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KARNAL BUNT AND ITS RISK TO THE PACIFIC NORTHWEST

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INTRODUCTION

Karnal bunt is a smut of wheat caused by the fungus *Tilletia indica*. The disease was first detected in the USA during March, 1996. This report provides a brief review of the disease (addendum) and its potential to become established in the Pacific Northwest.

The reported distribution of the Karnal bunt pathogen is limited to a few countries. Nearly all countries that import wheat use quarantines to delay the introduction of this pathogen. Most quarantines do not allow any spores (zero tolerance) of the Karnal bunt fungus. Consequences of contamination are severe for the Pacific Northwest, which exports 85% of its wheat to overseas customers. Major shifts in markets and prices are possible if this pathogen is introduced and becomes established in the Pacific Northwest.

The first report of Karnal bunt in the USA involved wheat produced in Arizona during 1995. The USDA-Animal and Plant Health Inspection Service (APHIS) implemented a program to eradicate the pathogen from areas known or thought to be infested, and to prevent further export of contaminated seed, products, equipment, and transport containers from areas where Karnal bunt occurred. The pathogen was then discovered in wheat produced in several southeast states (Alabama, Georgia, and Tennessee), and in grain produced as early as 1992 in Arizona and California. Seed from these states was distributed to farmers, millers, storage elevators, and wheat breeding and testing programs in other states and countries before *T. indica*-contaminated seed was discovered. The known distribution of this pathogen in the USA is increasing.

A smut fungus resembling the Karnal bunt pathogen has also been detected in seed of annual and perennial ryegrass and tall fescue produced in Oregon. The pathogen is present in 60 percent of the ryegrass seed lots and has been detected in seed packaged as early as 1989. It is also present in ryegrass seed imported into Oregon from at least seven other countries, including one seedlot dating back to 1967. It is still true, however, that the Karnal bunt fungus has not been detected in wheat produced anywhere in the Pacific Northwest, including wheat produced adjacent to ryegrass fields in Oregon. It remains unknown whether the fungi causing head smut of ryegrass and Karnal bunt of wheat are identical. Ryegrasses are susceptible to infection by *T. indica* (shown with artificial inoculations in the greenhouse, but never yet reported from field plantings) but it is not yet known whether the ryegrass pathogen can infect wheat. Nevertheless, current studies with the smut on ryegrasses in Oregon re-emphasize the need to evaluate the potential for the Karnal bunt fungus to become established on wheat. This information will become very important if soils in the region become contaminated with sufficiently high numbers of spores.

The potential for the Karnal bunt fungus to survive and infect wheat in the Pacific Northwest has not been reported. Data from other regions indicate that the potential geographic range for Karnal bunt is restricted less by physical requirements for survival of the pathogen than by synchronization of wheat heading with

climatic conditions favorable for teliospore germination, secondary sporidial multiplication, and penetration, and infection.

Survival of spores through the winter seems likely in most wheat producing locations in the Pacific Northwest. Teliospores of *T. indica* are durable and persist in soil for up to four years. Survival in field soil varies greatly in response to depth of burial, soil moisture and temperature, and perhaps other factors. Teliospore survival is relatively unaffected by freezing for several months at 32°F, and survival is reduced only slightly by deep freezing (0°F) in soil for 20 weeks. Subfreezing temperatures required to inhibit spore viability do not occur for sufficient times at any Pacific Northwest location where wheat is produced. For instance, at Pocatello, the coldest wheat-producing location in the region, temperature records indicate that 0°F is attained for only two days each year (averaged over 54 years of records), and that the length of freezing below 32°F averages 68 days per year. At Corvallis, the mildest climate in the region, air temperatures are below 32°F an average of six days per year and never reach 0°F.

Humidity during heading appears to be the most important environmental factor for Karnal bunt occurrence. Spores and mycelium presumably dehydrate, and infection is reduced or prevented, if humidity declines and solar radiation is high for even short periods during the day. Under experimental conditions at 25°F, secondary sporidia have survived 2 and 12 hours at 25 and 95 percent relative humidity, respectively. Droplets of condensation or guttation trapped in wheat heads would be expected to extend the effective wetting period when humidity is low. Humidity inside the leaf sheath also remains high for unemerged heads and portions of emerging heads.

Minimal climatic and plant growth requirements for Karnal bunt to occur are not well defined. There are, however, numerous published reports describing conditions in which the disease did or did not occur. The consensus of reports indicate that for infection to occur, measurable rain (>0.1 inch) or irrigation must occur on each of two or more successive days, at least one-third inch must be collected within the 2-day interval, and/or average daily relative humidity above the plant canopy must exceed 70 percent during both days.

The goal of this study was to estimate the environmental risk for Karnal bunt to occur if soils become contaminated by the Karnal bunt pathogen at 13 Pacific Northwest locations. We analyzed historical data to determine the frequency at which climatic requirements for infection, as described above, were satisfied during heading.

METHODS

Historic temperature records were examined to identify weather conditions favorable for infection shortly before and during heading in areas where wheat is produced in the Pacific Northwest. The National Climatic Data Center's daily temperature and precipitation records were evaluated for 13 locations; Moscow and Pocatello in Idaho, Corvallis, La Grande, Moro, Nyssa, Pendleton (experiment station and airport), and Pilot Rock in Oregon, and Lind, Moses Lake, Quincy, and Spokane in Washington.

Humidity was estimated as the ratio of saturation vapor pressures at the average and minimum daily temperatures. Saturation vapor pressure was computed from temperature records; minimum temperature was assumed to be the dew point. Numbers and percentages of years with at least one potential "infection period", based on periods in which the average relative humidity exceeded 70 percent over a 2-day period, were determined for each of four potential heading intervals.

Four possible heading intervals were selected to represent those that occur during heading of spring- and fall-planted wheat. In the Pacific Northwest, heading occurs from early May to late June, depending on location and planting date. Four time intervals were examined: May 1 to June 30 (60 days), May 7 to June 22 (45 days), May 15 to June 15 (31 days), and May 22 to June 7 (16 days). The longest interval slightly exceeds the range of heading dates, and the shortest interval is shorter than the range of heading at all sites.

For locations with a 50 percent or greater probability of infection during the longest heading interval tested, the frequency of possible infection events was re-evaluated under two more conservative estimates of humidity. The conservative estimates were made because humidity calculated from daily average temperature does not adequately reveal the duration of low humidity which can dehydrate fungus spores and hyphae. The most conservative (driest) estimate used maximum daily temperature. An intermediate estimate used the minimum and one degree lower than maximum daily air temperature. Humidity computed from maximum daily temperature indicates the minimum humidity for the day, but the interval of time for that maximum temperature and minimum humidity may be brief. The interval of time that daily temperature is at or above one degree less than the daily maximum will almost always exceed two hours in the Pacific Northwest. Humidity computed from the maximum temperature minus one degree would occur for a sufficient time (at least two hours) to determine the presence or absence of free moisture on heads of non-irrigated wheat.

Temperature was not used as a limiting factor because temperatures during heading in the Pacific Northwest were always well within the limits of optimum and minimum temperatures when Karnal bunt occurs in other regions.

RESULTS AND DISCUSSION

Environmental conditions appear favorable for *T. indica* to cause Karnal bunt in high humidity and irrigated wheat producing regions of the Pacific Northwest. Table 1 presents the percentage of years in which at least one potential infection period occurred at each location. These data include many years that were favorable for multiple or prolonged infection events. Based on the second shortest heading interval, May 15 to June 15, six of the 13 locations have possible infection periods at least half of the time. The five driest locations (Lind, Moro, Moses Lake, Nyssa, and Quincy) have possible infection periods in only two or three of every 10 years. Teliospores survive in some soils for up to four years. Since there are intervals of four years or more in the weather records from the dry locations when no weather conditions that produce a possible infection event occur, they would not be expected to be favorable habitats for *T. indica* to survive without irrigation.

Predicted infection periods are markedly influenced by the method used to calculate relative humidity (Table 2). The estimate of relative humidity considered most realistic in this study was the one based on the average of the minimum and maximum minus one degree daily temperature. Using this criterion, all except two locations had less than one year in five for naturally occurring infection opportunities between May 15 and June 15 (Table 2). In these locations, conditions for potential infection events occur infrequently enough that the pathogen would not be expected to sustain itself in nonirrigated cropping systems. However, at two locations, Corvallis and Spokane, the potential for naturally occurring infection occurs with a probability of about one year in three. If a more liberal estimate of humidity is used at these two locations, the predicted potential for infection exceeds six of every ten years. Possible infection events at these two locations occur frequently enough that the pathogen would be expected to sustain itself in rotations that include wheat at least every third year. Wheat is a major crop in these locations and is often produced during alternate years. For instance, the Willamette Valley produces 16 percent of the wheat and 95 percent of the ryegrass in Oregon.

Atmospheric conditions required for Karnal bunt appear to closely parallel those for wheat head scab and potato late blight. In Arizona, where wheat and potatoes are watered by furrow irrigation, the area of Karnal bunt occurrence during 1995 coincided with that of late blight. Head scab and late blight both occur in the Pacific Northwest. Head scab occurs in irrigated wheat and in high mountain valleys. Late blight occurs in irrigated fields.

Irrigation is known to favor the occurrence of Karnal bunt. Providing that soils are contaminated, an opportunity for infection appears to occur every year at all Pacific Northwest locations when overhead irrigation water is applied during heading. Approximately 20% of wheat in Oregon and Washington is produced with sprinker irrigation. More than half the production in Idaho is irrigated, with sprinkler irrigation being dominant in eastern Idaho. Most wheat near Moses Lake, Nyssa, Quincy, and Pocatello is irrigated. It is common for water to be applied at each location until the plant is mature.

This analysis was limited to climatic conditions required for spore survival, release, and infection. However, the potential for disease to occur also depends on the population of teliospores in soil, and their survival over time, depth of burial, and synchronization of germination with wheat heading. For instance, some teliospores survive for shorter periods in irrigated than non-irrigated soils, are less germinable when buried by tillage rather than left at the soil surface, and may germinate under favorable conditions at times when wheat is not heading. It is also probable for wheat to be produced less frequently in irrigated than in nonirrigated fields. Collectively, these conditions could reduce the risk associated with favorable infection periods in irrigated soils of the Pacific Northwest.

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Table 1. Percentage of years with favorable weather events[a] for infection of wheat by *Tilletia indica* during heading at 13 locations in the Pacific Northwest, based on 28-65 years of records for these locations.

Location	May 1 to June 30	May 7 to June 22	May 15 to June 15	May 22 to June 7
Corvallis, OR	96	85	74	54
LaGrande, OR	93	90	70	43
Moscow, ID	81	70	57	34
Spokane, WA	91	77	60	34
Pocatello, ID	79	71	55	26
Pendleton Airport, OR	70	72	53	32
Pendleton Exp Stn, OR	63	61	47	29
Pilot Rock, OR	61	56	39	17
Moro, OR	48	43	34	22
Nyssa, OR	40	33	29	24
Quincy, WA	33	29	27	13
Lind, WA	42	38	25	17
Moses Lake, WA	46	43	25	11

[a] Favorable weather conditions defined measurable rain (>0.1 inch) occurred on each of two or more successive days, at least 0.3 inch was collected within the 2-day interval, and average relative humidity above the plant canopy exceeded 70% during both days.

Table 2. Percentage of years with favorable weather events[a] for infection of wheat by *Tilletia indica* during four heading intervals at eight locations in the Pacific Northwest USA, based on calculations of minimum humidity at average daily temperature ("ave"; the least conservative estimate), maximum temperature minus 1° ("max-1"; the most likely estimate), or maximum daily temperature ("max"; the most conservative estimate).

Location	May 1 to June 30			May 7 to June 22			May 15 to June 15			May 22 to June 7		
	(ave)	(max-1)	(max)	(ave)	(max-1)	(max)	(ave)	(max-1)	(max)	(ave)	(max-1)	(max)
Spokane, WA	92	55	30	77	51	30	60	36	23	34	17	17
Corvallis, OR	96	45	23	85	34	15	74	30	11	54	19	4
Pendleton Airport	68	23	13	68	19	11	53	19	11	32	9	4
Pilot Rock, OR	61	32	12	56	20	10	39	15	7	17	5	2
Moscow, ID	81	19	11	70	19	11	57	11	6	34	6	2
Pocatello, ID	79	28	11	72	21	6	55	13	2	26	4	0
La Grande, OR	93	27	10	90	23	10	67	17	7	47	10	3
Pendleton Exp Stn	63	16	8	61	11	3	47	8	3	29	5	3

[a] Favorable weather conditions defined as: 1) measurable rain (0.1 inch) occurred on each of two or more successive days, 2) at least 0.3 inch was collected within the 2-day interval, and 3) average relative humidity above the plant canopy exceeded 70% during both days.

Addendum on

Karnal Bunt

Karnal bunt is a fungal disease of wheats, triticales, and rye. Individual cultivar reaction to this disease varies widely. Barley and oats are not susceptible. Karnal bunt is one of five known smut diseases of wheat -- common bunt, dwarf bunt (TCK), flag smut, loose smut, and Karnal bunt. While generally unfavorable for Karnal bunt, some environments in the Pacific Northwest are quite favorable for development and survival of other smuts. All of the other smuts except for Karnal bunt are already present in the Pacific Northwest, but are generally controlled through cultivar resistance, seed treatments, and cultural practices.

Karnal bunt was first described in Karnal, India in 1931. It has now been identified in all major wheat producing regions of India, Pakistan, Iraq, and Afghanistan. It was likely brought into Mexico on seed in the late 1960s, and is now well established in northwestern Mexico.

Like all smuts, the Karnal bunt fungus (*Tilletia indica*) has a complex life cycle with several spore stages. Teliospores are the initial inoculum. Teliospores can be brought into a field on infested seed, straw or chaff, in contaminated soil, on contaminated harvesting or transportation equipment, or by the wind. Infested seed is the most likely mode of long distance transport. Once in the area, soilborne teliospores are the principal inoculum source. These spores are thick walled and can survive for long periods of time and under adverse conditions.

Teliospores germinate at or near the soil surface in response to moisture. Unlike other smuts, Karnal bunt teliospore germination is delayed until late in the growing season when wheat plants are flowering. Each germinating teliospore produces other spores, called primary sporidia, which in turn produce secondary sporidia that are forcibly ejected under cool, moist conditions. Each sporidial stage is wind- or insect-dispersed. Secondary sporidia that land on moist foliage can germinate and produce additional secondary sporidia or hyphae that produce secondary sporidia. Hyphae from secondary sporidia infect through stomates in glumes of emerged wheat spikes, causing infection of the ovule. Sporidia may also be washed down into the flag leaf sheath, onto unemerged or emerging heads. Survival of sporidia and infection are favored by intermediate temperature (60-80°F optimum, 45-52°F minimum) and either high humidity (>70%) or rainfall that produces high humidity during several successive days at the time of heading. Once in the ovule, the fungus grows, develops, and ultimately produces teliospores.

Karnal bunt usually causes only partial smutting of the kernel. The disease is rarely detected in the field, and it is very difficult to find smutted kernels in harvested grain. The spores are easily released at harvest and teliospores are released to contaminate seed, soil, equipment, and handling facilities. The spores do not present a health risk to consumers of infested grain or grain products. Control of teliospores is the key to restricting further spread of the disease. Regulations in most countries, including the United States, prohibit importation of wheat seed, plants, unprocessed straw, chaff, and mill products, from countries or areas where Karnal bunt is known to occur. Likewise, movement of contaminated transportation equipment is restricted, and contaminated handling facilities are required to eradicate the fungus. Crops planted with contaminated seed are likely to be destroyed under current regulations for quarantines and eradication procedures.

Karnal bunt does not generally reduce the productivity of wheat. Economic losses from production *per se* are unlikely, and control measures are available for use in areas where the disease develops significantly. However, stringent export regulations, currently placed at zero tolerance for any detectable teliospores in any size shipment, impose huge consequences for marketing contaminated wheat. Until international sanctions against the Karnal bunt pathogen have been removed, all available means must be taken to prevent contamination of Pacific Northwest wheat crops.

Adapted from: R. Karow, R. Line, and D. Smiley. 1996. Karnal bunt: cereal disease causes worry. Oregon Wheat 47(4):6-9.