Sclerotinia Head Rot of Sunflower in North Dakota: 1986 Incidence, Effect on Yield and Oil Components, and Sources of Resistance

T. J. GULYA, USDA-ARS Research Pathologist, and B. A. VICK, USDA-ARS Research Chemist, Northern Crop Science Lab, Box 5677, North Dakota State University, Fargo 58105, and B. D. NELSON, Assistant Professor, Department of Plant Pathology, North Dakota State University, Fargo 58105

ABSTRACT

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Sclerotinia head rot of sunflower was observed in 98% of surveyed fields in eastern North Dakota in 1986. An estimated 10.2% of the crop was affected, which was a 200-fold increase over that recorded in 1984. The primary factor responsible for the epidemic was higher than normal precipitation during early August, which coincided with the blooming period. Yield loss, primarily due to reduction in seed number and seed weight and to disintegration of rotted heads, was estimated at 4.2%. Head rot caused a small but significant decrease in oil content and a significant increase in free fatty acid content. The proportions of palmitic, stearic, oleic, and linoleic acids were unaffected by head rot. Twenty-six of 164 genotypes tested, including open-pollinated varieties, wild *Helianthus annuus* accessions, and experimental hybrids, had significantly less head rot than the hybrid 894 check. Two genotypes, PI 377530 and PI 380571, exhibited significantly more resistance to both head rot and Sclerotinia wilt than the 894 check.

Sclerotinia sclerotiorum (Lib.) de Bary causes both a wilt (also referred to as basal stalk rot) of sunflower (*Helianthus annuus* L.), initiated by root contact with myceliogenically germinating sclerotia, and an upper-stalk rot and head rot, initiated by airborne ascospore infection (15). Wilt is the predominant Sclerotinia disease in the major sunflower production area of the United States (North Dakota, South Dakota, and Minnesota). In 1984, Sclerotinia wilt was observed in 48% of surveyed fields and affected an estimated 3.1% of the entire crop (7). In contrast, Sclerotinia head rot was observed in only 5% of surveyed fields and affected only 0.05% of the crop. In most sunflower production areas of the world, the predominant disease is wilt. Only in Argentina, France, and Japan is head rot considered a major disease (2,12).

In 1986, the incidence and severity of Sclerotinia head rot in the Dakotas and Minnesota was the highest observed in any year during the past decade (T. Gulya, *personal observation*). This unusual epiphytotic prompted a disease survey to determine head rot incidence in North Dakota and allowed us to 1) study the influence of rainfall patterns on disease incidence, 2) determine the effect of head rot on yield and oil quality components and thus assess yield losses to the 1986 crop, 3) determine if sclerotia from rotted heads were deposited on the soil, and 4) evaluate sunflower germ plasm for resistance to both Sclerotinia head rot and wilt in the same disease nursery.

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MATERIALS AND METHODS

Disease survey and influence of rainfall. Eight sites in eastern North Dakota (official National Oceanic and Atmospheric Administration [NOAA] weather-reporting stations) were selected as areas to survey for the incidence of both Sclerotinia head rot and wilt. The sites were Cooperstown, Devils Lake, Hurdsfield, Jamestown, LaMoure, Petersburg, Valley City, and Wahpeton. Each site was in a separate county and at least 70 km from the nearest other site. Ten sunflower fields located within a 16-km radius of each NOAA site, for a total of 80 fields, were surveyed in late October. Within each sunflower field, five strips of 50 plants each were examined while traversing an inverted V-shaped path halfway into the field. Two categories of head rot severity were recorded: "head intact," with varying amounts of the head affected, and "head shattered," in which the entire head was disintegrated and all seed lost onto the ground. Correlations among various precipitation data for the months of July–September and the average disease incidences for the eight NOAA sites were examined. Precipitation variables examined included weekly rainfall totals for the 11-wk period (14 July–29 September), all possible 2, 3, 4, and 5 consecutive week totals within the 11-wk period, the number of days per week and month with rainfall > 2.5 or 6.3 mm, and the number of 2 consecutive days per week and month with rainfall > 2.5 or 6.3 mm.

Effect of head rot on yield components and oil quality. Four fields with high incidences of head rot, two planted with oilseed and two with confection hybrids, were located within a 16-km radius of Fargo, ND. Within each field, 25 collections of 10 healthy heads and 25 collections of 10 infected intact heads were made, for a total of 1,000 heads of each type from all four fields. All heads were air-dried at 40 C for 48–72 hr and were threshed with a KEM research plot combine. Gross seed yield and 200 seed weight were determined after drying to 10% moisture. Sclerotia were hand-sorted from a 50-g subsample from each collection, and the average number and weight of sclerotia per head was determined. The trash expelled through the combine was collected and hand-sorted to determine the percentage of head rot sclerotia returned to the field.

Oil content was determined on samples from oilseed fields using a 10-g, 0% moisture sample of whole seeds in a Newport Mark 20 nuclear magnetic resonance spectrometer (6). Samples for oil quality analysis were prepared by extracting the ground seed with petroleum ether solvent, filtering the extract, and evaporating the solvent under reduced pressure. The free fatty acid content of the sunflower oil, dissolved in hot, neutralized isopropanol, was determined by titration with 0.1 *N* sodium hydroxide. Phenolphthalein was used as an indicator, and results were calculated as percent oleic acid. A small aliquot of the oil was reserved for determination of fatty acid composition. For this, the oil was dissolved in diethyl ether, transesterified with tetramethylammonium hydroxide in methanol (20%, v/v) (14), and analyzed with an HP 5880 gas chromatograph using an SP-2330 capillary column (30 m × 0.31 mm i.d.) with an isothermal oven temperature of 180 C.

Distribution of seed sizes was determined on the confection samples using a motorized sieve shaker. A 500-ml sample of clean seed was passed over 8.7-mm (22/64 in.) and 7.1-mm (18/64 in.) round hole screens, which separated the seed into three size categories. Confection seed is graded into different size categories and premiums are awarded for the larger size seed. Those seeds larger than 8.7 mm are referred to as "in-shells" or "roasters," those between 8.7 and 7.1 mm as "nutmeats," and those less than 7.1 mm were used as birdseed. Comparisons between healthy and diseased samples for all yield and oil variables were analyzed by *t* tests, and correlations between variables were examined.

Effect of harvesting on deposition of head rot sclerotia on the soil surface. This study was conducted in a sunflower (oilseed hybrid 894) field near Page, ND, that had a high incidence of Sclerotinia head rot. A 92 × 8 m strip within the field was delimited and 12 random strips of 100 plants each were evaluated to determine head rot incidence. The grower harvested the field with an International Harvester 915 combine equipped with a straw spreader and with a drum speed of 500 rpm. Before and immediately after harvest, the number of sclerotia on the soil surface was determined in the following manner. The sclerotia in 24 0.6 × 0.6 m^2 quadrants were counted at 7.6-m intervals on two zigzag patterns throughout the delimited area. The trash was hand-sifted to find any sclerotia covered by debris. The quantity of sclerotia on the soil was expressed as head rot sclerotia per square meter and also as percent of sclerotia produced per square meter.

Germ plasm evaluation. One hundred eighty-nine sunflower genotypes were planted in a Sclerotinia nursery in Moorhead, MN. The field had eight successive crops of sunflower and was naturally infested with *S. sclerotiorum* to a level so that susceptible sunflower varieties usually had > 50% wilted plants at harvest. The tested varieties included 121 open-pollinated varieties, 34 accessions of wild *H. annuus* (both groups from the USDA Plant Introduction Station, Ames, IA), and 34 experimental hybrids from four commercial seed companies. The oilseed hybrid 894 and the USDA inbred RHA801 were used as checks. Hybrid 894 is a widely adapted hybrid that is frequently used as a check in yield trials and is moderately susceptible to Sclerotinia wilt, whereas RHA801 is one of the most resistant genotypes (T. Gulya, *unpublished data*). Plots were single 7-m rows on 75-cm centers, with three replications in a randomized complete block design. Plots were overseeded and thinned back to about 22 plants per row. Wilt and head rot incidence were recorded at physiological maturity in mid-September and expressed as a percent of the stand. Date of 50% bloom was also recorded for all entries. Head rot and wilt data were examined by covariance analysis, with 50% bloom date being the covariate.

RESULTS

Disease survey and influence of rainfall. Sclerotinia head rot was observed in 78 of 80 fields (98%) surveyed in eastern North Dakota. The average incidence at each of the eight sites ranged from 1.7% in the Devils Lake area to 28% around Valley City. Average incidence over all 80 fields was 10.2%, of which 89% were intact rotten heads and 11% were shattered heads. Sclerotinia wilt was observed in only three fields (4%). The surveyed fields constituted approximately 2% of the total sunflower crop planted in the eight counties where the survey sites were located. Of all the precipitation variables examined, only the total rainfall during the second week of August was significantly correlated with disease incidence ($r^2 = 0.81$). Sites with > 28 mm of rainfall between 11 and 17 August had sunflower fields with 21% incidence of head rot, whereas only 4% incidence was observed at sites with < 10 mm of rainfall.

Effect of head rot on yield components and oil quality. Significant reductions in seed yield per head, seed weight, number of seed per head, and oil content were caused by Sclerotinia head rot (Table 1). Averaged over both oilseed and confection samples, there was a 34% decrease in seed yield of rotted, intact heads. There was no difference in gross yield (seed + sclerotia) between healthy and diseased heads of oilseed hybrids, but a 20% difference was noted with confection hybrids. Sclerotia accounted for 19 and 29% of the gross yield per head with oilseed and confection types, respectively. An average of 186 sclerotial pieces per rotted head were recovered, with an average weight of 71 mg. Yield reduction was caused primarily by a decrease in the number of seed per head and, to a lesser extent, by lower seed weight. No significant differences were noted in the distribution of confection seed sizes between healthy and rotten heads. Inshell, nutmeat, and birdseed fractions were 12, 61, and 27% in healthy samples and 10, 64, and 26% in diseased samples. Sclerotial recovery from trash expelled by the research combine averaged 0.3 sclerotia per infected head, which was 0.6% by weight of the sclerotia produced per infected head.

Head rot caused a small but significant reduction in oil content (Table 1), but did not alter proportions of the principal fatty acids. The palmitic, stearic, oleic, and linoleic acid fractions were 6.1, 3.6, 16.0, and 72.9% in diseased samples and 6.3, 3.7, 14.4, and 74.5% in healthy samples. There was a large, significant increase in the free fatty acid content due to Sclerotinia head rot, with oil from diseased seed averaging 10.1% free fatty acid compared with 0.6% for oil from healthy seed.

An estimate of the percent seed yield loss due to head rot in the 80 surveyed fields was obtained by multiplying the average head rot incidence (10.2%) with the seed loss per head (34%) times the proportion of intact, rotten heads (89%), plus the yield loss due to shattered heads (10.2% incidence × 11% shattered heads × 100% loss per head). Sclerotinia head rot was estimated to cause a 4.2% loss in overall yield in the surveyed fields in 1986, of which 3.1% occurred on intact, rotten heads and 1.1% was due to shattered heads. This figure is conservative because it does not include the oil reduction nor the dockage the grower would receive because of the contaminating sclerotia.

Effect of harvesting on deposition of head rot sclerotia on soil surface. The delimited area studied had 46% head rot. Before harvest, there were 0.3 head rot sclerotia per meter on the soil surface from rotted heads starting to disintegrate. No Sclerotinia wilt was observed in the delimited area. Following harvest, 14.3 head rot sclerotia per square meter were detected, which represented approximately 8% of the total sclerotial production per meter in this area of the field. Sclerotia were found scattered all over the harvested area, but were most common in a 1-m band of trash that was expelled by the combine. Sclerotia were counted in 21 of 24 quadrants and ranged from 1 to 23 per quadrant.

Table 1. Effect of Sclerotinia head rot on yield components of oilseed and confection sunflower[a]

Yield components	Oilseed Healthy	Oilseed Diseased	Oilseed Change (%)	Confection Healthy	Confection Diseased	Confection Change (%)
Yield per head, gross (g)	54	52	−4	81	64	−20
Yield per head, net[b] (g)	54	37	−31	81	52	−36
No. of seed per head	1,173	896	−24	755	520	−31
200 Seed weight	9.2	8.2	−10	22.2	19.7	−11
Oil content (%)	45.5	44.4	−2	···	···	···

[a] All comparisons between healthy and diseased heads were significantly different at the $P = 0.01$ level except gross yield of oilseed heads. Each value is the mean of 50 observations, with each observation being a bulked sample of 10 sunflower heads.
[b] Net yield is seed yield per head minus sclerotia.

Germ plasm evaluation. Of the 189 entries planted in the nursery, 164 produced stands suitable for testing and analysis. Entry means for Sclerotinia head rot severity ranged from 0 to 64%, with an average severity of 22%. Sclerotinia wilt averaged 14% over all entries, with a range of 0–46%.

Twenty-six entries (16% of the total) had significantly less head rot than the check hybrid 894 with 25% rotted heads (Table 2). The 26 entries included 20 open-pollinated varieties, four wild *H. annuus* accessions, and two commercial hybrids, or 18, 44, and 6% of the total number of the three types tested, respectively. Conversely, 9% of the 164 entries had more than 42% head rot infection and were significantly more susceptible than the check hybrid. With regard to wilt, 11 entries (7% of the total) were significantly more resistant than 894. Two entries, PI 377530 and PI 380571, were significantly more resistant to both head rot and wilt than 894. A small but significant correlation ($r^2 = 0.11$) was noted between head rot and wilt ratings for these genotypes. There was also a small, significant negative correlation between head rot ratings and flowering dates ($r^2 = 0.28$), which prompted us to use covariance analysis. Wilt ratings were not correlated with flowering date for the genotypes tested.

Table 2. Sclerotinia head rot and wilt ratings and bloom dates of sunflower genotypes with significantly less ($P = 0.05$) head rot than the hybrid 894 check

Entry[a]	Head rot[b] (%)	Wilt (%)	Bloom date[c]
380573	0	3	92
413021	0	3	84
413064	0	11	87
432517	0	7	90
172907	1	10	99
426200	1	20	93
377530	2	1	94
380562	2	2	93
432518	2	29	86
413132	2	21	85
426755	2	29	78
431516	2	5	68
380571	3	1	92
431539	3	4	83
323588	3	26	93
NK2387	3	11	77
431561	3	3	82
432513	4	6	95
406647	4	21	82
432523	4	12	92
432516	5	15	95
413133	5	6	84
431546	5	8	83
432515	5	19	88
NK2476	7	12	76
406022	7	45	94
RHA801	13	2	72
HYB894	25	19	76
LSD	17	18	4

[a] Entry designations are USDA Plant Introduction Station accession numbers with the exception of those with NK prefixes, which are Northrup King experimental hybrids.
[b] Head rot means are covariate (bloom date) adjusted means.
[c] Date of 50% flowering, expressed as number of days after planting.

DISCUSSION

Sclerotinia head rot affected an estimated 10.2% of the 1986 sunflower crop in eastern North Dakota, a 200-fold increase over the 0.05% affected in 1984 (7). The primary factor contributing to the 1986 epiphytotic was high rainfall, as shown both by contrasting 1984 and 1986 weather data and by comparing areas of low and high disease incidence in 1986. In the last documented outbreak of Sclerotinia head rot in North America, Hoes (8) also credited above-normal rainfall in July and August for the large amount of head rot observed in Manitoba in 1968. Adequate rainfall is a prerequisite for two important epidemiological events if head rot is to occur: first, the initiation of apothecia and release of ascospores (1,11) before or during the sunflower bloom period, and secondly, a minimum period of 42 continuous hours of free water to allow ascospore germination and penetration of senescent floral parts (13). Precipitation averages for eastern North Dakota, based on 30-yr data for the months of July, August, and September, are 70, 62, and 48 mm, for a total of 180 mm. In 1986, the 3-mo figures were 128, 72, and 96 mm, for a total of 295 mm, 115 mm above normal. In 1984, precipitation for July, August, and September was 41, 30, and 22 mm, for a total of 89 mm, or 91 mm below normal. Although rainfall for the entire 3-mo period in 1986 was higher than normal, the second week of August was the most important rainfall period with regard to disease incidence. According to the weekly crop-weather reports issued by the North Dakota Agricultural Statistics Service, 92% of the North Dakota sunflower crop was in bloom or past bloom during this week. Thus, high rainfall during the second week of August coincided with the onset of the sunflower growth stage of maximum susceptibility (13) for most of the North Dakota sunflower crop. Although at least one rainfall period was highly correlated with disease incidence, other researchers have observed that soil moisture (10) and leaf wetness (13) may be more highly correlated with *Sclerotinia* incidence on both snap beans and sunflowers.

The relatively low incidence (4%) of fields with Sclerotinia wilt in 1986, compared with 48% in 1984, was noteworthy. Although the low incidence may partially be due to difficulty in observing wilt symptoms late in the growing season, another factor contributing to the low incidence was the reduction in sunflower acreage. The area planted to sunflower in eastern North Dakota in 1986 was 42% lower than in 1984, thus greatly decreasing the possibility of sunflower being grown on land previously infested with *Sclerotinia*. Because Sclerotinia wilt is caused by soilborne sclerotia and low numbers of sclerotia can result in high disease incidence (9), the low incidence of wilt in 1986 indicated that most surveyed fields were not infested with sclerotia. Therefore, ascospore inoculum for head rot infection most likely originated from nearby fields. In North Dakota, apothecia have been observed between June and September under a wide variety of susceptible and nonsusceptible crops (15). Apothecia are infrequently observed in sunflower fields in the north central United States, but are more common in sunflower fields in other countries (11–13), presumably due to rainfall and temperature differences. Ascospores produced in nearby fields can be blown by the wind over distances of at least 1 km (1) and also may be transported by bees visiting infected flowers of other crops (18).

Sclerotinia head rot affected yield components and oil quality in a manner similar to that caused by rust, downy mildew, Verticillium wilt, and Rhizopus head rot (22). Zimmer and Zimmerman (22) observed that Rhizopus head rot caused a reduction in seed weight and oil content, but they did not measure seed number. Rhizopus head rot did not alter the proportions of fatty acids, but it caused a large increase in the free fatty acid content of oil (19,22). Free fatty acids are readily oxidized to aldehydes, which are responsible for a rancid taste in confection seeds or sunflower oil. These free fatty acids can be removed from the oil during refining, but with a resultant loss in oil. No significant changes in the percentages of linoleic and oleic acid, the two principal components of sunflower oil, were noted with Sclerotinia head rot in this study, or with Rhizopus head rot (19).

Sclerotinia head rot presents several other problems in addition to the effects on yield and oil. Seed intended for human consumption must adhere to certain color and appearance standards, but seed from infected heads are often discolored. Furthermore, sclerotia often are the same size and shape and have the same specific gravity as seed, making it difficult to completely remove them from a contaminated seed lot. Aside from their hardness, sclerotia do not appear to pose any health hazards, based on limited animal feeding trials. Ground sclerotia fed to pregnant rats had no effect on fetal weight or litter size, and maternal weight gain was affected only if sclerotia exceeded 4% of the diet (17). Solvent extracts of sclerotia, comparable to the commercial technique used to extract sunflower oil, had no effect in dermal tests on rabbits or when administered orally to mice (3), nor were any references to toxic metabolites produced by *S. sclerotiorum* found by Cole and Cox (4). In contrast, sclerotia have been found to contain immunomodulating compounds and may potentially be of pharmaceutical use (16).

No other research has addressed the importance of head rot as a source of sclerotia for infestation of soil. Data collected with a commercial combine suggest that only a small fraction of the sclerotia in rotted heads are returned to the field. These sclerotia, however, are concentrated in a band behind the combine, despite the use of straw spreaders. In addition, the number and size of sclerotia returned to the soil from shattered, *Sclerotinia*-infected heads are much greater than from a comparable incidence of Sclerotinia stalk. Enisz (5) calculated that 50–100 sclerotia, weighing an average of 27 mg, were produced on a single stalk rot affected sunflower plant, compared with the 186 sclerotia weighing 71 mg produced per plant with head rot in our study. These returned sclerotia, because they can infect many broadleaf crops, present a problem for future management of the field, and thus are an additional factor when estimating the total losses due to head rot.

Significant levels of resistance to Sclerotinia head rot were identified in diverse germ plasm. Several wild *H. annuus* accessions had head rot resistance, which may be different from that found in the open-pollinated varieties. Because head rot incidence and flowering date were correlated, caution must be exercised in interpreting data from natural infection. Most of the genotypes classified as resistant in this study flowered in the later part of August when rainfall was substantially less than in the first 2 wk. Thus, it is possible that some of the resistance observed may actually be disease escape. Inoculation techniques, such as those developed by French researchers (21), could circumvent the disease escape associated with natural infection, but special equipment is necessary to provide optimum environmental conditions (20).

Resistance to Sclerotinia head rot was not highly correlated with resistance to Sclerotinia wilt, which is in agreement with earlier reports (20,21). Only two entries (PI 377530 and PI 380571) exhibited significantly more resistance to both diseases compared with the check 894. These entries were very late maturing, with flowering dates 3 wk later than 894. Entries with acceptable head rot and wilt resistance plus maturity suitable for the north central United States included PI 413021, 431516, 431539, 431561, 413133, and 431546. Even among this group there are some accessions with less desirable traits, such as excessive height (>275 cm) in PI 413021 and susceptibility to the sunflower midge (*Contarinia schulzi* Gagne) in PI 431516. Whereas Sclerotinia head rot is only occasionally important economically to the United States sunflower crop, every effort should be made to recognize sources of resistance and incorporate it into hybrids, especially because Sclerotinia may affect so many other crops grown in North Dakota.

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