Executive summary: The Hessian fly *Mayetiola destructor* is an emerging economic threat to wheat grown in the inland Pacific Northwest. While screening for Hessian fly for wheat improvement has been funded by the Washington growers for several years (Pumphrey, Bosque-Pérez, & Rashed), it is critical to have new research on insect management practices for Hessian fly in Washington state based on its emergence as a new economic threat. The overall goal of this project is to increase the profitability and sustainability of Washington wheat-based cropping systems via evidence-based insect management decisions. Our specific goal is to provide new biological and ecological information on this important insect pest that will lead to improved Hessian fly management. We will accomplish this (1) providing a comprehensive review of known environmental factors contributing to Hessian fly outbreaks in the inland Northwest through surveys and collaboration with scientists, growers, and extension specialists and (2) focus specifically on genetic virulence of Hessian fly to new wheat germplasm development in several new and current genetic lines including Louise to precise recommendations for management.

Accomplishments since July 1, 2019 when this project was funded. Entomology M.S. student, Daniel Gallegos has sampled Hessian Fly from many locations including variety trial test sites in eastern Washington. Sampling has been done by hand sampling for pupae and with pheromone traps in collaboration with Ric Wesselman and Dan Maxfield from Syngenta. Sampling data is being analyzed and compared with sampling data from the summers of 2019 and 2020.

Daniel has set up a Hessian Fly wheat screening program at WSU in the older part of the CAHNRS Plant Growth Facility modeled on the facility at the University of Idaho so that we can increase the capacity of genetic lines screened.

Daniel has drafted a “What Fly is in my Grain; a visual key to identifying Hessian fly and look-alikes in PNW grains” that will be submitted for peer review in early 2021. In addition, in collaboration with Tavin Schneider (MS student in Pumphrey lab) and Samuel Prather (PhD student in Pumphrey lab), we have drafted an extension bulletin that will be submitted for peer review titled “Managing Hessian fly (*Mayetiola destructor* Say) in Washington and the greater PNW in early 2021. This extension bulletin specifically describes and provides information on management practices to control Hessian Fly that are currently available.
Impact:
Hessian fly resistance in the inland Northwest is valued from $45 to $104 per acre based on a study led by Dick Smiley at Oregon State University. Applying these values, a very conservative Washington statewide loss estimate without resistant varieties is over $10,000,000 per year, not including lower-level losses to winter wheat crops. Hessian fly infestations are widespread through the state every year and sampling with pheromone traps produces hundreds to thousands of flies at all locations sampled.

Hessian fly is largely controlled through genetic resistance maintained by expert screening of germplasm and by farmer adoption of resistant varieties. Typical insect pest management regimens for Hessian fly rely on prevention measures. From 2016-2018, we’ve seen heavy infestations at more sites, with heavier pressure than has been seen in over ten years or more. While newly released WSU varieties Glee, Alum, Chet, Seahawk, Tekoa, and Ryan are Hessian fly resistant due to the Hessian fly screening program funded by Washington growers, this work not only needs to continue, but the insect can and does adapt to resistant varieties. Therefore, additional research on Hessian fly population genetics and Hessian fly virulence is critical for successful management now and in the future.

No measurable impact has yet been shown in this project in the most recent funding cycle as we are setting up the foundational work for Hessian fly screening at WSU as we show in our output and outcomes table below.

Outputs and Outcomes:

A. Progress:

<table>
<thead>
<tr>
<th>Objective</th>
<th>Deliverable</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Comprehensive review of PNW Hessian fly biology</td>
<td>Published literature review of updated Hessian Fly biology; new extension bulletin published.</td>
<td>Literature has been reviewed; manuscript will be written in summer 2021; Visual key to identification of HF and look-alikes drafted</td>
</tr>
<tr>
<td>2: Field collections of HF; screen against varieties in greenhouse</td>
<td>MS grad student; HF screening at UI and at WSU (new).</td>
<td>HF screening at WSU in place. Screening has started and will continue using HF pupae collected in summer 2020 and from Univ of Idaho HF colonies.</td>
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</table>

B. Timeline:

<table>
<thead>
<tr>
<th>Objective</th>
<th>Timeline</th>
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</thead>
<tbody>
<tr>
<td>1: Comprehensive review of PNW Hessian fly biology</td>
<td>Summer 2021 with extension bulletin submitted to peer review by March 1, 2020</td>
</tr>
<tr>
<td>2: Field collections of HF; screen against varieties in greenhouse</td>
<td>Jan-June HF screening at WSU and UI; Wheat Life article after August 2021</td>
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D. Communication:
<table>
<thead>
<tr>
<th>Objective</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Comprehensive review of PNW Hessian fly biology</td>
<td>Presentations at virtual Field Days; peer reviewed extension bulletin</td>
</tr>
<tr>
<td>2: Field collections of HF; screen against varieties in greenhouse</td>
<td>Presentations at Field Days; peer reviewed scientific publication to be prepared; article for Wheat Life</td>
</tr>
</tbody>
</table>
What the Fly is in my Grain?

A visual key to identifying Hessian fly and look-alikes in PNW grains
Hessian fly (Mayetiola destructor)

Period of infestation

- May
- June
- July
- August

Damage

- Attacks wheat

Control

- Resistant wheat
- Host plant eradication
- Crop rotation
- Management of stubble
- Chemical control

(c) Scott Bauer, USDA Agricultural Research Service

Resistant vs. susceptible wheat lines under heavy Hessian fly pressure (Susceptible line is center, resistant lines are on both sides). Photo (c) Samuel Prather

(c) Dennis Schotzko, University of Idaho

(c) Samuel Prather
Wheat midge (Sitodiplosis mosellana)

**Period of infestation**

- July
- June
- August

**Damage**

- Attacks wheat
- Each larva is capable of reducing grain size by 30-50%

**Control**

- Early planting
- Crop rotation
- Resistant wheat
- Biological control
- Chemical control
Asian rice gall midge (Orseolia oryzae)

**Period of infestation**
- July
- June
- August

**Damage**
- Attacks rice - one of the worst pests of rice

**Control**
- Resistant wheat
- Host plant eradication
- Crop rotation
- Biological control

Source unknown
Wheat stem maggot (Mermomyza spp.)

Period of infestation
May
June
July
August

Damage
• Attacks wheat - more severe in southern US

Control
• Chemical control
Wheat stem sawfly (Cephus cinctus Norton)

Period of infestation

May

June

July

Damage

• Attacks wheat

Control

• Planting trap crops
• Planting wheat in large blocks
• Resistant wheat
Wheat strawworm (*Harmolita grandis*)

**Period of infestation**

- March
- February

**Damage**

- Attacks wheat - not a severe pest in PNW

**Control**

- Management of stubble
Managing Hessian fly (*Mayetiola destructor* (Say)) in Washington and the greater PNW

Authors: Tavin Schneider, Daniel Gallegos, Samuel Prather, Michael Pumphrey, Laura Lavine

**Introduction**

Hessian fly (*Mayetiola destructor* (Say)) is one of the most damaging insect pests of wheat around the world. Hessian flies originated in Southwest Asia, in the same regions that many of today’s economically important cereal crops did (Stuart et al., 2007). In the United States, Hessian fly damage amounts to over $100 million annually. In Washington state, studies have found that losses in susceptible varieties can reduce profits by $40-$100/ acre (Smiley et al., 2004; Bassi et al., 2019).

**Fly Lifecycle**

The Hessian fly inflicts its damage through larval feeding on basal leaf tissue in wheat and related species. The lifecycle begins when female flies lay tiny, orange eggs on the upper surface of a young leaf (Figure 5). Three to four days after being laid, the eggs hatch into small, red larvae (Stuart et al., 2007). Larvae crawl down the inside of the leaf and into the crown of the plant or leaf nodes, where they use their mandibles to probe for feeding sites. When the insect feeds on the plant, saliva interacts with the wheat triggering the wheat to grow new tissues that will feed the growing larva and take nutrients away from the wheat itself. If the

**Figure 1:** Hessian fly puparia in the crowns of potted wheat seedlings. Heavy infestation will split the stems of young plants, leading to lodging. Photo by Tavin Schneider.
wheat is susceptible to the Hessian fly, the larvae will feed for the next 10-20 days, providing the only sustenance during the pest’s lifetime (Figure 4, 5; Stewart et al., 2007; Harris et al., 2010).

Figure 2: A full grown fly on the tip of a wheat leaf. Photo by Scott Bauer, USDA ARS.

Figure 3: Resistant vs. susceptible wheat lines under heavy Hessian fly pressure (Susceptible line is center, resistant lines are on both sides). Photo by Samuel Prather

Figure 4: Multiple fly larva (small translucent white granules) inside a susceptible wheat tiller. Photo by Samuel Prather
Figure 5: Complete Hessian fly life cycle, from egg laying to adult emergence. Adult female lays eggs between grooves of leaves of young plants (top), from which red larvae hatch and crawl down leaf to stem (right). As larvae grow and mature, they change in color from red to translucent white. If infestation is successful, larvae feed during first and second instars then transition to ‘flaxseed’ pupae near the crown (bottom). Symptoms of infestation include dead or malformed tillers, lodged stems, and a blue tint in leaves and stem (bottom). Pupae can overwinter even in wheat stubble after harvest, then emerge under optimal conditions to repeat the cycle (left and top left). Graphic by Daniel Gallegos.

After the feeding period, larvae enter a state referred to as flaxseed or puparia (Schmid et al., 2018). During this stage, the larvae are encased by a shiny, brown cover that protects
them while they mature into adult flies (Figures 1 and 5). Hessian flies spend the winter and hot, dry periods during the summer in the pupal stage, where they are protected within plant material. Depending on weather conditions, either flies will emerge from the flaxseed in the same year of being hatched, or they will overwinter within the flaxseed in wheat stubble. Hessian flies rely on high humidity levels and temperatures around 50–79°F, with an optimum temperature of 70°F to survive (Flanders et al., 2013; Schmid et al., 2018). In the Pacific Northwest, it is more common for spring infestation to occur due to predominantly spring rain patterns, after over-wintering pupae emerge from flaxseeds, mate, and lay eggs on wheat seedlings. However, infestation and feeding can occur whenever green tissue is available and weather conditions are favorable, which is why most states experience multiple infestation events each year (Smiley et al., 2004; Flanders et al., 2013). Field observations in Washington in recent years have demonstrated potential for fall infestation of winter wheat planted during periods of fall precipitation with suitable temperatures.

**Plant Damage and Crop Loss**

Hessian fly larvae feeding on plant tissue results in long-term effects. Initial feeding damage is seen as darkened leaf tissue, stunted growth, and tillers with bent stems that lie on the ground (Figure 1 and 3). Long-term effects are seen through delayed and variable maturity, yield loss, lodging, and test weight reductions, which can translate to lower grain grades and dockages in elevator prices. Intense feeding can result in the death of seedlings and complete crop loss. Many infected plants will try to compensate for infestation by producing secondary tillers, which may also appear weak and dark green. If the secondary tiller avoids infestation, the plant continues to grow and stops supporting the primary tiller. Reduced wheat
competition may also lead to problematic weed management, and lodging and grain shriveling may increase volunteer seeding.

**Hessian fly Control**

Integrated pest management is required for Hessian fly management nationwide and in Washington state. Control methods include resistant wheat varieties, fly-free dates, host plant removal, and chemical control used in combination.

**Hessian fly Resistance Genes**

Resistant cultivars of wheat play a major role in mitigating the damage of Hessian fly and are an environmentally sustainable and cost-effective solution. In addition, the drawbacks and requirements associated with other control methods allow resistance genes to be among the most efficacious control option. When compatible with fly biotypes, Hessian fly resistance (HFR) genes inhibit larvae from establishing feeding sites on wheat and other host species (Figure 6). The presence of most HFR genes does not have a negative effect on wheat yields and quality parameters, so they are an attractive option to producers.

To date, 37 resistance genes have been identified; they are labeled as “H”, for Hessian fly, followed by a number or other designation, including H1-H36 and Hdic. (Zhao et al., 2020). Many have been successfully incorporated into wheat varieties, making resistant wheat relatively easy to acquire. Hessian fly can overcome heavily used resistance genes 7-10 years after their introduction if varieties with the same HFR gene are grown year after year (Ratcliffe et al., 1994). The development of new cultivars that are effective against this pest is a continuous challenge for wheat breeders. Rotation of resistance genes in wheat varieties along
with an integrated pest management program designed for Hessian fly is vital to keep Hessian fly populations from reaching economic injury levels.

Figure 6: The interactions between Hessian fly effectors and wheat resistance genes. For all scenarios, it is possible for both the Hessian fly and the wheat plant to produce many versions of effectors and resistance proteins, respectively. Only one matching effector/resistance gene pair is needed to trigger resistance in the plant (green box). Without a matching pair, the larvae will be able to establish a feeding site (red boxes). Figure by Tavin Schneider.

**Fly-free Dates:**

The most basic control method in parts of the US involves adherence to fly-free dates, which are aimed at minimizing the number of larvae that infest in the fall on winter wheat crops. These dates depend on air temperatures being cool enough and humidity levels being low enough to limit Hessian fly activity. Fly-free dates are traditional options for control of fall infestation in winter wheat but have not proven to be as effective of a control measure for spring wheat. Fly-free dates are not commonly practiced in the PNW because fall infestation levels are normally minimal and cold weather damage to wheat is a much greater concern.
Following recommended fly-free dates may reduce infestation risks from other pathogens, but the delayed planting can lead to increased cold-weather damage of wheat seedlings.

**Host Plant Removal:**

Wheat is the main host for Hessian fly, but barley, triticale, durum, and rye can also be hosts (Harris et al., 2010). Removal of the host plant, by crop rotation, destruction of stubble, and/or volunteer plant eradication, is another widely recommended method for reducing Hessian fly infestation severity. Wild grass families including the relatives of wheatgrasses (*Elymus*), wildryes (*Elymus*), and barleys (*Hordeum*) have been found to host the insect as well (Ziess et al., 1993).

**Crop Rotation:**

Rotation of crops allows for a disturbance in the host plant cycle by restricting susceptible grasses from being planted in the same field for consecutive years. Preventing wheat from growing on wheat stubble dramatically reduces the availability of plants for female flies to lay their eggs on. However, neighboring fields, volunteer plants, and other grass species can harbor and spread the insects. Schmid et al. (2018) noted that flies could be distributed by wind over distances of a few kilometers, which enforces the notion that fly control is a community-wide effort.

**Management of stubble:**

Managing the stubble in neighboring fields and control of volunteer species around field borders can aid in the reduction of the number of insects present. Studies have found that Hessian fly infestation has become much more intense since the widespread adoption of no-till farming, which allows fly pupa to overwinter in stubble (Flanders et al., 2013). Elimination of
stubble through fall tillage has been found to reduce fly emergence by up to 70%. One downside to this approach is that intense plowing has negative impacts on soil health, erosion, and soil water conservation. Burning of stubble is ineffective for Hessian fly control because the flaxseed resides below soil surface levels, where it is protected from fire damage (Flanders et al., 2013). Removal of straw through baling is not advised because it has the potential to transfer Hessian flies from one area to another. Grass hay and wheat straw that is destined for export to Asian countries is treated with fumigation before shipping in order to prevent the spread of these insects (Yokoyama, 2011). Although mainly used for shipping efficiency, hay compression can also reduce survival of Hessian fly puparia (Yokoyama, 2011).

**Chemical Control:**

Insecticides, in the form of seed treatments and foliar application, can serve as a control method for fly infestation with moderate to low efficacy. Seed treatments protect against feeding insects for 1-2 months after planting (Howell et al., 2017; Schmid et al., 2018). The most popular choice for seed treatments are neonicotinoids, which are favored due to their long-lasting residuals and low application rates. Neonicotinoid seed treatment options include clothianidin, imidaclorpid, and thiamethoxam. Recent discoveries in fungal-based seed treatments may provide another option for control of stem-feeding insects, such as Hessian fly (Jaronoski and Reddy, 2018).

Foliar insecticides have minimal fly control, difficult application timing, negative effects on beneficial insects, and can be expensive, making them a less appealing management option. Foliar applied insecticides may be used along with or in place of seed treatments but have serious limitations because of the Hessian fly life cycle. Sprays must be applied when eggs are
present on leaf surfaces or before larvae establish feeding sites within the plant, making timing of the spray critical (Flanders et al., 2013). The microscopic size of Hessian fly eggs makes them challenging to detect, which results in timing the applications around the most susceptible life stage very difficult. Additionally, adult flies do not all emerge at the same time, but rather throughout the wheat growing season, making damage ongoing. A single application of insecticides may reduce total fly populations by hindering one wave of hatchings, but one application of foliar insecticide does not provide control of populations throughout the entire growing season. Precipitation, wind, and temperature all affect field access and insecticide efficacy and thus may prevent farmers from making precisely timed applications.

**Hessian fly and Washington Wheat**

There is very little published research about Hessian flies in Washington, which furthers the need for identification of current resistance genes, implementation of additional resistance genes, and a modern understanding of the Hessian fly populations within the state and surrounding areas.

**History and distribution:**

The first record of the Hessian fly in Washington is disputed, with one report claiming Lewisville, Clarke County, Washington as the site of first detection of the fly in 1899, while Benson 1918 claimed that “the dreaded Hessian fly made its appearance in the state this year,” 1918, in Kent, King County, Washington (Cordley, 1900; Benson, 1918). In either case, by 1925 the fly had caused significant damage to wheat fields throughout western Washington, occurring from the Columbia River to near the southern end of the Puget Sound district in King County (Benson, 1918; Rockwood and Reeher, 1933). This was at a time when Hessian fly was
causing an average annual loss of 10% to wheat in the United States, with particularly destructive seasons resulting in losses in excess of 25% to 50% (Benson, 1918).

While the Hessian fly was known to occur throughout western Washington, ranging from the Columbia River to the Canadian border, by 1932, it was not known to occur in eastern Washington until its discovery there in 1977 (Rockwood and Reeher, 1933; Pike et al., 1978). The reason for this is twofold: virtually no records at all exist on the fly in Washington state from 1933 to 1978; and the common conception was that the fly was not as detrimental in Washington as it was in other areas of the United States during this time period (Rockwood and Reeher, 1933; Pike et al., 1978).

**Reaction to resistant wheat:**

A 1983 publication remains the most comprehensive overview of Hessian fly in Washington state (Pike et al., 1983). It includes the most recent distribution map of the fly, although an updated distribution map is needed.
Previous studies in the PNW have focused on characterizing Hessian fly populations by region, but more recent research has favored classification of flies based on their ability to overcome resistant wheat varieties (Ratcliffe et al., 2009; Carter et al., 2014). Virulence, or the ability of a fly to overcome a resistance gene and thus infect a host, can often be established in fly populations within ten years of deploying wheat cultivars carrying resistance genes in a given area. When the same wheat cultivars carrying resistance genes are grown on more acres every year, fly virulence is expected to increase and with it, increased economic injury.

In Washington, most genetic resistance is held within spring wheat cultivars since spring wheat is more often infested than winter wheat (Smiley et al., 2004; Table 1). However, this does not
mean that winter wheat is not infected by Hessian fly and that management can be disregarded. In fact, Pike et al. (1983) noted the heavy fall infestation was documented in XXXX area. Young wheat seedlings are most susceptible to infection, and in winter wheat, this occurs in the fall. Damaging levels of fly emergence in the fall is rare, because the dry weather and cool temperatures limit fly emergence. Irrigated winter wheat acres or years with unusually high early fall precipitation represent a higher risk. In the spring, when flies emerge from the flaxseeds, winter wheat has established multiple nodes and tillers. Stem nodes prevent movement of larvae into the basal feeding areas, and multiple tillers allow for infestation severity to be reduced. Secondary and tertiary tillers can be infected, but the yield loss isn’t normally large enough to see benefits from management strategies.

What else can be done?

Hessian fly should be managed in winter wheat to reduce the infestation potential in spring wheat. Winter wheat is grown on about 80% of all wheat acreage in Washington in any given year, therefore it is vital to integrate resistance mechanisms to avoid crop loss and to reduce spring infestation rates.

Table 1: Currently available Hessian fly resistant wheat varieties.

<table>
<thead>
<tr>
<th>Class</th>
<th>Name</th>
</tr>
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<tbody>
<tr>
<td>Hard Red Spring</td>
<td>Alum SY Selway</td>
</tr>
<tr>
<td></td>
<td>Chet WB 9668</td>
</tr>
<tr>
<td></td>
<td>Glee Net CL+</td>
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<tr>
<td></td>
<td>Hollis Kelse</td>
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<tr>
<td></td>
<td>AP Renegade</td>
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<tr>
<td>Hard White Spring</td>
<td>WB 7202 CLP</td>
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<tr>
<td>Soft White Spring</td>
<td>Diva Whit</td>
</tr>
<tr>
<td></td>
<td>Ryan WB 1035CL+</td>
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<tr>
<td></td>
<td>Seahawk Louise</td>
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<td></td>
<td>Tekoa WB 6341</td>
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<tr>
<td></td>
<td>WB 6121</td>
</tr>
<tr>
<td>Winter Club</td>
<td>ARS Castella</td>
</tr>
<tr>
<td>Hard Red Winter</td>
<td>Scorpio</td>
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</table>

Spring club wheat, a small market class of spring wheat, also lacks resistance in currently available varieties, which is one of the growers’ deterrents for growing this class of wheat (Allen, 2014). Current winter wheat
breeders at WSU are working to incorporate resistance genes into the germplasm. Only a few resistant winter varieties are available now, but with focused efforts, more are expected to be released in the future.

**Summary:**

- Spring wheat is the main host for this pest, but management in winter wheat can reduce spring infestation levels.
- Hessian flies can be observed on wheat leaves as tiny orange eggs, or in the crown of wheat plants as white larvae or hard brown puparia.
- The most effective ways to manage for Hessian fly damage include removing susceptible host plants, utilizing seed treatments, and planting resistant cultivars. A multi-faceted approach is highly recommended.
  - Seed treatment options for fly control include clothianidin, imidacloprid, and thiamethoxam.
  - Several Hessian fly resistant genes have been deployed in spring wheat varieties.
  - For more information please visit [smallgrains.wsu.edu](http://smallgrains.wsu.edu), where individual cultivar responses to Hessian fly can be found using the Variety Selection Tool.
- For more information:
  - The Pacific Northwest Conservation Tillage Handbook discusses Hessian fly management in reduced or no-till systems.
  - The Pacific Northwest Pest Management Handbook’s section on Hessian fly describes different pesticide options.
○ WSU’s Variety Selection Tool is useful for identifying resistant cultivars in different growing regions.

○ Extension documents from many other states go into further detail on management, identification, and economic assessments.

References:


Yokoyama, V. (2011). Approved quarantine treatment for Hessian fly (Diptera: Cecidomyiidae) in large-size hay bales and Hessian fly and Cereal Leaf Beetle (Coleoptera: Chrysomelidae)
control by bale compression. *Journal of Economic Entomology*, 104(3), 792-798, 

https://ntserver1.wsulibs.wsu.edu:2137/10.1603/EC10339