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Integrated Control of Septoria Diseases of Wheat

Septoria glume blotch of wheat incited by *Septoria nodorum* (Berk.) Berk. (perfect state: *Leptosphaeria nodorum* Müller) and Septoria leaf blotch of wheat caused by *S. tritici* Rob. ex Desm. (perfect state: *Mycosphaerella graminicola* [Fuckel] Schroeter) are major wheat diseases in many parts of the world, causing serious yield reductions (13,14, 21). The annual average losses in yield due to Septoria glume and leaf blotch in the United States were estimated at 1% in a 1965 report (1). With severe epidemics, some vulnerable wheat cultivars may suffer 30–50% losses in yield, resulting in shriveled grain unfit for milling.

Pycnidia bearing pycnidiospores of *S. tritici* were found on plants of wild emmer (*Triticum dicoccoides* Koern.) collected in 1902 in the Jerusalem area and on plants of durum wheat (*T. durum* Desf.) collected in the Jordan Valley in 1924. Some "land varieties" of bread (*T. aestivum* L.) and durum wheats supported annual incidences of the disease, yet only occasionally sustained appreciable yield losses. The increase in importance of these diseases is largely due to the widespread and rapid replacement over large growing areas of local wheat cultivars with the high-yielding, early-maturing, short cultivars that are susceptible to the pathogens, accompanied by changes in cultural practices.

Severe outbreaks of Septoria diseases have occurred in regions with ample rainfall in South America and in rain-sparse countries along the Mediterranean seacoast. Severe epidemics of Septoria leaf blotch causing substantial losses in yield have occurred in the semiarid southern plains of Israel, where average rainfall is 300 mm or less.

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Fig. 1. Septoria leaf blotch on the spring wheat cultivar Lakhish in the southern coastal plains of Israel.

Contributing Cultural Practices

The possible sources of primary inoculum for the initial establishment of Septoria diseases on lower foliar plant parts include viable pycnidia and perithecia on wheat refuse from previous seasons, infected volunteer wheat plants and alternative hosts, and infected seed.

Sanderson and Hampton (15) stressed the contribution of the perfect state to the primary source in the onset of Septoria leaf blotch epidemics in Australia and New Zealand when wheat plant refuse remained unmanipulated after harvest for an extended time. In many parts of the world, wheat straw is utilized for feed or bedding in the livestock industry and for other purposes or is removed shortly after harvest by deep ploughing (> 35 cm) or burning. Most removal practices leave wheat refuse that may provide sufficient inoculum for the incoming wheat crop. In the absence of the sexual stage, the only apparent source of primary inoculum is viable pycnidia in host refuse; pycnidia may retain viability for 3–18 months or longer, depending on natural conditions. Pycnidia of *S. nodorum*, but not of *S. tritici*, form in dead plant tissue.

Soil management practices (minimum tillage, stubble mulch, refuse management, ecofallow, etc.) designed to reduce hydrocarbon fuel consumption, evaporative water loss, and wind erosion of soil by leaving substantial amounts of wheat stubble may enhance the negative impact of Septoria diseases on wheat production (8). Soil and phylloplane microflora may be used in the future to suppress Septoria diseases, especially if minimum tillage practices are expanded (20). Resorting to continuous wheat cropping and the ecofallow system in the rain-sparse southern wheat belt of Israel has markedly increased the incidence of Septoria leaf blotch epidemics, especially in rainy years (Fig. 1). Long rainless years in this region have resulted in poor crops and yields, with sporadic Septoria leaf blotch epidemics.

Crop rotation with wheat cropping intervals of 3–5 years has decreased Septoria leaf blotch incidence in Israel (Fig. 2). Occasional outbreaks occur, however, even in isolated wheat fields sown after uninterrupted cropping of cotton for 6–8 years under irrigated systems.

Favorable Weather Conditions

Epiphytotics of Septoria diseases are associated with favorable weather conditions (frequent rains associated with temperatures ranging from 12 to

25 C) and widespread distribution of susceptible wheat cultivars. Long rainless intervals with high temperatures toward the end of the growing season interrupt the pathogen's progress to the upper plant parts from the lower infected leaves.

The horizontal movement of *S. tritici* in Israel from a single infected focus in 4 × 4 m drilled plots of susceptible cultivars separated by 2-m buffers was rather slow at the beginning of the season (60–87 days from seedling emergence, or from the end of January to the end of February 1980), despite frequent rains, mainly because of extended periods of suboptimal day and night temperatures (Figs. 3 and 4). The horizontal spread from the center of the plot was associated with a gradual building of disease in the focus during the cool period and slow establishment of secondary foci in proximity to the primary focus.

The major horizontal expansion of the foci occurred with a rise in average daily temperatures (85–95 days from seedling emergence) during the end of February; this corresponded to a fully extended wheat plant before or at the beginning of heading under the growing conditions in the central coastal plains of Israel where the trial was conducted. The time required for horizontal movement from a single focus may be longer in the rainy, cooler northern region or shorter in the southern part in rainy years. In southern Israel, average daily temperatures are higher early in the season and reduced plant tillering results in a less dense crop stand, which increases the raindrop splashing effect. The enhanced splashing effect is dramatically apparent on the exposed field edges where disease can be detected sooner and the pathogen moves faster than in the dense plant stand. The number of established initial foci is related to crop and soil management systems, to the abundance of primary inoculum, and to weather conditions.

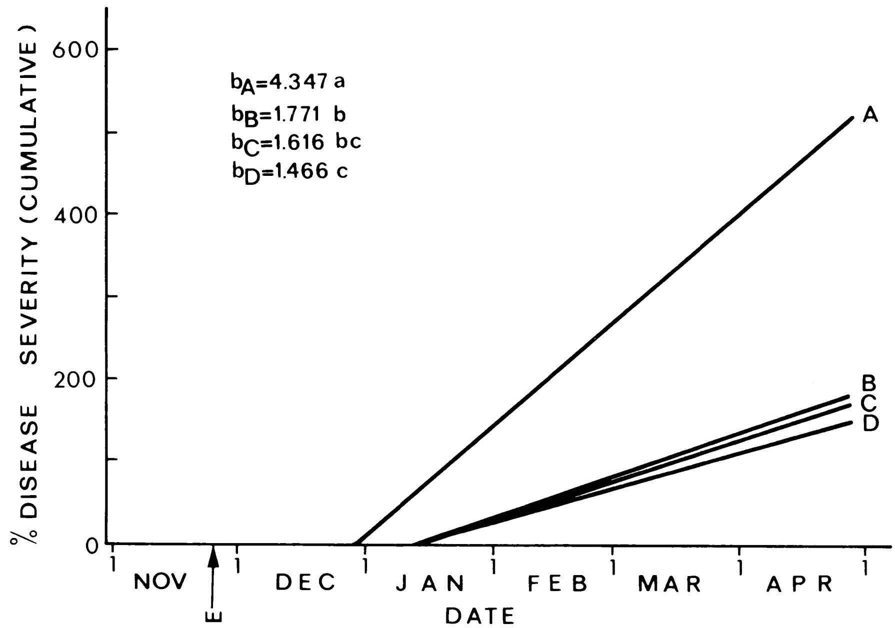

Fig. 2. Effects of previous crops in rotation on development of Septoria leaf blotch in the spring wheat cultivar Miriam at the Lakhish Experiment Station. A = wheat sown after wheat, B = wheat sown after fallow, C = wheat sown after peanuts, D = wheat sown after cotton, E = seedling emergence. Values followed by the same letter are not significantly different at $P = 0.05$, analyzed by Duncan's multiple range test on the b of the linear regression ($Y = a + bX$), where Y = cumulative Septoria severity and X = time.

Effect of Plant Height

The vertical progress of *S. tritici* from lower to upper leaves is affected by the distances between consecutive leaves—the ladder effect. Proximity of the leaves in the dwarf cultivars (70–90 cm) facilitates contact of newly emerging leaves with splashing pycnidiospores or with infected lower leaves. As a result, pycnidia appear earlier on upper plant parts responsible for grain filling than they do on comparable leaves of taller cultivars. Under favorable epidemic conditions, the differences in plant architecture of susceptible cultivars are readily overcome

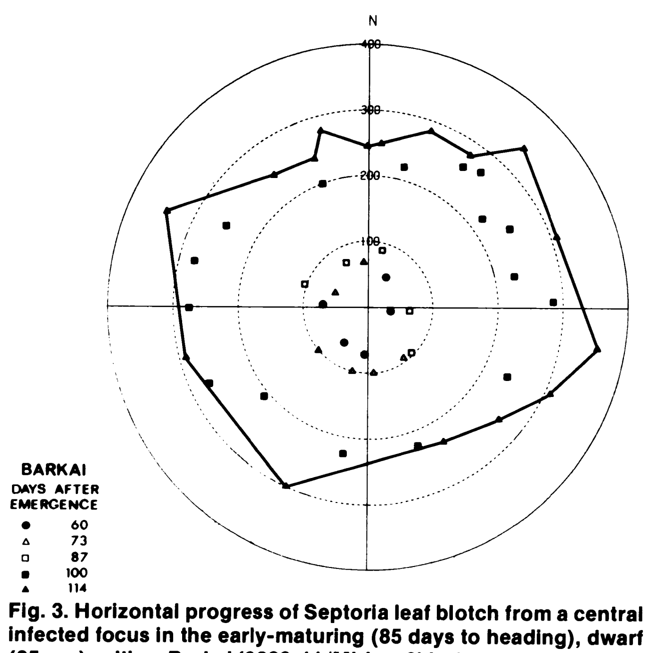

Fig. 3. Horizontal progress of Septoria leaf blotch from a central infected focus in the early-maturing (85 days to heading), dwarf (85-cm) cultivar Barkai (8822-11/Miriam 2) in 4 × 4 m drilled plots. Plants with pycnidia found at the maximal distance from the center were marked at 10–14 day intervals. Aerial observations were made to avoid mechanical disturbance of the crop and transmission of the pathogen.

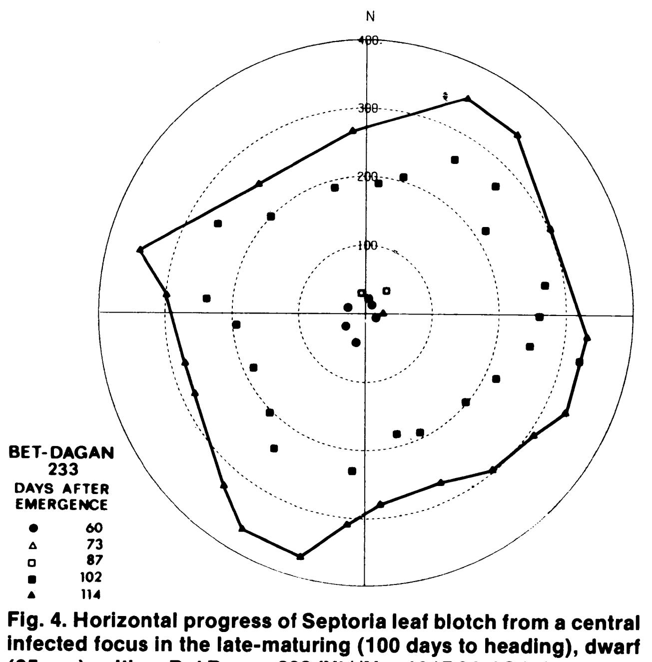

Fig. 4. Horizontal progress of Septoria leaf blotch from a central infected focus in the late-maturing (100 days to heading), dwarf (85-cm) cultivar Bet Dagan 233 (Yt//Nrn 10/B21-1C/3/FA) in 4 × 4 m drilled plots. Plants with pycnidia found at the maximal distance from the center were marked at 10-day intervals. Aerial observations were made to avoid mechanical disturbances of the crop and transmission of the pathogen.

by the pathogens. In moderate epidemics, however, the epidemiologic disadvantage of the dwarf cultivars is more pronounced than that of semidwarf wheats (2).

These considerations plus difficulties in weed management have made breeders in Israel reluctant to release wheat cultivars shorter than 90 cm. Designing a model to predict Septoria leaf blotch epidemics in the Mediterranean basin on the basis of currently available information is therefore extremely difficult.

Difficulties in Breeding for Genetic Protection

Resistant cultivars, chemicals, and suitable agronomic practices are the major means of controlling Septoria diseases. Breeding for resistance is the most economically feasible control measure, but resistant germ plasm is not abundant. Little is known about the types of resistance and their inheritance, manipulation, and accumulation. These aspects, together with the physiologic specialization in *S. tritici*, are major obstacles in breeding for resistance.

Resistance to Septoria glume and leaf blotch appears to be more widely distributed among *T. aestivum* cultivars with winter growth habit than among those with spring growth habit (Table 1). In Israel, the frequency of resistance to the current population of *S. tritici* is higher in *T. durum* and triticale than in spring bread wheat. However, Djerbi et al (5) in Tunisia reported that several bread wheat lines and cultivars were highly resistant to *S. tritici*, whereas very few durum wheat cultivars showed adequate resistance.

Resistance to both Septoria pathogens is often associated with late-maturing, tall cultivars (Figs. 5 and 6), whereas early-maturing, short resistant germ plasm is rather scarce. In Israel, almost no resistance to Septoria leaf blotch was found among spring bread wheat cultivars that matured in less than 100 days after seedling emergence and were shorter than 112 cm (Table 2). In later

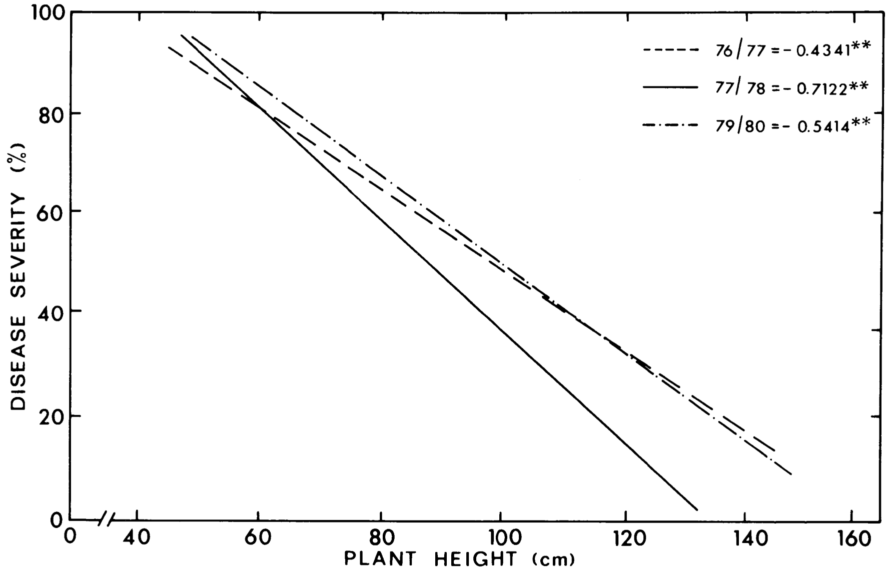

Fig. 5. Relationship between plant height and Septoria leaf blotch severity, derived from infected Septoria nurseries consisting of thousands of bread wheat (spring and winter), durum, and triticale cultivars. ** = Significant correlation coefficients (r) at $P = 0.01$.

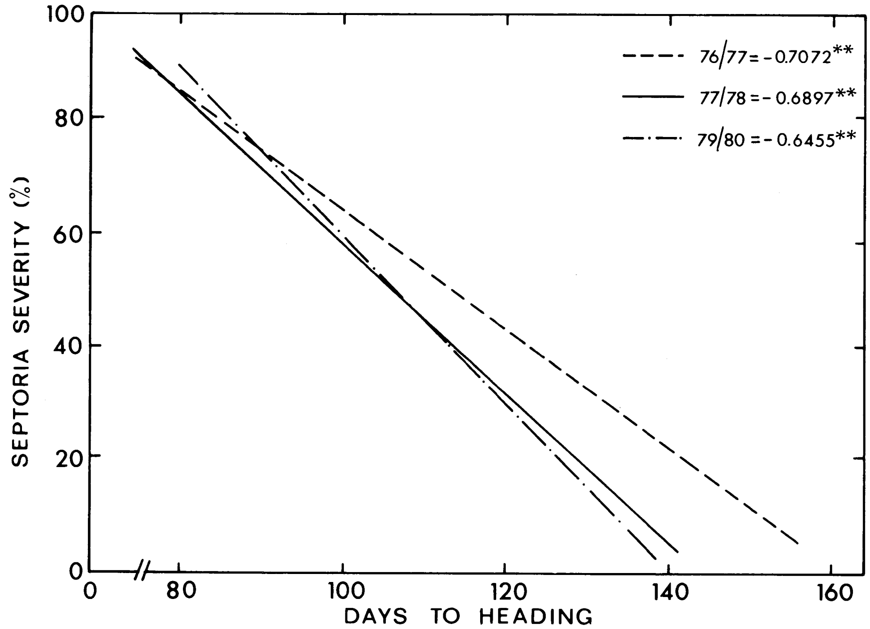

Fig. 6. Relationship between maturity levels and Septoria leaf blotch severity, derived from infected Septoria nurseries consisting of thousands of bread wheat (spring and winter), durum, and triticale cultivars. ** = Significant correlation coefficients (r) at $P = 0.01$.

Table 1. Relationship between Septoria disease severity and growth habit and phenotypic characteristics of three wheat classes and triticale in trials at Bet-Dagan Experiment Station, Israel, 1979–1980

Wheat class	Number of accessions	Septoria severity (%) Upper leaves[u]	F-2[v]	Septoria progress coefficient[w]	Days to heading[x]	Plant height (cm)
Triticum aestivum						
Spring wheat	2,007	50.9 ± 0.7 c[y]	56.0 ± 0.7 c	0.7241 ± 0.01 d	110 ± 0.2 b	107 ± 0.4 b
Winter wheat[z]	266	21.1 ± 1.3 a	24.8 ± 1.5 a	0.5421 ± 0.01 a	122 ± 0.9 d	105 ± 1.2 ab
T. durum	303	24.4 ± 1.2 a	28.7 ± 1.3 a	0.6869 ± 0.01 c	116 ± 0.5 c	103 ± 0.9 a
Triticale	400	28.9 ± 1.1 b	33.4 ± 1.2 b	0.6399 ± 0.01 b	103 ± 0.2 a	128 ± 0.6 c
Mean		42.6	47.4	0.6928	110	109

[u] Mean of four upper leaves: flag leaf, flag leaf minus 1, flag leaf minus 2, and flag leaf minus 3.
[v] Flag leaf minus 2.
[w] Disease height (cm)/plant height (cm).
[x] Seedling emergence on 5 December 1979.
[y] Standard error. Values followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.
[z] Winter wheat was vernalized for 8 weeks at 4 C.

Table 2. Relationship between Septoria disease severity class and plant height and heading date of three wheat classes and triticale in trials at Bet-Dagan Experiment Station, Israel, 1979–1980[a]

Plant height (cm)/days to heading[b]	Septoria severity class[c]: Very resistant (%)				Resistant (%)				Moderately resistant (%)			
	Spring	Winter	Durum	Triticale	Spring	Winter	Durum	Triticale	Spring	Winter	Durum	Triticale
⩾112/⩾100	7.97	15.04	13.86	19.00	6.48	9.77	2.31	12.75	5.63	6.02	1.65	13.25
⩾112/<100	0.05	0.00	0.00	1.25	0.00	0.00	0.00	1.50	0.05	0.00	0.00	2.50
<112/⩾100	3.19	19.55	7.92	0.25	3.14	13.16	11.22	0.00	3.99	7.52	31.02	1.00
<112/<100	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.75	0.00	0.25
Total	11.21	34.59	21.78	20.50	9.67	22.93	13.53	14.25	9.67	14.29	32.67	17.00
⩾112/⩾115	6.68	14.66	12.87	0.25	4.33	8.27	1.65	0.00	2.19	4.89	0.66	0.00
⩾112/<115	1.34	0.38	0.99	20.00	2.14	1.50	0.66	14.25	3.49	1.13	0.99	15.75
<112/⩾115	1.00	13.53	5.94	0.00	1.10	7.14	5.61	0.00	1.25	2.63	10.89	0.00
<112/<115	2.19	6.02	1.98	0.25	2.10	6.01	5.61	0.00	2.74	5.64	20.13	1.25
Total	11.21	34.59	21.78	20.50	9.67	22.92	13.53	14.25	9.67	14.29	32.67	17.00

[a] Number of accessions: spring wheat, 2,007; winter wheat, 266; durum wheat, 303; triticale, 400.
[b] Days from seedling emergence on 5 December 1979.
[c] Based on pycnidial coverage of four upper leaves: 0–5% = very resistant; 5–15% = resistant; 15–30% = moderately resistant.

Fig. 7. Wheat straw harboring viable pycnidia of *Septoria tritici* is used as a source of inoculum in breeders' yield trials, in which the relationships between disease severity and yield losses are assessed by comparing Septoria-infected plots with fungicide-protected plots.

maturing (by 15 days) germ plasm, frequency of resistance markedly increased among short cultivars of all wheat classes and triticale.

Dominant, partially dominant, and recessive genes were found to condition resistance to both Septoria glume and leaf blotch of wheat. Gene(s) that modify the expression of resistance of the dominant gene of the cultivar Atlas 66 to *S. nodorum* and another gene that modifies the expression of the dominant effect of the cultivar Bezostaya 1 to *S. tritici* were reported by Kleijer et al (11) and Danon (4), respectively. The modification of resistance expressed by dominant gene(s) may explain in part the lack of success in transferring adequate protection from these cultivars in certain crosses. Scharen and Eyal (17) have shown that resistance to *S. nodorum* and *S. tritici* does not often reside in the same line or cultivar.

It has become apparent that phenotypic traits (plant height) and growth habits (photoperiod and vernalization requirements) interact with specific genetic factors controlling disease expression and thus interfere with the evaluation of germ plasm to Septoria diseases. Scott and Benedikz (19) suggested that the association between plant height and resistance to *S. nodorum* may be due to chance association of shortness and susceptibility in parental lines, to genetic linkage, or to pleiotropy. Among F_3 families derived from randomly selected single F_2 plants, tallness was clearly associated with resistance, explicable by linkage or pleiotropy but not by chance.

In a recent study, Danon (4) analyzed the relationship between plant stature and maturity and resistance to *S. tritici*. Small negative correlations were found between plant height and pycnidial coverage in crosses between Bezostaya 1 and dwarf (triple dwarf) cultivars. These findings do not support a strong linkage or pleiotropic effect between plant height and susceptibility to *S. tritici*. Short (50–70 cm), early-maturing (heading in less than 110 days from seedling emergence), resistant (less than 15% of four upper leaves covered with pycnidia) plants could be recovered in F_2 populations and continued to express resistance in F_3 families to a wide spectrum of virulences of *S. tritici* in Israel.

Strategies and Concepts

Several strategies for incorporating resistance to Septoria diseases in agronomically acceptable wheats are being evaluated (4,9,16); all require concentrated joint efforts by breeders and plant pathologists to develop concepts and methods. Despite the lack in knowledge of specific genetic factors governing resistance, accumulation of diverse resistance sources into agronomically suitable wheats should lay the genetic foundation for improved wheats. Agronomically suitable resistant cultivars are becoming more readily available from international programs (International Maize and Wheat Improvement Center [CIMMYT], U.S. Department of Agriculture) and national Septoria programs, especially with the growing utilization of resistant winter wheat germ plasm in spring wheat breeding programs. International cooperation in testing and screening of the available germ plasm will greatly improve national resistance management schemes. With the relatively slow progress in producing resistant commercial wheat cultivars, breeders may be too eager to resort to rapid improvement by extensive use of the few resistant sources, thus reducing diversity and increasing genetic vulnerability.

Knowledge of the physiologic specialization of Septoria pathogens of wheat is a prerequisite to a reliable program for breeding resistant wheats. Some wheat cultivars reported to be resistant in one country do not have the same resistance levels when subjected to Septoria populations and environmental conditions in another country. Moreover, single sources of resistance were overcome by the pathogens in a relatively short time after being incorporated into agronomically suitable wheats. Physiologic specialization in *S. tritici* has been reported from Israel and the United States (6,12), but Scharen et al (18) were not able to find specific interactions between *S. nodorum* isolates and wheat cultivars and concluded that the 14 *S. nodorum* cultures isolated from various wheats and locations in the United States cannot be regarded as biotypes or races in the conventional connotation. There is no reason to expect that some types of resistance will maintain low disease expression under a variable and changing pathogen population, especially if the sexual stage is operative.

Since we cannot disregard the possibility that "new" biotypes of the pathogens may overcome the available resistant sources, we should resort to management strategies that will minimize the impact of new variants when they arise. Tolerance (that quality enabling a susceptible plant to endure severe attack by a pathogen without sustaining serious losses in yield) of wheat cultivars was identified to both *S. nodorum* and *S. tritici* (3,21). In theory, the characteristic of not placing selective pressure on the pathogen, the projected durability, and the reduced need for fungicide protection make tolerance an attractive concept to exploit as a means of protecting plants from disease damage. Difficulties in detection, transmission, and utilization of tolerant plants have so far limited its usefulness in breeding programs.

Tolerance to both glume and leaf blotch is incompatible with dwarf plant stature. The correlated vulnerability of dwarf cultivars (70–90 cm) to Septoria diseases may be due either to 1) unequal epidemiologic disease stress (time and space) exerted by the pathogens on dwarf cultivars in comparison to "equally" susceptible taller plants or 2) a genetic association between yield vulnerability and dwarf stature when subjected to disease stress.

Israeli breeders and cereal pathologists routinely evaluate the relationships between disease severity and losses in yield or in yield components of single plants in segregating populations and of advanced lines or cultivars in Septoria-infected vs. fungicide-protected plots (Fig. 7). Thus, the vulnerability of cultivars to disease can be assessed and a suitable chemical control scheme designed. For other protection types that may offer superior control from time to time (specific resistance) but do not provide the stability of tolerance, the addition of tolerance may provide a stable foundation.

Considerations in Designing a Chemical Control Program

Fungicide protection is used as a stopgap to secure the potentially high yields of the resistant-deficient semidwarf cultivars, ie, to give breeding programs time for incorporating genetic protection and to deal with unexpected Septoria outbreaks (7).

The lengthy association between the pathogen and the wheat host in Israel and in the Mediterranean region during the growing season (November–May) and the drastic fluctuations in the amount, frequency, and distribution of rainfall impose difficulties in designing an effective chemical protection program within economical and consumer health considerations. An economical chemical program against Septoria diseases depends on several crop management considerations by wheat growers and/or specialists before enforcement: 1) early assessment of yield potential of the specific wheat field and cultivar, 2) vulnerability of the wheat cultivar to Septoria or other diseases, 3) history of wheat cropping and Septoria epidemics in the specific field, 4) cultural practices before sowing (burning of refuse, deep ploughing, etc.) that may reduce the amount of primary inoculum, 5) early detection of the diseases and assessment of their progress, 6) weather conditions, and 7) cost of fungicide protection relative to other investments in the crop (fertilizers, herbicides, irrigation, etc.). These as well as other considerations are all directed toward deciding whether to resort to chemical control of a specific wheat field.

Continuous protection schemes—three or four maneb applications at 10–14 day intervals, depending on intervals between rainy days, to protect the upper plant parts responsible for grain filling—resulted in yields 15–30% higher than those of untreated Septoria-infected control plots and were economically justified. The chemical control program started when pycnidia of *S. tritici* had progressed to the third uppermost leaf (flag leaf minus 2) and disease severity on lower leaves intensified. With the current susceptible short, early-maturing commercial cultivars (80–95 days from seedling emergence to heading), the program is usually started at the boot–early heading growth stages (mid-February). Early enforcement of the chemical control program (December–January) may entail excessive applications, especially if leaf rust epidemics occur toward the end of the season (March–April).

Obviously, this action threshold is rather flexible and may introduce inaccuracies in timing. Moreover, fluctuations in environmental conditions, mainly rainless intervals, may delay the chemical control program until a time when daily temperatures are higher, which enhances disease progress when the rains resume. Prolonged rainless intervals toward the end of the growing season (March–April) can make the early fungicide applications a very costly endeavor, because disease progress halts and the lack of water during the grain filling period is detrimental to yields.

Systemic fungicides with curative properties and longer protective action against several foliar diseases may be beneficial when the action threshold has been misjudged or the chemical protection program improperly executed. The systemic fungicide benomyl controlled Septoria leaf blotch in Israel at an uneconomical level—four applications. Two applications caused timing difficulties and greatly reduced disease control. Seed dressing with benomyl in slurry slowed Septoria leaf blotch progress for a short time (3–4 weeks) after disease appeared in December, but then disease progress and yield losses equaled those of untreated control plots. Seed dressing with suitable systemic fungicides may prove more effective in reducing progress of Septoria glume blotch.

The effectiveness of some chemicals may be significantly increased by adding certain adjuvants that improve uniformity, redistribution, and duration of the protectant fungicide on the foliar plant parts. The economy and effectiveness of low-volume aircraft spraying may be improved by utilizing modern equipment that increases swath width and carrier penetration through the canopy in dense wheat fields. Combining protectant and systemic fungicides to control Septoria diseases may provide an alternative route, since tolerance to carbendazim was reported in *S. nodorum* (10). The systemic fungicides may lengthen the protection effect, counteracting outbreaks and timing difficulties, while the protectant fungicide reduces the selection pressure on the pathogen exerted by the site-specific systemic fungicide and expands the control spectrum against several wheat pathogens. A new generation of EPA-approved systemic fungicides effective against several major wheat pathogens may provide the needed protection, provided their use is within economic boundaries and no tolerant isolates of the pathogens are found.

Need for Disease Surveying

Clearly, an effective chemical control program for Septoria diseases should be accompanied by an intensive disease surveying system that enables early detection of disease foci for assessment of distribution and evaluation of disease development and intensification. Disease surveying in specified wheat fields is organized in Israel by the regional wheat growers commission as part of the crop management system. Pest and extension service specialists follow the weekly progress of the disease and recommend a chemical control program, if needed, according to the specific situation. Regional disease workshops are organized each year so scientists and extension service specialists can inform wheat growers about research activities and recent developments in pest management as an integrated part of the crop management system.

Success in decreasing the impact of Septoria diseases on the expression of yield potential depends on integrating all components—epidemiology, cultural practices, genetic protection, chemical control, biological control, and extension services—into a disease management scheme that is part of the crop management system.

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