizations, and this will be helped by a clearer understanding of the taxonomy, identification and importance of *Fumaria* species from Australia and the cost–benefits of control in cropping systems.

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References


