Potential Biosecurity Risks Associated with Poppy Straw and Pellet Importation

Report prepared for Poppy Growers Tasmania

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Disclaimer:

This report has been prepared to summarise the current scientific understanding of insect pests and diseases affecting opium poppy (*Papaver somniferum*) in Australia and worldwide. All details are current as of the date of publication. No recommendations are provided in this report. Responsibility for recommendations drawn from reading this work rests solely with the body providing those recommendations and do not necessarily represent the position of the authors, the Tasmanian Institute of Agriculture, the University of Tasmania or the Tasmanian Government.

CONTENTS

Background 1
Fungal diseases of opium poppy 2
Downy mildew 3
Causal agents 3
Symptoms 3
Australian records 3
Importation risks 4
Poppy fire 5
Causal agents 5
Symptoms 5
Australian Records 6
Importation risks 6
Capsule black mould 7
Causal agents 7
Symptoms 7
Australian records 7
Importation risks 7
Powdery mildew 8
Causal agents 8
Symptoms 8
Australian records 8
Importation risks 9
White mould 10
Causal agent 10
Symptoms 10
Australian records 10
Importation risks 10
Leaf smut 11
Causal agent 11
Symptoms 11
Australian records 11
Importation risks 11
Damping off 12

Causal agents 12
Symptoms 12
Australian records 12
Importation risks 12
Fusarium wilt 13
Causal agent 13
Symptoms 13
Australian records 13
Importation risks 13
Collar rot 15
Causal agent 15
Symptoms 15
Australian records 15
Importation risks 15
Viruses of poppies 16
Australia records 17
Importation risks 17
Bacterial diseases of poppies 19
Australian records 19
Importation risks 19
Insect pests of poppy 20
Pest species 20
Virus vector species 20
Australian records 20
Importation risks 21
Climate comparisons 22
Concluding comments 24
Acknowledgments 25
References 26

BACKGROUND

This report has been prepared by the Tasmania Institute of Agriculture upon the request of Poppy Growers Tasmania (PGT). The purpose of the report is to provide independent scientific information to PGT in response to Biosecurity Advice 2016/08 issued by the Australian Government. This advice outlines the proposed conditions for the import into Australia of poppy straw and pellets from Turkey, Hungary and Portugal for processing.

The aims of this report were to identify potential biosecurity risks to the Australian opium poppy (*Papaver somniferum* L.) industry and provide details of the current scientific knowledge surrounding those risks. Potential pests considered include pestiferous and virus-vectoring insects. Diseases considered include fungal, bacterial and viral pathogens of opium poppy. A simplistic climate comparison between Tasmania and the proposed regions of export has been provided for reference. All information presented is based on data and reports current at the time of preparation.

This report has been prepared on the understanding by all parties that it does form or convey an opinion either for or against the proposed importation. By the nature of its subject content, this report is focussed on negative aspects of poppy straw and pellet importation; the benefits of importation are beyond its scope.

FUNGAL DISEASES OF OPIUM POPPY

Papaver somniferum is subject to many fungal diseases around the world (Alam et al. 2014; Kapoor 1995). Brief details of the available records of each follow. For simplicity, diseases (downy mildew, damping off) caused by oomycete pathogens are listed here as well.

Downy mildew

Causal agents

Peronospora somniferi

Peronospora meconopsidis

The downy mildew pathogen of opium poppy was first recorded as the oomycete species *Peronspora arborescens* (Berk.) de Bary (Yossifovitch 1929). However, in more recent times, the advent of molecular techniques have allowed the re-evaluation of this description. In 2014, Voglmayr et al. (2014) confirmed that two distinct species can infect opium poppy, naming them *P. meconopsidis* Mayor and *P. somniferi* Voglmayr sp. nov.. *Peronospora aborescens* still exists as a distinct species within the genus, however its host range is now believed to be restricted to the weed species, *Papaver rhoeas* (Voglmayr et al. 2014).

Symptoms

Downy mildew is the most common and destructive disease of opium poppy worldwide (Alam et al. 2014; Montes-Borrego et al. 2011; Scott et al. 2003).

Symptoms of the disease range from localised necrotic lesions on leaves with associated sparse white conidiophores on the undersides of leaves, to systemic infection of the host resulting in plant deformation, blackening and, in severe cases, death. Under the revised classification of the downy mildew pathogens, *P. meconopsidis* was associated with localised infection of opium poppy, while *P. somniferi* is capable of both localised and systemic infections (Voglmayr et al. 2014). Due to the downy mildew pathogens' ability to rapidly produce conidia on infected plants, the disease is able to quickly disseminate itself once it is established in a field or region. Under favourable conditions of high humidity and moderate temperatures, conidia may be produced every 7 to 10 days during the cropping season (Scott et al. 2008).

Australian records

Downy mildew of opium poppy was first recorded in Tasmania in 1996 (Cotterill and Pascoe 1998). Initially described with symptoms of necrotic lesions of leaves surrounded by sparse, white conidiophores forming on the lower leaf surface, the causal agent was identified as *Peronospora arborescens* (Cotterill and Pascoe 1998). Under the revised classification, isolates of *Peronospora* from Australian crops were classified as *P. meconopsidis* (Voglmayr et al. 2014). Subsequently, in 2014, symptoms of systemic infection of opium poppy were recorded in Tasmania and the causal agent identified by multiple sources, including J. Scott (unpublished data) and Biosecurity Tasmania, as *P. somniferi*.

Importation risks

Peronspora species are obligate, biotrophic pathogens, and thus require living host tissue upon which to feed (Brown 1997). They are not able to actively grow in the absence of a living host. However, they are able to survive for extended periods in the absence of living hosts through the production of oospores (Thines and Choi 2016). Oospores are produced by the pathogen in infected host tissues, such as leaves, stems and seed, and then remain dormant until coming into contact with a viable host (Montes-Borrego et al. 2009). Oospores are not actively disseminated, but can be distributed by human mediated movement of infested soil and organic matter, including straw.

A compounding factor with the downy pathogens is the potential for pathotypes (also called races) to exist within species. Due to the close interaction between host and pathogen, an "evolutionary arms race" can occur whereby host resistance genes are countered by new virulence genes in the pathogen, leading to increasing host specialisation (Thines and Choi 2016). Distinct pathotypes are known to occur within other *Peronospora* species, such as spinach (Feng et al. 2014) and pea downy mildew (Liu et al. 2013; Taylor et al. 1989). The existence of pathotypes within either *P. meconopsidis* or *P. somniferi* is currently unknown, however results from ongoing studies suggest the possibility. Minor DNA sequence differences are observed between the *coxI* and *coxII* gene regions of *P. somniferi* from Australia and Europe (J. Scott, unpublished data). Additionally, *P. meconopsidis* oospores were only observed to form in specimens collected in Australia (Scott 2003) and Asia (Voglmayr et al. 2014), not Europe (Voglmayr et al. 2014). This suggests that population differences may be present. Due to the destructive nature and importance of downy mildew of poppy, the existence of pathotypes needs to be considered.

Poppy fire

Causal agents

Crivellia papaveracea

Brachycladium papaveris

The poppy fire pathogen was originally described as *Dendryphion penicillatum* (Corda) Fr., with *Pleospora papaveracea* (de Not.) Sacc identified as the sexual stage of the fungus (Sivanesan and Holliday 1982). However, molecular and morphological comparisons undertaken by Farr et al. (2000) indicated that these were two distinct species. The taxonomic identity of these species was subsequently revised by Inderbitzin et al. (2006) who described two species; *Crivellia papaveracea* (De Not.) Shoemaker & Inderbitzin nov. comb, and *Brachycladium papaveris* (K. Sawada) Shoemaker and & Inderbitzin comb. nov.. These new species did not strictly align with the descriptions of Farr et al. (2000).

Further complicating identification of pathogens occurs due to variation in the reported common name of the disease. Historical descriptions from Europe have frequently given the disease names including capsule rot, leaf blight and Helminthosporiosis. The fungus associated with such descriptions, *Helminthosporium papaveris* K. Sawada, is now considered an outdated synonym of *B. papaveris* (Inderbitzin et al. 2006; O'Neill et al. 2000).

Symptoms

Typical symptoms of poppy fire are red/brown necrotic lesions on leaves, stems and capsules of infected plants (Munro 1978; O'Neill et al. 2000). Upon its first description in Australia, poppy fire was also associated with seedling damping off (death under wet conditions) and dark lesions on the roots of mature plants (Munro 1978). Both causal species can also colonise inside poppy capsule and the developing seed (O'Neill et al. 2000).

Work by Bailey et al. (2000) suggests that pathogenic differences exist between the two species with host varietal susceptibility differences occurring when challenged by both species. In general, *P. papaveracea* was the more aggressive of the species (Bailey et al. 2000), a conclusion supported by O'Neill et al. (2000). Conversely, Gasich et al. (2013) found no pathogenic differences between the two species, suggesting that pathogenic variation may be present.

It should be noted that much of the research conducted into poppy fire has been done to evaluate its potential as a mycoherbicide for the control of illicit opium poppy crops (for example: Bailey et al. 2000; Bailey et al. 2004; O'Neill et al. 2000).

Australian Records

Poppy fire was first recorded on opium poppy in Australia 1971 by Munro (1978) with the causal organism identified as *Dendryphion penicillatum* (Corda) Fr. Prior to the discovery of downy mildew in Australian crops, the prevalence of poppy fire was such that it was main focus of disease control for the industry (Cotterill and Pascoe 1998; Ryan et al. 1997). Since the differentiation of the causal organism into two distinct species, no work has been recorded to indicate which, or if both, species are present in Australia.

Importation risks

If only one of the two causal organisms of poppy fire is present within Australia, then importation of the other species poses a risk to the poppy industry. However, no work has been published to indicate which species are present in Australia since the confirmation of two distinct species.

Both pathogen species have been recorded in a large number of poppy growing regions, on several poppy species, including *P. somniferum*. *Crivellia papaveracea* has been recorded in Austria, Hungary, USA, Switzerland, India, Turkey, Iran, Afghanistan, Germany (Inderbitzin et al. 2006), Russia, Ukraine (Gasich et al. 2013) and Slovakia (Pastirčák and Fejér 2014). Similarly, *B. papaveris* has been recorded in USA, Colombia, Turkey, Venezuela, Sweden, Germany (Inderbitzin et al. 2006), Russia, Ukraine (Gasich et al. 2013) and Slovakia (Pastirčák and Fejér 2014).

Both species are seed borne and can be carried on vegetative plant material (Bailey et al. 2000; Inderbitzin et al. 2006; O'Neill et al. 2000; Spitzer et al. 2014). *Crivellia papaveracea* can survive extended periods in soil and organic matter through the production of microsclerotia (Inderbitzin et al. 2006). *Brachycladium papaveris* does not form microsclerotia, but is believed to form chlamydospores as alternative survival structures in infected host tissue (Inderbitzin et al. 2006).

Once introduced into a region, *C. papaveracea* is capable of long distance dispersal through the formation of ascospores (Inderbitzin et al. 2006). No records of ascospore production by *B. papaveris* have been published to date.

Capsule black mould

Causal agents

Stemphylium vesicerium

Cladosporium herbarum

Cladosporium macrocarpum

Alternaria spp.

This disease is caused by a complex of pathogens, however only scant records exist. *Alternaria* species associated with the disease include *A. alternata* (Fr.) Keissler (Sampson and Walker 1982) and *Alternaria brassicae* var. *somniferi* Har. & Briard (Pastirčák and Fejér 2014). It should be noted that the genus *Alternaria* has recently undergone extensive taxonomic revision (Woudenberg et al. 2013), thus identifying the exact species in this case is difficult without dedicated research.

Symptoms

The symptoms of capsule black mould are typically brown, dark green or black blemishes on infected poppy capsules (Dennis 1998). Occurrence of this disease can reduce alkaloid content of infected capsules (Laughlin and Munro 1982). In addition, pathogens causing this disease, especially *Alternaria* spp., can contaminate seed from infected capsules which may inhibit seedling emergence in subsequent crops (Pastirčák and Fejér 2014; Spitzer et al. 2014)

Australian records

Black mould of poppy capsules was first recorded in Australia in 1971 (Sampson and Walker 1982). It is a minor disease in this country; observed under wet late season conditions (Laughlin et al. 1998).

Importation risks

This disease has been present in Australian poppy crops since 1971 and is caused by a group of pathogens commonly observed in many crops species. As such it is already established in this country and no evidence has been obtained to suggest there are related importations risks.

Powdery mildew

Causal agents

Erysiphe cruciferarum

Erysiphe macleayae

Powdery mildew of opium poppy is caused by ascomycete fungi from the genus *Erysiphe* (Audichya and Thakore 2000; Kothari and Verma 1972; Pastircakova et al. 2016). The main pathogen has historically been classified as *E. polygoni* DC (Audichya and Thakore 2000; Kothari and Verma 1972). Reports often list the pathogen under the name of its asexual stage, *Odium* spp. (Dennis 1998), which is now outdated. However, it has since been reclassified as *Erysiphe cruciferarum* Opiz ex L. Junell (Braun and Cook 2012; Pastircakova et al. 2016).

In addition, work published in 2016 demonstrated that a second species in the genus, *E. macleayae* R.Y. Zheng & G.Q. Chen, is also capable of infecting opium poppy (Pastircakova et al. 2016). Comparison of the pathogenicity of the two species towards poppy found no differences, with both readily infecting and producing spores (Pastircakova et al. 2016).

Symptoms

Powdery mildew is characterised by sparse white mould on the upper leaf surface, which can have a powder-like appearance (Dennis 1998). The disease typically presents in maturing plants and is favoured by temperatures between 25 and 35 °C (Kothari and Verma 1972).

Powdery mildew is considered a serious disease of poppy production in India (Audichya and Thakore 2000; Kothari and Verma 1972) causing seed and latex yield losses (Kothari and Verma 1972). In Australian production the disease is considered to be a disease of minor importance, unlikely to cause yield losses (Dennis 1998). However, no studies supporting this position were found in the literature.

Australian records

Powdery mildew of opium poppy is listed by Dennis (1998). It was first recorded in plants growing at Dunalley and New Town, Tasmania in 1977 (Sampson and Walker 1982). The causal agent in this case is listed as *Odium* spp. No work has been conducted to the authors' knowledge to confirm whether or not this constitutes *E. cruciferarum* or *E. macleayae* in Australia.

Importation risks

Erysiphe species are obligate biotrophic fungi that require living host tissue for nutrition. However, both *E. cruciferarum* and *E. macleayae* are capable of surviving in the absences of living hosts through the production of chasmothecia, which reside in crop residues and soil (Glawe 2008; Pastircakova et al. 2016). Chamothecia provide a key measure for the fungi to survive extreme (both hot and cold) environmental conditions (Glawe 2008). Under favourable conditions chasmothecia release ascospores into the atmosphere, facilitating dispersal of the pathogen.

Powdery mildew of poppy is recorded in a number of regions, notably India (Audichya and Thakore 2000; Kothari and Verma 1972) and Europe (Nemeth 1998), including Bulgaria, Switzerland, Romania, Czech Republic (Pastircakova et al. 2016) and Slovakia (Pastirčák and Fejér 2014).

Powdery mildews can often exhibit significant pathogenic specialisation forming pathotypes with differential rates of infectivity or aggressiveness against host genotypes (Brown and Ogle 1997). However, no work has been conducted to date into any role that pathotypes may play in the opium poppy downy mildew system.

White mould

Causal agent

Sclerotinia sclerotiorum

White mould, or stem rot, of opium poppy is caused by the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary (Laughlin and Munro 1983a; Priya and Singh 2003).

Symptoms

Symptoms of infection include water soaked lesions on leaves and bleached stem lesions (Dennis 1998). Later in the infection process, black sclerotia form in affected host tissue. Sclerotia act as survival structures for the fungus and are capable of surviving many years in the absence of host tissue (Ben-Yephet et al. 1993).

Australian records

Sclerotinia sclerotiorum infections were first recorded in Tasmanian in 1973 (Sampson and Walker 1982) and noted as common in Australian poppy crops prior to 1983 (Laughlin and Munro 1983a). *Sclerotinia sclerotiorum* is a common pathogen of many agricultural crops in Australia.

The timing of white mould infections in poppy crops typically occurs 5 to 7 weeks after flower bloom (Laughlin and Munro 1983b) Field studies conducted have indicated that the lateness of this infection means that yield losses associated with the disease are low to negligible (Laughlin and Munro 1983b). The detrimental effect of this disease occurs through weakening of the plant stem resulting in lodging and reduced ease of harvest (Laughlin et al. 1998).

Importation risks

Sclerotinia sclerotiorum is a cosmopolitan species affecting a large range of economically important crops (Bolton et al. 2006). It is commonly found in many crops used in rotation with poppies in Australia, including. green beans (Jones et al. 2011) and pyrethrum (O'Malley et al. 2015; Scott et al. 2014). *Sclerotinia sclerotiorum* has a wide host range (>400 host species)(Boland and Hall 1994), no recorded pathogenic specialisation within the fungus and it is well established within the current Australian poppy growing regions.

Leaf smut

Causal agent

Entyloma fuscum

Entyloma fuscum J. Schröt was first recorded as attacking *Papaver* species in Canada (Savile 1946). The pathogen is widespread throughout Europe (Mordue 1984) and is common in Tasmania (Dennis 1998; Laughlin et al. 1998; Shivas et al. 2013).

Symptoms

The first symptoms of leaf smut are pale, yellow (chlorotic) spots on infected leaves (Dennis 1998). Sparse mould forms on the undersides of leaves, with a powdery appearance occurring under humid conditions (Dennis 1998). Severe infections early in a season can lead to extensive defoliation of crops, resulting in yield reductions (Laughlin et al. 1998).

Australian records

Entyloma fuscum is common in Tasmanian crops, having been recorded prior to 1987 (Laughlin et al. 1998), but after 1982 (Sampson and Walker 1982).

Importation risks

Leaf smut is a common, minor disease of opium poppy in Australia (Dennis 1998; Laughlin et al. 1998) and well established in Australian crops (Laughlin et al. 1998).

Damping off

Causal agents

Pythium dissotocum

Pythium spp.

Damping has been associated with *Pythium* species in Australia and India (Alam et al. 1996; Sampson and Walker 1982). The disease is principally associated with *Pythium dissotocum* Drechsler (Alam et al. 1996; Bajpai et al. 1999). However, Alam et al. (2014) also lists *P. ultimum* and *P. mamillatum* as damping pathogens. Like *Peronospora* species, *Pythium* species are not true fungi, but rather belong to the Oomycota.

Symptoms

Damping off is a disease of young seedlings, typically occurring under excess soil moisture. Infected seedlings become chlorotic and wilt due to decay at the base of the plant stem, which leads to premature death (Alam et al. 2014).

Pythium species are able to survive in the soil environment via the production of oospores. Under moist conditions, oospores then germinate to produce motile zoospores, which are then able to move via free water in the soil environment and infect fresh hosts (Alam et al. 1996).

Australian records

A *Pythium* spp. was recorded as causing damping off of poppy plants at Deloraine, Tasmania 1974 (Sampson and Walker 1982). No further records have been found during the production of this report.

Importation risks

Damping off by *Pythium* spp. has not been reported in Europe.

Fusarium wilt

Causal agent

Fusarium oxysporum

Fusarium semitectum

Fusarium species have been associated with stem wilts, and root and stem rots in Europe and India. In Hungary, the causal agent was recorded as *Fusarium oxysporum* Schl. (Horompoli 1988). Alam et al. (2014) notes that *Fusarium oxsporum* have also been observed to infect Spanish opium poppy crops. In India, *Fusarium semitectum* Berkeley & Ravenel is the pathogen in question (Gupta et al. 1986). *Fusarium* sp. has been recorded as a contaminant of poppy seed in the Czech Republic (Spitzer et al. 2014).

Symptoms

Alam et al. (2014) records the symptoms of the disease as necrotic black lesions on the stems of plants. These then lead to wilting of plant stems and plant death under severe infections. Indian reports suggest that under favourable conditions the disease can kill up to 80% of young poppy seedlings (Alam et al. 2014; Gupta et al. 1986).

Australian records

No records of *Fusarium* spp. infection of opium poppy have been found for Australian crops. However, a *Fusarium* sp. was identified to attack *Papaver bracteatum* crops in 1978 (Sampson and Walker 1982).

Importation risks

Fusarium oxysporum is a common soil contaminant, attacking a wide range of host species in Australia (Summerell et al. 2011). However, within the species exists a large number of *formae speciales*; subgroups within the species that specifically attack a limited pool of host plants (Summerell et al. 2011). For example, a recent paper reported a new *formae speciales, F. oxysporum* f. sp. *papaveris* attacking *Papaver nudicaule* in Italy (Ortu et al. 2015). The quantity of *forma speciales* in the species is such that *F. oxysporum* is often considered a complex of species, rather than a single species (Baayen et al. 2000). Furthermore, pathotypes (races) can exist within *formae speciales* making identifications difficult (for example: Cai et al. 2003). Whether or not the *F. oxysporum* attacking opium poppy in Europe represents a *formae speciales* not present within Australia is unclear. If it does, efforts should be made to avoid its introduction to Australia.

Fusarium semitectum is common in soils of eastern Australia. However, it is usually associated with diseases of tropical crops, such as bananas (Summerell et al. 2011). This is consistent with this species being a pathogen of opium poppy under tropical production in India, but not in Europe.

Neither *F. oxyporum* nor *F. semitectum* have a recorded sexual stage and rely on asexually produced conidia for aerial dissemination, which are typically short lived when exposed to UV light. Asexual resting spores, called chlamydospores, may also be formed, enabling survival in the soil environment (Alam et al. 2014). *Fusarium* species are able to live as saprophytes, feeding on decaying organic matter, in the absence of a living host.

Collar rot

Causal agent

Rhizoctonia solani

Collar rot was reported as a new disease of opium poppy, caused by *Rhizoctonia solani* Kühn, in 2000 (Sattar et al. 2000).

Symptoms

Collar rot is a severe disease of opium poppy under tropical conditions (Trivedi et al. 2006). *Rhizoctonia solani* attacks the upper roots and collar of poppy plants, resulting in chlorosis, breakdown of the plant collar, stunted growth and lodging of plants. Reports of collar rot of opium poppy are currently restricted to India (Alam et al. 2014).

Australian records

Collar rot of opium poppy has not been reported in Australia. However, the disease has been recorded in *Papaver bracteatum* crops in Tasmania in 1978 (Sampson and Walker 1982).

Importation risks

Rhizoctonia solani is a common soil pathogen of many crops, including potato, thus opium poppy crops have undoubtedly been exposed to the pathogen. As the disease is currently restricted to production under tropical conditions, this suggests environmental conditions in Australia may not be conducive to severe outbreaks.

VIRUSES OF POPPIES

Viruses infecting *P. somniferi* are currently poorly characterised. While several virus species have been recorded as pathogens, reports are often restricted to virus identification with some reference to the insect vector responsible for transmitting the virus between plants. The most common virus family detected in poppies are potyviruses. These include Turnip mosaic virus (TuMV), poppy mottle virus (PoMV) and bean yellow mosaic virus (BYMV). Potyviruses are usually characterised by discolourations of the leaves of host plants either as mottles (diffuse yellowing) or mosaics (clearly defined yellowing or bleaching) which indicates loss of photosynthetic capability in the host plant, resulting in yield losses. Potyviruses are vectored (transferred) from one host to another by aphid species feeding on the host plant; especially by the green peach aphid (*M. persicae*).

TuMV was first recorded in commercial poppy fields in Hungary by Horvath and Besada (1975). It has also been recorded in Czechoslovakia (Špak and Kubelková 1990). Previously inoculation studies conducted in South Africa by McClean and Cowin (1952), demonstrated that TuMV (reported as cabbage ring-spot virus) can be particularly severe in opium poppy, capable of killing whole plants within 4 weeks of infection. TuMV has not been reported in opium poppy outside Europe, however the virus is widespread and capable of infecting a wide range of hosts, including brassica crops in Australia (Nyalugwe et al. 2015). Given the widespread distribution of the virus and its vector, this raises the question as to whether or not there is a poppy specific pathovar (equivalent of fungal pathotype) of TuMV that currently only has a limited geographic distribution. Some evidence for this exists, with a recent analysis indicating that the Australian TuMV strains were likely introduced from Europe 80 years ago, but have since evolved into a genetically distinct population from that currently present in Europe (Yasaka et al. 2015).

PoMV is a potyvirus whose records appear restricted to opium poppy, with the virus recorded in Turkey (Turkoglu 1979; Turkoglu and Fidan 1984) and India (Sattar et al. 1997; Zaim 1989; Zaim et al. 2014a; Zaim et al. 2014b). Infections by this virus result in plant stunting and malformed capsules, with severe infections leading to early plant death (Zaim 1989).

BYMV has been reported to infect opium poppies in Poland (Micinski and Przybylska 1983) and Bulgaria (Kovachevsky 1968), causing leaf malformations and mottling. However, it has not been reported in other poppy growing regions. BYMV is a potyvirus with a host range of at least 58 different plant species (Brunt et al. 1996). BYMV is a widespread virus and common in Australia, notably in subterranean clover pastures (Helms et al. 1993), but has not been observed in opium poppy outside of Europe.

Members of other virus families, including the umbraviruses and begomoviruses, have also been detected within opium poppy.

Opium poppy mosaic virus (OPMV) was identified in 2006 in New Zealand (Tang et al. 2016). Symptoms of the disease, mottling and mosaic of leaves, were observed in roadside weeds. No details on severity of the disease were provided. OPMV is a newly described virus, belonging to the umbravirus family and vectored by aphid species.

Tomato leaf curl New Delhi virus (ToLCNDV) has been recorded to infect opium poppies in India (Srivastava et al. 2016). Vectored by whitefly (*Bemisia tabaci*), ToLCNDV belongs to the begomovirus family. It was reported to cause severe leaf curling in infected plants, however not details on yield losses or extent of spread in India have been reported. ToLCNDV is known to be present in Spain, in tomato (Ruiz et al. 2015) and zucchini (Juarez et al. 2014) crops, but has not been reported in Spanish opium poppy crops to date.

Other viruses suggested as possible opium poppy pathogens, based on their records in other *Papaver* plant species, include: beet western yellows virus (BWYV), which has been recorded to infect the weed species *Papaver rhoeas* (Stevens et al. 1994); and Beet curly top virus and tobacco mosaic virus, which are demonstrated pathogens of Iceland poppy (*Papaver nudicaule*)(Brunt et al. 1996). However, no records of these viruses infecting opium poppy were found in preparing this report.

Australian records

Very little work has been conducted into viruses infecting *P. somniferum* in Australia. An unidentified virus causing mosaic symptoms was recorded in northern Tasmania crops in 1976 (Sampson and Walker 1982). Subsequently, work by Wilson (1999) demonstrated that poppies can be infected by the tospovirus, tomato spotted wilt virus (TSWV). However, infections were only observed under controlled conditions and infected plants exhibited no symptoms of infection. The main vector of TSWV, the western flower thrips (*Frankliniella occidentalis*) is common in mainland Australia (Clift et al. 1998) and has been recorded in Tasmania (Westmore 2012).

Surveys of Tasmanian poppy fields in 2004 and 2005 were conducted by Pethybridge et al. (2005) Samples were screened for BWYV, TSWV, and the potyvirus and carlavirus families. From these, one instance of an unidentified potyvirus, causing mottling of leaves and capsules, was detected.

Importation risks

To date only the potyviruses have been detected in European poppy crops. Thus discussion here is limited to this group.

Potyviruses are spread non-persistently by aphid species, meaning that viable virus particles survive on the aphid vector only for short periods of time (Gibbs et al. 2008; Ng and Falk 2006). Additionally, potyvirus are RNA viruses, particles of which rapidly breakdown when external to host cells. Thus

potyviruses are unlikely to be imported in completely dry poppy straw and/or pellets. Incompletely dry material may contain viable potyvirus particles within the remanent sap, however for the virus to become established in Australia would then require aphids to feed on the imported material (Ng and Falk 2006).

Counter to this, Gibbs et al. (2008) noted that dissemination of potyviruses via infected host seed likely occurs at a greater rate than experimental results suggest. Thus contamination of shipments with viable poppy seed is likely the greatest risk for the introduction into Australia. Once introduced, the widespread dispersal of aphid vectors could facilitate establishment of the introduced potyvirus.

BACTERIAL DISEASES OF POPPIES

Few reports of bacterial diseases affecting *P. somniferum* exist.

A bacterial soft rot disease, variously described as stem rot, capsule rot and soft rot has been recorded in India (Sattar et al. 1997; Sattar et al. 1988) and Spain (Aranda et al. 2008). The causal pathogen in these cases was recorded as *Pectobacterium carotovorum* (formerly *Erwinia carotovora* subsp. *carotovora*). In India, the disease has been observed to cause widespread crop damage, including wilting and rotting of affected plants under favourable conditions (Sattar et al. 1997; Sattar et al. 1988). *Pectobacterium carotovorum* is a widespread pathogen of many vegetable crops and is found in Australia (de Haan et al. 2008; Peltzer and Sivasithamparam 1985).

In New Zealand, a stem rot of *P. somniferum* has been recorded to be caused by *Pseudomonas viridiflava* (Wilkie et al. 1973), although little other information is available.

Australian records

Xanthomonas papavericola (now classified as *X. campestris* pathovar *papavericola*) recorded as causing a bacterial blight of poppy capsules at Scottsdale in 1961 (Sampson and Walker 1982). Beyond this, no evidence of surveys or records of bacterial pathogens of opium poppy in Australia was uncovered during the preparation of this report.

Importation risks

Given the dearth of information available on bacteria infecting poppies, only general comments can be made such that standard quarantine procedures to eliminate bacterial contaminants be maintained.

INSECT PESTS OF POPPY

Pest species

Biosecurity Advice 2016/08 outlines two weevil species (*Ethelcus denticulatus* and *Neoglocianus maculaalba*) and storage pests (*Liposcelis* spp. and *Trogoderma* spp.) as the greatest biosecurity threat faced by the importation of poppy straw and pellets. However, as *P. somniferum* is endemic throughout the Mediterranean region (Norn et al. 2005) a far greater number of pestiferous insects exist within European and Middle Eastern poppy crops, many of which reside within the proposed exporting countries named. Indeed, Hungary, Portugal and Turkey contain numerous poppy pests of economic significance, all of which would pose an undue hazard to Australia's biosecurity including the poppy gall forming midges *Dasyneura papaveris* and *Carpodiplosis papaveris* both of which have been recorded in Hungary (Barnes 1949).

Similarly, the poppy root weevil (*Stenocarus ruficornis*) is a common pest of *P. somniferum* in both pharmaceutical and ornamental poppy species in numerous European and Middle Eastern countries including Romania, Sweden, the Czech Republic (Bečka et al. 2014), the United Kingdom (Alexander 2005), Iran (Ghahari et al. 2010) and Turkey (Avgin and Colonnell 2011). *Stenocarus ruficornis* is known to damage both the roots and leaves of poppies causing significant financial damage and should be deemed an additional biosecurity threat to Australia's poppy industry.

Other poppy pests of economic importance not described in the submission are the poppy stem gall wasp, *Timaspis papaveris* (Kieffer) a known pest in several EU states including Hungary (Šedivý and Cihlař 2005). Other European pestiferous weevil species known to attack commercial poppy crops include *Ceutorhynchus abbreviates* and *C. albovittatus*, however, their exact European distribution is currently unclear.

Virus vector species

Furthermore, several insect species can act as vectors of poppy pathogens, namely viruses. These include the green peach aphid (*Myzus persicae*)(Horvath and Besada 1975; Sharma and Yadav 1985; Zaim 1989), the silverleaf whitefly (*Bemisia tabaci*)(Srivastava et al. 2016) and various thrips, including the western flower thrips (*Frankliniella occidentalis*), which oviposit (lay eggs) on or within plant tissues, are recognised pests of *P. somniferum* (Kapoor 1995). The co-occurrence of these species with their virus partner can facilitate the spread of virus species in Australia.

Australian records

Currently relatively few insect species have been identified as pests in Australian poppy crops. Species currently regarded as pests of economic significance include the cotton boll worm (*Helicoverpa*

armigera), red legged earth mites (*Halotydeus destructor*), lucerne fleas (*Sminthurus viridis)* and other spring tails, slugs and snails (Fist 2001). This lack of pestiferous insect species could be largely attributed to Australia's effective biosecurity regime.

Western flower thrips was discovered in Australia in April 1993 (Clift et al. 1998). It has since become a major pest of strawberries and other crops on mainland Australia. This species has since been recorded in Tasmania at low frequencies (Westmore 2012).

Silverleaf whitefly was first recorded in Western Australia in 1962 and has subsequently been record in New South Wales, Queensland, Northern Territory and Tasmania (Gunning et al. 1995). The pest appears to be established in greenhouse production in NSW (Childs et al. 2009). It is not established in Tasmania to date (Bishop 2015).

Green peach aphid is a widespread and common pest species in Australia (Plant Health Australia 2011).

Importation risks

It is unclear whether any of these species would successfully establish in Australia if introduced. However, it should be deemed possible due to the lack or deleterious biotic and abiotic factors including the absence of natural enemies (Liebhold and Tobin 2008). Their capacity to exploit the new environment, including food resources, which may include other plant species (Cassey et al. 2004; Snyder and Evans 2006) other than poppy, provides additional aid to their establishment.

Not all incursions overcome these factors and become established (Caley et al. 2015). However, many have, and since their initial introduction have gone on to become urban and agricultural pests or cause serious issues to ecosystem health (Lach and Thomas 2008). Numerous pestiferous insect species of European origin, which have been successfully established in both Tasmania and on the Australian mainland. Therefore, it should be considered possible that any undetected incursion could lead to species establishment. This is largely due to the similarities in southern Australia's climate (Fist 2001) to that of the *P. somniferum*'s origins and the numerous European plant species introduced into Australia by European settlers, which may serve as alternate hosts to these insect species.

CLIMATE COMPARISONS

As noted already in this report southern Australia's climate bears many similarities to *P. somniferum*'s origin (Fist 2001). Additionally, the cool temperate climate of Tasmania does not suffer climatic extremes that may be found in other regions of the world. As such, most pest and pathogen species found in temperate environments are unlikely to be inhibited by the climatic conditions in Tasmania. To demonstrate this point a very simple climate comparison was undertaken to compare the climate in the putative points of export listed in Biosecurity Advice 2016/08. Climate data for this comparison was sourced from The World Bank (http://data.worldbank.org/topic/climate-change) using the rWBclimate package (Hart 2014) in R (R Core Team 2015). Graphing was undertaken using ggplot2 package (Wickham 2009). As shown in Figures 1 and 2 below, Tasmania typically has moderate temperature and rainfall patterns which fall well within the ranges observed in the putative locations of export to Tasmania.

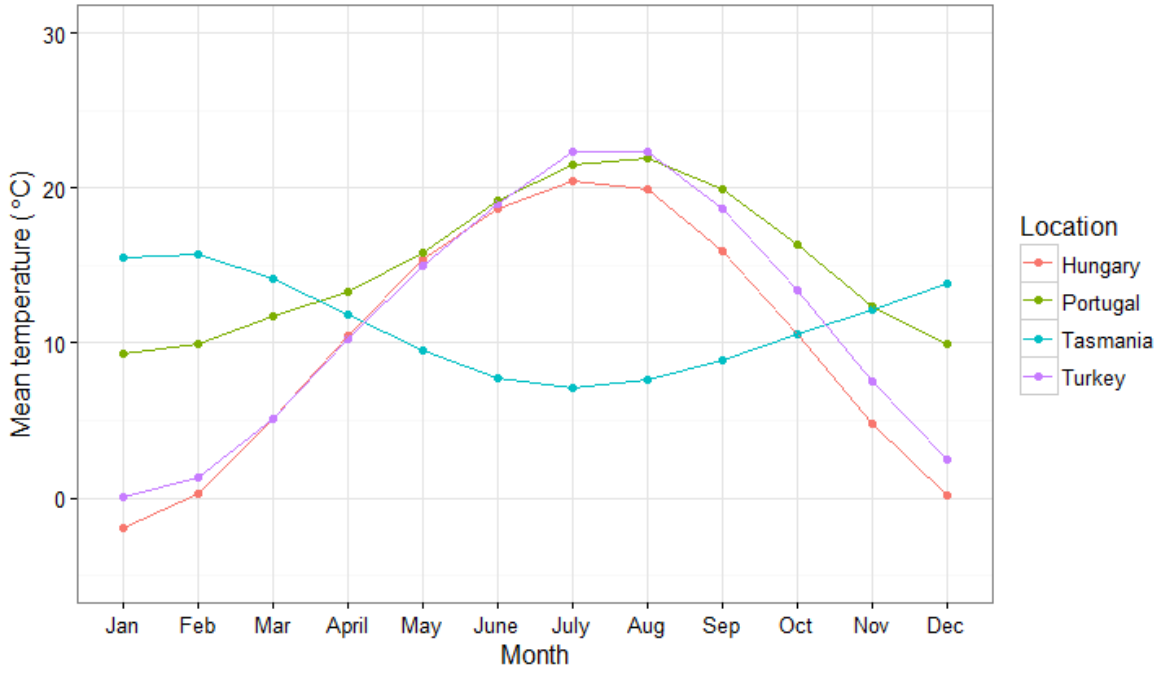

Fig. 1 Historical mean temperatures of the poppy producing regions, Hungary, Portugal, Turkey and Tasmania, Australia. Means for the first three regions was calculated from the period 1901 to 2009, while means for Tasmania were from the period 1960-2009.

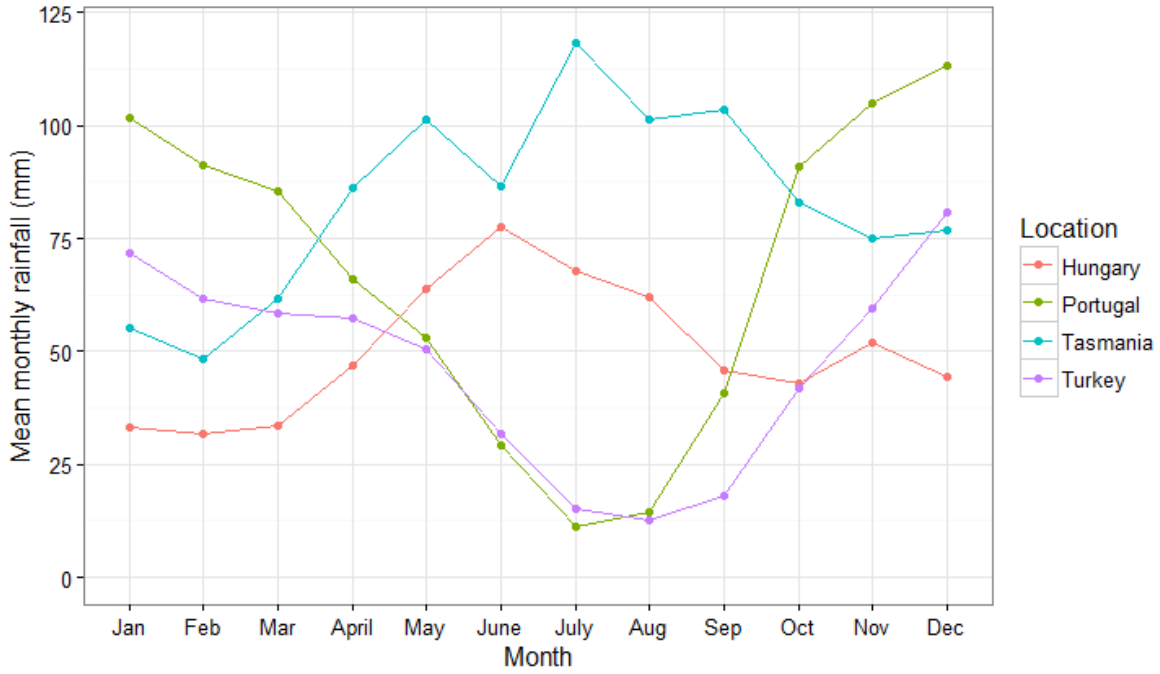

Fig. 2 Historical mean monthly rainfall of the poppy producing regions, Hungary, Portugal, Turkey and Tasmania, Australia. Means for the first three regions was calculated from the period 1901 to 2009, while means for Tasmania were from the period 1960-2009.

CONCLUDING COMMENTS

Several diseases and pests were identified as potential concerns for the poppy industry in Australia. However, in the preparation of this report it was noted by both authors that there is a general lack of in-depth information available for many diseases and nearly all insect pests affecting opium poppy. Little significant research has been published outside of the diseases downy mildew and, to a lesser extent, poppy fire. The extent of information presented in this report is broadly representative of the breadth of available information for a given disease or pest.

Recent work identifying two distinct downy mildew pathogen species and the subsequent detection of the second species, *P. somniferi* in Australia highlights the dangers of operating in systems with imperfect or limited available information. The timing of these two events is such that *P. somniferi* must have been introduced into Australia prior to its recognition as a separate species to be guarded against. Thus the risks of introducing new species and/or new pathotypes of existing species, especially in the downy mildew, poppy fire, Fusarium wilt and TuMV pathosystems, must be carefully weighed up in any decision process.

Similarly, insect pests of poppy, some with poorly defined geographic distributions, were also identified as potential risks. Although numerous species of both *Liposcelis* spp. and *Trogoderma* spp. have already been introduced into Australia (http://www.ala.org.au), any new introductions should be prevented.

The authors are in agreement that the importation of poppy straw represents a greater risk of introducing new diseases and/or insect pests than does pelletised material. Several fungal pathogens and insect pests identified in this report are capable of surviving in poppy straw. Thus if phytosanitation treatments of straw are ineffective or inefficient, there is a real risk of introduction. It is expected that pathogen propagules and/or insect infestations are less likely to survive the pelletising process prior to shipment. However, few studies have investigated the effect processing methodologies, such as palletisation, have on insect mortality (Ducom-Gallerne and Vinghes 2000; Opoku et al. 2010). Thus, while pelletisation should limit potential pathogen and insect pest contamination and reduce any biosecurity risk to both the Australian opiate industry, it would not eliminate this risk. Consideration should also be given to the volume of material to be imported, as it has been noted that the consistent interception of invasive insect pests by quarantine officials in large shipments of bulk commodities is unlikely (Caley et al. 2015).

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