INDUSTRY BIOSECURITY PLAN
For the Grains Industry

Threat-Specific Contingency Plan

COMMON NAME: **Hessian fly**

SCIENTIFIC NAME: *Mayetiola destructor* (Say) 1817

SYNONYMS: *Cecidomyia contractor; Cecidomyia culmicola* Morris 1849; *Cecidomyia destructor* Say 1817; *Cecidomyia frumentaria* Rondani 1864; *Chortomyia secalina* (Loew 1858); *Mayetiola secalis* Bollow 1950; *Phytophaga cerealis* Rondani 1843; *Phytophaga destructor* (Say 1817); *Mayetiola mimeuri* (Mesnil 1934)

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Background

General

M. destructor is a species of European origin accidentally introduced into North America in about 1776, and into New Zealand by 1888

Host range

The information below is mainly out of the Crop Protection Compendium (On-line version, 2005):

Primary hosts:

Triticum spp. (wheat).

Secondary hosts:

Agropyron (wheatgrass), *Hordeum vulgare* (barley), *Secale cereale* (rye).

The main host of *Mayetiola destructor* in Europe, North Africa, North America and New Zealand is wheat but it can also develop on rye, barley and some grasses.

Gagné *et al.* (1991), established that in Morocco *M. destructor* is mainly a pest of wheat, but occasionally infests barley, on which a morphologically distinct species, *M. hordei*, is the main pest.

M. destructor has been recorded from some grass genera (*Aegilops, Lolium, Elytrigia, Bromus, Elymus* and some species of *Agropyron)*. *Elytrigia repens [Elymus repens] is* an alternative host in Europe, and Barnes (1956) suggested that it may have been the original host of Hessian fly. Reproduction on non-Triticeae grass weeds is negligible.

The situation is complex and records of Hessian fly on alternative hosts should always be supported by adequate taxonomic studies to confirm identifications, as there may be confusion with other described and undescribed species of *Mayetiola*.

Part of plant/commodity affected

The Hessian fly, Mayetiola destructor, attacks the whole above ground part of the plant, including stems, growing points, and the inflorescence.

BIOLOGY

Identification

M. destructor is generally similar to other species of *Mayetiola*, and has been confused with *M. hordei* in North Africa. This confusion has been resolved by Gagné *et al.* (1991) to show that *M. destructor* and *M. hordei* are two distinct species. Critical identification of *Mayetiola* adults is based on microscopic differences in the male genitalia and other characters, and is best undertaken by expert taxonomists. *Vide* the PHA Pest Data Sheet for Hessian fly.

Hessian fly ***Photo:*** ARS USDA "Flax-seed" stage of Hessian fly ***Photo:*** CAB International
The above photos are also in Shea *et al*., 2000.

Eggs

Eggs are about 0.5 mm long, elongated with rounded ends, glossy red, darkening with age and are just visible on the upper surfaces of wheat leaves, where they are laid parallel with the veins. Foster and Hein (1998) compare their appearance as being "similar to a string of hot dogs" (when viewed with magnification").

Larvae

A detailed description of the three larval instars is given by Gagné and Hatchett (1989). The first instar is 0.5-1.7 mm long, dorsoventrally flattened at first, but becoming cylindrical with age. The second instar is 1.7-4.0 mm long, unevenly cylindrical and with the posterior end variably tapered. The integument is almost uniformly covered with elongate spicules and the head is directed ventrally beneath the first thoracic segment. While feeding, this instar is white, but it subsequently turns brown and hard, and its shape may be modified by compression, especially when crowded. It becomes a puparium within which the third instar, pupa and adult will develop. The third instar develops within the second, is not visible, and does not feed. It is glistening white, dorsoventrally flattened, becoming cylindrical as the pupal tissues develop. The integument is completely covered with rounded verrucae, except on the anteroventral areas of the ventral segments, which have verrucae tipped with anteriorly directed points. A median, ventral, bifid sternal spatula is present on the prothorax.

Pupae

The puparia, commonly known as 'flaxseeds', are 2-6 mm long, dark brown and slightly tapered anteriorly. Their shape may be modified by compression, especially when three or more puparia develop at the same feeding site. The pupae develop within the puparia and are not visible.

Adults

Adults are 2-4 mm long, resembling small mosquitoes. Females are generally larger than males. Both sexes have long antennae. In males the abdomen is elongate cylindrical, and in females the abdomen is heavier and markedly tapered, with a short terminal, partially retractile ovipositor.

Symptoms

In autumn and spring, larval feeding on young plants stunts growth and the central shoots yellow and die. Severe infestations at this stage may kill plants, resulting in gaps in the crop. At later stages of crop growth larvae feeding at the nodes weaken the developing stems. This results in withering (white heads) and lodging, which causes loss of yield since the earheads fail to develop. Any grain developing in affected heads tends to be of poor quality. Generations produced in spring attack wheat during stem elongation. In the USA damage from Hessian fly is greatest in winter wheat seeded early, before the so-called fly-free date, and in spring wheat seeded late, in synchrony with a spring generation of the pest. (Cook & Veseth, 1991).

Brown (1997) mentions that the first sign of Hessian fly attack in plants is frequently a change in leaf colour to a darker green or bluish-green colour. Infested young plants are generally stunted, lack an emergent leaf and have leaves which are shorter, broader and more erect than healthy plants. When heavily infested the plant may be killed. In older plants stems may be weakened by larval feeding and then collapse. Tillers may be prevented from heading, or if they do, will only produce shrivelled grain. Significant reduction in grain yields can occur and it is not uncommon for crops infested by Hessian fly to have 40-70 % of stems affected.

Life history

The following summary is out of the Crop Protection Compendium (1999) and based on Barnes (1956), which should be consulted for further details. Females mate soon after emergence from pupae and start to oviposit an hour or so after mating. They fly at low levels within crops to locate host plants. In calm weather they fly above crops and are then likely to be taken up in thermals and dispersed over distances of up to 8 km from emergence sites. Each female may continue to oviposit for 2-3 days, laying a total of 100-200 eggs. Adults may live for up to 6 days in moist cool weather. Eggs hatch after 3-12 days, depending on prevailing temperatures, and the main daily hatching period is after 5 p.m. and before 8 a.m. Eggs can withstand severe frost but both eggs and first-instar larvae are susceptible to desiccation. First-instar larvae spend 12-15 hours crawling down the leaves to feeding sites under the leaf sheaths and against the stems. They then moult to the second instar and feed for 2-3 weeks when temperatures are high, or for up to 2 months when the weather is cooler.

Feeding larvae are virtually static throughout this period and feed by secreting digestive enzymes and ingesting plant sap. When fully fed, the larvae moult to form distinctive spindle-shaped dark-brown puparia, about 2-6 mm long, which is sometimes referred to as the 'flax seed stage'. The final instar remains within this puparium for a variable period of time and at low temperatures enters a prolonged diapause which facilitates carry-over from one growing season to the next. Larvae eventually pupate within the puparia and the pupal stage lasts from 6-33 days, depending on temperature. The total duration of the life-cycle is therefore extremely variable with a minimum of about 20 days, and an observed maximum of at least 49 months.

The species is multivoltine and up to six generations per year have been reported from the more favourable southern areas of its range in the northern hemisphere. The number of generations can vary greatly depending on climate. In the northern part of its range in North America *M. destructor* has only one generation per year and it overwinters as diapause larvae, but in the southern part of its range there may be up to six generations per year, without a larval diapause, but with a period of aestivation during the summer which terminates in early September. In Europe, adults of the first generation emerge in April and adults of subsequent generations may be active throughout summer and autumn. Because of the variable lengths of larval diapause, any particular flight of adults may contain progeny from various generations of the previous 2 years. This species also produces unisexual families with the progeny of one mating being all of the same sex.

Research by Foster *et al.* (1991a, b) has elucidated pheromone biosynthesis and identified the female sex pheromone as (2S)-(E)-10-tridecen-2-yl acetate.

The first generation of adults in autumn emerges before normal wheat sowing dates and development is then primarily on volunteer wheat plants.

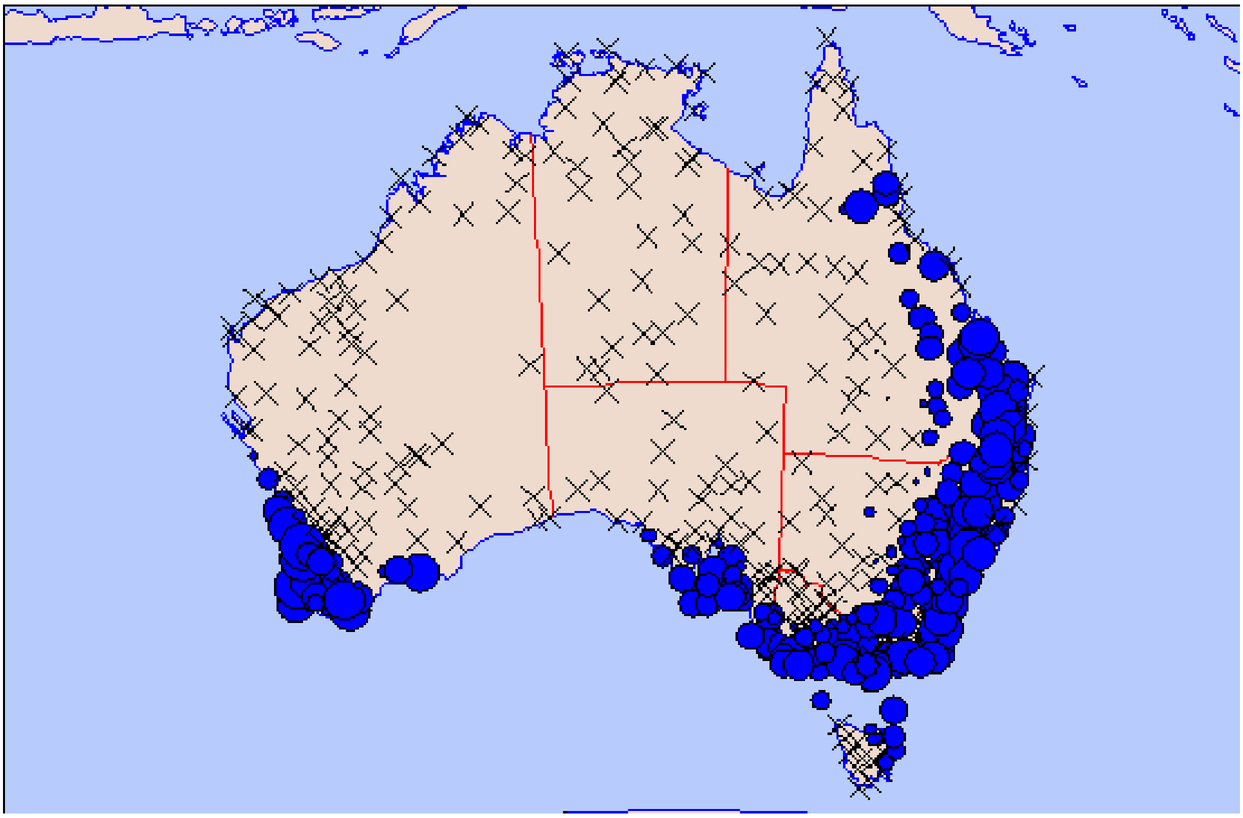
Pfadt (1985) published a brief general account of *M. destructor* in North America. He noted that there are two main broods, one attacking winter wheat in the autumn and the other attacking both winter and spring wheat in the spring. In addition to these main broods, favourable rainfall and temperatures may trigger the development of supplementary broods and during mild winters in the south-eastern USA development of successive broods is continuous. Adult activity is synchronised with humid, moderately warm periods. Dry, hot weather induces aestivation and, if prolonged, causes mortality of puparia. This combination of factors prevents *M. destructor* from causing serious injury to wheat crops in the arid sections of western and south-western USA.

Entry potential

The entry potential is affected by the possibility of transportation of diapausing larvae in wheat straw or of the cocoons with grain and other seed samples. Such an infestation could easily go undetected and could well start proliferation of Hessian fly. Factors increasing the risk include the robust nature of the diapausing puparia, the increase in air travel and the proximity of the insect to Australia (Brown, 1997).

Establishment Potential

Though the hot, dry summer in some of the Australian wheatbelt may exercise substantial control of Hessian fly, establishment potential still remains high due to the number of suitable hosts in the higher rainfall areas.



Potential distribution of the Hessian fly (*Mayetiola destructor* (Say)) in Australia. Figure based on climatic conditions in Algiers and superimposed in CLIMEX (Sutherst *et al*., 1999). Dot size represents suitability of climate.

The possible distribution of the Hessian fly in Australia (on the map above), is based on comparison with the climate surrounding Algiers, capital of Algeria, and central to the Hessian fly's present distribution. In nearby Morocco, the most serious damage is caused in the low rainfall zones (<300 mm.yr) (Ryan *et al.* 1998). As such, the Hessian fly presents a serious problem to Australian cereal cropping regions, much of which receives less than 300 mm a year.

Estimate of economic impact on production, allied industries and native ecosystems

General

The following paragraphs are mainly extracted from the Crop Protection Compendium (1999) and Brown (1997). Judging from the information available, it is foreseen that establishment of Hessian fly in Australia could lead to yield losses of 5 to 15% if no control is practiced. The continuous development of resistant wheat varieties and an increased understanding of biological control in an area with hot, dry summers may lead to yield reductions of less than 5%. *M. destructor* has been a major pest of wheat in the USA ever since its accidental introduction from Europe and there have been many damaging outbreaks. Yield losses in Indiana alone, over the period 1929-36, averaged 55 000 tonne per year, and similar losses occurred in other states. In Georgia, USA, there was a severe outbreak on winter barley in 1988-89 (Buntin and Raymer, 1992) and *M. destructor* also caused substantial reduction of forage production from winter wheat (Buntin and Raymer, 1989). Pfadt (1985) records that losses in the USA have gradually decreased as resistant varieties have become available. In 1945, which was the last year of general distribution of susceptible wheat varieties, the overall loss was about $37 million compared with average losses of about $16 million per year in the 1980s.

Skuhravá *et al.* (1984) reviewed outbreaks of *M. destructor* and other gall midge pests of cereals in Europe. They noted that *M. destructor* was an important pest of wheat in the Soviet Union and Poland after 1918 but decreased after 1940 (probably due to the combined effect of planting resistant varieties as well improved cultivation strategies). By 1970 it had practically disappeared from central Europe but continued to be an important pest of wheat in the southern European parts of the USSR, the east Mediterranean, the Transcaucasian region and Soviet Middle East and in Siberia.

A recent assessment of crop loss to this pest in Badajoz, Spain, recorded reduction of grain yields by 14-35% (Moral *et al.*, 1994) and field trials in Morocco in 1987-89 recorded a yield loss of 38% (Amri *et al.*, 1992).

Brown (1997) mentions that in most countries where Hessian fly is established it is a serious pest which requires a considerable research effort to counter. It is very damaging in the USA but not in the arid west where hot dry summers control it. However the fly is a serious pest in Morocco, Tunisia and Algeria where summer aestivation also occurs. It is possible that the hot dry summer in WA could exercise substantial control of Hessian fly, should it get in, but undue confidence should not lead to any relaxation of quarantine.
Arrival and establishment in Australia would cause large losses in wheat production initially with consequent expenditure on insecticides. The expense of breeding for resistance and biocontrol research would also be incurred.

Trade in hay to Japan would cease until a suitable fumigation was approved.
More seriously, grain exports could be affected to countries which do not already have the pest
Any effect on the environment would be imperceptible or nil (Brown, 1997).

Host Range within Australia

Alternative hosts such as barley, rye and a number of native grasses, including *Agropyron, Bromus* and *Lolium* are present all over the wheat belt. *Aegilops* has also been imported to serve as a genetic source for wheat breeding (Peirce, pers. com., 2000).
Though there is the possibility of Hessian fly infesting some non commercial grass species, with the importation of existing natural enemies the likelihood of it becoming a significant problem is minute.

Guidelines for the selection of control treatments

Cultural Control

Barnes (1956) reviewed the development of control measures and summarised general practices in the USA for cultural control, which include crop rotation, ploughing-in stubbles, destruction of volunteer wheat plants, good soil preparation with the use of good seed to ensure quick germination, and moderately late sowing of winter wheat to avoid infestation by the autumn generation of adults. Barnes emphasised that these practices must be modified to meet local conditions and noted the emphasis that had always been laid on a thorough knowledge of the local biology and bionomics of *M. destructor* and the integration of such information with good farming practice on a co-operative basis.

Refinement of these methods has continued in the USA (Chapin *et al.*, 1992; Buntin *et al.*, 1991; Buntin and Bruckner, 1990; Buntin *et al.*, 1990) and in other areas where *M. destructor* is a persistent pest, such as Spain (Moral *et al.*, 1994) and Kazakhstan (Evdokimov *et al.*, 1986).

Biological Control

High levels of natural parasitism have been recorded in many areas where Hessian fly is a pest, and conservation of these natural enemies is important. Classical biological control by introduction of non-indigenous agents has not been attempted in recent years, but some deliberate and some accidental introductions have been made in the past and these account for the presence of non-indigenous parasitoids in North America and in New Zealand. Most parasitoids in North America are chalcidoids which attack the spring generation of puparia but egg parasitoids of the superfamily Proctotrupoidea are also important. In Texas, during 1986-88, *Homoporus destructor* was the most abundant parasitoid, followed by *E. allynii* and the pteromalid *Trichomalopsis subapterus*. Parasitism was high (up to 87% puparia parasitised in May), indicating that parasitism is of considerable importance in limiting *M. destructor* populations. Research in New Zealand indicated that *P. hiemalis* was the most abundant parasitoid of *M. destructor* pupae on *Bromus willdenowii* in 1988 and 1989 (Brown, 1997).

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In North America the egg parasitoid *Platygaster hiemalis* shows greatest promise as a biological control agent as it attacks the autumn generation of the pest and therefore limits initial attack in the following season (Schuster and Liddell, 1990).

Barnes (1956) reviewed the many records of parasitoids and predators of *M. destructor* recorded up to that date. He noted the early work by Gahan (1933) on hymenopterous parasitoids (mainly Platygasteridae and Chalcidoidea), which indicated that 35 species were known from North America, 17 from Europe and 11 from both. Barnes also noted particular studies of various species, some of which had been introduced to the USA from Europe. This review is a useful source of a great deal of information, but must be used cautiously as some of the species names have been changed by subsequent taxonomic research.

Schuster and Lidell (1990) reviewed published records of parasitoids from the USA and reported their own studies of the distribution and seasonal abundance of *M. destructor* parasitoids in Texas. Most species in North America are chalcidoids which attack the spring generation of puparia as solitary parasitoids, but gregarious and solitary egg parasitoids of the superfamily Proctotrupoidea are also important. The distribution and relative importance of these species varies greatly in different geographic areas. Eighteen species have been recorded from the Atlantic region (North Carolina to Pennsylvania) with *Platygaster hiemalis* ranked as most important, followed by *Platygaster zosine* and *Eupelmus allynii*. In the North Central States 17 species were found during the period 1937-39 and *E. allynii* was judged most important, followed by *Homoporus destructor* and *P. zosine*. *Pseuderimerus mayetiolae*, *H. destructor* and *E. allynii* have been recorded as the most important parasitoids in California, and in Oregon and Washington State the egg parasitoids *Platygaster hiemalis* and *P. herrickii* have been considered of greatest value. *P. hiemalis* is the only significant parasitoid of the autumn generation. In Texas, during 1986-88, H. destructor was the most abundant parasitoid, followed by *E. allynii* and the pteromalid *Trichomalopsis subapterus*. Parasitism was high (up to 87% puparia parasitised in May), indicating that parasitism is of considerable importance in limiting *M. destructor* populations.

Relatively little information is available on predators. Barnes (1956) noted records of birds, ants and wireworms feeding on larvae and of adults being caught in spider webs, but there seem to have been few subsequent detailed studies.

Parasitoids as listed by the CPC (1999):

Aprostocetus zosimus, attacking: pupae, in Europe, New Zealand (intro)
Eupelmus allynii, attacking: pupae, in USA
Eupelmus microzonus, attacking: pupae, in Spain
Homoporus destructor, attacking: pupae, in Europe, USA
Macroneura vesicularis, attacking: pupae, in Europe, USA, New Zealand
Metaporus graminicola, attacking: pupae, in Spain
Pediobius acantha, attacking: pupae, in New Zealand (intro)
Pediobius epigonus, attacking: pupae, in UK, New Zealand (intro)
Pediobius metallicus, attacking: pupae, in Europe, USA (intro)
Platygaster heimalis, attacking: eggs, in Europe, USA, New Zealand (intro)
Platygaster pleuron, attacking: eggs, in Europe, Morocco
Platygaster zosine, attacking: eggs, in Europe, Kazakhstan, USA
Pseuderimerus luteus, attacking: pupae, in Spain
Pseudoderimus mayetiolae, attacking: pupae, in USA
Semiotellus nigripes, attacking: pupae, in Europe
Trichasis remulus, attacking: pupae, in Europe

Host-Plant Resistance

Plant breeding for resistance has been the main control strategy used against this pest in North America for many years, and includes the pioneering work by R H Painter and colleagues (Painter, 1951). Barnes (1956) reviewed this and other work.
At least 16 biotypes of *M. destructor* have been recognised (Patterson *et al.*, 1992, Clement *et al.*, 2003) and 25 genes conferring resistance have been identified in wheat (Dweikat *et al.*, 1994). Flanders in Reynolds (1999) states that "Selection pressure tends to be so strong with the few that survive that they evolve into new biotypes- groupings of flies that share the same genetic traits". In North America, one particular type, known as biotype "L", has developed resistance to every wheat variety currently available to growers (Reynolds, 1999). The H3 gene in certain varieties of wheat usually provides a high level of wheat resistance dominated by flies of biotype "GP", but, according to Clement *et al.* (2003) virulence in these populations of "GP" flies is starting to set in, and flies of biotypes "E" and "G" have long been known to be virulent to the H3 gene.

Chemical Control

Chemical control measures (based on the use of systemic or non-systemic insecticides) against ovipositing females, eggs and first-instar larvae, have been developed, but efficacy is variable and influenced by the time of application. Wilde *et al.* (2001) investigated the efficacy of three insecticides imadacloprid (Gaucho), thiamethoxam (Adage) and fipronil (Regent) as seed treatments for the control of insect pests on winter wheat. All three compounds effectively controlled autumn infestations of Hessian fly, but none were effective against the sole spring infestation that occurred. In field studies carried out in Spain, applications of cypermethrin, diazinon, dimethoate (0.1% a.i.) and chlorpyrifos (0.15% a.i.) at 500 litres/ha effectively controlled Hessian fly. Spring treatments with the insecticides were more effective than autumn treatments.

The use of an after-planting application of disulfoton (Disyston) for controlling the winter and spring generations of Hessian fly on wheat in Florida was studied by Hartman et al. (1992), and compared with the use of insecticides (phorate (Thimet), disulfoton) as an alternative to using resistant wheat cultivars. Although after-planting applications were found to reduce fly numbers, chemical treatments were not consistently linked to increases in grain yield. It was concluded that the use of systemic insecticides with susceptible cultivars did not compare favourably with the use of cultivars containing genetic sources of resistance to the cecidomyiid.
Lhaloui et al. (1992) report on a trail where carbofuran was applied, at 3 rates in furrows at planting or broadcast in spring, to fields of bread wheat (*Triticum aestivum*), durum wheat (*T. durum*) and barley in Morocco. Control of 1st and 2nd generations of Hessian fly and the barley stem gall midge (*M. hordei*) was assessed. Control in all crops improved with increasing concentration of carbofuran (from 0.36 to 1.12 a.i./ha) applied at planting. Control of the 1st and 2nd generations at the 1.12 a.i./ha was 65 and 62%, respectively, in bread wheat, 81% and erratic, respectively, in durum wheat and 67 and 51%, respectively, in barley. The yield increases in the 3 crops with the insecticide applied at planting were 29, 24 and 37%, respectively. Spring-time applications of carbofuran increased yield by 10, 12 and 17%, respectively. If both planting and spring-time applications were used yield increased by 42, 32 and 45%, respectively. Cost benefit analysis indicated that the applications at planting were economical on the wheats (>2.0 benefit/cost ratio), but the spring-time broadcast treatments were uneconomical and no treatments were economical on barley.

Pheromonal Control

Behavioural studies indicate that females attract males by releasing a sex pheromone from the ovipositor (McKay and Hatchett, 1984). Pheromone biosynthesis has been studied by Foster *et al.* (1991a) and the pheromone has been identified by Foster *et al.* (1991b). This research should lead to the use of this pheromone in monitoring and/or controlling this pest.

Integrated Pest Management

In North America, *M. destructor* attack on wheat has been limited mainly by plant breeding for host-plant resistance, combined with clean cultivation, good management of volunteer wheat and delayed sowing in autumn to escape infestation of overwintering crops.
Safe 'Fly-free'dates have been calculated, with sowing as soon as possible after these dates ensuring that young plants establish after the autumn generation of females has died out. The dates range from mid-September in the Canadian wheat belt and the northern USA to late October in southern USA.

Technical information for planning surveys

Protocol for targeted surveillance

Field infestations can be detected by visual inspection for symptoms, supported by dissection of samples of plants to establish the presence of larvae and/or puparia. Standard methods of assessment have been developed in the USA and have been used for many years (Barnes, 1956).

Survey methods have also been developed to determine the extent to which puparia are present during the winter in autumn-sown crops, volunteer plants and stubble (Barnes, 1956).

Adult activity may be monitored by light, suction, sticky or water traps, but mixed catches will make identification difficult at times. Behavioural studies indicate that females attract males by releasing a sex pheromone from the ovipositor. Pheromone biosynthesis has been researched by Foster *et al.* (1991). Their findings could lead to the use of the pheromone in monitoring and/or control.
Pheromone traps, when developed, will be much more selective and accurate. These traps should be concentrated in those areas where volunteer wheat occur, as well as within wheat crops where infested young plants are generally stunted, lacking an emergent leaf and with leaves which are shorter, broader and more erect than healthy plants. Older plants suspected of being infested with Hessian fly should be examined for the presence of larvae and puparia by stripping the leaf sheaths back to the base of the plant. Tillers may be weakened by larval feeding, and would show collapse.

Surveillance for Hessian fly could be combined with surveillance for a number of other target pests and diseases by focussing on an annual survey of wheat crops. Sampling biased toward plants exhibiting unusual symptoms or which appeared less vigorous, could be taken from preselected sites collected over the wheatbelt. Sub-samples could then be subjected to a range of available and cost-effective tests by AgWest Laboratory Testing Services.

However, even with substantial inputs, surveys would be most unlikely to detect Hessian fly quickly enough for any action to be taken.

Current distribution

General

M. destructor is present throughout western Europe, including Scandinavia, and extends into North Africa, the Middle East and eastwards into the CIS as far as Lake Baykal. In North America it occurs in Canada and in the USA from the Atlantic to the Pacific, and it is also well established in New Zealand's North and South Islands.

List of countries

Europe; widespread

Asia; Cyprus, Iraq, Israel, Kazakstan, Syria and Turkey

Africa; Algeria, Morocco and Tunisia

Western Hemisphere; Canada [widespread], USA [widespread]

Oceania; New Zealand

Potential distribution in Australia

Based on presence in other countries, it is likely that all of the Australian wheat belt with high (more than 450 mm p.a.) would offer an acceptable climate to Hessian fly.

Dispersal

Natural

In calm weather Hessian flies fly above the crop, and are then likely to be taken up in thermals. Adults have been recorded to disperse over distances of at least 8 km.

In areas of intensive cultivation or areas with a continuous presence (no more than 10 km gaps) of suitable native hosts, emerging adults may successfully disperse to adjacent grain fields. The wheat fields in Australia provide such continuity.

Human aided

The initial accidental introduction of this pest from Europe to North America was probably in straw carried by Hessian troops at the time of the Revolutionary War - hence its common name of 'Hessian fly'. Transport of diapausing larvae in wheat straw would certainly seem the most likely cause of long distance transfers and phytosanitary measures should be aimed at preventing this. It is also possible to transport flax-seed cocoons with grain and seed samples.

Risk mitigation protocols through development of quarantine zones and movement controls

National strategy for Australia

Hessian fly is considered a QPWA (Quarantine Pest WA) and does not occur anywhere in Australia.

Transport of diapausing larvae (flax-seeds) in wheat straw or with bulk grain or seed grain is the most likely source of long distance transfer and quarantine measures should be aimed at preventing this. As Hessian fly is not in Australia, this is an AQIS responsibility. To minimise the risk of entry, AQIS strictly regulates the importation of straw of wheat, barley and rye. Plants or plant parts of these cereals are also prohibited, except by permit, and if straw is used for packing it is removed and destroyed by quarantine before the goods are released. Straw bedding, in special containers, used to transport animals to Australia is removed and destroyed before the container is released from quarantine (Commonwealth Department of Health, 1980). The obvious sources of straw are thus well covered by current barrier inspection and treatment. Fragments of straw in personal or household luggage remain a possible risk area which is obviously very difficult to counteract.

If an increase in barrier activity was thought desirable, then farmers and farm workers from areas where the fly is endemic should be especially targeted (Brown, 1997).

There is pressure on AQIS from those with interests in animal production to allow the importation of feed grains for general use after a suitable treatment. Wheat, particularly lower grade wheat would carry a significant risk of introducing viable pupae should treatment be imperfect (Brown, 1997).

Staff involved with wheat production should be made aware of the signs of infested wheat and the methods for observing the feeding larvae.

There are no further skills required at present, but there could be a future requirement for identification and trapping skills (Brown, 1997).

Phytosanitary measures elsewhere

In the USA, hydrogen phosphide fumigation has been shown to kill *M. destructor* puparia in compressed hay for export (Yokoyama *et al.*, 1994b; Yokoyama *et al.*, 1994a). Heat treatment may also be used and research in Canada indicates that pupae mixed with chopped hay are all killed when maintained at 58°C for at least 3 minutes (Sokhansanj *et al.*, 1993).

Eradication

Feasibility

Eradication would be difficult to achieve. Introduction of Hessian fly would take place by the pupal stage. Adults are capable of significant flights which would distribute the insect quite widely before detection is likely. Establishment will depend on the ability of the insect to survive the environment over summer in stubbles. Treatment of large areas of stubble and volunteer wheat, physically or by the use of insecticides, would be unlikely to prevent a proportion of flies hatching and migrating elsewhere (Brown, 1997). If surveillance clearly and accurately establishes the extent of the infestation, and the infestation is found to be present in an isolated area, it may be possible to eradicate the population in a cost effective way.

Eradication Program

If pupae are detected before any distribution of the infested product, normal quarantine procedures should be followed. As mentioned before it is unlikely that eradication would be achieved after larvae or pupae are detected in-field. If a preliminary survey has indicated that no more than one localised infestation is present, and that no adults have emerged from that area (check for empty puparial cases), then in that isolated area eradication may be achieved if a "scorched earth" policy is followed. Remove all possible host plant material (dry or living) within a 5m radius of the affected area and dispose through burning. Keep the area within a 10m radius host plant free by spraying with a selective herbicide. Continue to keep the area bare of any host plants for at least 18 months. If a thorough surveillance campaign (the extent of which to be based on a Cost/Benefit analysis) reveals more than one further point infestations indicated by either eggs (unlikely to see them) larvae or pupae or any clear signs of a emerging or previous Hessian fly infestation located further than 500m away from the first find, then the eradication campaign should probably be terminated.

Technical debrief and analysis for stand down

General

When an incursion response and related cost sharing activities are terminated, certain generic procedures need to be followed. These are described in Merriman and McKirdy (2005). The debriefing report would vary depending on the reasons for stand down, and will need to reflect the changed status of action. If the decision is that Hessian fly has irreversibly established, then control and containment options should be investigated.

Research on control and containment options

Brown (1997) suggests the examination of resistance in WA wheats (that should apply to all of Australian wheat) by forging a suitable alliance with a partner, preferably with a similar environment. New Zealand is suitably infested. Research should also concentrate on rotation and the grazing or destruction of volunteer wheat in paddocks returning to pasture. Testing other breeding material for resistance should also be investigated. Additionally, acquisition of the range of insecticide options (also to slow spread of the fly and maintain production) should be undertaken and kept updated since there would be heavy reliance on them initially (Brown, 1997).

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