Evaluation of the need for continued quarantine of foreign strains of the wheat flag smut pathogen, *Urocystis agropyri* (Preuss) Schroet.

Pest-Specific Plant Pest Risk Analysis

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Executive Summary

A. Background

The Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA) conducted a plant pest risk assessment to evaluate the potential risks associated with changing the quarantine status of foreign strains of the fungus *Urocystis agropyri* (Preuss) Schroet. (=*Urocystis tritici* Koernicke), the causal agent of the flag smut disease of wheat. The quarantine was established in 1919 to prohibit the introduction of *U. agropyri* contaminating wheat seed or other plant parts originating from countries that have reported flag smut disease of wheat. At the time that the quarantine was established, wheat growers did not have the option to use other disease control strategies such as resistant varieties of wheat and highly effective seed treatments. Since that time, scientists and growers have gained a greater understanding of effective, practical measures that can mitigate flag smut.

The flag smut quarantine (Title 7, Code of Federal Regulations, Part 319.59) prohibits movement, from countries where flag smut is reported, of commodity wheat seed and grain, and commodity shipments of grains other than wheat when wheat seed is found admixed with the crop (as occurs in crop rotation systems where volunteer wheat plants occur among subsequent crops). APHIS has received requests from scientists and grain traders to modify or eliminate the quarantine in the light of current agricultural practices that mitigate the potential plant pest risks presented by all strains of *U. agropyri* and questions as to whether foreign strains pose any greater risk than those already present in the United States.

B. Brief Description of the Pest and Its Impact

In 1868, flag smut was first described in Australian wheat fields (McAlpine, 1910). It was not until 1919 that flag smut was first reported in the United States, in Illinois and Indiana (Humphrey and Johnson, 1919). Based on the circumstantial evidence that the disease occurred in Australia and appeared in the United States contemporaneously with wheat shipments from Australia to the U. S., officials concluded that the pathogen may have entered the United States in those wheat shipments (Tisdale, *et al.*, 1923). Consequently, in August of 1919, the USDA promulgated Federal Quarantine No. 39, which prohibited importation of raw, unprocessed cereal grain from countries affected by flag smut and take-all disease. Quarantine 39 was superceded in 1926 by Quarantine 59 which removed restrictions regarding take-all but prohibited the "importation into the United States . . . of all species and varieties of wheat and wheat products, except such as have been so milled or so processed as to destroy all flag smut spores." By 1932, flag smut had essentially been eradicated from the Midwestern United States through the use of resistant varieties, seed treatments, and the implementation of quarantines as a precaution to protect domestic wheat production from potentially damaging foreign strains of the flag smut pathogen. The quarantine prohibited the importation of wheat seeds or other plant parts from countries where flag smut was known to occur. Agricultural officials considered a domestic quarantine of wheat grown in Illinois and Indiana, but decided against such measures.

Flag smut of wheat occurs in the United States and elsewhere in the world where autumn-sown wheat is grown in regions with dry summers and mild winter temperatures. These conditions occur in some

limited areas of the northwestern United States as well as parts of Australia, South America, Asia, and Europe. Flag smut does not occur in spring-sown wheat even when highly susceptible cultivars are grown (Line, 1998), due to current agronomic practices in the United States.

The disease cycle begins in the autumn. Teliospores of the fungus that are present either in the soil or as a contaminant of seed germinate to produce an infectious spore, the sporidium. These sporidia directly infect wheat seedlings prior to emergence. Mild temperatures between 10 and 20ºC and soil moisture conditions that are optimum for seed germination and seedling emergence favor infection of wheat. The fungus overwinters as a mycelium within the seedling. In spring, the mycelium systemically invades the host and eventually produces teliospores within the upper portions of host plants, particularly the flag leaf, but not in the developing seed. The teliospores are long-lived (up to 3 years in the soil and 4 years as contaminants of seed) and are spread by wind. Contamination of seed and soil by wind-blown spores and from spores shed during harvest is the source of inoculum for subsequent crops. Pathotypes that can infect a range of grass species and wheat exist but there is no clear description available of the races and their host specificity. U. *agropyri* has been reported to infect wheat, barley and a number of other grasses. However, isolates show marked host specialization and most wheat isolates will not infect other grass species (Mordue and Waller, 1981).

Affected plants within the growing crop are often severely stunted and plants may tiller excessively. Major symptoms include long grayish-black streaks on leaf blades, especially the flag leaf, and on leaf sheaths. In some cases, the head fails to emerge. Where heads do emerge the glumes and necks may be striped. Throughout the world's wheat growing regions today, flag smut is not as damaging as it once was reported. Flag smut is no longer a major problem in the United States. Where flag smut occurs, losses are largely controlled through the use of resistant wheat cultivars, fungicidal seed treatments, and crop rotation.

Like other plant diseases, the control of flag smut can be achieved through a variety of strategies or disease control measures which aim to influence one or more of the three components of the disease triangle: host, pathogen and environment. Disease control measures can be classed in accordance with the four basic principles of disease prevention they exemplify: (1) exclusion and (2) eradication; which involve control of the pathogen; and (3) protection (treating a healthy plant before it becomes diseased) and (4) development of resistance; which deal with the plant's defense mechanisms (Pscheidt, 1997).

C. Scope of Assessment and Summary Conclusions

APHIS concludes that categorization of these foreign strains of *U. agropyri* as quarantine pests is not supported by the available biological/ scientific information, international agreements on criteria for quarantine pests, the United States Acts cited in Section I.B., and existing USDA policies regarding quarantine pests. It appears that the circumstances under which the quarantine was established in 1919 no longer apply. Therefore, we conclude and we recommend that APHIS discontinue the quarantine of foreign strains of *U. agropyri*. As part of the pest risk assessment, APHIS has considered the following:

1. Although the first reports of flag smut in the United States were from the Midwest region, flag smut has not been reported in the literature from these locations since 1934 (Line, 1998).

2. Because of temperature and moisture requirements of the pathogen, flag smut occurs in the United States only on wheat in the Pacific Northwest when seed is sown in late August and early September at depths of more than 2 inches (Line, 1998).

3. The incidence and severity of flag smut on wheat grown in the United States has declined as scientists and growers developed reliable strategies to minimize the impact of this disease.

4. Currently, effective flag smut control strategies include the use of (a) resistant wheat varieties, (b) chemical treatments to eliminate viable spores of the pathogen on seeds or in the soil, and (c) crop rotation and other agronomic practices.

5. There is no evidence in the scientific literature which unequivocally confirms that foreign strains of *U. agropyri* pose a greater risk than domestic strains to wheat production in the United States. Current control strategies should be effective in limiting the impact of foreign strains of *U. agropyri.* In fact, research comparing the morphological, biological, and molecular characteristics of Australian and U.S. isolates suggested there were few if any differences (Brown, *et al.*, 1994).

6. The fungus is unlikely to be eradicated since once established it can survive as persistent teliospores within spore balls, both in the soil and also as a seed contaminant for up to 3 or 4 years, respectively (Griffiths, 1924; Sattar and Hafiz, 1952).

D. Likely consequences of discontinuing quarantine by APHIS

Plant pest risk: A discontinuation of the quarantine appears to pose little, if any, increased plant pest risk for domestic wheat production. The limited distribution of flag smut disease in the United States and its lack of spread despite being present for decades with no domestic quarantines provides circumstantial evidence that suitable environments are restricted. Earlier occurrences of the disease in the central United States were attributed to a combination of factors: (1) use of highly susceptible cultivars, (2) inadequate crop rotation, (3) cultural practices, and (4) lack of satisfactory seed treatments. This combination led to an inoculum build-up sufficient for disease expression. Current agricultural practices would not allow such a build-up to occur (Line, 1998).

The flag smut quarantine was originally promulgated based on the possibility that foreign strains of the fungus, more virulent than those already in the United States, might exist in flag smut countries and should be excluded. However, as stated in Line (1998), "Evidence for the existence of pathogenic races of *U. agropyri* is based on reports that flag smut collections from different regions of the world have different virulences. However, some of the conclusions are based on nonreplicated data consisting of a small population of plants compared under greenhouse conditions in different years, and the development of new pathogenic races has not been confirmed. In regions where flag smut is endemic, new races of the pathogen have not been detected even with the selection pressure via the use of resistant cultivars for decades." A recent research study conducted in Australia and presented to APHIS (Brown, *et al.*, 1994) concluded genetic and cytological features of *U. agropyri* spores make genetic recombination between different strains extremely rare, hence the "fungus should be genetically very uniform with little opportunity of different races within a given population."

Pest risk encompasses not only the likelihood of a hazardous event occurring, but also the consequences of such an event. Given the cultural practices in use today and the control measures available, it seems unlikely that flag smut would ever become a major disease of wheat in the United States. The economic impact of the disease where it occurs in the Pacific Northwest is virtually nil and at times the disease is difficult to find (Line, 1998; MacLatchy, 1995). A number of plant pathologists contend that the quarantine against foreign strains of *U. agropyri* is not necessary to protect the wheat grown in the United States. This view was expressed by scientific experts at the 1997 International Workshop on Smuts and Bunts that was co-sponsored by APHIS and NAPPO (North American Plant Protection Organization). Relevant scientific literature suggests that introduction of foreign strains of *U. agropyri* would not trigger any significant environmental impacts. Non-wheat strains of the fungus are reported from 36 States and seed treatments effective against *U. agropyri* are already in use on wheat for control of this and other pathogens. Two recent plant pest risk assessments by Canada (MacLatchy, 1995) and the United Kingdom (Sansford, 1998) concluded that the pest risk posed by *U. agropyri* did not warrant specific quarantine measures.

Impacts on Trade: The current quarantine restricts the importation of crops that are grown in rotation with wheat, such as oats grown in Australia. Domestic production of oats has declined in recent years, and a discontinuation of the quarantine would permit the importation of oats from Australia or any of the 33 other quarantined countries to meet the needs of producers of animal feeds. *U. agropyri* is listed as a prohibited pest by several countries, including Brazil, Canada, Kenya, Oman, South Africa, Tanzania, Turkey, Uganda and Venezuela. Since the United States does not have, nor has it ever had any domestic flag smut quarantines, relaxation of our external quarantine would likely not have any impact on trading partners' willingness to accept U.S. grain. Also, unlike other bunts and smuts of wheat (*e.g.*, Karnal bunt), the quality of harvested grain both for feed and flour is unaffected by *U. agropyri* since the grain does not become infected.

Impacts on Treaty Obligations: Under the provisions of the General Agreement on Tariffs and Trade (GATT), phytosanitary trade restrictions are permissible if they are justified by scientific evidence. In addition, GATT stipulates that any restrictions of pest introductions via importation must be consistent with domestic restrictions on the movement of the pest. There are no domestic restrictions on the movement of wheat seeds or plant parts from regions of the country where flag smut occurs.

E. Recommendation:

Evidence suggests that the *Urocystis agropyri* organism which causes flag smut disease of wheat was unintentionally introduced into the United States with wheat seed imported from Australia. Additional research has demonstrated that comparative inoculations of both susceptible and resistant wheat cultivars detected no significant pathogenic differences among U. S. and Australian isolates of *U. agropyri*. In the Pacific Northwest of the U. S. flag smut disease has shown little or no ability to genetically modify itself and "new races of the pathogen have not been detected even with selection pressure via the use of resistant cultivars for decades." (Line, 1998). "*Urocystis agropyri* test results indicate very little susceptibility in wheat to the flag smut of grasses" (Fischer, 1943). We conclude that the quarantine for flag smut disease of wheat imported into the United States may be discontinued, and therefore we recommend that action.

I. Introduction

A. Purpose

This plant pest risk analysis was prepared by the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA). We conducted the analysis to examine the plant pest risk posed by foreign strains of the fungus, *Urocystis agropyri* (Preuss) Schroet., the causal agent of the wheat disease called flag smut. Currently, foreign strains of this fungus are the subject of a quarantine (Title 7, Code of Federal Regulations, Part 319.59). The flag smut quarantine prohibits movement, from countries where flag smut is reported, of commodity wheat seed and grain, and commodity shipments of grains other than wheat when wheat seed is found admixed with the crop (as occurs in crop rotation systems where volunteer wheat plants occur among subsequent crops). Plant Protection and Quarantine (PPQ, within USDA-APHIS) has taken action on (*i.e.*, denied entry) shipments of oat grain found to be contaminated with wheat seeds when these shipments originated from countries where flag smut is known to occur. The decision to take action on these shipments was correct, based on scientific information available at the time of the decision and longstanding USDA practices. In response to requests from our trading partners and interested parties in the United States, APHIS agreed to reconsider the quarantine and the action status of these pathogens and to analyze in greater detail the risk posed by foreign strains of *U. agropyri*. This analysis addresses two basic questions: (1) Is there compelling evidence to warrant continued quarantine actions to minimize the introduction of foreign strains of *U. agropyri* into the United States, *i.e*., do the foreign strains pose a risk which is greater than that posed by the strains of *U. agropyri* that are already in the United States, and (2) Is the Federal quarantine an appropriate control mechanism in light of the biology of the fungus and our national obligations under treaties relevant to trade and plant pests?

B. Legal Authorities

Under the Federal Plant Pest Act, as amended 1957 (7 United States Code 150aa *et seq*.) and the Plant Quarantine Act of 1912, as amended 1967 (7 United States Code 150aa *et seq*.), USDA has broad authority to regulate the importation and interstate movement of organisms that may directly or indirectly injure, damage, or cause disease in plants. APHIS's authority to regulate these organisms is granted by Title 7 of the Code of Federal Regulations (CFR), Part 330 (*i.e.*, 7 CFR §330). Section 330.101 states: "The purpose of the regulations in this part is to prevent the dissemination of plant pests into the United States or interstate, by regulating the movement of plant pests into or through the United States . . .".

Part 319 of Title 7 (7 CFR §319) establishes foreign quarantines, specifically: 319.37 covers Nursery Stock, Plants, Roots, Bulbs, Seeds, and Other Plant Products and 319.59 covers diseases of wheat. The APHIS regulations as amended in 1983 provide the following definition for "foreign strains of flag smut: Plant diseases caused by foreign strains of highly infective fungi, *Urocystis agropyri* (Preuss) Schroet., which attack wheat and substantially reduce its yield, and which are new or not widely

prevalent or distributed within and throughout the United States." In practice, APHIS quarantine actions exclude wheat seeds and plant parts originating from other countries which have flag smut. Those countries are specifically listed in 7 CFR 319.59- 2(a)(2) as Afghanistan, Algeria, Armenia, Australia, Azerbaijan, Bangladesh, Belarus, Bulgaria, Chile, China, Cyprus, Egypt, Estonia, Falkland Islands, Georgia, Greece, Guatemala, Hungary, India, Iran, Iraq, Israel, Italy, Japan, Kazakstan, Kyrgystan, Latvia, Libya, Lithuania, Moldova, Morocco, Nepal, North Korea, Oman, Pakistan, Portugal, Romania, Russia, Spain, Tajikistan, Tanzania, Tunisia, Turkey, Turkmenistan, South Africa, South Korea, Ukraine, Uzbekistan, and Venezuela.

C. Initiation and Consistency with International Guidelines

International plant protection organizations such as the North American Plant Protection Organization (NAPPO) and the International Plant Protection Convention (IPPC) of the United Nations Food and Agriculture Organization (FAO) provide guidance for conducting pest risk analyses. This analysis was pest-initiated according to international standards, *i.e.*, "A policy decision is taken to revise phytosanitary regulations or requirements concerning specific pests " (FAO, 1996; NAPPO, 1993). The methods we used to initiate, conduct, and report this plant pest risk analysis are consistent with guidelines provided by NAPPO, IPPC and FAO. Our use of biological and phytosanitary terms (*e.g.*, introduction, quarantine pest) conforms with the *NAPPO Compendium of Phytosanitary Terms* (NAPPO, 1996) and the *Definitions and Abbreviations* (Introduction Section) in *International Standards for Phytosanitary Measures, Section 1—Import Regulations: Guidelines for Pest Risk Analysis* (FAO, 1996).

The *Guidelines for Pest Risk Analysis* provided by FAO (1996) describe three stages in pest risk analysis: initiation, risk assessment, and risk management. This document satisfies the requirements of all three FAO Stages. FAO (1996) defines "pest risk assessment" as "Determination of whether a pest is a quarantine pest and evaluation of its introduction potential." "Quarantine pest" is defined as "A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled" (FAO, 1996; NAPPO, 1996). Thus, the pest risk assessment portion should consider both the likelihood and consequences of introduction of quarantine pests. Both issues are addressed in this qualitative pest risk analysis. Risk management is the decision-making process of dealing with the risk of introduction of a quarantine pest (NAPPO, 1993). This analysis satisfies that requirement by documenting PPQ's decision regarding the quarantine status of foreign strains of *U. agropyri* from the countries listed in 7 CFR Part 319.

D. Pathogen Species Covered By This Risk Analysis

We assess the risk posed to the United States by foreign strains of the wheat flag smut pathogen, *U. agropyri*. The risk of the foreign strains is evaluated in light of the impacts of domestic strains of *U. agropyri*. The regulations found at 7 CFR Part 319 specifically identify the quarantined organisms as "foreign strains of flag smut." The domestic strains of flag smut are not regulated by APHIS. The definition of strain in this case has both biological and legal relevance.

Like the concept of speciation, the designation of a strain is shaped by the perceptions and values of the people evaluating the strain. In the case of plant pests, designations often are used to indicate populations of the organism which differ in their biological properties which influence pathogenicity or virulence with respect to host plants: "pathotype – variant of a given pathogen; pathogenic reaction on a given host"; "race -- group of individuals within a variety or species distinguished by behavior but not by morphology"; "strain -- descendants of an isolated organism; biotype; race" (Wiese, 1987). This is the interpretation that APHIS will utilize to assess whether the foreign strains need to be quarantined.

Pathogenicity (*i.e.*, the capability of a pathogen to cause disease) is a consequence of inherent traits of the pathogen, as influenced by the host genotype as well as abiotic environmental factors such as temperature and moisture. Agriculturalists can frequently mitigate the effects of plant pathogens by means that enable the host plant to escape overwhelming challenges by the pathogen propagules. Altering crop rotations, sowing times and depths, other cultural practices such as planting cultivars which resist the pathogen modify the host-pathogen- environment disease triangle to prevent or reduce infection.

Two organisms may have many characteristics, such as morphological or physiological attributes, in common, yet they may form biologically distinct subsets of a fungal species. From 1877 until 1943 *U. tritici* was accepted as the valid name for the wheat flag smut fungus (Purdy, 1965). Then, on the basis of morphological similarities with *U. agropyri*, a species causing flag smut of various grasses, it was recommended that the two species be synonymized under the *agropyri* epithet (Fischer and Holton, 1943). The names *U. tritici* and *U. agropyri* were synonymized, but without an unequivocal demonstration of the interspecific host preference of the fungi from wheat and those from grasses. Thus, *U. agropyri* has been reported to infect wheat, barley and a number of other grasses. However, isolates show marked host specialization and most wheat isolates will not infect other grass species (Mordue and Waller, 1981). Many grasses, especially *Poa* spp., are susceptible to the other strains of the pathogen (MacLatchy, 1995). Wheat **or** grass isolates of *U. agropyri* have been reported from 36 States and Canada even though the wheat flag smut disease only occurs in the Pacific Northwest.

An early study comparing U.S. and South African wheat isolates suggested the isolates did not differ in pathogenicity, although the South African isolates appeared to be more virulent (where virulence is defined as the degree of pathogenicity) (Verwoerd, 1929). Studies in China (Yu, *et al.*, 1945), Pakistan (Hafiz, 1951) and the United States (Holton and Johnson, 1943) differentiated varying numbers of pathogenic races, while studies by Watson and Baker in Australia (Purdy, 1965) were unable to detect different races. More recently, research comparing the morphological, biological and molecular characteristics of Australian and U.S. isolates suggested there were few if any differences (Brown, *et al.*, 1994). Line (1998) states, "Evidence for the existence of pathogenic races of *U. agropyri* is based on reports that flag smut collections from different regions of the world have different virulences. However, some of the conclusions are based on nonreplicated data consisting of a small population of plants compared under greenhouse conditions in different years, and the development of new pathogenic races has not been confirmed. In regions where flag smut is endemic, new races of the pathogen have not been detected even with the selection pressure via the use of resistant cultivars for decades." Thus, the situation regarding the presence of races is not clear and there remains a question whether the foreign strains of *U. agropyri* meet the standard of a quarantine pest.

E. Description of the Pest and Its Impact

In 1868, flag smut was first described in Australian wheat fields (McAlpine, 1910). It was not until 1919 that flag smut was first reported in the United States, in Illinois and Indiana (Humphrey and Johnson, 1919). Based on the circumstantial evidence that the disease occurs in Australia and appeared in the United States contemporaneously with wheat shipments from Australia to the U. S., officials concluded that the pathogen may have entered the United States in those wheat shipments (Tisdale, *et al.*, 1923). Consequently, in August of 1919, the USDA promulgated Federal Quarantine No. 39 as a precaution to protect domestic wheat production from potentially damaging foreign strains of the flag smut pathogen. The quarantine prohibited the importation of wheat seeds or other plant parts from countries where flag smut was known to occur. Agricultural officials considered a domestic quarantine of wheat grown in Illinois and Indiana, but decided against such measures.

Flag smut of wheat occurs in the United States and elsewhere in the world where autumn-sown wheat is grown in regions with dry summers and mild winter temperatures. These conditions occur in some limited areas of the northwestern United States as well as parts of Australia, South America, Asia, and Europe. Flag smut does not normally occur in spring-sown wheat even when highly susceptible cultivars are grown (Line, 1998).

The disease cycle begins in the autumn. Teliospores of the fungus that are present either in the soil or as a contaminant of seed germinate to produce an infectious spore, the sporidium. These sporidia directly infect wheat seedlings prior to emergence. Mild temperatures between 10 and 20ºC and soil moisture conditions that are optimum for seed germination and seedling emergence favor infection of wheat. The fungus overwinters as a mycelium within the seedling. In spring, the mycelium systemically invades the host and eventually produces teliospores within the upper portions of host plants, particularly the flag leaf, but not the developing seed. Although the pathogen initiates infection of the seedling before emergence from the soil, the characteristic disease symptoms become conspicuous at mid-season during stem elongation and heading when gray-black stripes appear between the veins of the leaf blades and sheaths. These stripes later break open and release masses of black spores. After this, the infected leaves look frayed. If the infection is severe, plants may be extremely dwarfed and will fail to produce heads. The teliospores are long-lived (up to 3 years in the soil and 4 years as contaminants of seed) (Griffiths, 1924; Sattar and Hafiz, 1952), and are spread by wind. Contamination of seed and soil by wind-blown spores and from spores shed during harvest is the source of inoculum for subsequent crops.

Affected plants within the growing crop are often severely stunted and plants may tiller excessively. Major symptoms include long grayish-black streaks on leaf blades, especially the flag leaf, and on leaf sheaths. In some cases, the head fails to emerge. Where heads do emerge the glumes and necks may be striped.

In this century, the importance of flag smut as a disease of wheat has varied with outbreaks generally associated with the growing of susceptible varieties (Mordue and Waller, 1981). Shortly after flag smut was reported in Illinois in 1919, losses were reported as within a range of 5 to 30 percent (Purdy, 1965). In the following five years, the average **incidence** was estimated to be 2 percent with localized areas ranging as high as 50 percent infected plants (Purdy, 1965). These localized areas were in “hot spots” in

a small part of a field where threshing machines had operated (Line, 1998). Martens, *et al.*, (1984) calculated that every 1 percent incidence will cause a yield loss of 0.4 – 0.6 percent. Flag smut has not been reported in the Midwestern United States since 1934 and is rare in the northwestern U. S. (Line, 1998).

In the Pacific Northwestern United States, incidence and yield losses increased in the early 1960's with the advent of early fall "deep seeding" and the use of susceptible or moderately susceptible cultivars (MacLatchy, 1995). By the late 1960's, flag smut was the most important disease of wheat in two counties in the U. S. Pacific Northwest. Incidence ranged from trace amounts to 30 percent (Purdy, 1965). By the early 1970's the disease was effectively controlled with the introduction of resistant cultivars, effective seed treatments, and changes in cultural practices. The economic impact of the disease where it occurs in the Pacific Northwest today is virtually nil and at times the disease is difficult to find (Line, 1998; MacLatchy, 1995).

Throughout the world's wheat growing regions today, flag smut is not as damaging as it once was reported. In Australia, where losses once ranged from 10-15 percent in the northeastern hard wheat areas, the disease has been all but eliminated through the use of crop rotation and resistant varieties (MacLatchy, 1995). Similarly, in Turkey where the disease was once considered to be of some importance, effective seed treatments have relegated flag smut to minor disease status (MacLatchy, 1995).

Flag smut still occurs, but losses are largely controlled through the use of resistant wheat cultivars, fungicidal seed treatments, and crop rotation and other management methods. The limited distribution of the flag smut disease in the United States and its lack of spread despite being present for decades with no domestic quarantines provides circumstantial evidence that suitable environments are restricted. Earlier occurrences of the disease in the central United States were attributed to a combination of factors: (1) use of highly susceptible cultivars, (2) inadequate crop rotation, (3) cultural practices, and (4) lack of satisfactory seed treatments. This combination led to an inoculum build-up sufficient for disease expression. Current agricultural practices would not allow such a build-up to occur (Line, 1998).

Like other plant diseases, the control of flag smut can be achieved through a variety of strategies or disease control measures which aim to influence one or more of the three components of the disease triangle: host, pathogen, and environment.

For example, in the 1999 Online Guide for Plant Disease Control (Pscheidt, 1997), Oregon State University recommends the following cultural control measures for flag smut:
1.Use resistant cultivars.
2.Rotate 2 years out of winter wheat.
3.Plant seed shallowly (less than 1 inch) when soils cool in fall.

In addition, the guide describes the following chemical control agents which are effective against seedborne and soilborne spores (http://plant-disease.orst.edu/disease.cfm?RecordID=1135.00000):

A. Vitavax®
B. Dividend®
C. Raxil-Thiram®

Other fungicides have also been demonstrated to provide 100% control of flag smut, such as:

D. triadimenol
E. tebuconazole
F. difenoconazole [available as Dividend®] (Line, 1998).

Line also listed:

G. Plantvax® oxycarboxin
H. Vitavax® carboxin

on his website: http://www.wsu.edu:8080/~wheaties/fd96smut.html.

Disease control measures can be classed in accord with the four basic principles of disease prevention they exemplify: (1) exclusion and (2) eradication, which involve control of the pathogen; and (3) protection (treating a healthy plant before it becomes diseased) and (4) development of resistance, which deal with the plant's defense mechanisms (Pscheidt, 1997).

F. Current and Previous Importations and Previous Risk Assessments

Neither flag smut of wheat nor foreign strains of *U. agropyri* have been the subject of previously documented risk analyses by APHIS.

G. Brief Discussion of Issues Regarding the Quarantine of Foreign Strains of *Urocystis agropyri*

The Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA) conducted a pest risk assessment to evaluate the potential plant pest risks associated with changing the quarantine status of foreign strains of *U. agropyri*, the causal agent of flag smut of wheat. The quarantine was established in 1919 to prohibit the introduction of *U. agropyri* spores contaminating wheat seed or other plant parts originating from countries which have reported flag smut of wheat. APHIS has received requests from scientists and grain traders to modify or eliminate the current quarantine in light of agricultural practices which mitigate the potential plant pest risks presented by foreign strains of *U. agropyri*.

Issue No. 1. Certain stakeholders have asserted that these foreign strains are no more of a threat to United States wheat production than the strains of *U. agropyri* which occur within the United States.

APHIS Response: APHIS agrees that there is no definitive demonstration that foreign strains of *U. agropyri* pose a greater risk to U.S. grown wheat than the strains which are in the United States.

Issue No. 2. Certain stakeholders have maintained that there are adequate flag smut control measures available to U. S. wheat growers to minimize any impact of new strains of *U. agropyri*.

APHIS Response: APHIS agrees that there are presently adequate disease control measures for flag smut of wheat. APHIS recognizes that both the incidence and severity of flag smut have been declining, especially during the past 30 years. Beginning in the late 1960s, research efforts have yielded effective disease control practices. These control practices have proven durable through decades of use.

Issue No. 3. Certain stakeholders have asserted that because species in this fungal genus occur in the United States, the intercepted species do not satisfy the geographic and regulatory criteria as quarantine pests.

APHIS Response: Although *U. agropyri* occurs in the United States, the prevailing assumption from the institution of quarantine in 1919 has been that *U. agropyri* originated from outside the United States and quarantine of foreign strains of the pathogen would reduce the risk of continual re-introductions or introduction of more virulent strains. Historically, APHIS-PPQ has taken action on intercepted pests when the following conditions exist:

- an intercepted pest is identifiable only to genus,
- the intercepted species, although unnamed, has characteristics that allow it to be distinguished from species known to occur in the United States, and
- one or more species in the genus are known to be plant pests, and
- the commodity is destined for propagation.

Action typically takes the form of requiring treatment of the commodity or prohibiting entry. It appears that the foreign strains of *U. agropyri* do not meet these criteria for quarantine.

Issue No. 4. Certain stakeholders have suggested that regardless of whether these foreign strains satisfy the geographic and regulatory criteria as quarantine pests, they may not satisfy the economic criteria because they are not significant plant pests.

APHIS Response: APHIS agrees that the economic significance of flag smut to U.S. wheat production is slight, but the primary purpose of this plant pest risk analysis is to evaluate available information concerning the plant pest potential of these strains and to estimate their biological potential as plant pests in the United States.

II. Risk Assessment

A. Regulatory Literature on Flag Smut Occurrence/Distribution

Information regarding the flag smut pathogen was sought from a variety of sources including:

- Literature reviews using electronic databases (*e.g.*, AGRICOLA, CABI database, *etc.*)
- The USDA-APHIS files of previous decisions regarding importations.
- The USDA-APHIS files and databases regarding previously intercepted pests.
- C.M.I. Distribution Maps/Descriptions of Plant Pests (*e.g.*, Fungi)
- Various texts and indices of plant diseases and pathogens.
- USDA-ARS plant pest database.
- EPPO (1994) plant pest database
- FAO (1993) plant pest database

To be considered a quarantine pest, a pest must satisfy two criteria (FAO, 1996; NAPPO, 1996). First, the pest must satisfy geographic and regulatory criteria. With respect to the PRA area (*i.e.*, the United States), the pest must be "not yet present there, or present but not widely distributed and being officially controlled." Second, the pest must be "of potential economic importance" (FAO, 1996; NAPPO, 1996).

B. Geographic and Regulatory Criteria

By the definition of foreign strains in the regulation, these foreign strains of *U. agropyri* are assumed not to occur in the United States and therefore satisfy a portion of the geographic and regulatory criteria of a quarantine pest. This assumption and its implications are complicated by the fact that the regulation does not provide detail on the definition of the term "strain." We utilize the following definitions: "race – group of individuals within a variety or species distinguished by behavior but not by morphology"; "strain – descendants of an isolated organism; biotype; race" (Wiese, 1987). It is therefore necessary to interpret the intent of the regulation in light of our current understanding of the plant pest risk (see Section **I. D. Pathogen Species Covered By This Risk Analysis**).

C-a. Economic Importance / Consequences of Introduction

In this section, we assess whether the foreign strains of *U. agropyri* satisfy the economic criteria of a quarantine pest. According to FAO (1996) and NAPPO (1996), an organism can be classified a quarantine pest when it is "of potential economic importance." We rate the potential consequences of introduction (*i.e.*, economic importance) according to five risk elements (RE's, described below). Our risk assessment process, and our five RE's in particular, are consistent with international guidelines (*e.g.*, FAO, 1996; NAPPO, 1993; NAPPO, 1996). These elements reflect the biology of the organism and its hosts. This is a qualitative ranking. For each RE, we assign the pest a rating of High, Medium, or Low according to the following criteria. A discussion of our findings is provided with each RE.

RE #1: Climate—Host Interaction

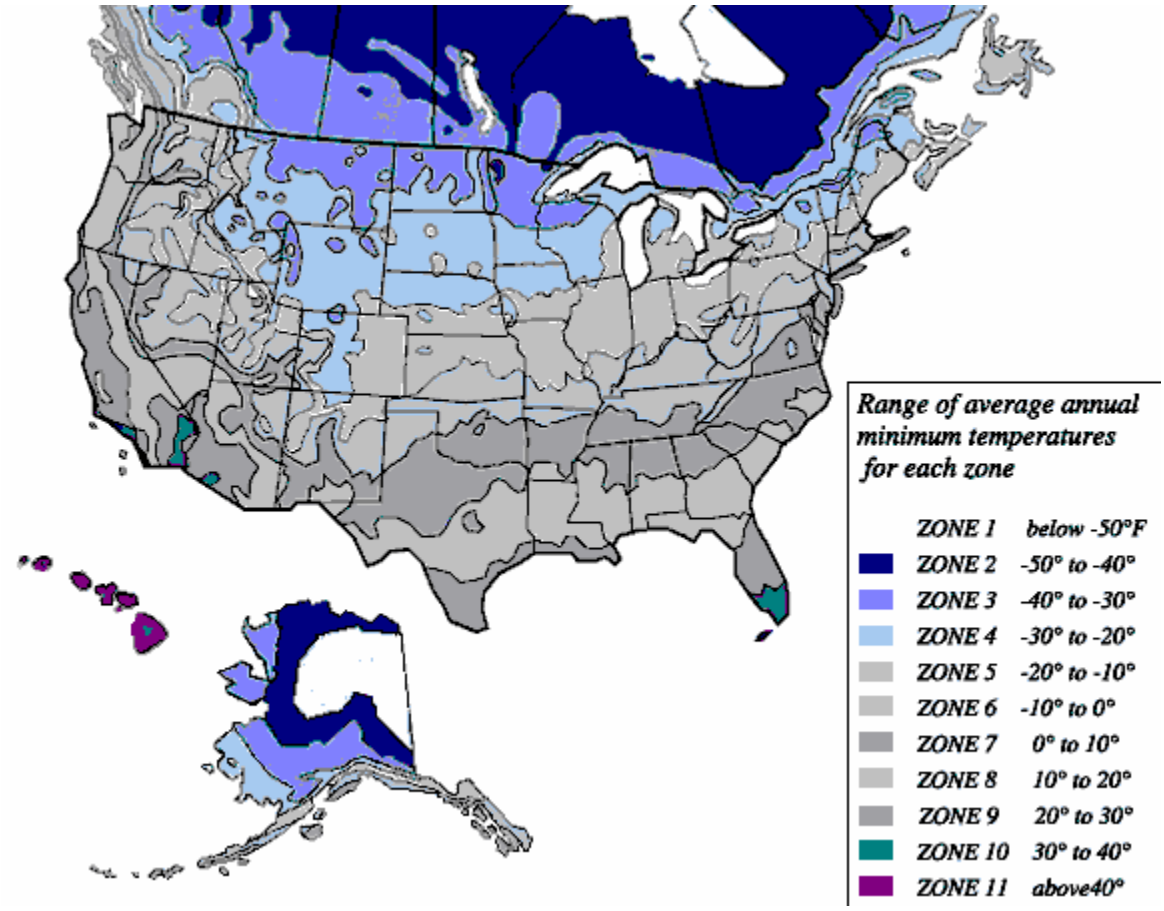
When introduced to new areas, pests can be expected to behave as they do in their native area if host plants are available and the climate is similar. We consider ecological zonation and the interaction between the geographic distributions of the fungus and host. Estimates are based on availability of both host material and suitable climate conditions. To rate this RE, we use the U.S. "Plant Hardiness Zones" as described by the U.S. Department of Agriculture (USDA, 1990) (Figure 1). We assign ratings as follows:

Due to the availability of both suitable host plants and suitable climate, the fungus has potential to become established:

High (3): In four or more plant hardiness zones.
Medium (2): In two or three plant hardiness zones.
Low (1): In at most a single plant hardiness zone.

<u>Finding for RE#1</u>

Flag smut occurs on autumn-sown wheat in regions of the world which have dry summers and mild (10 – 20 deg. C.) winter temperatures (Wiese, 1987). Climatic conditions greatly influence the survival of the spores of *U. agropyri* which are borne on the seed or in the soil. These conditions occur in some limited areas of the northwestern United States as well as parts of Australia, South America, Asia and Europe. The most recent information on U.S. incidence of flag smut indicates that flag smut occurs only in the northwestern United States. But based on the biology of the pathogen it can survive anywhere that the host, autumn sown wheat, occurs and temperatures range between 10 - 25 C. during seedling emergence (Line, 1998). Previously recorded outbreaks of flag smut in the Central and Pacific Northwestern United States have occurred in essentially two, possibly three hardiness zones: zones 5, 6 and 7 (Figure 1). For these reasons, RE #1 is rated as **medium**.



RE #2: Host range

The risk posed by a plant pest depends on both its ability to establish a viable reproductive population and its potential for causing plant damage. For pathogens, risk is assumed to depend on host range, aggressiveness, virulence and pathogenicity; for simplicity, we rate risk as a function of host range.

High (3): Pathogen attacks multiple species within multiple plant families.
Medium (2): Pathogen attacks multiple species within a single plant family.
Low (1): Pathogen attacks a single species or multiple species within a single genus.

Finding for RE #2

While the species, *U. agropyri,* has been reported to infect wheat, barley and a number of other grasses, isolates show marked host specialization and wheat isolates do not naturally infect other grass species (Mordue and Waller, 1981). Because wheat isolates of *U. agropyri* generally infect only wheat (*Triticum aestivum* L.), RE #2 is rated as **low**.

RE #3: Dispersal Potential

Fungi disperse after introduction to a new area. The following items are considered:

- reproductive patterns of the fungus (*e.g.*, reproductive output)
- innate dispersal capability of the fungus
- what factors (*e.g.,* wind, water, animals, humans) facilitate dispersal

High (3): Fungus has high reproductive potential (*e.g.*, many generations per year, many offspring per reproduction, high innate capacity for population increase), ***AND*** evidence exists that the pest is capable of rapid dispersal (*e.g.*, over 10 km per year) either under its own power, human-assisted, or by natural forces such as wind or water.
Medium (2): Fungus has either high reproductive potential ***OR*** is capable of rapid dispersal.
Low (1): Neither high reproductive potential nor capable of rapid dispersal.

Finding for RE #3

Spore balls, "compact, round groups of spores, or of spores and sterile cells, that function as units of dispersal" (Ulloa and Hanlin, 2000) liberated from tattered infected leaves contaminate the soil and seed. There is usually one generation of spores produced per season. Spores may be spread by winds to some extent, especially after harvest; however such spread is expected to be limited to the local farm level. Overall, the reproductive potential is not considered to be particularly high, although spores may remain viable in the soil for up to four years under optimal*, i. e.*: warm and dry, soil conditions (Line, 1998; Wiese, 1987). Because of these considerations, RE #3 is rated as **medium**.

RE #4: Economic Impact

Although a variety of impacts may occur, economic impacts caused by introduced plant pests are divided into three primary categories:

- Lower yield of the host crop (*e.g.*, by causing plant mortality).
- Lower value of the commodity (*e.g.*, by increasing costs of production, lowering market price, or a combination).
- Loss of markets (foreign or domestic) due to presence of new quarantine pest.

High (3): Pathogen causes all three of the above impacts.
Medium (2): Pathogen causes any two of the above impacts.
Low (1): Pathogen causes any one or none of the above impacts.

Finding for RE #4

An analysis of the available evidence suggests that in the absence of current disease control practices, the foreign strains of *U. agropyri* could be just as detrimental as the strains of *U. agropyri* currently found in the United States. According to Line (1998), the "disease caused losses of three to four percent in south central Australia in 1931 and has reduced yields in individual fields by as much as 50 percent." Experimentally, under conditions conducive to disease development yield losses have exceeded 95 percent. Normally, however, conditions conducive to such severe losses are rare. In countries where the disease is established, breeding programs have incorporated durable resistance genes into wheat cultivars and this, combined with the use of systemic fungicide seed treatments and cultural practices, including late and shallow planting and non-host crop rotations, has reduced the effect of the disease to insignificant levels (Sansford, 1998). Disease control measures **are** already being used effectively in the United States. It appears likely that such measures would be effective against foreign strains, since physiologic specialization has not proven to be a problem in breeding programs (Ballantyne, 1996). "Resistance occurs in many cultivars, has been easy to transfer into new cultivars and has remained durable for decades. New races of the pathogen have never circumvented that resistance" (Line, 1998).

Brazil and Turkey are important customers for U.S. wheat, and in addition to Canada, have laws prohibiting wheat from countries having flag smut disease. The United States presently does not have domestic flag smut quarantines to prevent movement of wheat from areas in the Pacific Northwest where the disease occurs. It seems unlikely that relaxation of our external quarantine would have any impact.

Because of these considerations, RE #4 is rated as **low**.

RE #5: Environmental Impact

Our assessment of the potential of each pest to cause environmental damage (FAO, 1996) considers the following factors:

- Introduction of the pest is expected to cause significant, direct environmental impacts (*e.g.*, ecological disruptions, reduced biodiversity). When used within the context of the National Environmental Policy Act (NEPA), "significant" has a special meaning different from its use in a scientific or statistical context (*e.g.*, different from its use in the term "statistically significant"). As used by NEPA, significance is qualitative and encompasses both the likelihood and severity of an environmental impact.
- Pest is expected to have direct impacts on species listed by Federal or State agencies as endangered, threatened, or candidate. "An example of a direct impact would be feeding on a listed plant" (USDA, 2000). If feeding trials have not been conducted with the listed organism and the pest, a pest will be expected to feed on the plant if it feeds on other species within the

genus or other genera within the family.

- Pest expected to have indirect impacts on species listed by Federal or State agencies as endangered, threatened, or candidate (*e.g.*, by disrupting sensitive, critical habitat).
- Introduction of the pest would stimulate control programs including chemical pesticides.
- Introduction of the pest would stimulate control programs including release of nonindigenous biological control agents.

High (3): Two or more of the above.
Medium (2): One of the above.
Low (1): None of the above. It is assumed that introduction of a nonindigenous pest will have some environmental impact (*e.g.,* by definition, introduction of a nonindigenous species generates competition or displacement).

Finding for RE #5

There is no evidence to suggest that the foreign strains of *U. agropyri* would present any direct or indirect environmental impacts. All available evidence indicates that the current flag smut disease control measures will be adequate for any strains of *U. agropyri*, consequently no new control programs would be expected. The wheat isolates of the pathogen naturally infect only wheat (Mordue and Waller, 1981), so there is no reason to believe that foreign strains of *U. agropyri* will have any impact on any organisms described on the Federal list of endangered, threatened, or candidate species. Likewise, these foreign strains should not produce any negative effects on biodiversity on the United States.

Consequently, RE #5 is rated as **low**.

C-b. Consequences of Introduction: Cumulative Risk Element Score

We sum the ratings for the five RE's to produce an overall estimate of the Consequences of Introduction Risk Rating. The Consequences of Introduction Risk Rating are considered to be a biological indicator of the potential of the pest to become established and spread, and its potential to cause economic and environmental impacts. The overall risk rating is used to assign a Consequences of Introduction Risk Score as follows:

Table 1. Risk: Consequences of Introduction (Sum RE #1-5)

Cumulative Risk Element Score	Risk Rating	
5 -- 7	8 -- 11	12 -- 15
Low	Medium	High

The Cumulative Risk Element Score for *U. agropyri* for RE #1-5 is 7, which is equivalent to a **low**

"Consequences of Introduction" risk rating.

Table 2. *U. agropyri* Risk Rating: Consequences of Introduction

Climate/Host	Host Range	Dispersal	Economic	Environmental	**Risk Rating**
Med (2)	Low (1)	Med (2)	Low (1)	Low (1)	**Low (7)**

D. Likelihood of Introduction (Entry and Establishment)

The foreign strains of *U. agropyri* covered by this risk analysis are assumed to be capable of following the pathways of shipments of wheat, oats, and other agricultural commodities which may be admixed with wheat seed or debris. Spores of *U. agropyri* are known to be carried as contaminants on the surface of seeds or plant debris (Brown, et. al., 1994; Pollack, 1945). USDA pest interception records indicate that since 1985, *U. agropyri* was interecepted at least once on a wheat seed shipment.

It is reasonable to assume agricultural commodities (such as grain for animal feed) will be utilized in a variety of habitats, some of which may actually encourage spore survival. For such surviving spores to cause disease, they will have to reach a suitable host plant before they lose viability due to physical and biological environmental conditions. The presence of the flag smut disease in the United States provides unequivocal evidence that the fungus, once introduced, can become established even if only in limited geographic areas. On the other hand, even in the absence of domestic quarantines restricting the movement of seed and grain, the flag smut disease has not spread from areas in the United States where the disease does occur. This is likely the consequence of either unfavorable environment or commonly employed agricultural practices unfavorable for disease establishment, or both. In summary, the likelihood that *U. agropyri* could enter as a seed or grain contaminant seems quite high, but establishment and persistence of the pathogen outside of areas where the disease already occurs seems unlikely, and "quarantine regulations have not controlled flag smut and are not necessary" (Line, 1998).

E. Assessment Conclusion: Risk Potential and Quarantine Status

A considerable body of published evidence indicates that there is physiological specialization within the wheat infecting strains of *Urocystis agropyri* (Ballantyne, 1996; El-Khadem, *et al.* 1980; Hafiz, 1951; Holton and Johnson, 1943; Johnson, 1959; Yu, *et al.*, 1945) although the validity of some studies has been called into question (Line, 1998). What is less clear is whether, in fact, foreign strains differ genetically in such a way as to increase their potential capacity for causing economic damage. An early study comparing U.S. and South African wheat isolates suggested the isolates did not differ in pathogenicity (the capability to cause disease), although the South African isolates appeared to be more virulent (the degree of pathogenicity) (Verwoerd, 1929). More recent research comparing Australian and U.S. isolates suggested there were few if any differences (Brown, *et al.*, 1994). What the literature does seem to indicate is that resistance to the flag smut fungus, currently incorporated into many if not most of the wheat varieties grown in at risk areas, is durable and broad spectrum (Ballantyne, 1996; Line, 1998). In addition to resistant varieties, simple chemical and cultural control practices have been widely adopted to effectively eliminate flag smut as a disease of economic consequence in the United

States (Purdy, 1965; Line, 1998).

Given the data outlined in the preceding paragraph, there is no compelling evidence to indicate that the foreign strains will differ from strains already present in their pathogenic or economic impact on wheat production in the United States. With the resulting "consequences of introduction risk rating" of low, we find that foreign strains of *U. agropyri* do not satisfy the economic/ environmental criteria as quarantine pests. Furthermore, APHIS finds that the foreign strains of *U. agropyri* described in the regulations may not satisfy the international geographic and regulatory criteria of quarantine pests. That is, according to available survey data and other relevant scientific information, this species is known to occur in the United States, and there appears to be little difference between domestic and foreign strains with respect to the plant pest risk which they pose. It is not clear that foreign strains differ genetically in such a way as to increase their potential capacity to cause economic damage. Thus, *Urocystis agropyri* fails to satisfy both the geographic/regulatory criteria and the economic criteria as a quarantine pest.

III. Risk Management and Decision on Quarantine Status

Categorization of these foreign strains of *U. agropyri* as quarantine pests is not supported by the available biological/ scientific information, international agreements on criteria for quarantine pests, the United States Acts cited in Section I.B., and existing USDA policies regarding quarantine pests. It appears that the circumstances under which the quarantine was established in 1919 no longer apply. Therefore, it is appropriate for APHIS to discontinue the quarantine of foreign strains of *U. agropyri*.

USDA and its stakeholders will continue to collect scientific information concerning the biology (*e.g.*, host range, pathogenicity) of *U. agropyri* as well as the incidence and severity of flag smut of wheat both in the United States and overseas in the unlikely event that the current situation regarding flag smut changes, and APHIS would take corrective measures to protect US agriculture from *U. agropyri* .

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