Survival of *Puccinia recondita* and *P. graminis* Urediniospores as Affected by Exposure to Weather Conditions at One Meter

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ABSTRACT

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Viable urediniospores and dormant mycelia are the principal inoculum sources that contribute to the establishment and development of destructive wheat rust epidemics in the central Great Plains of the United States. Inoculum survival was measured by exposing urediniospores of *Puccinia recondita* and P. *graminis* to field conditions occurring at 1 m above ground level throughout two crop years. Four phases (summer, fall, winter, and spring) important in survival of urediniospores as potential inoculum in epidemic development were used in data analysis. Survival of *P. recondita* and *P. graminis* urediniospores during wheat dormancy (winter) was reduced to 10–11 and 17–21%, respectively, within 24 h. Only 2% of *P. recondita* and 3% of *P. graminis* urediniospores survived 72 h of subfreezing temperatures, and no spores germinated after 96 h. Survival of inoculum exposed in the field during wheat green-up (spring), with daily temperatures of 18 to −4 C, was measured at 10–20% after 120 h. Trace amounts of *P. recondita* urediniospores remained viable for 336 h and less than 1% of *P. graminis* urediniospores survived for up to 456 h. During the harvest period (summer), when maximum temperatures were above 30 C and minimum temperatures were above 10 C, at least 60% of urediniospores of both species survived for 120 h, and trace amounts of germination were observed for up to 456 h. During the period of wheat-stand establishment (fall), over 50% of the urediniospores exposed in the field remained viable for 120 h, with trace amounts of survival for 456 h. Survival of urediniospores exposed to below 0 C at 1 m above ground level was not significantly different at 2,300 versus 335 m above sea level. No significant differences ($P = 0.05$) in survival occurred among isolates of either *P. recondita* or *P. graminis* when exposed to extended subfreezing temperatures during wheat dormancy. However, differences among isolates were observed at 72 h with extended exposure to temperatures above 0 C.

Additional keywords: dispersal, primary inoculum, *Triticum aestivum*, urediniospore germination.

Severe wheat leaf and stem rust epidemics caused by *Puccinia recondita* Roberge ex Desmaz. f. sp. *tritici* and *P. graminis* Pers. f. sp. *tritici* Erik. & E. Henn., respectively, have reduced wheat (*Triticum aestivum* L.) yields by as much as 50% in the Great Plains region of the United States (7–9). Viable urediniospores and dormant mycelia are the principal inoculum sources that contribute to the establishment and development of destructive epidemics in the central Great Plains (5,6,10,12,14). Survival of inoculum from winter dormancy to spring green-up of wheat plants normally results in epidemics that reduce crop production by at least 2% (3,13). During those years in which inoculum does not survive to spring green-up, the primary sources of inoculum are urediniospores transported into the field from overwintering areas. Rapid development of epidemics caused by wheat rust fungi on a susceptible host crop depends on the effectiveness of urediniospore production (6,19), dispersal (1,12,15,18), and survival (2,5,10,14,16).

The first objective of this study was to determine how long *P. recondita* and *P. graminis* urediniospores would remain viable under temperatures and other environmental conditions in the Great Plains when actively sporulating uredinia might not be available within a field. A second objective was to determine the temperature conditions most detrimental to survival of urediniospores and if significant differences in urediniospore survival among the isolates tested could be measured after 24–120 h of exposure to Great Plains weather conditions.

MATERIALS AND METHODS

Urediniospores of four isolates each of *P. recondita* (PRTUS3, PRTUS6, PRTUS19, and PRTUS25) and *P. graminis* (TNM, QFB, RKQ, and MBC) were exposed throughout the period of July 1987 to June 1989 to weather conditions occurring at 1 m above ground level at the Rocky Ford plots near Manhattan, KS, 335 m above sea level. Several tests were made near Estes Park, CO, at 2,300 m above sea level, when minimum temperatures were near or below freezing at both locations. Weather variables recorded by standard weather station instruments during the tests included hourly temperature, relative humidity, precipitation, cloud cover, and solar radiation. Isolates of *P. recondita* were from collections made in the wheat-producing areas of Kansas, Oklahoma, and Texas. *P. graminis* isolates were from collections made in the same areas and were identified to the avirulence pattern established by the Cereal Rust Laboratory, St. Paul, MN, except for isolate MBC, which was obtained from their collection.

Tests were replicated as many as four times for each isolate depending on availability of urediniospores and were repeated throughout two crop years. *P. recondita* and *P. graminis* urediniospores used in survival tests were increased on susceptible wheat cultivars Trison and McNair 701, respectively, at 20 C and 35–50% relative humidity in environmental chambers. Urediniospores for each test were collected from the plants by vacuuming with a cyclone collector. A thin layer of spores was deposited over and trapped within nylon-mesh material stretched over 8- × 8-cm samplers constructed with 5-mm wire. Germination of urediniospores ranged between 85 and 100% when they were initially placed in the samplers. Samplers were suspended vertically from a line between two uprights, which allowed air to move freely around each frame. Samplers were separated to prevent shading from sunlight. Control samplers for the survival tests were exposed in 20-C environmental chambers without lights.

Urediniospores were collected from the exposed samplers 3–5 days a week at 0900 by tapping the nylon to allow spores to fall onto 4-cm-diameter plates of 2% water agar. The plates were incubated in darkness at 20 C for 16 h. Viability was assessed by counting a total of 100 urediniospores per plate to determine the percent germination. Germination was assumed if the germ tube was longer than the diameter of the spore. Less than 1% of the spores assessed for viability were in clumps of three or more spores. Sampling continued for each isolate until either no urediniospores could be dislodged from the nylon of the sampler, no germinating urediniospores were observed on the water-agar plates, or measurable precipitation had occurred. Therefore, exposure times for the urediniospore survival tests ranged from 4 to 45 days.

Four phases (summer, fall, winter, and spring) important in survival of urediniospores as potential inoculum in development of severe epidemics in the Great Plains were used in data analysis. The summer phase, during which inoculum from the previous epidemic survived to infect newly emerging wheat plants, was from wheat harvest (July) to fall wheat emergence (October). The fall phase, which was important to establish inoculum for development of fall epidemics, was from wheat emergence to the beginning of wheat-plant dormancy (November). The winter phase was from wheat dormancy to green-up (February) of the wheat crop, during which inoculum overwintered (13) and developed severe epidemics during the spring phase, which was from wheat green-up to harvest. Mean survival data from all replications of *P. recondita* isolate PRTUS25 and *P. graminis* isolate TNM are shown in Figure 1. Statistical computations to determine significant differences among means of survival data from the replicated field data were made by procedures from the Statistical Analysis System (SAS Institute Inc., Cary, NC).

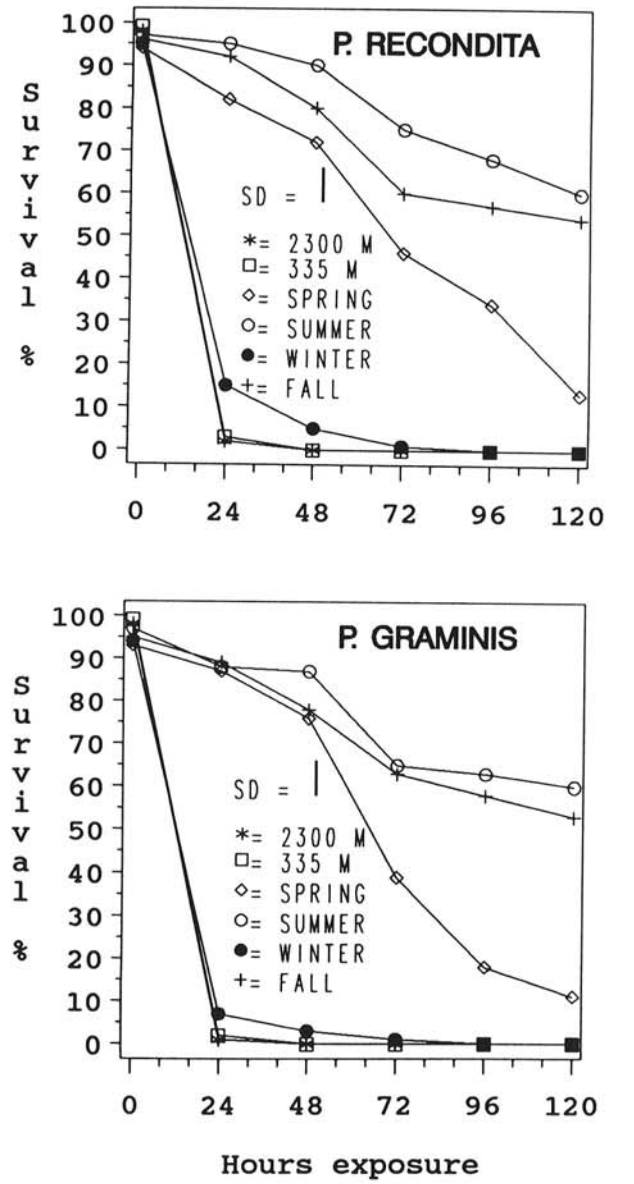

Fig. 1. Survival of *Puccinia recondita* and *P. graminis* urediniospores exposed to weather conditions at 1 m above ground for 120 h during the winter, spring, summer, and fall phases of a wheat rust epidemic. Values are mean survival data of all replications of *P. recondita* and *P. graminis* isolates PRTUS25 and TNM, respectively. Winter = overwintering of inoculum; spring = wheat green-up to harvest; summer = harvest to fall emergence; fall = emergence to winter dormancy; 335 M = winter survival at Manhattan, KS; and 2300 M = winter survival at Estes Park, CO.

RESULTS

Survival of urediniospores of *P. recondita* and *P. graminis* exposed in the field during wheat dormancy (winter; Fig. 1) was

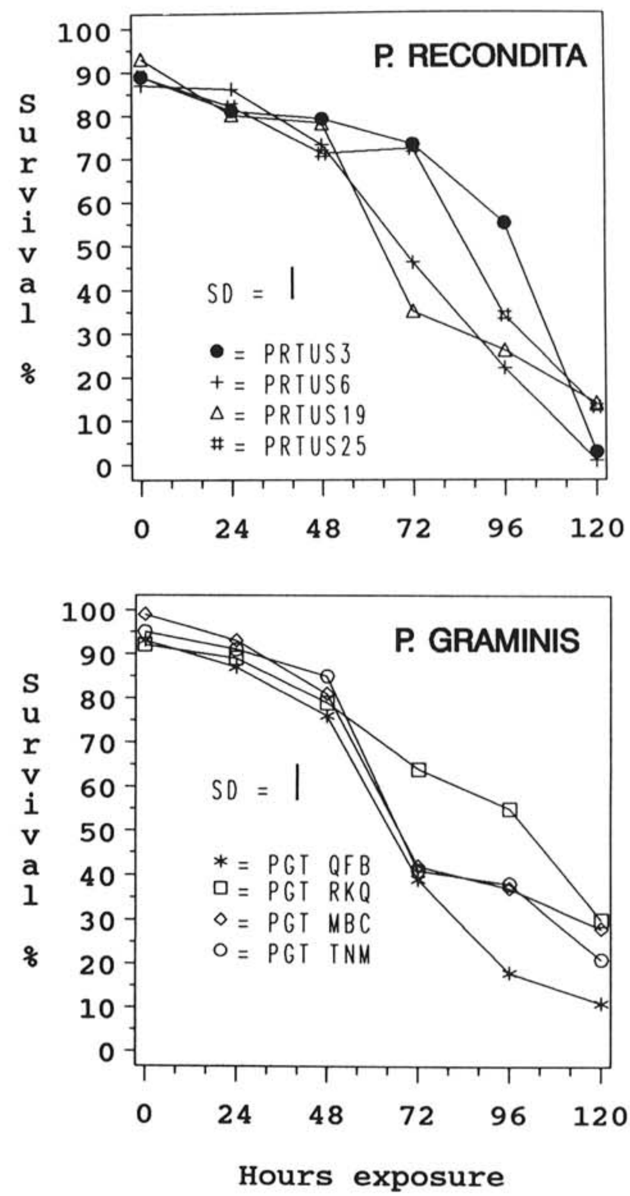

Fig. 2. Survival of *Puccinia recondita* and *P. graminis* urediniospores exposed to spring (wheat green-up to harvest) environmental conditions at Manhattan, KS, for up to 120 h.

reduced to 15 and 7%, respectively, within 24 h. No significant differences in survival occurred among isolates of the two species. Only 2% of *P. recondita* and 3% of *P. graminis* urediniospores survived for 72 h in subfreezing temperatures, and no spores of either species germinated after 96 h. Maximum and minimum temperatures below 0 C were recorded during all periods when spores were exposed in the atmosphere during the wheat dormancy tests. Daily temperatures during green-up of the wheat crop (spring, Fig. 1) ranged from 18 to −4 C, with a total of 4–5 h below freezing, resulting in a decrease of urediniospore survival to 10–20% after 120 h. Significant differences ($P = 0.05$) in survival were observed among isolates of both *P. graminis* and *P. recondita* after 48 h of exposure (Fig. 2). The wheat leaf rust epidemic would be in its initial stages of spring development during this period in Kansas and Oklahoma, during which 1–2% of the *P. recondita* urediniospores survived for 336 h and 1% of the *P. graminis* urediniospores were viable for up to 456 h. During harvest, when maximum temperatures were above 30 C and minimum temperatures were above 10 C, at least 60% of *P. recondita* and *P. graminis* urediniospores survived for 120 h (summer; Fig. 1). No significant differences in survival of urediniospores were observed among isolates of either *P. recondita* or *P. graminis* after exposure to summer weather. Viability of urediniospores sampled after 456 h of exposure to summer weather was 1–2%. As temperatures began to cool during October, when most of the fall-seeded wheat plants were still in the two- to three-leaf stages, over 50% of urediniospores remained viable after exposure for 120 h, and 1–3% remained viable after 456 h of exposure (fall; Fig. 1). Significant differences ($P = 0.10$) were measured only among the isolates of *P. graminis* as exposure to stand-establishment weather conditions increased.

Exposure of *P. recondita* and *P. graminis* urediniospores to temperatures below 0 C for up to 72 h at Estes Park, CO (2,300 m; Fig. 1), and Manhattan, KS (335 m; Fig. 1), resulted in no significant differences in viability among isolates of either species or between elevations. Viability decreased to 1–2% for *P. recondita* isolates and to 2–3% for *P. graminis* isolates within 24 h, and no germination was observed after 96 h of exposure. Minimum nighttime temperatures reached −5 to −9 C, and daytime maxima were −3 to 7 C with 4–5 h above 0 C during the 96 h of exposure at each location. Comparison of daily values or dosage effects due to exposure to solar radiation, relative humidity, and cloud cover versus exposure in a 20-C environmental chamber in the dark did not show any pattern in either increasing or decreasing survival of urediniospores during the 2 yr of tests.

DISCUSSION

The majority of *P. recondita* and *P. graminis* urediniospores are dispersed from the Great Plains wheat fields into the atmosphere between 1000 and 1600 (18). They are released after the leaves in the canopy have dried and as wind velocity and temperature increase during the morning and early afternoon. Most of the inoculum produced within a field is dispersed within the wheat canopy of that field or surrounding fields. Effective long-distance dispersal (>1 km) occurs when urediniospores are produced in the upper portions of the wheat canopy and released in large quantities into the air mass moving across the source canopy (11). Most leaf and stem rust inoculum is believed to be transported at altitudes of between 1,000 and 2,000 m in the Great Plains region (4).

During the overwintering (December through February) or wheat green-up (March through April) phases of an epidemic, air temperatures at 1,000 to 2,000 m above ground level often are below 0 C during the daytime hours, when *P. recondita* and *P. graminis* inoculum would be in the air masses moving about the Great Plains. Viability of inoculum is more important during the winter survival and early spring initiation stages of an epidemic than during other stages of disease development. This is due to the smaller inoculum concentrations, and the potential for different or new virulences in the exogenous inoculum.

Survival of primary inoculum for initiation of leaf rust epidemics during those years in which overwintering does not occur is greatly affected by weather conditions during transport. Factors other than temperature that have been reported to influence the survival of *P. graminis* and *P. recondita* urediniospores, either in storage or in long-distance transport, include the moisture content of the spore (2), relative humidity (2), pathogen genotype (2), host cultivar (17), and light intensity (16,17). All these factors reduce percent viability and length of survival of spores. Bromfield (2) noted that the moisture content of the spores, as well as temperature, has a major influence on survival of urediniospores in storage. Line (17) observed that light intensity during *P. graminis* urediniospore production and the wheat cultivar on which the spores were produced influenced the viability of spores in storage. The effects of shading or protection of clumps of spores, as reported by Chester (6) and Hwang (16) and Line (17), must be considered in storage survival, although it would not be a factor in long-distance dispersal of single urediniospores.

Urediniospores exposed to field light intensities at Manhattan, KS, after maturity of the wheat crop and until wheat emergence in the fall (June through October), when temperatures ranged from 10 to 40 C, survived up to 30 days (end of exposure). This was in contrast to Hwang's (16) observation of survival for only 2 days in the field under high light intensity at 12–26 C. Significantly more inoculum survived exposure to the higher temperatures and solar radiation occurring during the summer and fall than survived the lower temperatures and lower solar radiation exposure during the winter (Fig. 1). Exposure of urediniospores at 2,300 versus 335 m above sea level, where differences in solar radiation could occur with elevation, did not show significant differences in survival when subjected to below 0 C temperatures. Based on the results of our field studies, temperature is the most important weather factor in survival of individual *P. recondita* and *P. graminis* urediniospores during long-distance transport. Significant differences in urediniospore survival among isolates of either *P. recondita* or *P. graminis* were not measured until after exposure for 72 h. Most of the inoculum transported during the time associated with initiation of a spring epidemic would not be in an air mass traversing areas of wheat production longer than 48–120 h. We would not expect differences noted in survival percents among the various isolates to play a significant role in development of severe leaf or stem rust epidemic in the central Great Plains.

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