Effect of *Puccinia coronata* on Straw Yield and Harvest Index of Oats

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ABSTRACT

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The effect of *Puccinia coronata* infection on straw yield and harvest index (ratio of grain yield to grain-plus-straw yield) was determined for 110 strains of oats (*Avena sativa*). Rust was artifically initiated, and controls were maintained rust-free with a fungicide. Because of inherent differences among the strains, the data were expressed as ratios obtained by dividing the value for a rusted plot by the corresponding value for the rust-free plot. The 110 strains differed significantly in yield of both grain and straw and in harvest index in the rust-free plots. Ratio values for straw yield (which showed statistically significant effects of *P. coronata*) ranged from 0.539 to 1.039 in 1976 and from 0.477 to 1.225 in 1977. The ratios of rusted to rust-free harvest-index values ranged in 1976 from 0.667 to 1.260 and in 1977 from 0.497 to 1.359, showing that harvest indexes of the 110 strains were affected differentially by crown rust. There was no correlation between inherent grain yield and the effect of crown rust on either grain or straw yields. Heritability values calculated from components of variance derived from appropriate analyses of variance were 50 and 64% for straw-yield ratio in 1976 and 1977, respectively, and 83 and 61% for harvest-index ratio in 1976 and 1977, respectively.

Additional key words: resistance, crown rust, genetics.

According to Eagles and Frey (3) oat (*Avena sativa* L.) straw has significant economic value as bedding for livestock; straw yield should therefore be considered by oat breeders and pathologists. Relatively little information has been published on the effect of rust diseases on straw of the small grains. Weiss (15) observed that infection of wheat (*Triticum aestivum*) with either leaf rust (caused by *Puccinia recondita*) or stem rust (caused by *P. graminis*) caused a significant reduction in yield of both straw and grain, with the yield of grain being most affected. Johnson and Miller (6) noted that, in a susceptible cultivar of wheat, leaf rust materially reduced height, leafiness, tillering, and size of stems. Yields of various plant parts of a resistant cultivar, however, were little affected. Murphy (7), as a part of a basic study on the effect of crown rust (caused by *Puccinia coronata* Cda.) infection on oats, inoculated two cultivars with crown rust in the greenhouse at relatively early stages of development. Yields of both grain and straw were progressively reduced when inoculations were made at anthesis, boot, and seedling stages of growth. The percentage reduction in yield of straw was much less than the percentage reduction in yield of grain. Inoculation in the dough stage did not significantly reduce yield of either grain or straw.

The relationship between the yields of grain and straw produced by a given cultivar is closely related to straw yield. According to Donald (1,2), plants that produce a relatively high grain yield in relation to their straw yield are more efficient photo-synthetically than those with a lower ratio of grain to straw. He coined the term "harvest index" to describe this ratio, and defined it as the weight of grain divided by the weight of grain-plus-straw, expressed as a percentage. Thus, a high harvest index indicates a high percentage of grain. In developing the concept of an ideotype of a crop species, Donald believed that the model plant must not only have a high weight or production of grain or other economic plant part, but

that the weight of grain relative to total dry matter production also must be high.

With oats, Sims (13) reported that improvement in yield of certain new cultivars over older cultivars was due almost entirely to increased harvest indexes, without an increase in total dry-matter produced. This mechanism was not universal; one new cultivar that he studied yielded more grain without any change in harvest index. A subsequent review of the literature by Singh and Stoskopf (14) substantiated Sims' conclusion that in many instances the high yields of new cultivars of small grains were expressed in higher harvest indexes with no significant increase in total yield of straw plus grain. More recent literature on the relationship of harvest index to yield and on the inheritance of harvest index has been reviewed by Rosielle and Frey (8).

In view of the current interest in straw yield and harvest index, and the paucity of information on the effect of the rust diseases on these traits, the investigation reported here was undertaken to determine the effect of crown rust on straw and grain yield of currently grown cultivars and advanced breeding lines of oats.

MATERIALS AND METHODS

I selected 110 strains, consisting of named cultivars and advanced breeding selections (mainly from the Uniform Early and Midseason Oat Performance Nurseries and the Iowa Station oat-breeding program) to represent the range of material adapted to central Iowa growing conditions and also to provide a relatively wide range of reaction to *P. coronata*. The strains were grown in 1976 and in 1977 in hill plots, planted 30 seeds in a clump, with hills at 30.5-cm intervals in rows 30.5 cm apart (4). Eight replications were rusted and eight more were protected from rust with maneb fungicide in each of the 2 yr. A mixture of *P. coronata* cultures representative of currently common biotypes of the fungus was used to initiate the epidemic by methods described previously (9). For straw-yield and harvest-index data, plants were cut as close to the soil line as practical with a hand sickle. Seed weight (11) was recorded as the weight of a 200-seed sample. Heading date was recorded as the date that one-half the panicles were fully emerged from the boot.

To remove the effect of inherent differences among the oat cultivars and lines on the various traits being studied, and also to simplify visualization of the effects of disease, I divided values for rusted plots by values for rust-free plots of the same strain. The resulting quotients for grain yield, straw yield, seed weight, and harvest index will be referred to as ratios.

Heritability values were calculated from components of variance derived from appropriate analyses of variance as described by Hess and Shands (5) and Simons (10).

RESULTS AND DISCUSSION

Performance in rust-free control plots. Growing conditions in 1976 were good, and the mean grain yields of the 110 strains ranged from 14 to 47 g/plot. Straw yields, as expected, also were high (Fig. 1). Analysis of variance of grain and straw yield, and of harvest indexes showed significant variation among the 110 strains for these three traits in rust-free plots.

Drought was a problem in 1977, but irrigation permitted plant growth adequate for the purposes of these experiments, with grain yields ranging from 10 to 37 g per plot. Straw-yield data are shown in Fig. 2. Analysis of variance showed significant variation among strains for grain and straw yield and for harvest index, as in 1976.

Severity of crown rust. In both 1976 and 1977, fungicide applied to the rust-free control plots was very effective, disease control was nearly complete, and only a few scattered uredia occurred on the plants. This high degree of control facilitated the quantitative estimation of disease severity in the corresponding rusted plots.

Severity of infection can best be judged by the effect of infection on host plants. Reduction in seed weight is the single best measure of such effects (11). In 1976, seed weight of the most susceptible strains was reduced by almost half (Table 1), indicating severe infection. Analysis of variance showed that differences among strains were statistically significant, and that the most resistant strains were not seriously damaged. Reductions in grain yield also indicated high levels of disease, with yields of susceptible strains reduced by about two-thirds. Yields of the most resistant strains were not measurably reduced. Experimental error for yield was high, but differences among strains were statistically significant. Results of seed-weight data analyses suggested that disease severity was even higher in 1977 than in 1976. This conclusion was corroborated by the yield data for the more susceptible strains. Differences in reduction of both seed weight and yield among strains in 1977 were statistically significant.

Effect of crown rust on straw yield. In 1976, yields of straw of the 110 strains ranged from 43.6 to 85.2 g/plot in rust-free plots, and from 26.7 to 68.8 g/plot in rusted plots (Fig. 1). When these data

TABLE 1. Effect of infection with *Puccinia coronata* on yield of grain and on seed weight for selected strains of oats[a]

Strain no.[b]	Yield ratio		Seed weight ratio	
	1976	1977	1976	1977
10	1.036	1.028	0.918	0.876
20	0.920	0.975	0.896	0.850
30	0.878	0.914	0.880	0.820
40	0.847	0.875	0.865	0.788
50	0.802	0.825	0.854	0.770
60	0.786	0.778	0.840	0.754
70	0.746	0.731	0.814	0.723
80	0.720	0.660	0.786	0.709
90	0.678	0.590	0.767	0.685
100	0.632	0.516	0.744	0.658
110	0.384	0.260	0.600	0.535
LSD ($P = 0.05$)	0.210	0.271	0.072	0.080

[a] The effect of *P. coronata* is shown as the ratio obtained by dividing values for rusted plots by values from unrusted control plots of the same strain.
[b] Means of the 110 strains of oats were arrayed from highest to lowest for each trait. The value for every tenth strain is shown.

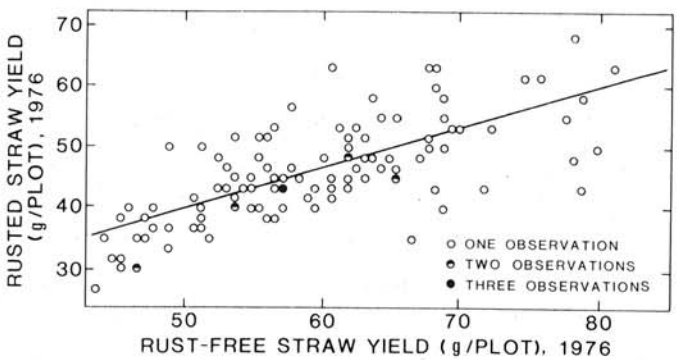

Fig. 1. Yields of straw of 110 strains of oats in rusted and in rust-free control plots in 1976.

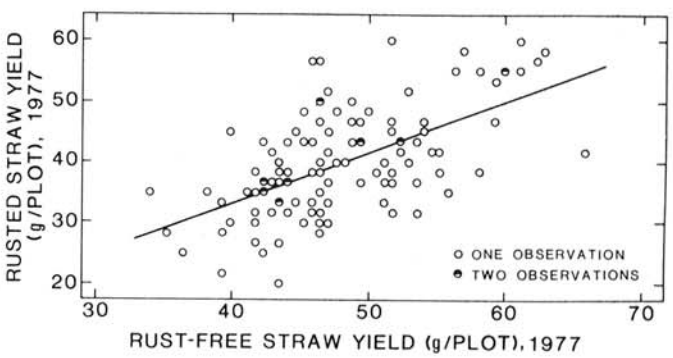

Fig. 2. Yields of straw of 110 strains of oats in rusted and in rust-free control plots in 1977.

were converted to ratios that provided direct comparisons of effects of rust among strains, free of inherent differences in straw yields, analysis of variance showed significant variation among strains. The ratios covered a wide range of response to infection, and were rather uniformly distributed from a high of 1.039, indicating no loss of straw yield from rust, to a low of 0.539, indicating a loss of almost half the potential yield. The mean ratio was 0.775, and the standard deviation, 0.191.

In 1977, yields of straw ranged from 34.3 to 65.7 g/plot in rust-free plots, and from 20.7 to 59.8 g/plot in rusted plots (Fig. 2).

TABLE 2. Correlation coefficients[a] between certain pairs of traits in a study of the effect of *Puccinia coronata* on straw yield and harvest index of oats

Trait	Rust-free yield	Yield ratio	Seed weight ratio	Rust-free HI[c]	HI ratio	Rust-free straw weight	Straw ratio	Heading date
Rust-free yield	*	0.08	0.16	0.69	0.04	0.54	0.19	0.11
Yield ratio[b]	0.05	*	0.69	0.09	0.63	0.03	0.61	0.18
Seed wt. ratio	0.03	0.55	*	0.19	0.41	0.02	0.47	−0.04
Rust-free HI	0.27	−0.01	0.02	*	0.02	−0.20	0.11	−0.04
HI ratio	0.03	0.50	0.61	−0.02	*	−0.06	−0.16	−0.23
Rust-free straw wt.	0.67	0.04	0.00	−0.38	−0.03	*	0.14	0.21
Straw ratio	0.05	0.71	0.14	−0.03	−0.20	0.08	*	0.01
Heading date	0.16	−0.01	−0.08	−0.13	−0.10	0.31	0.07	*

[a] Coefficients below asterisks are for 1976; those above, for 1977.
[b] See text for explanation of ratios.
[c] HI = index (weight of grain divided by weight of grain-plus-straw).

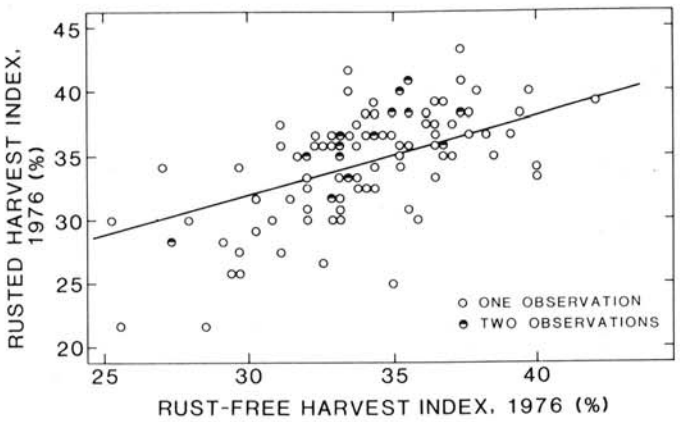

Fig. 3. Harvest-index values of 110 strains of oats in rusted and rust-free control plots in 1976. Two observations are not shown; their coordinates are 53.3 and 47.2, and 35.5 and 39.1 for rust-free and rusted harvest indexes, respectively.

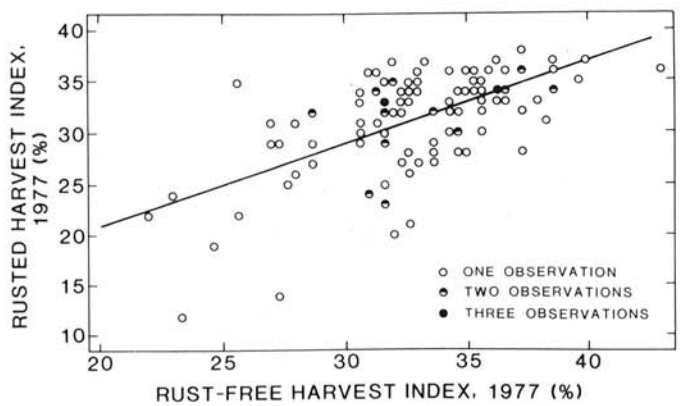

Fig. 4. Harvest-index values of 110 strains of oats in rusted and in rust-free control plots in 1977.

The ratios derived from these data ranged from 1.225 to 0.477, with a mean of 0.838 and a standard deviation of 0.213. Analysis of variance of the ratios showed that the straw yield of the strains varied significantly in response to crown rust infection.

Effect of crown rust on harvest index. In 1976, harvest indexes of the 110 strains in disease-free plots ranged from 53.3 (not shown) to 25.2% in rust-free plots, and from 43.3 to 21.4% in rusted plots (Fig. 3). The ratios derived from these data ranged from 1.260 to 0.667. This array, however, was skewed toward the high end; 65 strains had ratios greater than 1.000. There were only a relatively few strains with ratios in the low end of the array, but these held the overall average to only 1.015. Analysis of variance indicated statistically significant variation among the strains. Duncan's multiple range test at $P = 0.05$ indicated that six strains had ratios significantly higher than 1.000, and thus, that their harvest indexes (or percentage of grain) apparently were increased by crown rust infection. The same test showed that ratios of 13 strains were significantly lower than 1.000, and thus that their harvest indexes apparently were reduced by crown rust.

In 1977, harvest indexes ranged from 43.1 to 21.9% in rust-free plots, and from 37.9 to 12.0% in rusted plots (Fig. 4). The ratios derived from these data ranged from 1.359 to 0.497. If the single high value of 1.359 is assumed to be a sampling anomaly and discarded, the range extends from 1.179 to 0.497. Compared with results in 1976, there were fewer high values and more low values, with only 40 strains having ratios above 1.000. Analysis of variance indicated significant variation among the strains. However, because of the high experimental error in 1977, few differences among individual means were significant. According to Duncan's multiple range test, $P = 0.05$, only two strains had ratios significantly higher than 1.000 and only four had ratios significantly lower than 1.000.

Correlations. Correlation coefficients between selected pairs of traits are shown in Table 2. In rust-free plots, grain yields were positively and significantly correlated with straw yields in both 1976 and 1977, as might be expected. Grain yields also were positively correlated with harvest indexes in the rust-free plots, but in 1976 this correlation was not strong. Correlations between the yields in rust-free plots and the yield and seed-weight ratios (which measure response to *P. coronata*) were negligible, as were the correlations between the yield of grain and the effect of rust on yield of straw. From the practical standpoint, these results suggest that there should be no special problem in selecting for high yield combined with rust resistance in breeding programs.

Differences in relative maturity, as expressed in date of heading, are sometimes associated with effects of crown rust (12). In this study, however, there was no indication from the pertinent correlation coefficients that such a relationship existed, and hence there was no need to consider maturity when interpreting the results.

Heritability. Heritability values, calculated from components of variance, were 50 and 64% for straw-yield ratio in 1976 and 1977, respectively, and 93 and 61% for harvest-index ratio in 1976 and 1977, respectively. These relatively high values suggest the likely effectiveness of selection in breeding programs for strains whose straw yields and harvest indexes are little affected by *P. coronata*.

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