Effect of Pasmo Disease on Flower Production and Yield Components of Flax

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ABSTRACT

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Petals of flax (*Linum usitatissimum*) flowers abscise and drop off 4–6 hr after full expansion of the flower. Therefore, daily flower counts can be taken without having to mark or account for the previous day's flowers. This characteristic was used in making daily counts of flowers of plants in field plots to determine what effect pasmo (caused by *Mycosphaerella linorum*) has on the flowering process and subsequent yield parameters of flax. The flower counts were fitted to a curve using the NLIN procedure of Statistical Analysis Systems Institute and the logistic function CUMF = $a/[1+\exp(b+c^*\text{days})]$, where a = final cumulative number of flowers, b = arbitrary constant, c = proportionality constant, and days = date of count. Flowering curve parameters derived from this equation included maximum rate of flowering ($s=(-ca)/4$), date at which maximum flowering occurred ($sd = b/-c$), and period over which maximum linear daily flower production occurred ($d=4/-c$). Several fungicides, timings of application, and maturity dates of varieties were used to determine their effect on the disease and the interaction of the disease with flowering parameters and yield components. Both benomyl and mancozeb significantly reduced the severity of pasmo ($P=0.05$), whereas cultivar and timing did not. Fungicide treatments resulted in increased yield but did not significantly alter any of the flowering parameters. Pasmo was correlated with sd (1982) and d (1983) ($P=0.01$, df = 70). In both years, pasmo was negatively correlated with yield (1982, $r=-0.243$; 1983, $r=-0.332$). In 1982, disease severity was negatively correlated with number of seeds per boll ($r=-0.241$) and in 1983 with seed weight ($r=-0.263$). Yield in both years was significantly correlated ($P=0.05$) with seed weight (1982, $r=0.310$; 1983, $r=0.371$) and in 1982 negatively correlated with seeds per boll ($r=-0.252$). The flowering parameter sd was correlated ($P=0.01$) with yield (1982, $r=0.233$; 1983, $r=0.288$).

Pasmo, which is caused in flax (*Linum usitatissimum* L.) by the fungus *Septoria linicola* (Speg.) Garassini (perfect stage *Mycosphaerella linorum* (Wr.) Garcia Rada) causes consistent yield losses (about 5%) in South Dakota flax fields (4,7; *personal observations*). In the north-central flax-growing region, infection during favorable environmental conditions may be severe and yield losses of 50% may occur (1,4,8,9,12,14). Most reports indicate that highest yield losses occur when infection takes place during the flowering period (12,14). However, earlier infections have also been reported to cause considerable losses (4). Reductions in seed weight and size account for most of the reduction in yield (3,12). Severe infection also reduces oil content and iodine number (drying quality) of the oil (14).

Dybing et al (2) have noted that, since fruit abortion in flax is generally considered to be low (7), there should be a relationship between flower count and seed yield. A series of equations has been developed by them to describe the flowering process in flax (2). Although there are disease progress models to describe the spread of foliar disease (15) and models or equations describing reproductive growth (5,11), to our knowledge there are no reports of the influence of disease on a reproductive model of plant growth.

The purpose of this experiment was twofold. The first was to determine the effect of pasmo on the flowering process and subsequent yield of flax by testing the influence of the disease on the parameters of a mathematical model of the flowering curve. The second was to utilize flowering curves and model parameters to determine what influence fungicide formulations, timing of applications, or maturity date of cultivars might have on disease ratings and yield components.

MATERIALS AND METHODS

Fungicide treatments. To determine which stage of flowering was affected by pasmo, benomyl (Benlate 50WP, formulation of methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate, 0.3 kg a.i./ha) or mancozeb (Dithane M-45, 80WP formulation of a coordination product of zinc ion and manganese ethylene bisdithiocarbamate, 1.8 kg a.i./ha) was applied once at either the prebloom, full-bloom, or postbloom stage of reproductive development. Applications were made with a hand-held, CO_2-pressurized spray device (R and D Sprayers, Opelousas, LA 70570) at the equivalent of 568 L/ha (60 g/acre). Triton CS-7 (Rohm and Haas) was used as a spreader-sticker.

Experiments were conducted on the Plant Science Research Farm, Brookings, SD. The soil type was a Vienna loam (Udic Haploboralls, fine loamy, mixed). Plots were located in the same area, with flax being rotated with oats each year. Weeds were controlled by standard commercial practices.

Field plots. The field plots consisted of four replications of 18 factorially arranged treatments (3 × 3 × 2) in a randomized complete block design. Each application time (prebloom, full-bloom, or postbloom), fungicide (benomyl, mancozeb, or water), and variety (Wishek or Dufferin) combination was considered a treatment. Each subplot consisted of four rows at 0.36-m spacing and 6 m long.

Flower counts were made on two subsamples of 15.2-cm row length each (mean of 25 plants per subsample) that were chosen randomly in the middle two rows. Each was marked with flags and a loop of string tied around the group of plants in the subsample. The same set of plants was counted each time. Newly opened flowers were counted daily until termination of the flowering stage of development. These subsamples were harvested separately, and all yield component data were derived from them. In addition to flower counts, data were obtained on number of plants per sample, bolls per plant, seeds per boll, and 1,000-seed weight. Total yield estimates were taken from 3 m of each of the two center rows of each subplot.

The flax varieties Wishek (early) and Linnott (late) were used to test the effect of maturity date on disease severity.

Disease. Infection was through natural inoculum. Pasmo ratings used in 1982 were estimates of percentage of stem area infected (scaled as 0–100), and check plots had plants with lesions on 50% of the stem area. In 1983, the percentage of stem area infected was rated on a 0–10 scale (0 = 0%, 10 = 100%). Check plots the second year had stems with 90–100% of the stem infected.

Data analysis. Flowering data were collected and analyzed in the following manner. Counts of each subsample were taken daily throughout the reproductive stage of development of the flax plants. Cumulative flowering data (CUMF) were generated for each subplot, in the SAS (Statistical Analysis Systems Institute, Cary, NC 27511) data step, using the general formula:

$$\text{CUMF} = \text{Present day's flowers} + \text{total flowers to date.}$$

Cumulative flowering data from each subplot were then fitted to a curve using the logistic function:

$$\text{CUMF} = a / [1 + \exp(b + c^{*}\text{days})]$$

where a = final cumulative number of flowers, b = arbitrary constant, c = proportionality constant, and days = date of count. A flowering curve was generated for each subplot and the logistic function parameters (a, b, and c) were then determined using the NLIN procedure of the SAS software on a mainframe computer.

Flowering curve parameters, determined from the equations that were derived from the logistic function, included maximum rate of flowering ($s = (-ca)/4$), date at which maximum flowering occurred ($sd = b/-c$), and period over which maximum linear flower production occurred ($d = 4/-c$) (C. D. Dybing, *personal communication*). These values were also calculated during the SAS data step.

Finally, the logistic function parameter a (total flowers) and flowering curve parameters s, sd, and d, along with yield, yield components (seeds per boll [sb], bolls per plant [bp], and 1,000-seed weight [swt]), and disease severity data, were analyzed by analysis of variance (ANOVA/SAS) to determine whether chemical treatments, timings of application, or cultivars would alter the flowering process and therefore influence the yield potential of the flax plants tested.

RESULTS

Flowering curve. The cumulative flower counts from each subplot were fitted to the logistic equation and a flowering curve generated for each subplot. Of the 144 curves produced (72 for each year), the mean R^2 = .98 for all curves generated, indicating an excellent fit of the flowering data to the logistic curve. An example of the flowering curve with flowering curve parameters is shown in Figure 1.

Effects of fungicide treatments, timing of applications, and cultivars on disease. Application of benomyl (systemic) or mancozeb (contact/protectant) significantly reduced severity of pasmo compared with controls (Table 1). Benomyl gave significantly better disease control (P = 0.05) than mancozeb in 1983 but not in 1982. Cultivar and timing of fungicide applications did not significantly influence disease severity.

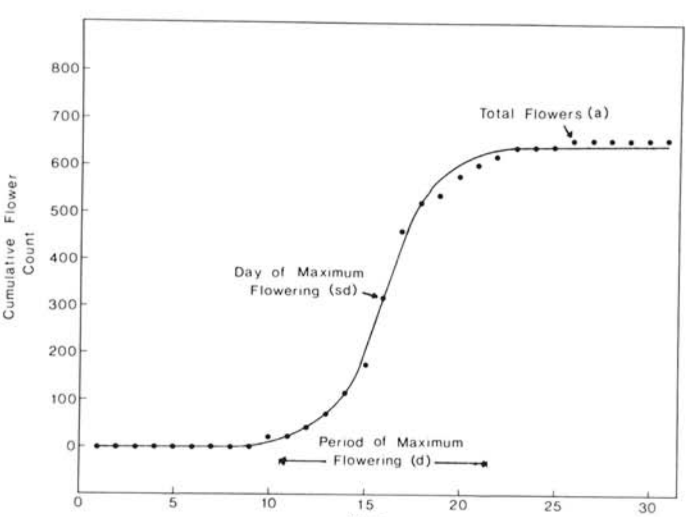

Fig. 1. Example of data from one subplot fitted to logistic equation where variety = Wishek, treatment = mancozeb, application = prebloom, replications = three, a = 645.24, b = 11.44, c = −0.712, s = 114.88, sd = 16.07, and d = 5.616.

Effects of fungicide treatments on yield and flowering curve parameters. In both years, yields of fungicide treatments were significantly greater than those of the controls (Table 1), and increases in yield of 6.7 and 7.2% for single applications of benomyl occurred in 1982 and 1983, respectively. A significant difference in cultivars (P = 0.05) with respect to bolls per plant and seeds per boll (1983) was seen (Table 2). There was also a treatment by application interaction in 1983 for the variable of bolls per plant. No other significant differences were seen for the influence of either fungicide treatments, timing of applications, or cultivars on the individual yield components of bolls per plant, seeds per boll, and seed weight in either year.

With the exceptions of a significant cultivar/treatment interaction (1983 only) in the parameter rate of flowering (s) and a cultivar effect on day of maximum flowering (sd) (1983 only) (Table 3), there were no significant differences in total flowers, day of maximum flowering, rate of flowering, or period of maximum flowering as a result of fungicide treatment, spray timing, or cultivar for either year.

Correlations between disease and flowering curve parameters and yield components. Pasmo was significantly correlated with the date of maximum flowering (sd) (r = 0.325) in 1982 and negatively with the period of maximum linear daily flower production (d) (r = −0.233) in 1983 (Table 4). No significant correlations (P = 0.05) were found with total number of flowers or rate of flowering. Further, no correlations were found with the parameters sd and d in alternate years. Disease severity was negatively correlated with yield in both 1982 (r = −0.243) and 1983 (r = −0.332) (Table 4). Disease severity was negatively correlated in 1982 with number of seeds per boll (r = −0.241) and in 1983 with seed weight (r = −0.263). Other components were not affected.

Correlations of yield with yield components. In both years, yield was significantly correlated with seed weight (1982, r = 0.310; 1983, r = 0.371), and in 1982 yield was negatively correlated with seeds per boll (r = −0.253) (Table 5). Of the various parameters associated with the flowering curve, date of maximum flowering (sd) was significantly correlated (1982, r = 0.223; 1983, r = 0.228) with yield.

TABLE 1. Fungicide effects on control of pasmo disease (caused by *Mycosphaerella linorum*) and subsequent yield of flax

	Mean disease[y] (percentage stem infection)		Mean yield (kg/ha)	
Treatment	1982	1983	1982	1983
Control	18.3 a[z]	7.8 a	1,355 b	1,824 b
Mancozeb	7.6 b	6.4 b	1,401 ab	1,854 ab
Benomyl	3.2 b	1.9 c	1,452 a	1,955 a

[y] Disease ratings were based on area of stem covered by pasmo lesions. In 1982, ratings were scaled 0–100; in 1983, 0–10.
[z] Means with same letter do not differ significantly at P = 0.05 level of significance according to Walter-Duncan multiple range test.

TABLE 2. Analysis of variance of flax yield component response to effects of chemical sprays, timing of sprays, and cultivars

		Bolls/plant (mean square)		Seeds/boll (mean square)		1,000-seed weight (mean square)	
Variable	df	1982	1983	1982	1983	1982	1983
Treatment (T)	2	1.092	1.478	0.136	0.027	0.013	0.650
Application (A)	2	9.500	0.757	0.098	0.055	0.088	0.048
Cultivar (C)	1	1.227	216.04**[z]	2.428*	1.227	1.071	0.007
T × A	4	5.496	6.56**	0.138	0.265	0.028	0.098
C × T	2	3.204	4.432	0.201	0.210	0.222	0.054
C × A	2	3.065	2.480	0.109	0.216	0.058	0.009

[z] * = Significant at P = 0.05, ** = significant at P = 0.01.

TABLE 3. Analysis of variance of response of flax flowering curve parameters to effects of chemical sprays, timing of sprays, and cultivars

		Total flowers (mean square)		Rate of flowering (mean square)		Day of maximum flowering (mean square)		Period of maximum flowering (mean square)	
Variable	df	1982	1983	1982	1983	1982	1983	1982	1983
Treatment (T)	2	4,119.36	41,118.44	51.45	654.89	1.04	12.75	1.035	1.825
Application (A)	2	1,540.90	17,242.53	58.04	351.07	6.45	2.40	0.378	0.546
Cultivar (C)	1	14,822.06	14,815.62	479.73	99.17	163.26	153.48**[z]	0.005	3.673
T × A	4	20,022.50	15,776.70	556.85	230.06	2.44	1.95	3.223	2.244
C × T	2	6,535.22	17,736.00	259.84	474.40*	16.72	1.13	0.213	1.049
C × A	2	27,288.12	7,802.62	1,511.89	91.50	4.01	1.43	2.726	0.356

[z]* = Significant at $P = 0.05$, ** = significant at $P = 0.01$.

DISCUSSION

Because of the excellent fit of cumulative flower counts to the logistic curve, the curves and subsequent flowering parameters provided a novel method of assessing the relationship of the disease pasmo to the reproductive phase of the flax plant. Fungicides were used to control pasmo during various stages of flower development, thus testing the influence of the disease on the flowering process and resulting yield components. We hypothesized that if pasmo significantly affected flowering, then flowering curves should be altered.

The fungicides benomyl and mancozeb were effective in disease control, with benomyl giving a 7% increase in yield for a single application. This indicated that protection of the plants during the reproductive period is important. Multiple applications (6) give approximately the same increase, which shows that a single application of fungicide at a critical stage of the disease progress can be effective.

It is apparent from the data that the effect of pasmo on seed weight and yield occurs after anthesis. If this is the case, the fungicide applied postbloom should have been the most effective. This was true, although the increase in yield resulting from time of application was not statistically significant.

Since late multiple sprays did not contribute significantly to yield over late single sprays, we may ask what is being protected and what is the subsequent source of the photosynthates that contribute to seed fill. In speckled leaf blotch of wheat caused by *Septoria tritici* Rob. ex Desm., infection of the upper plant parts is considered to be the most significant factor in reduction of yield (16–18). Infection on upper plant parts usually affects kernel weight and grain number. Protection of the upper plant parts of flax also appears to contribute to kernel fill. Further investigation will be needed to determine whether certain yield components might be influenced by very early fungicide treatments. Although use of either fungicide resulted in increased yield, there was no significant correlation between disease and total number of flowers. This result indicates that *S. linicola* does not interact with flower production per se, but with postflowering events such as seed set or seed fill. The conclusion is supported by significant (alibi low) negative correlations of seeds per boll (1982) and seed weight (1983) with pasmo. The presence of fewer seeds per boll is a result of ovary abortion, whereas decreased seed weight could be caused by loss of photosynthate resulting from pasmo-induced early senescence. Previous workers have also shown that pasmo primarily affects seed weight and quality (13).

Correlations of yield with yield parameters also indicate seed weight as the more important component of yield (Table 5). The negative correlation of seeds per boll with yield in 1982 (Table 5) reflects an inverse relation of seed size to number of seeds that occupy the boll. In other words, the fewer the seeds, the larger they can be. Why this was not the case in 1983 is not known.

The flowering parameter *sd* was positively correlated and *d* negatively correlated with pasmo in 1982 and 1983, respectively. The day of maximum flowering (*sd*) is the midpoint of the exponential portion of the flowering curve. Changes in *sd* are a result of either a change in the actual midpoint (with *d* for both curves the same length) or a change in the period of flowering (*d*) that results in a shift of the midpoint. Since pasmo is normally associated with earlier flowering, it would seem odd that in this study it is positively correlated with *sd*. However, since the curves are generated from the first day of flowering and not from a specific date, *sd* only predicts "lateness" relative to the first day of flowering. If calendar date were used, then *sd* could be used to measure actual "lateness" or "earliness" of flowering. This parameter would be the best measure of the relation between maturity date and disease. Sackston and others (4,9,10,12,14) observed that early cultivars tended to be more susceptible than late ones. Pederson and Michaelson (10) noted that selection for resistance to *S. linicola* resulted in selection for "lateness." There should be a positive correlation between maximum disease progress and the date of maximum flowering. This notion will be tested.

The negative correlation of pasmo with *d* indicates that the longer the flowering period, the less the expression of pasmo. One explanation might be that weather that is conducive to flowering (e.g., cool temperatures) is not adequate for expression of the symptoms of pasmo. Our observations of pasmo in the field support this view.

TABLE 4. Correlation of pasmo disease severity with flowering curve parameters derived from logistic equation and various yield components

	Correlation with disease severity	
Parameter/component	1982	1983
Total flowers	0.213	0.059
Rate of flowering	0.153	−0.086
Period of maximum flowering	0.015	−0.233*[z]
Day of maximum flowering	0.325**	−0.214
Yield	−0.244*	−0.333**
Seeds per boll	−0.241*	0.046
Seed weight	0.165	−0.263*
Bolls per plant	0.104	0.067
Oil content	−0.335	−0.126

[z]* = Significant at $P = 0.05$, df = 70, and ** = significant at $P = 0.01$, df = 70.

TABLE 5. Correlation of total yield of flax with flowering curve parameters derived from logistic equation and various yield components

	Correlation with yield	
Parameter/component	1982	1983
Bolls per plant	−0.044	0.174
Seeds per boll	−0.253*[z]	0.093
Seed weight	0.310**	0.371**
Total flowers	−0.173	0.036
Rate of flowering	0.002	0.123
Period of maximum flowering	−0.134	−0.142
Day of maximum flowering	0.223*	0.228**

[z]* = Significant at $P = 0.05$, df = 70, and ** = significant at $P = 0.01$, df = 70.

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