EFFECT OF POWDERY MILDEW, *ERYSIPHE GRAMINIS* F. SP. *TRITICI* ON PLANT GROWTH AND GRAIN YIELD OF WINTER WHEAT

By

JERRY DEE FRANKLIN

Bachelor of Science in Agriculture

Oklahoma State University

Stillwater, Oklahoma

1979

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1981

EFFECT OF POWDERY MILDEW, ERYSIPHE GRAMINIS
F. SP. TRITICI ON PLANT GROWTH AND
GRAIN YIELD OF WINTER WHEAT

Thesis Approved:

Erwin Williams, Jr.
Thesis Adviser

George L. Barnes

L. L. Singleton

F. J. Gough

W. L. Klarman

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

I wish to express my sincere thanks to my major adviser, Dr. E. Williams, Jr., for his personal attention and patient advice. Appreciation is also due to Dr. L. L. Singleton, for his wise counsel throughout the course of this study. Gratitude is also extended to Dr. F. J. Gough, who provided the chemical, ethirimol, used in the growth chamber, and critical review and suggestions concerning the manuscript. I am also grateful to Dr. G. L. Barnes and Dr. W. L. Klarman, for their review and correction of the manuscript.

The author is thankful for the help of Dr. R. D. Morrison in the statistical design and analysis for this experiment.

I am indebted to Dr. E. E. Sebesta and Dr. H. C. Young, for the use of their facilities and equipment. Thanks are expressed to the Wilber Ellis Company for providing the wettable sulfur formulation "Golden Dew." I am especially grateful to James Schilitz for allowing me to put plots within one of his wheat fields.

Many thanks are due to the faculty and graduate students in the Department of Plant Pathology at Oklahoma State University, for their instruction and encouragement.

I will always be indebted to my parents, Mr. and Mrs. Harold Schultz, and to the rest of my family, for their continual guidance. I am joyfully obligated to innumerable friends for their fellowship, love, and eternal commitment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

Situation in Oklahoma

Two and eight tenths million hectares (seven million acres) of winter wheat (*Triticum aestivum* L. em. Thell) were planted in Oklahoma during the fall of 1979. The cultivars TAM-W-101, Sturdy, TAM-W-103, Caprock, and Payne (30) comprised 40.3% of the planted acreage. These cultivars are ultra-susceptible to the fungus, *Erysiphe graminis* D. C. ex Merat f. sp. *tritici* em. Marchal, which incites the disease of wheat commonly called "powdery mildew." Other cultivars currently grown in the state usually express moderate susceptibility to powdery mildew. Effects of *E. graminis* on wheat development and yield have not been clearly defined. The purpose of this study was to determine the effects of *E. graminis* on grain production in Oklahoma.

During the spring of 1980 this study was initiated both under controlled conditions in a growth chamber, and in the field. The winter wheat cultivar TAM-W-101 was chosen for this study because it had been planted on 35.8% of Oklahoma's acreage in 1979 (30).

Growth Chamber Objectives

Objectives of the growth chamber study were to determine the effects of a severe infection of *E. graminis* f. sp. *tritici* in

TAM-W-101 on seed weight per head, single kernel weight, seed number per head, root weight, root volume, dry straw weight, tiller number, tiller height, and any other observable effects on the growth and development of the plants.

Field Objectives

Objectives of the field experiment were to determine the effect of powdery mildew on yield and 1000 kernel weight; and to determine if gradations in mildew control result in gradations in the yield of wheat.

CHAPTER II

REVIEW OF LITERATURE

Powdery mildew has been damaging to cereal crops at various times in the past. Dimitrou (9) stated that "between 1885 and 1889, the cultivation of cereals in the neighborhood of Stockholm (Sweden) was seriously threatened by the prevalence of mildew" (8, p. 52). Salmon (35) made note of the presence of powdery mildew in Ontario, Canada, during 1900.

Wheat undergoes physiological changes when it is infected with powdery mildew. Pratt (31) showed that after infection of seedlings respiration rose within nine days to a maximum 2.5 to 3.0 times that of controls. This high rate of respiration then fell considerably below that of the controls. The fungal respiration was insufficient to account for the increased oxygen consumption of mildewed leaves. Allen and Goodard (1) reported that the increase in respiratory rate occurs in mesophyll tissue immediately underlying powdery mildew colonies. Allen and Goddard (2) reported a respiration increase of 250% above healthy wheat. Allen (3) showed that chlorophyll content and photosynthesis rapidly drop in heavily infected leaves. Wiese (49) stated that "*E. graminis* f. sp. *tritici* utilizes nutrients, reduces photosynthesis and increases respiration and transpiration of its hosts" (p. 29).

The physiological changes caused by powdery mildew on small seeded cereal grains has been thoroughly reviewed by Jenkyn and Bainbridge (17); therefore, a complete review of these findings is not essential for this study.

Baenziger et al. (4) worked with three selections of wheat of varying susceptibility to powdery mildew. Healthy seedlings were not significantly different in root and shoot length and weight. They did, however, report the following:

> When inoculated, the susceptible line (Chancellor) has 11-13% shorter roots, 52-57% less root wt and 35-61% less shoot wt than the resistant selection (Asosan) the intermediate selection (Sonora) was better than Chancellor which had 13-14% shorter shoots, 33-44% less root wt, and 32-48% less shoot weight (p. 164).

Lupton and Sutherland (28) used ^{14}C to show that a reduction in root and shoot weight of spring wheat was associated with a reduction in proportion of carbohydrate translocated to roots at the third-leaf stage. Baenziger et al. (5) found that a susceptible cultivar and an intermediately resistant line had, respectively, 31% and 22% fewer tillers than a completely resistant line. Root dry weight of the susceptible cultivar was reduced 54%, shoots were 10% shorter and weighed 46% less than the resistant line.

Allen and Goodard (2) reported that wheat infected with *E. graminis* f. sp. *tritici* gradually declined in vigor and growth, resulting in death when severely infected. Pratt (31) stated that infected seedlings quickly showed symptoms of physiological derangement and died in three to four weeks when kept at 18-22 C.

Johnson et al. (18) found that powdery mildew caused soft red wheat to produce grain with lower flour protein content, but it did not effect milling and baking qualities. Therefore, in soft wheat economic loss was related primarily to yield loss and not milling and baking qualities.

Fried et al. (11) found highly significant reductions in seeds per head and seed weight, correlated with infections on the flag and penultimate leaves. Smith and Smith (39) found a 34% and 53% loss, respectively, in tiller number and grain yield with a moderately susceptible cultivar in a greenhouse trial. Two cultivars with general resistance sustained a 16% to 20% reduction in grain yield over controls sprayed with colloidal sulfur when mildew infection was encouraged for the entire period of plant growth. On Prince Edward Island, Canada, Johnston (19) reported a significant difference in yield and 1000 kernel weight between powdery mildew infected spring wheat and a control using soil-applied benomyl. Partial control resulted in yield increases of 35.6% and 1000 kernel weight increases of 5.6%.

Vik (47) stated that over the 20 years preceeding 1938, spring wheat at the Royal Agricultural College of Norway was repeatedly attacked by mildew. Powdery mildew also occurred in other parts of Norway, sometimes in epidemic form. He estimated yield reduction to be 30% to 40%, a greater reduction than that caused by any other fungal disease of the crop.

Herbert et al. (12) found a significant reduction of wheat yield in North Carolina associated with the interaction of powdery mildew and spring topdressing with nitrogen fertilizer in 1948. Where nitrogen was topdressed in the spring, plots on which mildew was controlled yielded as much as 40% more than plots on which mildew was not controlled.

Large (25) found, in 1963, that 2.5% to 7.5% yield losses occurred with light infections of powdery mildew in England. Losses for three of the four years were one hundredweight per acre with the mildew assessment seldom exceeding 5%. During the other year, powdery mildew was found in only trace amounts. None of his ratings exceeded 16% mildew at Feeke's growth stage 10.5 (21). Shanner (36) obtained, in 1972, a 13.8 bushel per acre, or 20% yield increase using benomyl on powdery mildew-infected wheat in Indiana.

Smith and Wright (38) stated, in 1973, that mildew seemed to become more severe in the 1940's with improvements in soil fertility. Yield losses due to powdery mildew on wheat in New Zealand on all trials were just over 5%. In other experiments, losses as high as 15% were not rare. Severe infections coupled with a late spring drought, or barley yellow dwarf virus, caused losses up to 30%. One severely infected cultivars yielded 35% less than when mildew was controlled with Tridemorph. The national yield loss from powdery mildew in New Zealand was estimated at 1.54%.

In 1980 Jenkins and Lescar (16) estimated wheat yield losses in Europe due to powdery mildew as 2.5% to 5.0%. Data from the Imperial Chemical Industries Chemical Company (14) in Europe shows increases of up to 16% in France, and 13% in West Germany from control of wheat powdery mildew.

Foliage disease surveys conducted on winter wheat by James (15) in Ontario, Canada, during 1959 and 1970 led him to estimate that powdery mildew caused an average loss of not more than 1% in 1969 and between one and two percent in 1970. However, in 1971, on Prince Edward Island, Canada, Johnston (20) reported a 36% yield increase and a 16% increase in 1000 kernel weight for susceptible spring wheat. The seed had been treated with ethirimol to achieve powdery mildew control during early growth. Powdery mildew severity levels at flowering were significantly different but were reduced only 20% by the seed treatment.

Johnson et al. (18), in 1974 and 1975, found yield losses of 34% in soft red winter wheat in Maryland field plots. In that experiment, mildew covered an average of 51% of the surface of each flag leaf.

Tuleen (46), during 1976 in Texas, obtained a 5.3 bu or 48% yield increase by controlling powdery mildew on wheat grown under extreme drought by using triadimefon. Sturgeon et al. (42), in 1979, observed a 7.8 bushel or 16% increase in yield of TAM-W-101 wheat by controlling mildew with triadimefon during the early season. However, as the wheat reached Feeke's growth stage 10.5 (21) and for the remainder of the season, infection became severe even on sprayed plots.

CHAPTER III

MATERIALS AND METHODS

Growth Chamber Experiments

TAM-W-101 wheat had been previously sown on November 1, 1979, in a field near Stillwater, Oklahoma. On January 25, 1980, each of 24 seedlings were transported from the field into a 3.78 liter, glazed stone jar with a 1.27 cm diameter drain hole located near the base. Each jar was filled to within 3 mm of the top with clay loam soil. Transplanted, field grown, wheat seedlings were used because of the need for vernalization in winter wheat. None of the wheat seedlings were damaged by transplanting. All transplanted plants were watered equally as needed. Each plant received 0.3 g per jar of "Scotts" fertilizer (18-12-14 NPK formulation) every 21 days with watering. Plants were maintained in a greenhouse for 33 days until a suitable location and experimental design could be determined. Twelve plants were then chosen at random for a growth chamber experiment.

Powdery mildew inoculum was increased on TAM-W-101 seedlings planted at a rate of 20 to 30 in each of 12 four-inch clay pots. The seedlings were inoculated with conidia from a natural infection of seedling wheat grown in a laboratory light bank. Seedlings used to increase inoculum were moved to the Sherer-Gillett model 3714 growth chamber 14 days after planting and kept there until the test plants were inoculated and placed in the growth chamber. At the beginning of the experiment, seedlings maintained for inoculation production were moved to a laboratory bench near a window with southern exposure. Inoculated plants were kept only in the growth chamber and on the laboratory bench to prevent powdery mildew contamination of other ongoing experiments in wheat.

On February 27, 12 plants were randomly chosen from those transplanted from the field and placed in the growth chamber. Light within the chamber was provided by ten, 60 watt incandescent lamps and 16 F72112/Cw/SHO 1500 milliampere fluorescent lamps. Intensity was maintained at 100 microeinsteins M^{-2} S^{-1} at the level of the jar tops and 153 microeinsteins M^{-2} S^{-1} at the flag leaf level. Light measurements were taken with a Lamda quantum/radiometer/photometer model LI-185A, using the quantum sensor near the central portion of the growth chamber. A photoperiod regime of 12 hr light and 12 hr darkness was maintained with temperature at 21 $\pm$ 1 C during light and 15 $\pm$ 1 C during darkness. This temperature is within the range of powdery mildew growth (8, 24, 29, 32, 37, 44, 49). Hygrometer readings indicated that humidity reached 70% in darkness and dropped to 40% during light periods. Humidity, therefore, remained within the range for infection (8, 37, 44).

Jars were arranged in three, two by two latin squares within the growth chamber (Figure 1). Each square contained two infected plants and two on which mildew was controlled by eight sprayings of ethirimol, 5-butyl-2-ethylamino-6-methylpyrimidin-4-ol, trade name Milgo E (Imperial Chemical Industries, Surrey, England) (14). One milliliter of a 280 g/l solution of ethirimol was mixed with 200 ml of water.

The entire plant was then misted to the point of drip with a hand-operated 500 ml polyethylene trigger sprayer. Plants were sprayed at seven-day intervals through jointing and at 14-day intervals after appearance of the head.

Fig. 1. Arrangement of the growth chamber test for comparison of powdery mildew infected and powdery mildew free wheat plants, cultivar TAM-W-101.

Conidia used to inoculate the test plants were collected by lightly tapping a mildew infected leaf, and catching the conidia that dropped on a glass microscope slide held beneath the leaf. These spores were picked up by a cotton swab and rolled onto young host leaves with one forward and one backward roll going from base to tip as described by Sadasivan Nair and Ellinboe (34).

A record of the data of leaf appearance, head emergence, and maturity were kept for each tiller. This was done by designating as day one the date plants were transplanted and numbering successive days from that point. These dates were used in statistical analysis of leaf appearance, heading date, and maturity.

Severity of infection was rated on a zero to nine scale. Like the zero to nine scale of Browder (7), this code allowed rapid and direct recording of data on cards with a keypunch. A "zero" indicated no colonies, and a nine indicated total coverage. Disease assessments of awns and of glumes were made with a similar zero to nine scale.

On day 95 a Vapona ® strip (Shell Chemical Company, San Ramon, CA.) which contained dichlorvas (2,2-dichlorovinyl dimethyl phosphate), was added to control an infestation of the two-spotted spider mite, _Tetranychus telarius_ L. Plants were grown to maturity and harvested 109 days after inoculation.

Height of tillers from the soil surface was measured at harvest. Heads were removed, threshed individually, and counted to obtain number of seed per head. Weight of seed per head was obtained by using a Mettler toploading balance, type P-1200. Single kernel weight was obtained by dividing the weight of seed per head by the number of seed per head. Straw weight was determined for the entire plant on the same balance by weighing air dry straw. Roots were cleaned by gently rinsing the soil from them with a fine stream of water. After soil and particles of organic matter were removed. Roots were air dried for 20 minutes to remove excess water. Root volume was then determined by slowly immersing roots into a completely filled beaker and measuring overflow. Roots were dried in a microwave oven (Model 747, Sears Roebuck and Company, Chicago, IL., 60684) with a power setting of 75% of the 625 watt capacity for 12 minutes. Root weights were determined using a Mettler toploading balance type PN-1210. Data were analyzed as shown in Table I.

Table 1. Source of variation for statistical analysis of growth chamber data

Source of variation	df
Total	11
Squares	2
Rows within squares	3
Columns	1
Col*Sq	2
Treatment	1
Sq*Trt (error)	2

Field Experiments

Field plots were located on the James Schilitz farm west of Ponca City, Oklahoma, in the lowland along the Chikaskia River. The area had a recent history of high prevalence and severity of powdery mildew (50). The field containing the plots was planted on October 7, 1979, with a 20.3 centimeter drill spacing. Anhydrous ammonia was applied at the rate of 40.8 kg of actual nitrogen per 0.4 hectares immediately prior to planting. Such high levels of nitrogen are known to increase powdery mildew (12, 24, 25, 37, 40, 44, 45). In the field experiments, powdery mildew disease severities were dependent entirely on natural infection.

Field trials were established and sprayed initially on April 4, 1980. A split plot design was used (Figure 2). Each replication contained three main plots, one of which was sprayed at intervals of 10-days, another at 20-day intervals, and another at 30-day intervals. One of two subplots in each mainplot remained unsprayed, allowing mildew to reach near normal levels. Subplots were 1.83 x 7.33 meters in size, and contained seven to eight rows of wheat. Two locations, each having four replications, were established in the same field. Each location had different environmental factors acting on them.

Mildew control was achieved by using spray treatments composed of wettable powder sulfur, "Golden Dew," which contained 92% sulfur produced by the Wilbur-Ellis Chemical Company of Fresno, California. Sulfur has been shown effective in controlling powdery mildew on wheat (10, 12, 39). Spray was applied with a 9.46 liter knapsack sprayer equipped with a Teejet 8002 nozzle tip. The suspension contained 0.226 kg Golden Dew per 7.6 liters of water. The spray was applied only over the top of the wheat for the first three applications. The last two applications were over the top and between each row within the canopy.

DESIGN OF FIELD EXPERIMENT

60'

Rep I	30-day sprayed	10-day sprayed	unsprayed	
	unsprayed	unsprayed	20-day sprayed	
Rep II	unsprayed	unsprayed	unsprayed	
	20-day sprayed	10-day sprayed	30-day sprayed	
Rep III	20-day sprayed	unsprayed	unsprayed	40'
	unsprayed	30-day sprayed	10-day sprayed	
Rep IV	unsprayed	unsprayed	30-day sprayed	
	20-day sprayed	10-day sprayed	unsprayed	

Fig. 2. Split plot plan for 10-, 20-, and 30-day sulfur spray treatments at Ponca City, Oklahoma, in the spring of 1980.

Disease ratings were taken at seven day intervals using a zero to nine scale like that used in the growth chamber work. Ratings were applied to entire subplots by examining several plants in each subplot, and estimating an average reading for the subplot. Average disease ratings for each subplot were later kept on the flag leaves, penultimate leaves, third leaves, and heads.

A severe armyworm infestation observed by the producer on May 31, 1980, was controlled on June 2 by an air application of toxaphene and parathion. Flag leaves and all other green leaf tissue was severed by the armyworms but heads were not cut.

Subplots were harvested by hand on June 21, 1980, by laying a 2.44 meter pole between the third and fourth rows, and harvesting the plants on both sides of the pole. Heads were bagged and dried for two weeks in a greenhouse. Threshing was done using a stationary Vogel ® thresher.

Weight of grain from each subplot was determined using an Ohaus 25 kg capacity balance. A 1000 seed count was taken using an electronic seed counter (Model 850-2, The Old Mill Company, Savage, MD.). These seeds were weighed in lots of 250 with a Mettler toploading balance type P-1200.

CHAPTER IV

RESULTS AND DISCUSSION

Growth Chamber Experiments

Between day 33 and 95, colonies of E. graminis f. sp. tritici developed profusely on newly emerging leaves of infected plants (Figures 3 and 4), while sprayed plants were kept mildew free. On infected plants, lower leaves reached an average disease level rating of nearly eight. Following day 95, however, colony development rarely occurred and average disease levels did not rise significantly (Figures 4 and 5). Average disease ratings on the first four tillers to produce heads were, therefore, higher than for the remaining tillers.

Possible explanations of this reduction in colony development on the upper leaves and heads include the following:

1. The dichlorvos strip used to control mites may have altered the host-parasite relationship and reduced or prevented powdery mildew infection.

2. Reduced infection may be partially attributed to the slowing of the hosts' growth rate which is known to reduce susceptibility (49).

3. During an inoculation on day 94, mites were observed to be more active, and seemed to be feeding on applied conidia. Mites may also have been browsing on the conidia and conidiophores of established colonies. This may explain the reduced condia production and infection before addition of the dichlorvos strip.

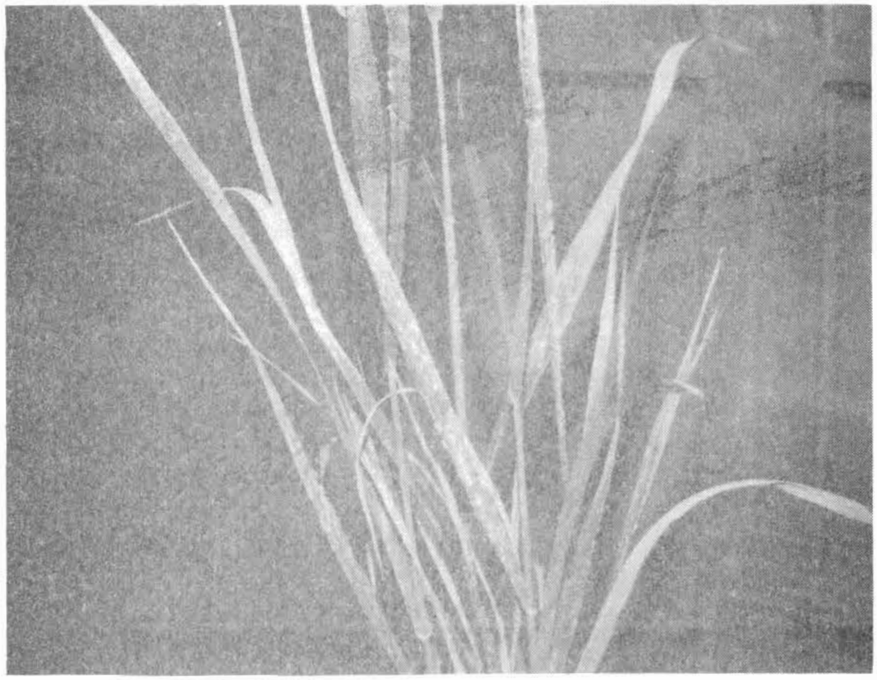

Fig. 3. An example of the powdery mildew disease level obtained on infected wheat plants in the growth chamber experiment.

4. Miticides and insecticides have previously been shown to control powdery mildew (36, 41) and dichlorvos is known to influence the physiology of fungi (6, 33, 51, 52, 53). Sporulation stopped within a week after introduction of the insecticide. Hunter and Caplan (13) and Sutton et al. (43) obtained control of insects and mites using dichlorvos strips for 4 to 72 hours. Therefore, it was unnecessary to leave the dichlorvos in the growth chamber for such a long period.

Average disease ratings (Figures 4 and 5) show that glumes, awns, flag leaves, and penultimate leaves did not have disease levels as high as lower leaves. Smith and Wright (38) obtained data showing

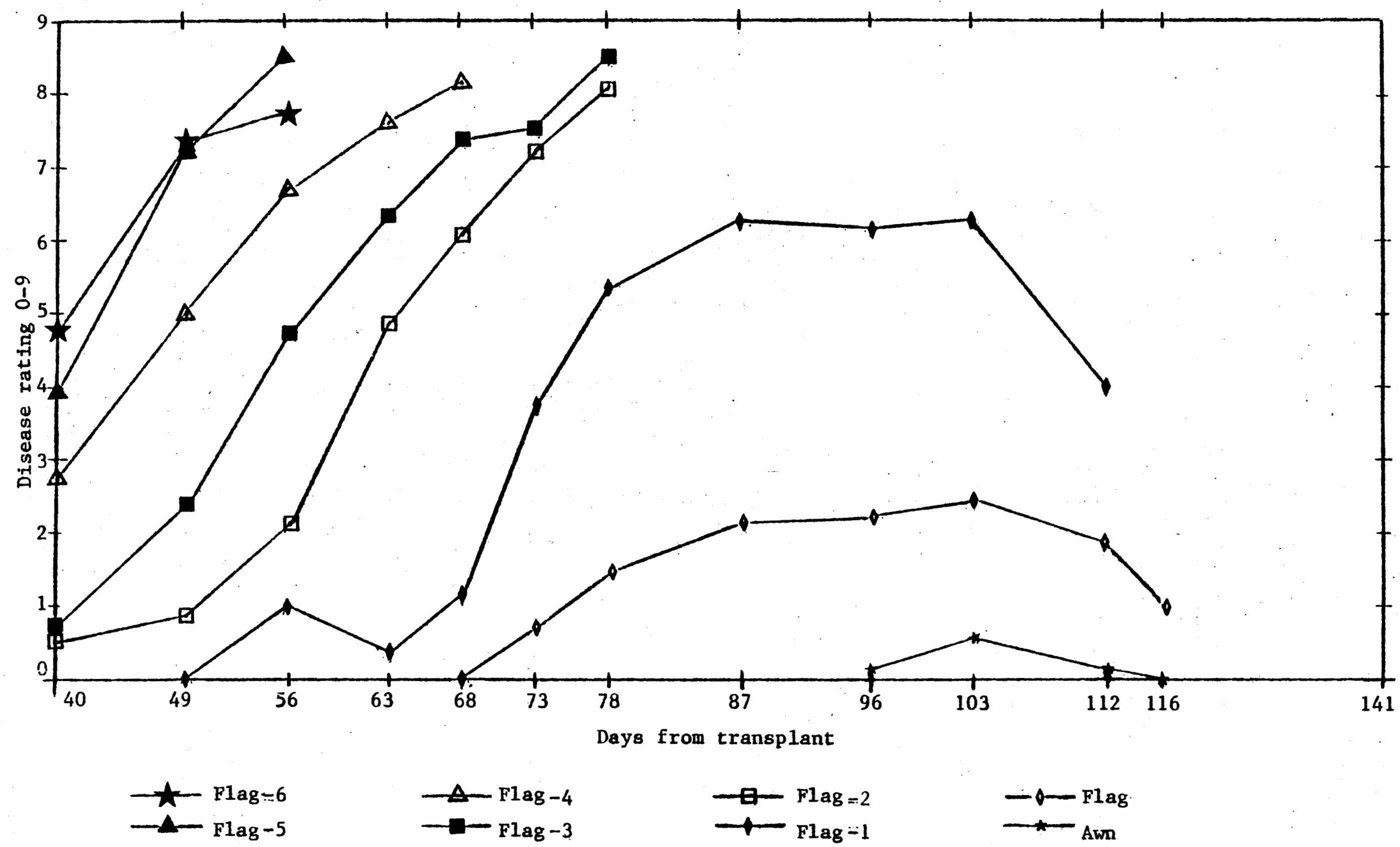

Fig. 4. Average powdery mildew disease levels on the first four tillers of mildew infected plants in the growth chamber. Inoculation was on day 33

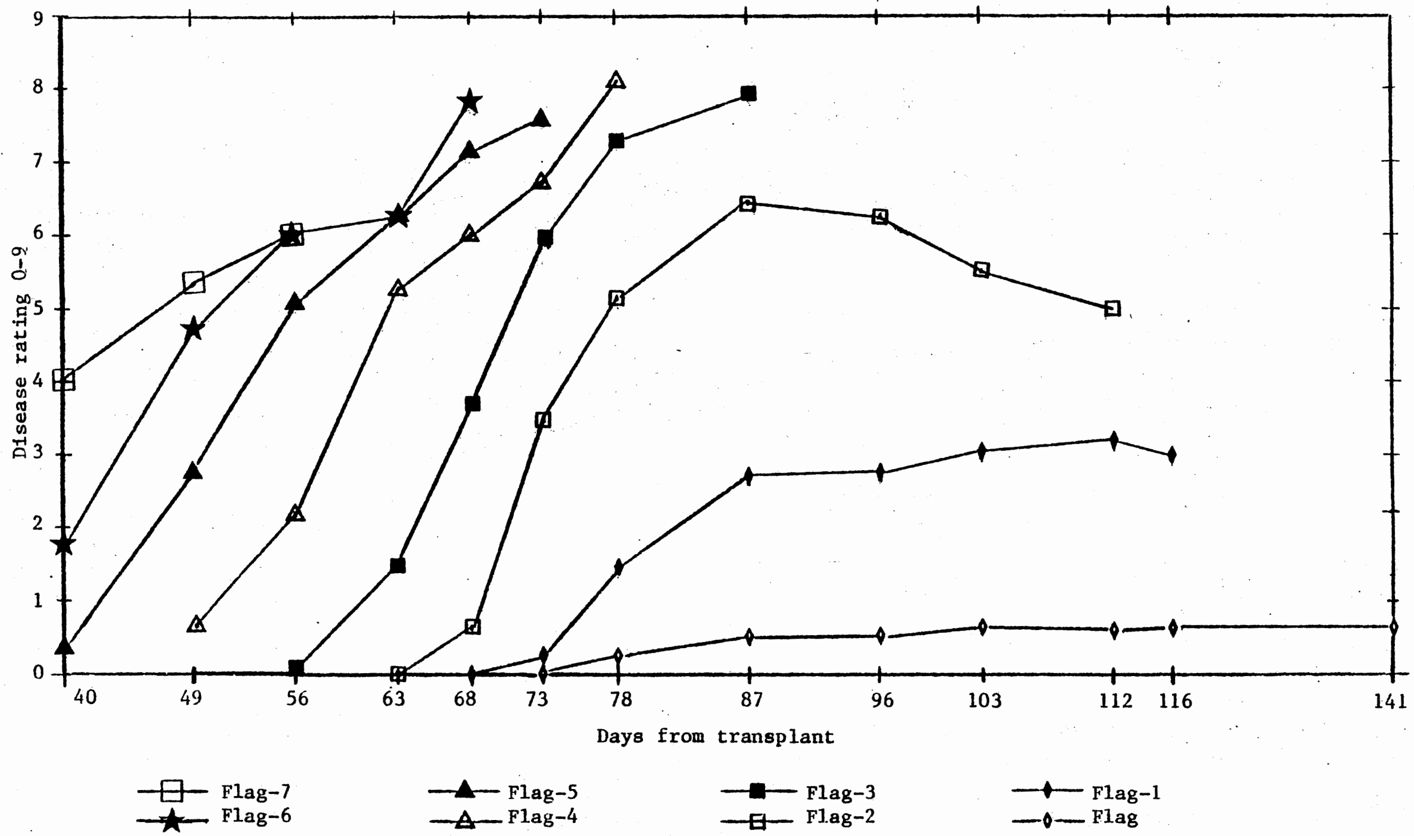

Fig. 5. Average powdery mildew disease levels on all tillers (excluding the first four) of mildew infected plants in the growth chamber. Inoculation was on day 33

that yield losses of 26% can be caused by infections that are not severe on the flag leaf. However, Large and Doling (22, 23) found the flag leaf to be very important to grain filling, and they assess mildew damage in the field on the entire plant at stage 10.5. Johnson et al. (18) also estimated mildew damage at this growth stage, using the percent disease on both the entire plant and the flag leaf. In England, Lupton (27) found that translocation from the flag leaf was entirely toward the ear, and there was no translocation away from the ear. Translocation from the third leaf was totally downward, and assimilates from the penultimate leaves moved partially upward until the death of the third leaf. Assimilates from the penultimate leaf were then translocated mainly to the grain. From this it may be theorized that if the infection had been severe on the awns, glumes, flag, and penultimate leaves; seed weight would have been further reduced.

Single kernel weight was obtained by dividing weight of seed per head by number of seed per head. Individual kernel weights were 15.67% greater in sprayed than in unsprayed plants (Figure 6). This indicated that grain filling was reduced by powdery mildew infection. Seed number per head was increased 23.55% and total weight of seed per head was increased 46.91% by control of powdery mildew (Figure 6). Weight of seed per head is influenced by both kernel number per head and individual kernel weight.

The first four tillers of each plant were more severely infected than those that headed later. An indication of damage done by high levels of powdery mildew may be obtained by comparing the first four tillers of each mildewed plant with the first four tillers of each

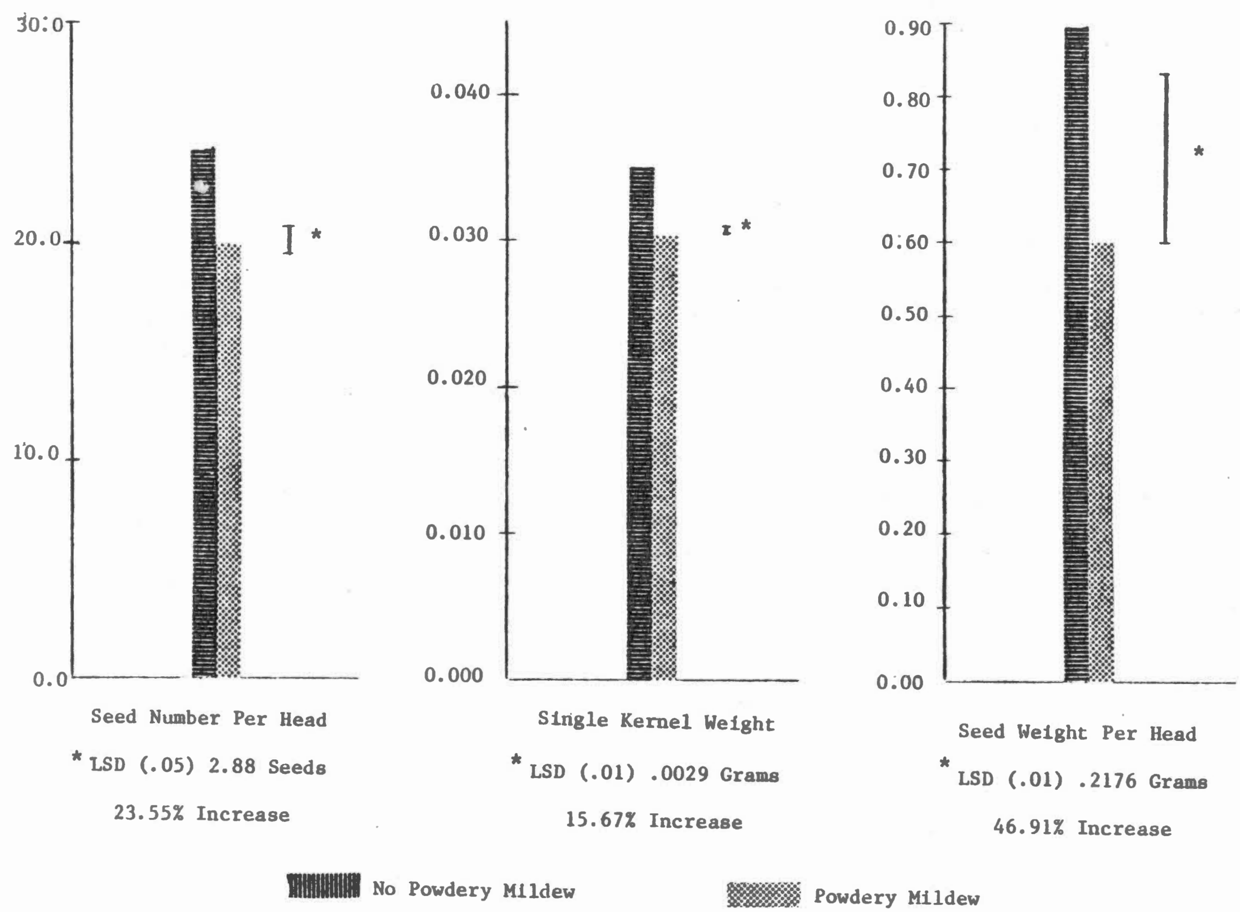

Fig. 6. The effect of powdery mildew on seed number per head, individual kernel weight, and seed weight per head, on all tillers of each plant in the growth chamber

sprayed plant. Seed number per head, individual kernel weight, and seed weight per head on these tillers showed a much greater increase with control (Figure 7).

Remaining tillers could also be compared in a similar way for an indication of damage by lower levels of powdery mildew. In this comparison, seed number per head was not significantly different and increase in both individual kernel weight and seed weight per head was less dramatic, although still significant (Figure 8). Tillers that died before producing heads were shown by Lupton (29) to make no contribution to grain yield by transfer of photosynthates and were thus not included in the data.

Tiller number per plant was not significantly different between the treatments. This is an apparent disagreement with Baenziger et al. (5). However, they inoculated untillered plants less than 13 days old; while in this experiment, plants were inoculated after they were three months old and had initiated tillers. In Oklahoma, powdery mildew symptoms occur almost entirely in the spring (50). For this reason, no effort was made to study affects of powdery mildew on untillered seedlings.

No significant difference was found for root weight, root volume, tiller height, and straw height between treatments. This is in seeming opposition to Baenziger et al. (4). However, they used seedlings inoculated before they were 14 days old and, thereafter, kept under continuous disease pressure. Plants in this experiment had a long period of powdery mildew free growth.

In evaluating results of the growth chamber experiment, it is necessary to examine the data shown in Table II which lists the

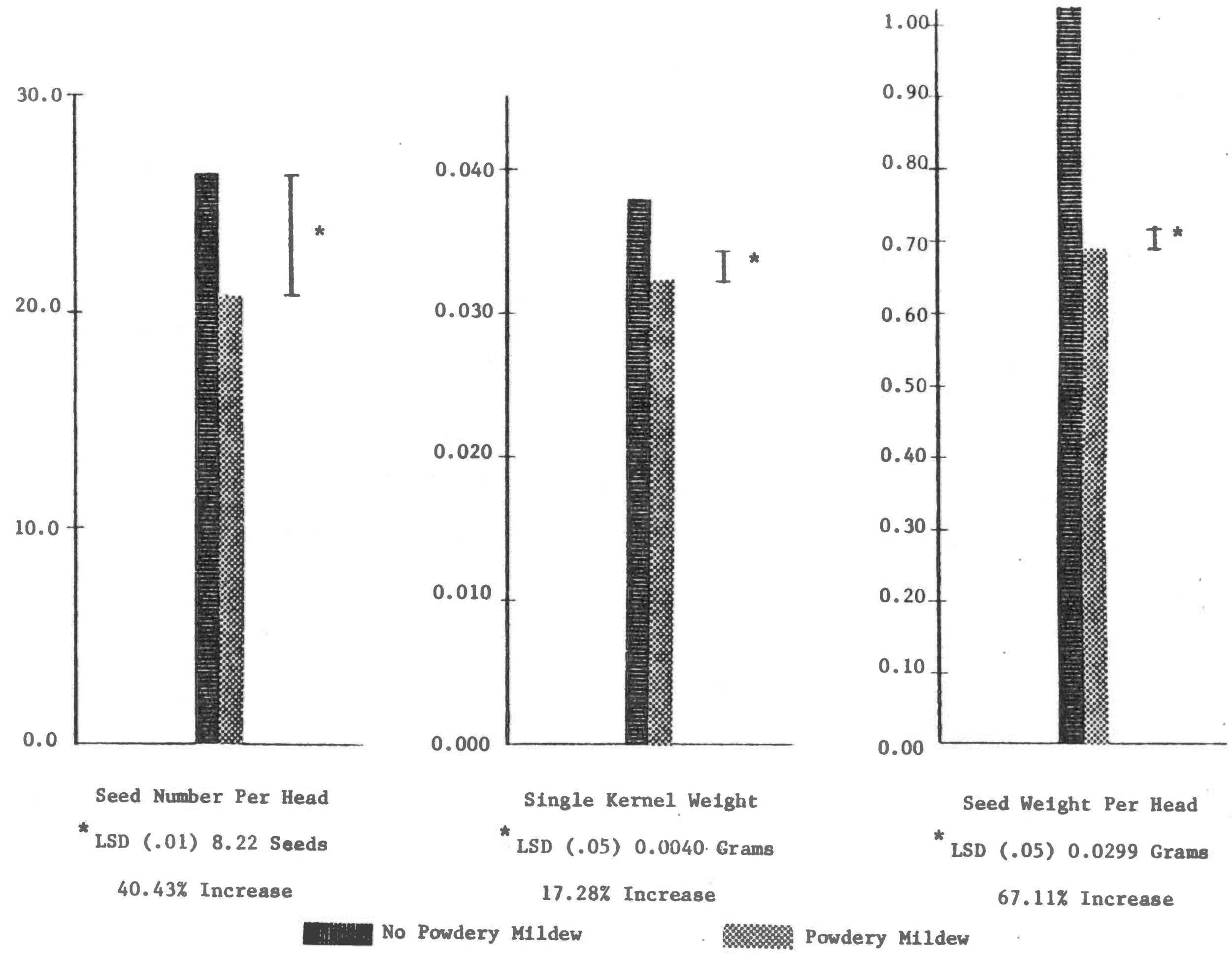

Fig. 7. The effect of powdery mildew on seed number per head, individual kernel weight, and seed weight per head, on the first four tillers of each plant in the growth chamber

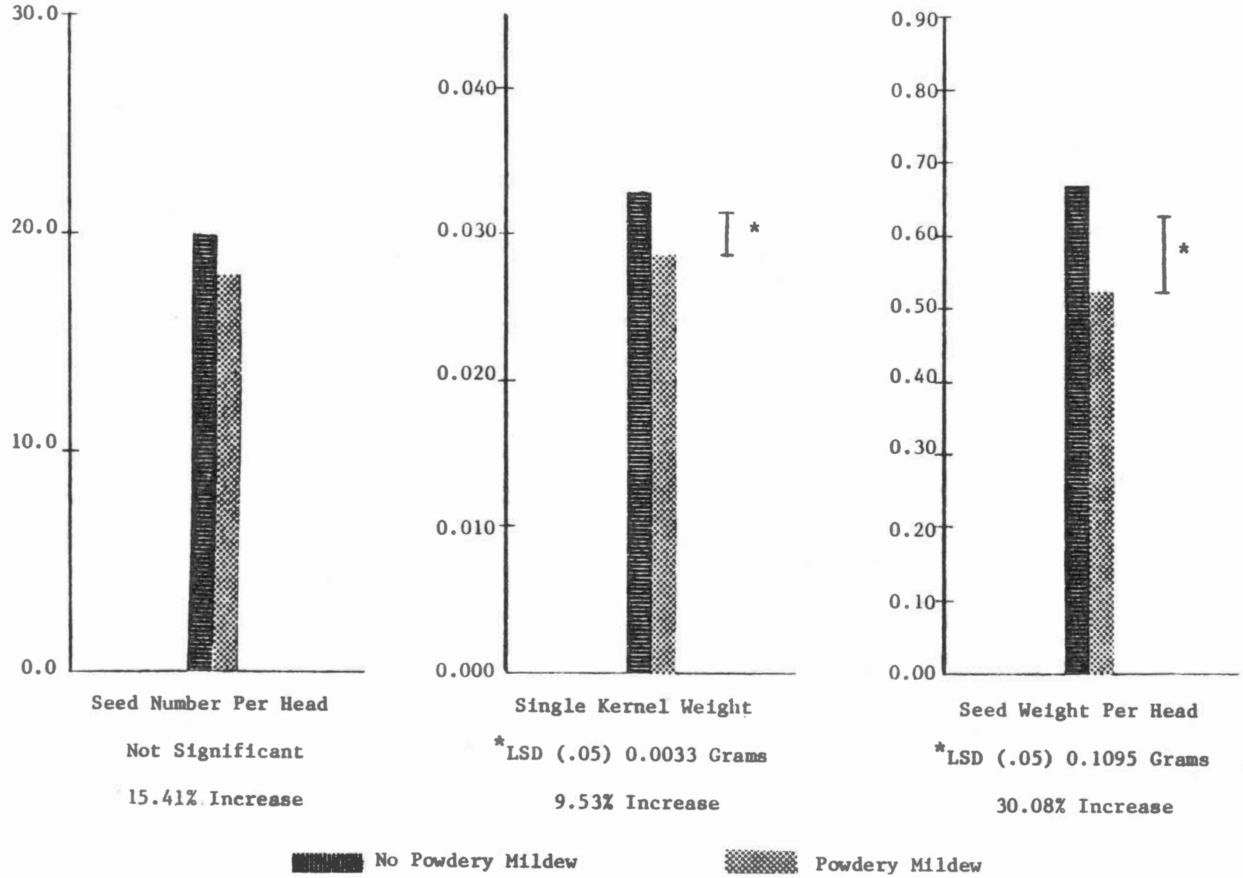

Fig. 8. The effect of powdery mildew on seed number per head, individual kernel weight, and seed weight per head of all tillers (excluding the first four) on each plant in the growth chamber

Table 2. Individual wheat plant data for growth chamber test

Square	Treatment	Root Weight (g)	Root Volume (ml)	Total Number of Seeds	Seed Weight (g)	Straw Weight (g)
1	Powdery Mildew Infected	5.20	36	120	4.24	7.03
1	Powdery Mildew Infected	4.35	31	129	4.08	6.83
1	Powdery Mildew Free	13.98	86	219	8.73	10.03
1	Powdery Mildew Free	16.56	80	277	11.19	11.43
2	Powdery Mildew Infected	8.46	54	185	5.54	9.73
2	Powdery Mildew Infected	6.88	46	150	4.47	8.27
2	Powdery Mildew Free	12.89	74	205	7.30	8.67
2	Powdery Mildew Free	6.81	55	190	6.59	8.10
3	Powdery Mildew Infected	4.90	37	129	3.46	8.49
3	Powdery Mildew Infected	18.33	80	234	6.90	11.41*
3	Powdery Mildew Free	10.62	50	188	6.32	8.05
3	Powdery Mildew Free	9.54	70	183	5.88	7.35

*Obvious powdery mildew tolerant plant.

response for each individual plant. (Note data listed in the line marked with an asterisk.) Yields from this plant were as high or higher than those from powdery mildew free plants. Obviously, this individual plant expressed some form of tolerance or resistance to powdery mildew. The fact that yields from this plant were so much higher than other infected plants contributed to the lack of statistical significance for root weight, root volume, and straw weight.

Sprayed plants grew and matured more rapidly than powdery mildew infected plants. The date of flag leaf appearance and maturity was significantly different at the 5% level of probability, and heading date was significantly different at the 1% level. Head emergence for all six sprayed plants occurred before any of the powdery mildew infected plants (Figure 9).

To determine if heading date was affected by ethirimol sprayings, the experiment was repeated in the same manner except that no plants were inoculated. Traces of powdery mildew did develop, however, before the test was completed. There was no observable evidence that ethirimol spraying alone affected flag leaf or head emergence. This indicated that within the growth chamber experiment, powdery mildew did significantly delay head emergence and plant maturity of TAM-W-101 winter wheat.

Field Experiments

Natural infestations of powdery mildew reached severity levels above 5.0 within the field plots at location one (Figure 10). At location two, the severity level was never greater than 5.0 (Figure 11). The same scale of zero to nine, described for the growth chamber

Fig. 9. The difference in maturity for wheat plants in the growth chamber study. Six sprayed plants with heads (left); six mildewed plants on which heads have not yet appeared (right)

study, was used for disease ratings in the field. Although complete control was never achieved, the 10-day spray interval with wettable sulfur reduced the severity level to below 1.0 at location one, and to slightly above 1.0 for location two (Figures 10 and 11).

At both locations disease severity appeared uniform throughout the test area at zero days; i.e., the time of initial spraying for all treatments. The first notable differences in powdery mildew severities between spray intervals were recorded 20 days after initial spraying. At location one powdery mildew severities continued to increase through the first 50 days of the experiment. At location

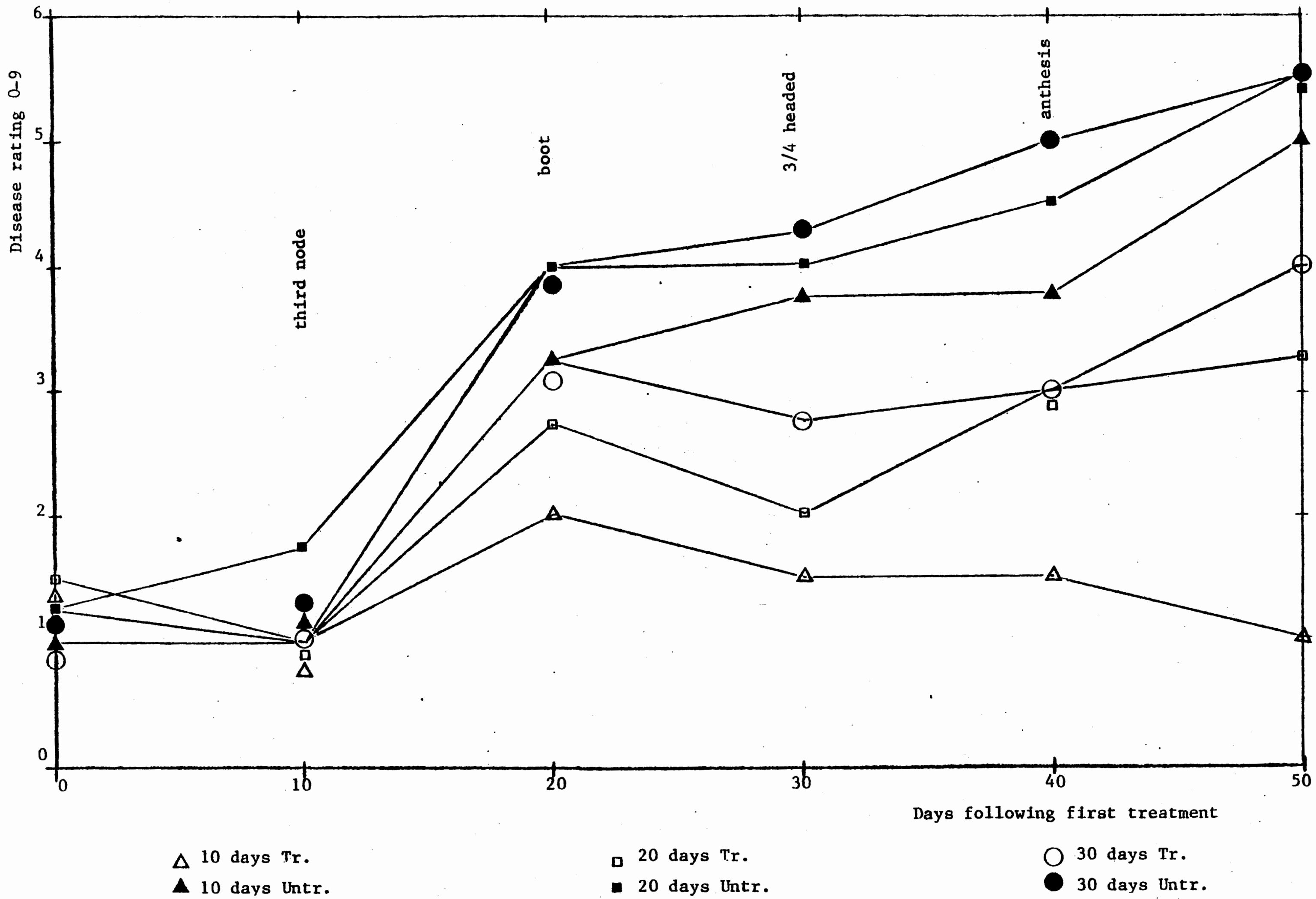

Fig. 10. Powdery mildew control at 10-, 20-, and 30-day spray intervals at location one.

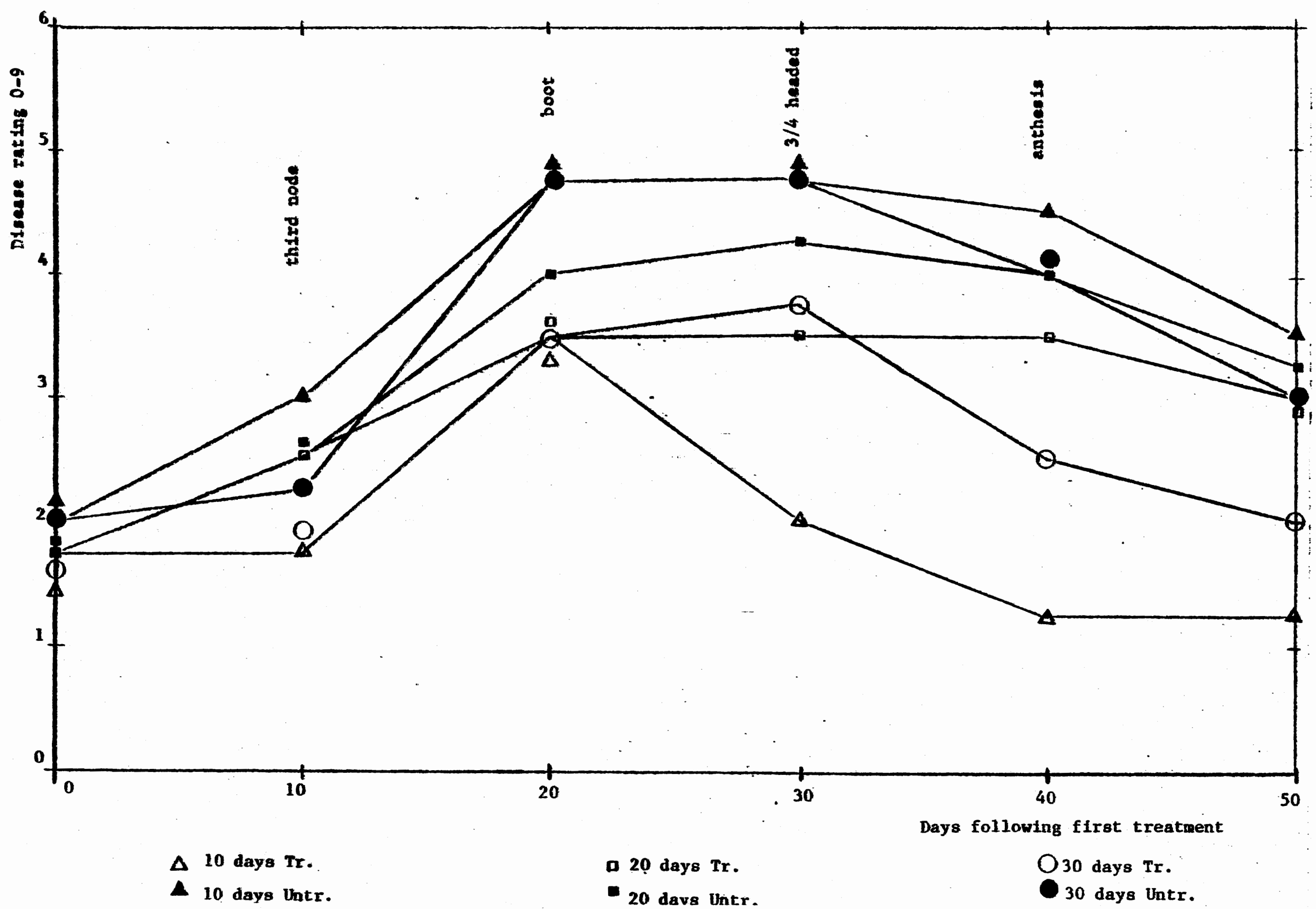

Fig. 11. Powdery mildew control at 10-, 20-, and 30-day spray intervals at location two.

two severity increased through the first 30-day period and then showed a decline after 40 days. No severity readings were taken at 60 days because an infestation of armyworms had eaten or severed all green leaves.

E. graminis f. sp. tritici was certainly the predominant foliar pathogen at the two locations. Other disease symptoms observed on wheat foliage were traces of tan spot, caused by Pyrenophora trichostoma (Fr.) Fekl., leaf rust, caused by Puccinia recondita Rob. ex Desm. f. sp. tritici, and soil-borne mosaic virus. Because evidence of these pathogens was very limited, and there were no noticeable effects of the sulfur spray except for a reduction of powdery mildew colonies, it was assumed that control of the powdery mildew was the major variable factor in this experiment.

Spraying with wettable sulfur at three different spray intervals was chosen for two primary reasons: (1) to achieve, as nearly as possible, powdery mildew free wheat subplots for determining the effects of powdery mildew on grain production, and (2) to produce different levels of disease that would enable one to determine at what disease level powdery mildew may cause economic losses of winter wheat in north central Oklahoma.

Plots treated with the 10-day spray interval received a total of five applications of wettable sulfur at a rate of 9.4 kg/ha/spray treatment (8.3 lbs/acre/spray treatment) of elemental sulfur per application. The 20-day interval received three applications and the 30-day interval was sprayed only twice.

At location one, which had the highest level of powdery mildew, a yield comparison of all sprayed subplots with all unsprayed subplots indicated that grain production was increased by 13.48% in the sprayed subplots (Figure 12). This yield difference could also be calculated as a 11.87% decrease in grain production, which would amount to a loss of 7.34 kg/ha (6.47 bushels/acre). The coefficient of variation for this test at location one was 14% for error A and 12% for error B.

An 11.87% decrease in yield is in approximate agreement with losses projected by Large and Doling (23). They devised a formula stating that twice the square root of the percent powdery mildew assessment at 10.5 Feeke's growth stage [59 on decimal code developed by Zadoks et al. (54)] estimates the percent yield loss. Large and Doling (22) described an infection of 50% as follows: "Upper two leaves fully green with up to 5 percent mildew; 3rd leaves half yellow with 50 percent mildew on green parts; 4th leaves nearly all dead with marks of heavy mildew on them" (p. 52). They estimated a 75% mildew infection as follows: "Three quarters of all the upper leaves covered with mildew or yellow or killed by it" (p. 52).

In this study, at location one, levels of powdery mildew could be derived at about 60% from the following severity estimate in all the unsprayed subplots at the 59 decimal growth stage: flag leaf fully green with 30% mildew; penultimate leaf beginning to yellow with 45% mildew; flag-3 leaves yellowing with 70% mildew; flag-4 leaves dead. The sum of these values divided by the number of values yields a value of 61.2%. Assuming a 60% infection, losses could be estimated by Large and Doling's equation in the following manner:

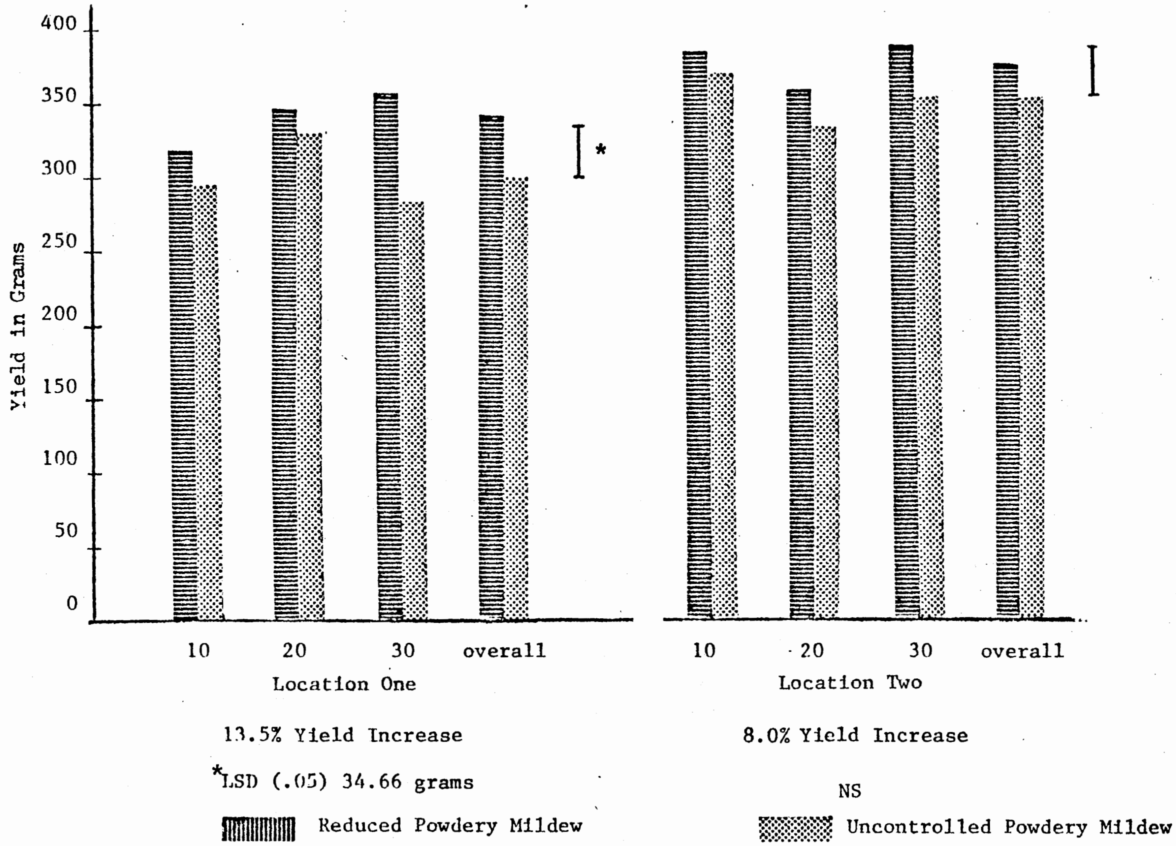

Fig. 12. Average yield of subplots sprayed every 10-, 20-, and 30-days, compared to adjacent unsprayed subplots at both locations (location one, CV error A 14%, CV error B 11%, location two, CV error A 5%, CV error B 10%)

$$\text{Loss} = 2\sqrt{\%\text{ powdery mildew}}$$

$$\text{Loss} = 2\sqrt{60}$$

$$\text{Loss} = 15.49\%$$

This loss estimate is 3.62% higher than the measured loss obtained in this experiment. However, control of the disease was not complete. Therefore, actual loss indicated in this experiment would be less than that which would be expected with complete control. Thus, it would seem that mildew losses in Oklahoma may approximately fit Large and Doling's formula (23). However, more work is needed to more accurately determine the amount of loss attributable to powdery mildew in the field.

At location two, no significant difference was found between any of the comparisons. It is important to note, however, that powdery mildew reached its highest level at the 20-day reading, then leveled off and started to decline by 30 days (Figure 10). The decline in powdery mildew development during late stages of wheat growth may explain why no significant yield reductions occurred at location two. However, a nonsignificant loss was shown (Figure 12).

No significant differences in grain yields were found between the 10- and 20-day spray intervals and their subplots at location one, or between all spray intervals and their subplots at location two. This occurred in spite of a considerable reduction in powdery mildew severity when the spray frequencies were increased (Figure 12). At location one, subplots sprayed every 30 days produced significantly more grain at the 5% level than unsprayed subplots.

The lack of significant differences between yields in the 10- and 20-day intervals is difficult to explain when the 10-day spray intervals reduced powdery mildew levels to one or below. There was no correlation between gradations in powdery mildew levels, obtained with different spray intervals, and grain yields. Possible reasons for lack of significant differences in the field experiments may be:

1. High rates of sulfur may be phytotoxic to winter wheat, although there was no visible evidence of phytotoxicity. On the 10-day interval subplots, a total of only 47 kg/ha of elemental sulfur was applied.

2. TAM-W-101 wheat, even though ultra-susceptible, may express high tolerance to mildew. However, this hypothesis conflicts with results obtained in the growth chamber.

3. Mildew levels obtained in the field epxeriments were not severe enough to seriously reduce grain production, but this hypothesis ignores the significant gain with the 30-day spray interval.

4. E. graminis infections would have lessened the flow of photosynthates and decreased the amount of yield loss had not the armyworm infestation destroyed all leaves.

5. Excessive rain and lodging of wheat in subplots may have obscured the true measurement of the effects of powdery mildew. Lodging is known to reduce kernel weight if it occurs after heading (26, 48). Lodging occurred in the milk stage in some subplots at location one, and as late as maturity in others. The earlier after heading that lodging occurs, the more serious the loss (26, 48). This variation in lodging date obviously caused variations in degree of shriveling among subplots.

Degree of shriveling was measured by taking 1000 kernel weights. At location one, no significant difference in 1000 kernel weights occurred overall between sprayed and unsprayed plots. With the 30-day spray interval, the sprayed subplot was significantly higher in 1000 kernel weight than the unsprayed subplots at the 5% level of probability (Table III). The 10- and 20-day interval subplots at both locations and the 30-day interval subplots at location two were not significantly different from their unsprayed subplots in 1000 kernel weight. Reasons for this may include the following:

1. Sulfur sprays were toxic to wheat and lowered 1000 kernel weights below that caused by powdery mildew. However, at location two, which had less disease pressure and had been sprayed in the same way, no statistical difference between spray treatments interacting with subplots was indicated.

2. _E. graminis_ f. sp. _tritici_ interacts with high sulfur levels to reduce kernel weight.

3. Lodging may have produced variation that masked significance in the 10- and 20-day spraying interval subplots, but the 30-day interval subplots escaped. The first subplot to lodge had the lowest 1000 kernel weight. Other subplots that followed two days later, after heavy rain, also showed reduced 1000 kernel weights. By recalling which subplots had lodged wheat first, it can be determined that, generally, wheat in the 10- and 20-day sprayed subplots and the 30-day unsprayed subplots had lodged during either the first rainstorm of 3.5 cm which occurred sporadically with high winds between May 14-22, or during the second 5 cm rainfall which occurred between May 24-27. The remainder of the subplots did not have lodged wheat

until 8.4 cm of rain fell between the 18th and 19th of June. Subplots were harvested on June 21, 1980.

Table 3. Significance of average 1000 kernel weights in sprayed versus unsprayed field subplots with three spray intervals at location one.

Spray Treatment	1000 Kernel Weight (g)
10-Day Interval Spray	28.6
10-Day Unsprayed	29.1
20-Day Interval Spray	29.7
20-Day Unsprayed	32.5
30-Day Interval Spray	31.9*
30-Day Unsprayed	27.6

*Significant, LSD (.05) = 2.97 g.

As a result, little consideration should be placed on the 1000 kernel weight results. Variation from lodging definitely distorted the data. The distortion may also account for the seemingly greater yield increase with the 30-day spray treatment and the reduced yield increases from the 10- and 20-day spray treatments, especially since 1000 kernel weights in subplots with early lodged wheat were 20% to 30% less than in the other subplots.

The facts remain, however, that at both locations, yields were increased by partial control of powdery mildew, although the increase was not significant at location two. Loss did occur and was related to the amount of mildew present in both growth chamber and field tests. Powdery mildew is causing loss to producers; therefore, further research is necessary to determine the amount of loss that occurs with varying levels of powdery mildew and to develop adequate and inexpensive control measures.

CHAPTER V

SUMMARY

The following is a summary of results obtained from this study:

1. Control of powdery mildew in the growth chamber was shown to increase seed number per head by 23.33%.

2. Kernel weight was increased 15.67% in the growth chamber when powdery mildew was controlled. This was true even with sparse infections on the flag leaves.

3. Weight of seed per head was increased 46.9% by control of powdery mildew on growth chamber plants.

4. In the growth chamber experiment grain yields were reduced more on the first four tillers than on the other tillers, due to higher levels of powdery mildew.

5. Root weight, root volume, straw weight, tiller height, and tiller number were not significantly effected by powdery mildew control in the growth chamber test.

6. A delay in appearance of flag leaf, heading, and maturity was obvious with powdery mildew infected plants in the growth chamber.

7. Overall yields were increased in all field plots by control of *E. graminis*. A 13.48% increase was significant at location one, but an 8.01% increase was not significant at location two due to lower disease levels.

8. A 10-day spray schedule proved more effective in controlling powdery mildew in the field than either the 20- or 30-day spray schedule.

9. Differences in 1000 kernel weight with decreased levels of powdery mildew were not significant in the field because data was obscured by lodging.

LITERATURE CITED

1. Allen, P. J., and D. R. Goddard. 1938. A respiratory study of powdery mildew of wheat. Am. J. Bot. 25:613-621.

2. Allen, P. J., and D. R. Goddard. 1938. Changes in wheat metabolism caused by powdery mildew. Science 88:192-193.

3. Allen, P. J. 1942. Changes in the metabolism of wheat leaves induced by infection with powdery mildew. Am. J. Bot. 29: 425-435.

4. Baenziger, P. S., R. A. Kilpatrick, and J. G. Moseman. 1978. Effect of Ersiphe graminis on roots and topgrowth of related wheat plants. Phytopathology News 12(9):164 (Abstr.).

5. Baenziger, P. S., R. A. Kilpatrick, and J. G. Moseman. 1979. Reduced root and shoot growth caused by Erysiphe graminis tritici in related wheats grown in nutrient solution culture. Can. J. Bot. 57:1345-1348.

6. Bennett, J. W., L. S. Lee, and A. F. Cucullu. 1976. Effect of dichlorvos on aflatoxin and versicolorin a production in Aspergillus parasiticus. Bot. Gaz. 137(4):318-324.

7. Browder, L. E. 1971. A proposed system for coding infection types of the cereal rusts. Plant Dis. Reptr. 55:319-322.

8. Cherewick, W. J. 1944. Studies on the biology of Erysiphe graminis D. C. Can. J. Res., C. 22:52-86.

9. Dimitrou, G. 1910. Ann. Rep. Quebec Soc. for the Protection of Plants from Insects and Fungus Diseases 2:16-19.

10. Doling, D. A., P. J. Saunders, and J. K. Doodson. 1971. Seasonal and geographical variation of powdery mildew on susceptible cereal cultivars. 1958-1968. Ann. Appl. Biol. 67:1-11.

11. Fried, P. M., D. R. Mackenzie, and R. R. Nelson. 1976. Critical point model to estimate yield loss caused by powdery mildew on Chancellor wheat. Proc. Am. Phytopathological Soc. 3:304-305.

12. Herbert, T. T., W. H. Rankin, and G. K. Middleton. 1948. Interaction of nitrogen fertilization and powdery mildew on yield of wheat. Phytopathology 38:569-570 (Abstr.).

13. Hunter, P. E., and I. Caplan. 1963. DDVP resin cylinders for the control of spider mites and some greenhouse insect pests. J. Econ. Ent. 56:419-420.

14. Imperial Chemical Industries. 1976. Ethirimol technical data.

15. James, W. C. 1971. Importance of foliage diseases of winter wheat in Ontario in 1969 and 1970. Can. Plant Dis. Surv. 51:(1):24-31.

16. Jenkins, J. E. E., and I. Lescar. 1980. Use of foliar fungicides on cereals in Western Europe. Plant Disease 64:987-994.

17. Jenkyn, J. F., and A. Bainbridge. 1978. Biology and pathology of cereal powdery mildews. The Powdery Mildews. Ed. O. M. Spencer. New York: Academic Press, Inc. pp. 296-298.

18. Johnson, J. W., P. S. Baenziger, W. T. Yamazaki, and R. T. Smith. 1979. Effects of powdery mildew on yield and quality of isogenic lines of Chancellor wheat. Crop Sci. 19:349-352.

19. Johnston, H. W. 1970. Control of powdery mildew of wheat by soil-applied benomyl. Plant Dis. Reptr. 54(2):91-93.

20. Johnston, H. W. 1972. Control of powdery mildew of wheat by systemic seed treatments. Can. Plan Dis. Surv. 52(3):82-84.

21. Large, E. C. 1954. Growth stages in wheat, oats, barley and rye. Plant Pathology 3:128-129.

22. Large, E. C., and D. A. Doling. 1962. The measurement of cereal mildew and its effect on yield. Plant Pathology 11(2):47-57.

23. Large, E. C., and D. A. Doling. 1963. Effect of mildew on yield of winter wheat. Plant Pathology 12(3):128-130.

24. Last, F. T. 1952. Some effects of temperature and nitrogen supply on wheat powdery mildew. Ann. Appl. Biol. 40:312-322.

25. Last, F. T. 1954. The effect of time of application of nitrogenous fertilizer on powdery mildew of wheat. Ann. Appl. Biol. 41(3):381-392.

26. Laude, H. H., and A. W. Pauli. 1956. Influence of lodging on yield and other charactors in winter wheat. Agron. J. 48:452-455.

27. Lupton, F. G. H. 1966. Translocation of photosynthetic assimilates in wheat. Ann. Appl. Biol. 57:355-364.

28. Lupton, F. G. H., and J. Sutherland. 1973. The influence of powdery mildew (*Erysiphe graminis*) infection on the development of four spring wheats. Ann. Appl. Biol. 74:35-39.

29. Newton, M., and W. J. Cherewick. 1947. *Erysiphe graminis* in Canada. Can. J. Res., C. 25:73-93.

30. Oklahoma Department of Agriculture. 1979. TAM W-101 replaces Triumph as number one variety. Oklahoma Wheat Varieties. Crop Reporting Board. Vol. III, No. 1.

31. Pratt. R. 1938. Respiration of wheat infected with powdery mildew. Science 88:62-63.

32. Pratt, R. 1943. Influence of temperature on the infection of wheat by the powdery mildew *Erysiphe graminis tritici*. Bull. Torrey Bot. Club 70:378-385.

33. Rao, H. R. G., and P. K. Harein. 1972. Dichlorvos as an inhibitor of aflatoxin production on wheat, corn, rice, and peanuts. J. Econ. Ent. 65:988-989.

34. Sadasivan Nair, K. R., and A. H. Ellingboe. 1962. A method of controlled inoculations with conidiospores of *Erysiphe graminis* var. *tritici*. Phytopathology 52:714.

35. Salmon, E. S. 1900. A monograph of the Erysiphaceae. Torrey Bot. Club Mem. 9:211.

36. Shanner, G. 1972. Performance of two fungicides against wheat powdery mildew in the field. Plant Dis. Reptr. 56:358-361.

37. Smith, H. C., and I. D. Blair. 1950. Wheat powdery mildew investigations. Ann. Appl. Biol. 37:570-583.

38. Smith, H. C., and G. M. Wright. 1973. Yield losses caused by powdery mildew on wheat. New Zealand Wheat Review 12:30-34.

39. Smith, H. C., and M. Smith. 1974. Surveys of powdery mildew in wheat and an estimate of national yield losses. New Zealand J. of Experimental Agric. 2(4):441-445.

40. Spinks, G. T. 1973. Factors affecting susceptibility to disease in plants. J. Agric. Sci. 5(3):231-247.

41. Strider, D. L. 1976. Activity of pyrethroid insecticides against powdery mildew fungi. Plant Dis. Reptr. 60:512-514.

42. Sturgeon, R. V., K. E. Jackson, and E. Williams, Jr. 1979. Unpublished wheat foliar disease control trials on file at Okla. Agr. Exp. Sta.

43. Sutton, R. A., P. A. Norman, and A. K. Burditt, Jr. 1969. Dichlorvos strips, a nonresidual fumigant for insects and mites in the green house and laboratory. J. Econ. Ent. 62:1230-1231.

44. Tapke, V. F. 1951. Influence of preinoculation environment on the infection of barley and wheat by powdery mildew. Phytopathology 41:622-632.

45. Trelease, S. F., and H. M. Trelease. 1928. Susceptibility of wheat to mildew as influenced by salt nutrition. Bull. Torrey Bot. Club. 55:41-68.

46. Tuleen, D. M. 1976. Chemical control of powdery mildew in central Texas. Dept. of Plant Science, Texas A & M University. Fungicide and Nematicide tests 32:133(248).

47. Vik, K. 1938. Mildew resistance in spring wheat. Rev. Appl. Mycol. 17:383-384.

48. Weibel, R. C., and J. W. Pendleton. 1964. Effect of artificial lodging on winter wheat grain yield and quality. Agron. J. 56:487-488.

49. Wiese, M. V. 1977. Compendium of Wheat Diseases. The American Phytopathological Society pp. 29-31.

50. Williams, E., Jr. 1980. Personal communication. Oklahoma State University Department of Plant Pathology, Stillwater, OK. 74078.

51. Wolf, J. C., J. R. Lieberman, and C. J. Mirocha. 1972. Inhibition of F-2 (zearalenone) biosynthesis and perithecium production in Fusarium roseum 'Graminearum.' Phytopathology 62:937-939.

52. Wolf, J. C., and C. J. Mirocha. 1973. Regulation of sexual reproduction in Gibberella zea (Fusarium coseum 'Graminearum') by F-2 (zearaleone). Can. J. Microbiol. 19:724-734.

53. Wu, M. T., and J. A. Ayres. 1974. Effects of dichlorvos on ochratoxin production by Aspergillus ochraceus. J. Agr. Food Chem. 22:536-537.

54. Zadoks, J. C., T. T. Chang, and C. F. Konzak. 1974. A decimal code for the growth stages of cereals. Weed Research 14: 415-421.

VITA

Jerry Dee Franklin

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF POWDERY MILDEW, ERYSIPHE GRAMINIS F. SP. TRITICI ON PLANT GROWTH AND GRAIN YIELD OF WINTER WHEAT

Major Field: Plant Pathology

Biographical:

Personal Data: Born in Enid, Oklahoma, September 25, 1957, the son of Mr. and Mrs. Lloyd Franklin.

Education: Graduated from Enid High School, Enid, Oklahoma, in May, 1975; attended Eastern Oklahoma State Junior College from September, 1975 to May, 1977; attended Oklahoma State University from September, 1977 to May, 1979, receiving Bachelor of Science degree in Agriculture with a major in Agronomy; completed requirements for the Master of Science degree at Oklahoma State University in May, 1981.

Professional Experience: Graduate Research Assistant, Department of Plant Pathology, Oklahoma State University, 1979-1981.