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AND

POWDERY MILDEWS

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Cereal Rusts and
Powdery Mildews Bulletin

Vol. 16, Part 1, 1988

EVALUATION OF SOME INDIAN WHEATS FOR THE ATTRIBUTES OF SLOW LEAF RUSTING

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SUMMARY

Five wheat cultivars viz. Sonalika, WH147, WH157, Lerma Rojo 64A and Chhoti Lerma possessing different levels of slow rusting resistance to Puccinia recondita f.sp. tritici were studies under growth room and screenhouse conditions. Infection frequency was signficantly higher in fast rusting cultivars Agralocal, Kalyansona and C306 compared to that of slow rusting cultivars at seedling and flag leaf stages. Shorter latent period (LP) was recorded in Agralocal (6.39 days) and Kalyansona (6.99 days) at seedling stage but slow rusting cultivars had extended LP by 1-2 days. Flag leaf stage generally had longer LP (approximately 2 days) in all the cultivars though differences in LP among cultivars also exist.

Slow rusting cultivars exhibited smaller pustule size (0.10 mm^2 or less than 0.10 mm^2) under growth room conditions and it was sigificantly lower than susceptible cultivars Agralocal and Kalyansona. Pustule size was larger under screen house conditions in all the cultivars. Urediospore production per pustule was maximum in Agralocal and Kalyansona whereas slow rusting cultivars produced almost 3 times less urediospores. It appears, that genotype WH147 has the attributes of slow rusting while in WH157 it is combined with vertical resistance as well.

Regression analysis between area under disease progress curve (AUDPC) and four components of slow rusting revealed that pustule size and spore production are directly correlated with AUDPC whereas latent period, thogh negatively correlated, has less influence on AUDPC and therefore is not of great significance.

INTRODUCTION

Slow rusting in cereals possesses characteristics that interfere with the pathogen's reproduction so that its rate of spread is retarded. This resistance of a non-hypersensitive type could act at any of several stages of pathogenesis and thus result in slow rusting. Identification of stages of pathogenesis at which

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Part of Ph.D. thesis of Senior author submitted to Haryana Agricultural University, Hisar - 125004

slow rusting is expressed will help plant breeders in selecting slow-rusting genotypes. Slow rusting resistance was largely ignored until Van der Plank (1963) suggested its epidemiological implications, that such resistance can give effective control. The reduced rate of disease spread in slow rusting genotypes has often been attributed to low infection frequency, reduced spore production, increased latent period and small lesion size (Van der Plank, 1963; Shaner, 1973b; Parlevliet, 1975; Ohm and Shaner, 1976 and Shaner *et al*. 1978). We report here the results of our studies on these parameters in the wheat - *Puccinia recondita* f. sp. *tritici*, host - pathogen interaction system.

MATERIALS AND METHODS

During 1982-83, parameters that contribute to slow rusting in wheat were investigated in the Department of Plant Pathology, Haryana Agricultural University, Hisar using eight cultivars namely Agralocal, Kalyansona, C 306, Sonalika, WH147, WH157, Lerma Rojo 64A and Chhoti lerma. These cultivars were inoculated at the seedling stage under growth room conditions with leaf rust race 77 and at the flag leaf stage under screenhouse conditions with a mixture of races (12A, 77, 77A, 104, 104A and 162)

The growth room temperature was maintained at 20 ∓ 2°C during winter and saturated relative humidity in a small chamber for post inoculation for 48 hours. The seedlings were maintained at 3000 lm m^{-2} alternating light and darkness as 12 h d^{-1}. Five seedlings per plastic pot of 15 cm diameter were maintained and inoculations were done at the two leaf stage while adult plants in 30 cm diameter plastic pots were inoculated at the boot stage. Inoculations of the adult plants were done in the evening (18.00 hrs) to ensure better infection.

Fresh urediospores collected from sporulating pustules maintained on Agralocal were used. For evaluating the components of slow rusting, 10 mg of urediospores were suspended in 100 ml of sterilized water with a few drops of tween-20 (1% polyoxythylene sorbitan monolaurate) to break surface tension and get a uniform inoculation. One light jerk of a hand atomizer sprayer was enough (80-140 urediospores/microscopic field of 400 x) to inoculate a pot of seedlings. Flag leaves of the adult plants were inoculated by the same method.

The four components of slow rusting viz. infection frequency, latent period, pustule size and spore production were studied. Infection frequency and latent period were calculated by the method described by Shanner *et al.* (1978). The area under active sporulation of uredopustule (pustule size) was measured by taking its length and breadth under 50 x magnification on 16th day of inoculation after detaching the primary leaf of the seedling and flag leaves following Kochman and Brown (1975). For counting of urediospores per pustule, the lower surfaces of microscope slides were marked linearly with a glass marking pencil equal in width to

the microscopic field at 10 x 10 X. One pustule from each pot was randomly scraped on 16th day of inoculation with the help of a needle onto a slide having two drops of liquid paraffin. Uniform suspension was made in paraffin drops and urediospores were counted in each linear strip demarked.

RESULTS

Infection frequency: The data in Table 1 reveal that under growth room conditions, Agralocal showed maximum infection frequencies of 51.79 and 46.84 per cm^2 at the seedling and flag leaf stages respecitvely, whereas those of Chhoti lerma were only 19.15 and 19.22 per cm^2. The infection frequency in Agralocal did not differ significantly from that of Kalyansona at both the stages in the growth chamber whereas these cultivars differed signficantly from one another in the uncontrolled conditions. Infection frequencly of Sonalika, WH147, Wh157 and Lerma Rojo 64A did not differ significantly from each other at the seedling stage, but on the flag leaf the infection frequency of WH157 (27.51/cm^2) and Lerma Rojo 64A (25.50/cm^2) differed significantly from Sonalika (32.86/cm^2) and Chhoti lerma (19.22/cm^2).

Under screenhouse conditions, infection frequency at the flag leaf stage was maximum in Agralocal (45.88/cm^2) and minimum in Chhoti lerma (13.44/cm^2). Infection frequency in C306 (39.55/cm^2) and Kalyansona (40.11/cm^2) did not differ significantly and these values were lower than Agralocal but higher than other cultivars. Cultivars WH157, Lerma Rojo 64A and Sonalika also did not show significant differences among them.

Latent period: Under growth room conditions, the latent period (LP) at the seedling stage of Agralocal (check) and Kalyansona was 6.39 and 6.44 days, respecitvely (Table 1). The LP of C306 was 6.62 days which was significantly less than Sonalika, Lerma Rojo 64A, WH147, Chhoti lerma and WH157. The longest LP (9.43 days) was observed in WH157. At the flag leaf stage, the LP in Kalyansona and C306 did not differ signficantly while that of Sonalika, WH147, WH157, Lerma Rojo 64A and Chhoti lerma was 2 days longer than the check.

Under screenhouse conditions, Kalyansona showed the shortest LP (8.84 days) at flag leaf stage and differed significantly from Agralocal and C306. These were significant differences between the LPs of Lerma Rojo 64A and Chhoti lerma. In general the LP of all the 8 cultivars increased by 2 days at the flag leaf stage when compared with that of the seedling. However, under sreenhouse conditions, increase in LP was one or less than one day in cultivars C306, Kalyansona and Agralocal whereas in Sonalika, WH147, WH157, Lerma Rojo 64A and Chhoti lerma the increase was 1-2 days.

Pustule size: Table 2 shows that under controlled conditions at the seedling stage, pustule size was largest in Agralocal (0.19

mm^2) followed by Kalyansona (0.17 mm^2) and both were significantly larger than other cultivars. Differences in pustule size among C306, Sonalika, WH147 and Lerma Rojo 64A were non-significant. A near similar trend was observed at flag leaf stage.

Under screenhouse conditions, the pustule size was significantly greater in Agralocal (0.38 mm^2) than Kalyansona (0.28 mm^2), C306 (0.28 mm^2), WH147 (0.17 mm^2), Sonalika (0.16 mm^2), Lerma Rojo 64A (0.16 mm^2), WH157 (0.16 mm^2) and Chhoti lerma (0.14 mm^2). All the cultivars at flag leaf stage showed greater area under pustulation in the screenhouse than was observed in controlled conditions.

Number of urediospores per pustule: Urediospore production was highest in Agralocal (1886.04) followed by Kalyansona (1624.41) and C306 (1256.49) and these values differed significantly. The least production per pustule was observed in cultivar WH157 (443.08) followed by Chhoti lerma (551.70) and WH147 (573.99). Intermediate levels of urediospore production were recorded in cultivars Lerma Rojo 64A (799.54) and Sonalika (814.87).

The areas under the disease progress curves (AUDPC) for Agralocal, Kalyansona, C306, Sonalika, WH147, Lerma Roja 64A, Chhoti lerma and WH157 were 1355, 1155, 855, 460, 310, 265, 210 and 120, respecitvely. A regression analysis was carried out taking the AUDPC as the dependent variable and infection frequency, latent period, pustule size and spore production as the independent variables separately and simultaneously. The coefficient of determination was maximum (91.78%) when pustule size was used as an independent variable followed by spore production (90.72%), infection frequency (78.92%) and latent period (70.84%). Latent period gave a negative correlation coefficient value with AUDPC, whereas infection frequency, pustule size and spore production had a significant positive correlation (Fig.1). In the multiple regression the combined effect of all the four compoenents on AUDPC had a coefficient of determination of 95.31 per cent.

DISCUSSION

Studies on components of slow rusting revealed that these differed markedly in eight cultivars, influencing the AUDPC. Cultivars WH147, WH157, Lerma Rojo 64A and Sonalika exhibited minimum variation for the infection frequency at seedling stage. At flag leaf stage, only WH147 showed slightly lower infection frequency (19.90 and 20.37/cm^2) under both growth room and screenhouse conditions. However, the pustules per unit leaf area was significantly lower on C306 than on Kalyansona and Agralocal at seedling stage but was similar to Kalyansona at flag leaf stage. Pustules per unit leaf area was considerably lower in Chhoti lerma, Lerma Rojo 64A, WH147, WH157 and Sonalika. Such a difference in pustule number per unit leaf area in Puccinia recondita has been reported by many to be related with slow rusting (Caldwell, et al. 1957; Ohm and Shaner, 1976, Kuhn et al. 1978),

though, Shaner et al. (1978) failed to observe such a relationship between Suwon 85 and P6028 on the one hand and fast rusting Monon and Suwon 92 on the other.

Yet another important component of slow rusting is latent period (LP). The LP observed in WH157 was longer by three days than that of Agralocal while the differences were less for the remaining cultivars both at seedling and adult plant stages. Sonalika had a day longer LP at seedling and two days at flag leaf stage when compared to the check. Differences among cultivars for LP were more pronounced at the adult stage as the LP was enhanced by 2 days. Under screenhouse conditions the LP was slightly longer at flag leaf stage by 1-4 days when inoculated with the mixture of leaf rust races. Ohm and Shaner (1976) also observed increased LP on slow rusting cultivars such as Suwon 85 and P6028. Differences in LP were more pronounced at the boot stage than at other growth stages. Similar observations made by Shaner (1973), Ohm and Shaner (1976), Shaner et al. (1978), Johnson and Wilcoxson, (1978) and Kuhn et al. (1978) further confirmed the dependence of slow rusting on the LP.

Based on pustule size under growth room conditions, the eight varieties studied can be classified into three groups. The first group consists of fast rusting cultivars such as Kalyansona and Agralocal with pustule size 0.15-0.20 mm^2; the second group consists of cultivars such as C306, Sonalika, WH147 and Lerma Rojo 64A with intermediate pustule size (0.07-0.11 mm^2) and the third group consists of WH157 and Chhoti lerma (0.03-0.04 mm^2). In all these cultivars the pustule size was larger in the screenhouse than under growth room conditions. The possible reason for smaller uredia under growth room conditions may be change in photosynthetic activity and slight yellowing of the plant. Relatively smaller sized uredia were observed on WH157, a slow rusting cultivar, as was noted by Shaner et al. (1978) in their studies involving Suwon 85 and P6028.

The restricted spore production significantly reduced the 'r' value (Van der Plank, 1963) due to reduced inoculum potential and therefore is an important parameter in the epidemic development (Ohm and Shaner, 1976; Shaner et al. 1978; Gupta and Singh, 1982). The urediospore production per pustule on the 16th day after inoculation was maximum (1886.04/pustule) in Agralocal and minimum in Wh157 (443.08/pustule). The urediospore production in Agralocal and Kalyansona was nearly twice that of Sonalika and Lerma Rojo 64A (Table 2) and 3-4 times that of WH157, Chhoti lerma and WH147. Gupta and Singh (1982) noted urediospore production in cultivars WH147, UP310 and Janak.

The present studies indicate that the following components, namely low infection frequency, longer latent period, small pustule size and less spore production influence the AUDPC. Of these, LP and pustule size had the greatest influence on AUDPC. Cultivars WH157 and Chhoti lerma which show lower values, apart from

possessing vertical resistance, may in addition possess slow rusting characters.

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REFERENCES

Caldwell, R.M., Schafer, J.F., Compton, L.E. and Patterson, F.L. 1957. A mature-plant type of wheat leaf rust resistance of composite origin. Phytopathology 47, 690-692.

Gupta, R.P. and Singh, A. 1982. Slow rusting in wheat infected with brown rust. Indian J.Genet. 42, 176-182.

Johnson, D.A. and Wilcoxson, R.D. 1978. Components of slow rusting of barley infected with Puccinia hordei. Phytopathology 68, 1470-1474.

Kochman, J.K. and Brown, J.F. 1975. Host and environmental effects on post penetration development of Puccinia graminis avenae and P. coronata avenae. Ann. Appl. Biol. 81, 33-41.

Kuhn, R.C., Ohm, H.W. and Shaner, G.E. 1978. Slow leaf-resistance wheat against twenty two isolates of Puccinia recondita, Phytopathology 68, 651-656.

Ohm, H.W. and Shaner, G.E. 1967. Three components of slow leaf rusting at different growth stages in wheat. Phytopathology 66, 1356-1360.

Parlevliet, J.E. 1975. Partial resistance of barley to leaf rust, Puccinia hordei. II. Effect of cultivar and development stage on latent period. Euphytica 24, 21-27.

Shaner, G.E. 1973b. Reduced infectability and inoculum production as factors of slow mildewing in knok wheat. Phytopathology 63, 1307-1311.

Shaner, G.E., Ohm, H.W. and Finney, R.E. 1978. Response of susceptible and slow leaf rusting wheats to infection by Puccinia recondita. Phytopathology 68, 471-475.

Van der Plank, J.E. 1963. Plant diseases: Epidemics and control. Academic Press, New York and London. pp 349.

Table 1: Infection frequency and latent period on different wheat cultivars under growth room and screen house conditions.

Cultivar	Infection frequency/cm^2			Latent period (days)		
	Growth room Race 77		Screen house Mixture of races	Growth room Race 77		Screen house Mixture of races
	Seedling stage	Flag leaf stage	Flag leaf stage	Seedling stage	Flag leaf stage	Flag leaf stage
Agralocal	51.79	46.84	45.88	6.39	8.28	9.09
Kalyansona	49.93	42.56	40.11	6.44	8.47	8.84
C 306	39.72	40.24	39.55	6.62	8.60	9.28
Sonalika	30.15	32.86	28.83	7.55	10.39	11.55
WH 147	26.05	19.90	20.37	8.16	10.80	12.60
WH 157	27.72	27.51	24.99	9.43	10.87	13.30
Lerma Rojo 64A	26.02	25.50	24.66	8.15	10.18	11.15
Chhoti lerma	19.15	19.22	13.44	8.35	10.60	12.84
C.D at 5%	9.35	5.94	4.59	0.17	0.18	0.23

Table 2: Size of uredopustule and number of urediospores produced per pustule in different wheat cultivars under growth room and screen house conditions.

Cultivar	Size of uredopustule (mm^2)			urediospores/ pustule
	Growth room Race 77		Screen house Mixture of races	Growth room Race 77
	Seedling stage	Flag leaf stage	Flag leaf stage	Seedling stage
Agra local	0.19	0.20	0.38	1886.04
Kalyansona	0.17	0.15	0.28	1624.41
C 306	0.10	0.11	0.28	1256.49
Sonalika	0.09	0.10	0.16	814.87
WH 147	0.09	0.11	0.17	573.99
WH 157	0.04	0.04	0.16	443.08
Lerma Rojo 64A	0.07	0.07	0.16	799.54
Chhoti lerma	0.03	0.04	0.14	551.70
C.D. at 5%	0.03	0.03	0.08	155.03

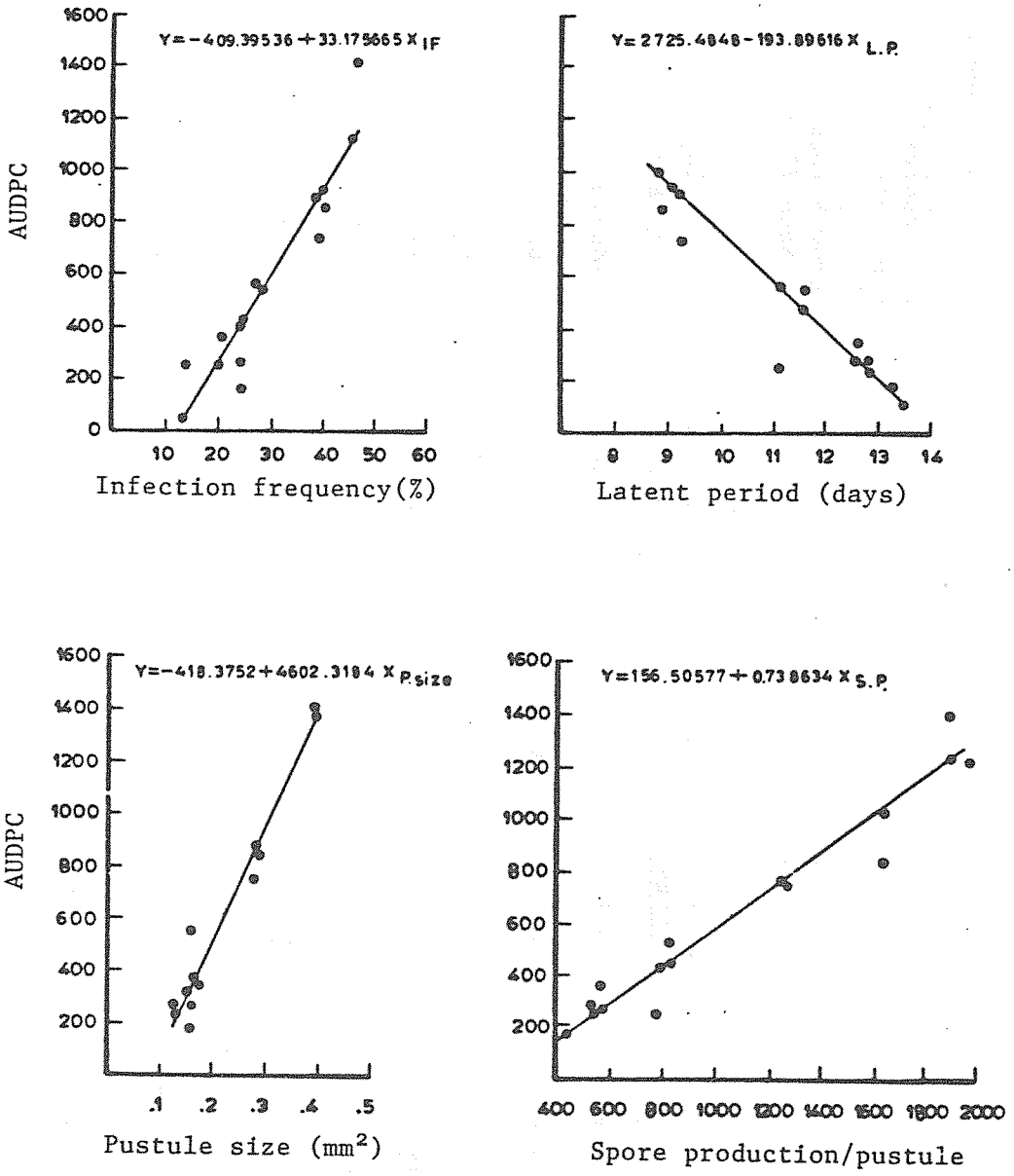

Fig. 1. Correlation between area under disease progress curve (AUDPC) and four components of slow leaf rusting.

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A MATHEMATICAL MODEL FOR STUDYING AEROBIOLOGY OF LEAF RUST OF WHEAT (*Triticum aestivum* Linn.) CAUSED BY *Puccinia recondita* f.sp.*tritici* Rob.Ex Desm.

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In an aerobiology study, uredospore load in the atmosphere was determined by using an Aeroscope. For predicting and forecasting spore load, autoregression and spline function models were estimated, with correlation coefficients of 0.7 and 0.6 respectively. The autoregression model was found more advantageous than the spline function model.

The study of aerobiology is useful in the prediction and forecasting of disease severity and decisions on effective control measures. That spores of fungi are disseminated by air currents has been known almost as long as the spores themselves. Micheli (1729) published the results of epoch-making investigations on the reproduction of fungi by means of spores and showed that clouds of them might be liberated into the air. Stakman *et al.* (1923) studied the dissemination of spores by air currents and attempted to correlate the data with the spread of rusts.

In India, Cunningham initiated aerobiological studies in 1873. Chatterjee (1931) devised an apparatus for trapping spores (*P.graminis tritici* Erike and Henn. and *P.recondita*) in the upper air. Vaseline coated slides were exposed in aircraft, balloons and kites at different heights in order to trap cereal rust spores (Mehta 1940 and 1952). Roelfs *et al* (1968) described the glass rod impaction trap method for quantifying spores above a rusted field. Several workers (Gregory and Stedman 1953; Bromfield *et al.* 1959; Knutson, 1972; Karki, 1977) have shown that rod samplers were better than microscopic slides in trapping the spores more efficiently.

Sahni and Prasada (1963) trapped spores of *P.recondita* on 28th and 20th January in 1959 and 1961, respectively and lesions were observed on 15th and 12th February. The incubation period was 11-20 days. Rowell and Romig (1966) devised a continuously operating rain sampler for monitoring cereal rust uredospores.

Later on, it was modified by Roelfs et al (1970). Nagarajan et al (1977) applied a rain sampler spore detection technique for epidemiological studies in India. Kulkarni and Ramakrishnan (1977) used a Burkard Recording Volumetric spore trap and observed diurnal and seasonal variations in spore number in the atmosphere and noticed the influence of favourable humidity and temperature on the sporulation and spore discharge of Drechslera oryzae (Breda, de Hann) Subram. and Jain Ex.M.B.Ellis. Eversmeyer and Kramer (1980) used Kramer collins volumetric samples to sample air six metres above ground level to measure downward dispersal of uredospores of P.recondita and P.graminis from a source plot of wheat.

A Kramer - collins seven day spore sampler was used to study availability, viability and movement of uredospores from October 1974 to August 1977 and further wind trajectories to indicate spore movement patterns (Eversmeyer et al 1984). Air sampling for D.oryzae spores was carried out using a Burkard recording Volumetric spore trap (Kulkarni et al 1982 and 1984).

MATERIALS AND METHODS

To study the ureodspore load in the atmosphere during the entire rabi season of 1985-86 a spore trapping experiment was carried out. For this, an Aeroscope for exposure of stationary slides was mounted at a height of about five feet at the Agricultural College Farm, Dharwad. A slide which was thinly smeared with vaseline was used for catching spores, by keeping smeared slides in the slot inside the box as shown in fig. 1. Slides were removed every day at 08.30 hrs. The average number of uredospores per microscopic field was recorded under low power 10x by taking counts of ten microscopic fields on a slide. These observations were studied in relation to weather factors, viz. temperature, humidity and wind velocity.

Data were analysed to find out the trend in fluctuation of spore load throughout the season. The various methods of estimating the spore load in terms of days after commencement of observation (23-11-1985) as well as other weather factors and auto correlations were explored and the following methods were found to be of use with high correlation coefficients.

Method - 1 : Autoregression Model

Autoregression coefficients for spore load were obtained to find out the internal relation among the spore load of consecutive days. The auto sum of products as well as sum of squares of spore load were calculated by the use of following formulae:-

(a) $a_{oo} = \sum_{k=1}^{n} (Y_k - \bar{Y})^2$ formula as per definition

$= \sum_{k=1}^{n} Y_k^2 - \frac{(\sum Y_k)^2}{n}$ computational formula

where, a_{oo} - refers to sum of squares (adjusted) due to spore load

Y_k - is kth observation spore load value

n - total number of days considered for calculation

Similarly, auto sum of products of different order were obtained by the use of following formula:-

(b) $a_{01} = \sum_{k=2}^{n} (Y_k - \bar{Y})(Y_{k-1} - \bar{Y})$ formula as per definition

$= \sum_{k=2}^{n} Y_k Y_{k-1} - \frac{(\sum Y_k)^2}{n}$ computational formula

where, a_{01} stands for first order auto sum of products (adjusted)

(c) $a_{02} = \sum_{k=3}^{n} (Y_k - \bar{Y})(Y_{k-2} - \bar{Y})$ formula as per definition

$= \sum_{k=3}^{n} Y_k Y_{k-2} - \frac{(\sum Y_k)^2}{n}$ computational formula

where, a_{02} stands for second order autosum of products (adjusted)

(d) $a_{03} = \sum_{k=4}^{n} (Y_k - \bar{Y})(Y_{k-3} - \bar{Y})$ formula as per definition

$= \sum_{k=4}^{n} Y_k Y_{k-3} - \frac{(\sum Y_k)^2}{n}$ computational formula

where, a_{03} stands for third order autosum of products (adjusted)

(e) $a_{04} = \sum_{k=5}^{n} (Y_k - \bar{Y})(Y_{k-4} - \bar{Y})$ formula as per definition

$= \sum_{k=5}^{n} Y_k Y_{k-4} - \frac{(\sum Y_k)^2}{n}$ computational formula

where, a_{04} stands for fourth order autosum of products (adjusted)

The autoregression equation written in the form:-

$\hat{S.P_d} = b_1 S.P_{d-1} + b_2 S.P_{d-2} + b_3 S.P_{d-3} + b_4 S.P_{d-4}$
was found to fit the data.

Where,

$\hat{S.P_d}$ = estimated spore load of dth day as per autoregression model.

b_1, b_2, b_3 and b_4 are autoregression coefficients

$S.P_{d-1}$, $S.P_{d-2}$, $S.P_{d-3}$ and $S.P_{d-4}$ are spore load of previous one, two days, three days and four days respectively.

The autoregression coefficients were estimated by solving the equations:-

$$\begin{bmatrix} a_{oo} & a_{01} & a_{02} & a_{03} \\ a_{10} & a_{11} & a_{12} & a_{13} \\ a_{20} & a_{21} & a_{22} & a_{23} \\ a_{30} & a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} a_{01} \\ a_{02} \\ a_{03} \\ a_{04} \end{bmatrix}$$

Where, the matrix being symmetrical

$a_{ij} = a_{ji}$ $\quad i, j, = 0, 1, 2, 3$

by cyclic nature of the autoproducts like

$a_{00} = a_{11} = a_{22} = a_{33}$; $\quad a_{01} = a_{12} = a_{23}$; $\quad a_{02} = a_{13}$

The sum of squares due to autoregression were calculated using the formula:

$S.S_a = b_1 a_{01} + b_2 a_{02} + b_3 a_{03} + b_4 a_{04}$

The error sum of squares due to autoregression were calculated from the formula:

$E.S.S_a = s_{00} - S.S_a$

The coefficient of determination due to autoregression was calculated from the formula:

$$K = \frac{S.\ S_a}{a_{00}}$$

The multiple auto-correlation coefficient was derived by the formula:-

$$R^* = +\sqrt{K}$$

Method - 2 : Spline function Model

This method lays emphasis on local relations among the observations with at least some of the functions being of local importance. The following functions were found to fit the data with high correlation:-

$$\hat{S.P_d} = \frac{a_1}{\left(\frac{d-b_1}{c_1}\right)^2+1} \quad \frac{a_2}{\left(\frac{d-b_2}{c_2}\right)^2+1} \quad \frac{a_3}{\left(\frac{d-b_3}{c_3}\right)^2+1} \quad \frac{a_4}{\left(\frac{d-b_4}{c_4}\right)^2+1} \quad \frac{a_5}{\left(\frac{d-b_5}{c_5}\right)^2}$$

Where, 'd' stands for number of days after commencement of spore load observations.

a_1, b_1, c_1; a_2, b_2, c_2; a_3, b_3, c_3; a_4, b_4, c_4; a_5, b_5, c_5; are constants chosen suitably in accordance with local behaviour of observations and their effects on long range variations.

The error in spore load was calculated for each day by the help of the relation:-

$$S.P_{Ed} = \hat{S.P_d} - O.S.P_d$$

Where, $O.S.P_d$ stands for observed spore load on dth day. $\hat{S.P_d}$ stands for estimated spore load of dth day as per spline functions.

Error sum of squares of these functions were obtained by the help of the formula:-

$$E.S.S._{S.P} = \sum_1^n (S.P_{Ed})^2$$

S.S. due to spline functions was calculated by the help of the formula:-

$$\text{Spline S.S.} = O.S.S._{SP} \text{ (adjusted)} - E.S.S._{SP}$$

The correlation coefficient of these functions was calculated by the help of the formula:-

$$R = \sqrt{\frac{\text{Spline S.S.}}{O.S.S._{SP}}}$$

Method - 3 : Cross covariance Analysis

To identify the relation between the spore load and weather factors cross products of spore load with each weather factors were calculated using the formula:-

$$a_{SP1} = \sum_{K=1}^{n} (X_{SP_k} - \bar{X}_{SP}) (X_{ik} - \bar{X}) \text{ formula as per definition}$$

$$= \sum_{K=1}^{n} X_{SP_k} X_{ik} - (\sum X_{SP_k}) (\sum X_{ik}) \text{ computational formula}$$

Where, X_{SP_k} = spore load value on kth day.

Weather factors were given notation as T^M, RH_2, Kl for high temperature, relative humidity (evening) and wind velocity respectively. The cross products among the weather factors and S.S. due to weather factors were obtained from the formula:-

$$a_{ij} = \sum_{k=1}^{n} (X_{ik} - \bar{X}_i) (X_{jk} - \bar{X}_j) \text{ formula as per definition}$$

$$= \sum_{k=1}^{n} X_{ik} X_{jk} - \frac{(\sum_{k=1}^{n} X_{ik}) (\sum_{k=1}^{n} X_{jk})}{n}$$

with i, j = 1, 2, 3.

An attempt was made to estimate spore load in terms of first and second autosum of squares and sum of products as well as the weather factors.

RESULTS AND DISCUSSION

An aerobiology experiment was conducted during rabi season of 1985-86 to determine the uredospore load in the atmosphere and its correlation with weather factors in predicting and forecasting disease severity in the field. During the season a lot of variation in uredospore catch was observed from 23rd November 1985 to 30th March 1986. High daily uredospore loads were recorded throughout February and during the first twelve days of March. Various methods were used to calculate estimated spore load. Results of the methods along with meteorological parameters are presented in Table 1.

The internal relation among the spore load of consecutive days was explored by the help of autoregression technique. The autosum of products and sum of squares up to fourth order were calculated and are presented in Table 1(a). The auto correlation matrix was derived from this matrix and is presented in Table 1(b).

From the matrix of autosum of products and sum of squares autoregression equations were formulated and they are presented below:-

$$\begin{array}{c} \\ S_{d-1} \\ S_{d-2} \\ S_{d-3} \\ S_{d-4} \end{array} \begin{array}{c} \begin{array}{cccc} S_{d-1} & S_{d-2} & -S_{d-3} & S_{d-4} \end{array} \\ \begin{bmatrix} 220.35 & 131.12 & 136.57 & 90.20 \\ 131.12 & 220.35 & 131.12 & 136.57 \\ 136.57 & 131.12 & 220.35 & 131.12 \\ 90.20 & 136.57 & 131.12 & 220.35 \end{bmatrix} \end{array} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{array}{c} S_d \\ \begin{bmatrix} 131.12 \\ 136.57 \\ 90.20 \\ 61.79 \end{bmatrix} \end{array}$$

The solution of these equations was found to be of considerable importance with coefficient of auto determination being 0.49, i.e. the multiple auto correlation coefficient was found to be 0.7 with the following autoregression model:-

$$\hat{S.P}_d = 0.3705\ S.P_{d-1} + 0.5356\ S.P_{d-2} - 0.0231\ S.P_{d-3} - 0.1865\ S.P_{d-4}$$

Where, 'd' - denotes number of days after commencement of observations (23.11.1985), $\hat{S.P}_d$ = estimated spore load of the respective day.

It is evident from the above equation that the values of the partial autoregression coefficients are as follows:-

$b_1=0.3705$, $b_2=0.5356$, $b_3=-0.0231$, and $b_4=-0.1865$

The estimated values of the spore load obtained from the above equiation are presented in Table 1 and Figure 2 along with observed values and meterological parameter. The spore load in the atmosphere was estimated in terms of number of days after commencement of observation on spore load by another method known as the method of spline functions. The exact form of the function is presented here:-

$$\hat{S.P}_d = \frac{3}{\left(\frac{d-33}{8}\right)^2+1} \quad \frac{3}{\left(\frac{d-53}{2}\right)^2+1} \quad \frac{3}{\left(\frac{d-79}{5}\right)^2+1} \quad \frac{5}{\left(\frac{d-99}{9}\right)^2+1} \quad \frac{1}{\left(\frac{d-117}{3}\right)^2+1}$$

Where,

$\hat{S.P}_d$ = estimated spore load for the respective days.

d = number of days after commencement of observations (23.11.1985)

The correlation coefficient between $S.P_d$ and day number 'd' was found to be 0.6. A further attempt was made to extract information about spore load, its autoregression of first and second order as well as weather factors S.a. maximum temperature (T^M), relative humidity evening (RH_2) as well as wind velocity (W). The matrix of calculated sum of squares and sum of products of these factors is presented in Table 1(c). From the Table 1(c), the auto correlations and cross correlations of spore load and other weather factors were derived and are presented in Table 1(d).

All the correlations presented in Table 1(d) were found to be significant at 5% level of significance except for the correlations of wind velocity with first order auto correlations, second order auto correlation, maximum temperature and relative humidity (evening). However, the correlation of wind velocity of a day with the spore load of that day was found to be significant.

Studies on aerobiology of a disease are important in order to forecast and predict the occurence of disease in a particular locality. Based on presence and absence of uredospores in the atmosphere and weather conditions, supervisory control measures could be developed. Aeroscope studies revealed that aerial transport of uredospores from the Nilgiri and Pulney hills or from off season wheat growing areas are closely related to wind. This statement is in accordance with the explanation given by Stakman et al (1923) and Tilak (1986) in respect of wheat rusts. Information obtained from Aeroscope studies would be of significant importance in developing an efficient disease forecasting system in India, with practical use in disease assessment and disease severity which could be reduced below the economic threshold. Further, uredospore load in the atmosphere is also closely related to disease incidence in the field under favourable environmental conditions. In the present study, it was observed that uredospores started to appear in the atmosphere from 25th November 1985, but the disease was observed on local red wheat in the third week of December. This indicated that rust spores were present well in advance of the actual outbreak of the disease. This is in agreement with the observations made by Sahni and Prasada (1963) in leaf rust of wheat (P.recondita f.sp.tritici).

In this study, maximum numbers of uredospores were caught per microscopic field in the month of February. This may be because of floating of uredospores over infected field and uredospores coming through air current from Nilgiri and Pulney hills or from off season wheat of Karnataka.

For the estimation of uredospore load in the atmosphere, various prediction models have been developed. The autoregression method with correlation coefficient 0.7

(coefficient of determination 49 per cent) was found to be superior in many respects to the method of spline functions (which has coefficient of determination 36 per cent), i.e. correlation coefficient 0.6, as well as mixed method of first two autoregressions with weather factors. The chief drawback of the spline function is that it is most subjective with regard to nature and form of the functions incorporated in the study. In other words, the nature of function may be quadratic in case of one researcher while cubic for the other. At the same time, even though the nature of the function is the same, there is scope for variation in the values of the function depending on the judgement of the investigator. Moreover, there is little basis for the comparisons of spline functions of one season with the other. In the mixed model, it was not possible to establish any prediction model due to high variability in maximum temperature (with sum of squares adjusted = 1255.67°C) as well as relative humidity (even on 17380.55 per cent) in comparison with S.S. due to spore load (220.35). The basis for selection of maximum temperature and relative humidity (morning) is that these factors as indicated by scatter diagrams explain variation in spore load better than the other two. It is however interesting to note that temperature and relative humidity are related significantly to spore load of the same day as well as the spore load of previous two days (Tables 1(c) and 1(d)). The wind velocity is significantly related only with the spore load of the same day and is not related in a statistical sense to either the spore loads of previous days or other weather factors (the respective correlation coefficients were found to be not significant).

The determination of spore load in terms of wind velocity alone is to the extent of four per cent with correlation coefficient being 0.207. It means that the remaining 96 per cent of the variation can be explained in terms of other factors. Due to large variation in maximum temperature and relative humidity, it was not possible to use these values for estimating spore load.

The autoregression method is most objective without any scope for subjective judgement. It is more sound than the spline function method in the sense that the results of one season can be compared with the results of any other season. It is evident from the autoregression prediction model, that with spore load values of successive four previous days, the spore load of a day can be predicted with correlation coefficient 0.7. The prediction models were based on either first two sum of products and sums of squares mixed with three weather factors, viz. maximum temperature relative humidity (evening) and wind velocity or 4th order autoregression equation as well as spline functions. However, the two prediction models indicate that there is scope for estimation of spore load with higher correlation coefficient by plugging

in higher order autoregression model in combination with other weather factors by considering suitable transformations of these factors. Further,the aerobiology study can be more meaningful and useful with such a model being considered in conjunction with disease incidence and intensity under field trials.

The average uredospore load of P.recondita f.sp.tritici increased from January and reached a peak in February and first week of March. This may be due to collection of uredospores from hills and also the higher incidence in the field. The weather factors also played a significant role in the spore deposition and incidence in the field. Disease incidence was maximum in the month of February (on crop sown in December month Table 2). This supports the findings of Kulkarni and Ramakrishnan (1977) on Drechslera oryzae and Jhalander (1983) in case of P.graminis var.tritici.

The studies indicated that the uredospore load in the atmosphere was very important in developing prediction models to prevent the incidence of disease by adopting suitable control measures (cultural practices, a chemical method, adjusting the date of sowing).

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REFERENCES

BROMFIELD, K.R., UNDERWOOD, J.E., REEL, C E., GRISSINGER and KINGSOLVER, C H., 1959. Epidemiology of stem rust of wheat. IV. The use of rods as spore collecting devices in a study on the dissemination of stem rust of wheat uredospores. Pl.Dis.Reptr., 43, 1160-1168.

CHATTERJEE, G., 1931. A note on an apparatus for catching spores from the upper air. Indian J. Agric.Sci., 3, 306-308.

CUNNINGHAM, D.D., 1873. Microscopic examinations of air. Government printers, Calcutta, p.58.

EVERSMEYER, M G., KRAMER, C.L., 1980. Horizontal dispersal of uredospores of Puccinia recondita f.sp.tritici and P.graminis f.sp.tritici from a source plot of wheat. Phytopathology, 70, 683-85.

EVERSMEYER, M.G., KRAMER L.L. and BROWDER, L.E., 1984. Presence, viability and movement of Puccinia recondita and P.graminis inoculum in the great plains. Pl.Dis., 68, 392-95.

GREGORY, P.H. and STEDMAN, O.J., 1953. Deposition of air borne Lycopodium spores on plain surfaces. Ann. Apply Biol. 40, 651-674.

JHALINDER, G., 1983. Studies on black stem rust of wheat caused by Puccinia graminis f.sp. tritici (Pers.) Eriks and Henn. unpublished M.Sc.(Agri.) Thesis, University of Agricultural Sciences, Bangalore.

KARKI, C.B., 1977. Aerobiology of stem rust over an infected wheat field. M.Sc. Thesis. Division of Mycology and Plant Pathology. IARI, New Delhi.

KNUTSON, D.M., 1972. Cylindrical rods more efficient spore sampler. Pl.Dis.Reptr., 56, 719-20.

KULKARNI, S. and RAMAKRISHNAN. K., 1977. Epidemiology and control of brown leaf spot of rice caused Drechslera oryzae (Breda de Hann.) Subram. and Jain in Karnataka. Mysore J.Agric.Sci., 11, 598.

KULKARNI, S., RAMAKRISHNAN, K. and HEGDE, R.K., 1982. Epidemiology and control of brown leaf spot of rice in Karnataka Indian Phytopath. 35, 80-82.

KULKARNI, S., RAMAKRISHNAN, K and HEGDE, R K., 1984. Epidemiology and control of brown leaf spot rice caused by Drechslera oryzae (Breda de Hann) Subram, and Jain in Karnataka VII. Effect of low temperature and high relative humidity on spore production and release of D.oryzae. Mysore J.Agric.Sci., 18, 208-210.

MEHTA, K.C., 1940. Further studies on cereal rusts in India. Monograph. Indian Counc. Agric.Res.Sci., No.14. p.224.

MEHTA, K.C., 1952. Further studies on cereal rusts, Part II. Monograph. Indian Counc. Agri.Res.Sci., No.18. p.368.

MICHELI, P.A., 1729. Nova plantarum Genera. p.234.

NAGARAJAN, S., SINGH, H., JOSHI, L.M. and SAARI, E.E., 1977. Prediction of Puccinia graminis f.sp.tritici on wheat in India by trapping the uredospores in rain samples. Phytoparasitica, 5, 104-108.

ROELFS, A.P., DIRKS, V.A and ROMIG, R.W., 1968. A comparison or rod and slide samples used in cereal rust epidemiology. Phytopathology, 58, 1150-1154.

ROELFS, A.P., ROLELL, J.P. and ROMIG, R.W., 1970. Sampler for monitoring cereal rust uredospores in rain. Phytopathology, 60, 187-188.

ROWELL, J.B. and ROMIG, R.W., 1966. Detection of uredospores of wheat in spring rains. Phytopathology, 56, 807-811.

SAHNI, M.L. and PRASAD, R., 1963. Study of environmental conditions influencing the development of 3 rusts of wheat in the neighbourhood of Delhi. An incidence of wheat rusts in relation to initial spore shower and weather condition. Indian Phytopath. 16, 285-300.

STAKMAN, E.C., HENRY, A.W., CURRAN, G.C. and CHRISTOPHER, W.N., 1923. Spores in the upper air. J.Agric.Res., 24, 599-605.

TILAK, S.T., 1986. Aerial transport of plant pathogens. Vistas in Plant Pathology, Malhotra publishing house. p.337.

Table 1(a) Matrix of autosum of products and sum of squares

	S_d	S_{d-1}	S_{d-2}	S_{d-3}	S_{d-4}
S_d	220.35	131.12	136.57	90.20	61.71
S_{d-1}	131.12	220.35	131.12	136.57	90.20
S_{d-2}	136.57	131.12	220.35	131.12	136.57
S_{d-3}	90.20	136.57	131.12	220.35	131.12
S_{d-4}	61.79	90.20	136.57	131.12	220.35

Table 1(b) Autocorrelation matrix

	S_d	S_{d-1}	S_{d-2}	S_{d-3}	S_{d-4}
S_d	1.000	0.595	0.620	0.409	0.280
S_{d-1}	0.595	1.000	0.595	0.620	0.409
S_{d-2}	0.620	0.595	1.000	0.595	0.620
S_{d-3}	0.409	0.620	0.595	1.000	0.595
S_{d-4}	0.280	0.409	0.620	0.595	1.000

Where,

S_d = Spore load of the day
S_{d-1} = Spore load of previous one day
S_{d-2} = Spore load of previous two days
S_{d-3} = Spore load of previous three days
S_{d-4} = Spore load of previous four days

Table 1(c) Matrix of sum of squares, sunm of autoproducts and cross products of spore load and weather factors

	S_d	S_{d-1}	S_{d-2}	T^M	RH_2	W
S_d	220.35	131.12	122.36	127.71	-275.28	75.79
S_{d-1}	131.12	220.35	131.12	136.57	-482.58	57.39
S_{d-2}	122.36	133.12	220.35	176.61	-549.25	50.60
T^M	127.71	136.57	176.61	1255.67	-3711.88	112.36
RH_2	-275.28	-482.58	-549.25	-3711.68	17830.55	-105.25
W	75.72	57.39	50.60	112.36	-105.25	608.31

Table 1(d) Matrix of 1st and 2nd autocorrelation of spore load and cross correlations of weather factors

	S_d	S_{d-1}	S_{d-2}	T^M	RH_2	W
S_d	1.000	0.595	0.555	0.242	-0.139	0.207
S_{d-1}	0.595	1.000	0.595	0.260	-0.243	0.157NS
S_{d-2}	0.555	0.595	1.000	0.336	-0.277	0.138NS
T^M	0.242	0.260	0.336	1.000	-0.785	0.129NS
RH_2	-0.139	-0.243	-0.277	-0.785	1.000	-0.032NS
W	0.207	0.157NS	0.138NS	0.129NS	-0.032	1.000

Where,

M^T = Maximum temperature
RH_2 = Relative humidity (evening)
W = Wind velocity

Table 2. Incidence of leaf rust of wheat caused by P.recondita f.sp.tritici with different dates of sowing along with meteorological parameters.

Sl. No.	Date of Sowing	Terminal severity with average co-efficient of infection	Meteorological parameters	
			Mean relative humidity (%)	Mean temperature (°C)
1.	9.11.1985	10 MR-40MS (8.41)	73.35	22.25
2.	24.11.1985	40 MR-80S (40.30)	74.92	22.56
3.	9.12.1985	20 MS-100S (68.72)	80.04	21.54
4.	24.12.1985	20 MS-100S (61.31)	72.43	23.92
5.	9.1.1986	40 MS-90S (58.00)	64.49	27.88

Note: Figures outside and inside the parentheses indicate the severity of the disease and average coefficient of infection, respectively.

Table 1. Mean number of uredospores of leaf rust of wheat caused by P.recondita f.sp.tritici caught per microscopic field in a day along with estimated spore load and meteorological parameters from 23.11.1985 to 13.3.1986

Day Number	Date	Observed spore load	Estimated spore load by		Wind velocity (km/hr)	Temperature (°C)		Per cent relative humidity	
			a*	b*		Minimum	Maximum	Morning	Evening
1	2	3	4	5	6	7	8	9	10
1	23.11.85	0.0	0.2	-	3.9	15.4	31.9	87	59
2	24.11.85	0.0	0.2	-	3.5	15.7	32.2	88	60
3	25.11.85	0.6	0.2	-	4.0	14.3	32.1	85	65
4	26.11.85	1.0	0.3	-	7.9	13.2	30.0	88	66
5	27.11.85	1.1	0.3	0.7	7.3	12.3	29.4	87	62
6	28.11.85	1.5	0.3	0.9	8.7	12.2	28.6	85	62
7	29.11.85	0.7	0.3	1.0	8.2	11.5	28.6	86	63
8	30.11.85	0.4	0.3	0.9	10.6	11.2	28.2	84	73
9	1.12.85	1.0	0.4	0.2	9.6	10.9	27.2	80	60
10	2.12.85	0.7	0.4	0.3	7.8	15.9	29.4	82	59
11	3.12.85	1.1	0.4	0.7	9.5	16.5	29.4	86	63
12	4.12.85	0.7	0.4	0.7	8.4	16.8	28.9	85	59
13	5.12.86	0.6	0.5	0.6	9.7	16.8	30.0	86	55
14	6.12.85	0.7	0.5	0.4	6.9	14.8	29.2	85	54
15	7.12.85	1.5	0.6	0.4	6.2	14.3	29.4	79	58
16	8.12.85	0.7	0.6	0.8	5.8	15.9	28.4	82	57
17	9.12.85	0.4	0.7	0.9	6.5	14.8	29.4	79	58
18	10.12.85	0.5	0.7	0.4	4.4	15.7	31.4	82	49
19	11.12.85	0.4	0.8	0.1	5.4	17.6	31.7	86	65
20	12.12.85	0.6	0.9	0.3	7.0	17.6	29.7	89	61

Contd...)

Table 1 Contd...)

1	2	3	4	5	6	7	8	9	10
21	13.12.85	0.9	1.0	0.4	7.5	14.6	29.4	87	55
22	14.12.85	2.7	1.1	0.6	6.3	16.5	30.0	88	63
23	15.12.85	2.0	1.3	1.4	11.5	18.7	28.9	95	67
24	16.12.85	2.1	1.4	2.1	5.3	15.9	27.2	93	65
25	17.12.85	1.2	1.6	1.6	6.4	15.1	30.6	89	60
26	18.12.85	3.1	1.8	1.0	7.5	14.6	30.0	86	54
27	19.12.85	3.0	2.0	1.4	8.2	13.2	30.0	87	55
28	20.12.85	2.6	2.3	2.4	7.2	14.8	31.1	88	61
29	21.12.85	2.1	2.5	2.3	8.8	14.6	30.8	86	65
30	22.12.85	1.8	2.7	1.5	10.5	13.7	30.9	89	71
31	23.12.85	1.3	2.0	1.2	10.0	14.3	28.9	87	66
32	24.12.85	3.1	3.1	0.9	9.6	17.1	29.4	88	68
33	25.12.85	3.6	3.1	1.4	10.1	15.9	29.4	86	69
34	26.12.85	3.6	3.1	2.6	10.6	13.7	29.0	89	64
35	27.12.85	3.0	3.0	2.9	10.8	15.4	30.6	87	62
36	28.12.85	1.7	2.8	2.4	4.6	15.4	31.9	82	63
37	29.12.85	0.4	2.6	1.5	7.2	14.3	31.1	86	65
38	30.12.85	0.7	2.3	0.3	8.3	14.3	31.1	83	74
39	31.12.85	1.8	2.1	0.0	9.2	13.0	30.0	86	72
40	1.1.86	0.7	1.9	0.7	8.8	14.3	30.4	88	63
41	2.1.86	2.1	1.7	1.1	7.3	13.7	30.4	90	69
42	3.1.86	2.0	1.5	1.0	7.2	12.9	30.0	86	75
43	4.1.86	0.4	1.4	1.5	8.5	12.6	28.9	85	75
44	5.1.86	0.3	1.3	1.0	8.2	12.6	28.9	86	74
45	6.1.86	0.5	1.2	0.0	9.0	12.6	28.8	81	75
46	7.1.86	0.4	1.2	0.0	9.5	11.4	28.9	90	78
47	8.1.86	0.0	1.2	0.3	9.1	13.2	28.9	89	73

Contd...)

Table 1 Contd...)

1	2	3	4	5	6	7	8	9	10
48	9.1.86	0.0	1.3	0.0	9.2	12.3	29.6	91	69
49	10.1.86	1.0	1.4	0.0	7.1	13.4	29.7	92	73
50	11.1.86	2.1	1.7	0.3	9.3	14.0	29.2	90	78
51	12.1.86	2.7	2.3	1.3	9.9	14.3	28.2	90	70
52	13.1.86	1.9	3.1	2.1	10.4	14.8	29.0	89	81
53	14.1.86	3.1	3.7	1.9	6.9	18.2	28.3	87	100
54	15.1.86	2.9	3.1	1.7	9.9	18.2	23.9	98	100
55	16.1.86	2.4	2.2	2.2	11.2	15.4	21.4	93	61
56	17.1.86	0.2	1.6	2.0	8.5	10.7	26.7	80	77
57	18.1.86	2.2	1.3	0.7	6.3	11.1	26.9	81	68
58	19.1.86	0.3	0.9	0.0	3.8	15.4	29.4	91	68
59	20.1.86	2.2	1.0	0.8	8.7	15.1	28.9	91	67
60	21.1.86	0.3	0.9	0.0	3.8	15.4	29.4	91	66
61	22.1.86	2.2	0.9	0.9	9.3	14.8	29.4	91	68
62	23.1.86	2.4	0.9	0.9	10.0	13.2	30.0	89	67
63	24.1.86	0.4	0.9	1.7	9.0	14.8	30.0	89	56
64	25.1.86	2.2	0.9	1.3	5.4	15.7	31.7	86	62
65	26.1.86	2.3	0.9	0.6	4.7	15.4	31.1	90	61
66	27.1.86	1.0	1.0	1.6	8.8	15.4	31.1	87	61
67	28.1.86	0.4	1.0	1.5	10.4	12.6	30.3	85	67
68	29.1.86	0.5	1.1	0.2	6.0	15.4	30.2	89	63
69	30.1.86	2.6	1.2	0.0	10.2	15.4	30.6	87	74
70	31.1.86	0.8	1.3	1.0	7.8	15.4	28.9	89	70
71	1.2.86	3.3	1.5	1.6	8.9	12.6	29.0	90	71
72	2.2.86	2.4	1.7	1.5	7.8	12.9	28.9	90	67
73	3.2.86	2.3	1.9	2.2	4.8	14.9	30.1	91	51
74	4.2.86	2.7	2.2	1.9	5.7	15.6	32.2	87	47
75	5.2.86	0.9	2.6	1.6	5.2	16.5	32.8	90	57

Contd...)

Table 1 Contd...)

1	2	3	4	5	6	7	8	9	10
76	6.2.86	2.7	3.0	1.3	4.5	16.9	32.8	88	48
77	7.2.86	0.5	3.4	1.0	5.3	15.7	35.3	82	47
78	8.2.86	2.8	3.8	1.1	7.3	16.9	32.8	88	60
79	9.2.86	4.1	4.3	1.1	7.7	15.9	30.2	91	64
80	10.2.86	2.5	3.9	2.5	8.0	15.4	29.7	91	56
81	11.2.86	0.9	3.7	3.0	6.8	15.2	30.3	91	53
82	12.2.86	1.7	3.4	1.0	6.3	15.9	31.4	85	64
83	13.2.86	2.6	3.1	0.3	7.3	17.1	31.1	86	65
84	14.2.86	2.4	2.9	1.4	7.6	16.9	30.6	86	64
85	15.2.86	2.4	2.8	2.1	8.0	14.8	30.3	90	62
86	16.2.86	2.5	2.7	1.8	8.7	12.3	30.6	88	80
87	17.2.86	0.7	2.7	1.7	8.6	12.6	27.8	85	63
88	18.2.86	2.0	2.8	1.1	7.9	15.9	31.1	87	60
89	19.2.86	2.1	2.9	0.6	6.4	17.6	32.2	82	60
90	20.2.86	4.7	3.1	1.4	12.1	18.2	33.3	81	64
91	21.2.86	4.7	3.3	2.7	12.7	17.0	32.8	86	55
92	22.2.86	3.0	3.6	3.8	10.3	19.3	36.6	84	54
93	23.2.86	2.9	3.9	3.1	9.4	19.8	34.7	89	55
94	24.2.86	3.8	4.1	1.7	7.8	16.4	32.5	83	54
95	25.2.86	3.9	4.4	2.0	10.2	18.2	32.8	82	54
96	26.2.86	3.3	4.7	2.9	10.1	17.6	33.9	83	52
97	27.2.86	5.1	5.0	2.7	13.4	17.9	34.3	82	56
98	28.2.86	3.4	5.1	2.9	7.9	17.6	33.7	83	53
99	1.3.86	6.5	5.2	3.2	9.2	18.2	34.4	87	49
100	2.3.86	5.7	5.1	3.5	1.7	17.6	32.9	85	50
101	3.3.86	2.3	4.9	4.6	11.3	16.8	33.9	83	50
102	4.3.86	3.0	4.6	3.1	7.2	18.7	34.8	83	52
103	5.3.86	2.5	4.3	1.0	6.4	19.3	34.2	78	42

Contd...)

Table 1 Contd...)

1	2	3	4	5	6	7	8	9	10
104	6.3.86	2.6	3.9	1.4	6.2	20.4	34.4	85	50
105	7.3.86	3.4	3.6	1.8	7.9	18.7	35.2	86	50
106	8.3.86	3.2	3.2	2.0	9.4	19.6	35.6	80	50
107	9.3.86	4.6	2.7	2.5	7.9	18.7	35.6	87	50
108	10.3.86	2.5	2.5	2.9	11.8	19.0	34.7	87	44
109	11.3.86	3.4	2.2	2.7	13.0	20.4	35.8	82	44
110	12.3.86	3.6	2.0	1.9	10.8	20.3	36.1	87	43
111	13.3.86	2.0	2.0	2.2	7.1	19.3	36.0	87	41
112	14.3.86	2.9	2.6	2.1	9.2	20.9	36.7	90	40
113	15.3.86	2.9	2.0	1.4	7.5	21.5	37.1	88	41
114	16.3.86	2.3	2.0	1.9	13.3	20.4	37.2	84	40
115	17.3.86	2.6	1.9	2.0	12.0	20.9	37.2	83	48
116	18.3.86	1.9	2.0	1.7	10.4	20.8	34.7	88	46
117	19.3.86	2.4	2.0	1.5	7.3	18.7	35.2	85	42
118	20.3.86	1.7	1.8	1.4	7.7	19.3	35.8	91	43
119	21.3.86	2.0	1.5	1.4	8.3	18.7	36.1	83	45
120	22.3.86	2.6	1.3	1.2	8.6	19.1	36.7	81	41
121	23.3.86	2.2	1.1	1.5	9.9	21.0	37.8	86	41
122	24.3.86	2.8	0.9	1.8	8.2	20.1	37.5	86	38
123	25.3.86	1.1	0.8	1.8	10.5	19.3	37.1	83	38
124	26.3.86	0.8	0.7	1.4	8.3	19.3	37.8	85	39
125	27.3.86	0.0	0.7	0.4	10.1	21.2	37.9	81	40
126	28.3.86	0.0	0.6	0.0	10.4	20.7	37.5	85	39
127	29.3.86	0.0	0.5	0.0	10.3	21.0	37.8	82	44
128	30.3.86	0.0	0.5	0.0	14.1	20.1	36.1	91	45

a* - spline function model
b* - autoregression model

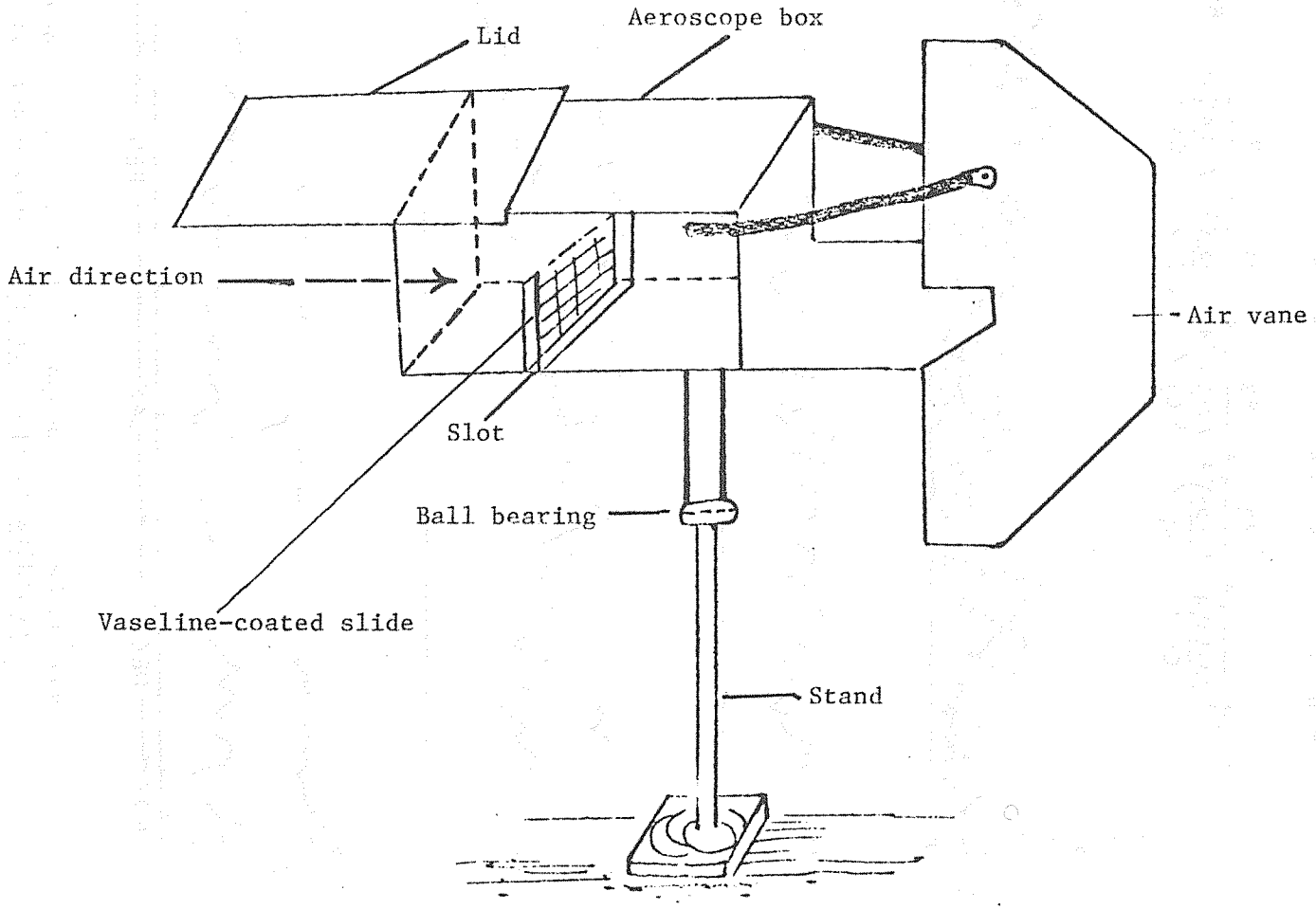

Fig. 1. Aeroscope for exposure of stationary slides

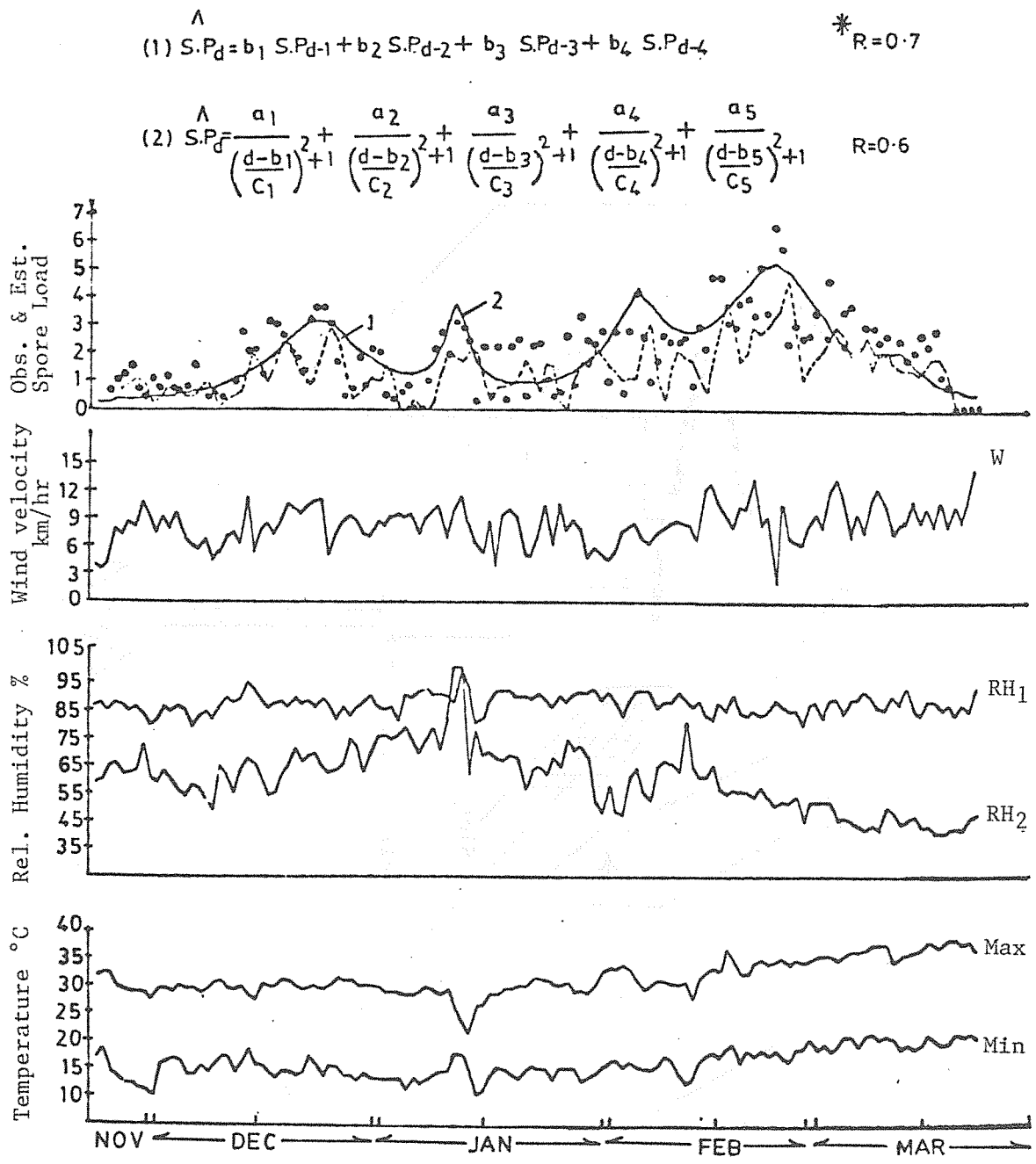

Fig. 2. Mean number of uredospores of leaf rust of wheat (P. recondita f. sp. tritici) observed per microscope field in a day, together with estimated spore load and meteorological parameters from 23.11.85 to 30.3.86.

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INTERNATIONAL PATHOGENICITY SURVEY OF WHEAT LEAF RUST PATHOGEN AND SOURCES OF RESISTANCE

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For many years now leaf rust caused by Puccinia recondita tritici has posed a great problem in wheat production, as the most widespread wheat disease in the world.

Samborksi and Peturson (1960) reported reduction in yield of 58 percent at Winnipeg. Applying fungicides, Conzales (1966) found differences in yields between two varieties susceptible to leaf rust amounting to 28-34% in one year and 34-45% the following year. Trials conducted over a period of several years showed that the degree of susceptibility and tolerance of various wheat varieties have a considerable influence on the yield losses caused by leaf rust which varied between 5-45% (Boskovic, 1971).

Wheat rusts are a typical example of the necessity for international co-operation because of the nature of the problem.

Long distance dissemination of the rust pathogens is a well established phenomenon. Wind is a great uncontrolled carrier of inoculum. Uredospores of rust fungi are recognised as international travellers along the "wind-routes". Rust spores travel from Africa to Europe (Guyot et al., 1956; Zadoks, 1967), from Mexico to USA and Canada (Stakman, 1942), from Australia to New Zealand (Watson and Cass Smith, 1962), from China to Japan and from Ethiopia to Israel (Dinoor and Levi, 1971). In the Indian sub-continent rust spores make big jumps from the source areas to the plains (Mehta, 1952; Nagarajan and Singh, 1975). Long distances are covered either in a single jump, or by a series of jumps which necessitate the build up of inoculum at each successive step. At high elevations, uredospores are exposed to certain adverse, lethal climatic conditions. Wheat rust uredospores cannot stand temperature extremes and ultraviolet radiation. However, despite these limitations, some uredospores are carried in a viable state and cause infections thousands of kilometers away.

In order to find the best and the most suitable solutions for numerous problems of wheat rusts, it was necessary to establish international co-operation within a broad epidemiological region. The importance and necessity of co-operative international investigations of the wheat rusts was emphasised at the European and Mediterranean Cereal Rusts Conferences in Cambridge (1964), Oeiras/Portugal (1968),

Prague/Czechoslovakia (1972), Interlaken/Switzerland (1976), Bari and Rome/Italy (1980) and Grignon/France (1984). Resolutions passed by the First International Congress of Plant Pathology, London, 1968, recommended a worldwide survey of virulence genes in pathogen populations by means of lines monogenic for resistance factors. The International Biological Program was already following these recommendations with the help of the European and Mediterranean Cereal Rusts Foundation.

Co-operative research on yellow rust of wheat for Europe and some countries of Asia and Africa started in 1962 in The Netherlands and Germany. Somewhat later, similar investigations of stem rust for a broad area started in Portugal and finally of wheat leaf rust in Yugoslavia in 1966.

These investigations were primarily directed towards the geographic distribution of physiologic races, the discovery of new races and testing sources of resistance. Most of these research results have already been published.

INTERNATIONAL PATHOGENICITY SURVEY OF PUCCINIA RECONDITA TRITICI

From the beginning of the leaf rust project standard differential varieties with differentiation of U.N. (Unified Numeration) races proposed by Johnston (1965) and Basile (1957) were used. In the four year period, 1967 to 1970, 24 U.N. races were identified for 34 countries of Europe, Asia and Africa (Boskovic, 1972, 1974). The dominant one was U.N. race 3 with 42.29% of the total isolates. The second place was occupied by U.N. race 13 with 29.45% followed by U.N. race 17 (8.39%), U.N. race 8 (4.60%), U.N. race 6 (3.10%), U.N. race 9 (2.84%), U.N. race 2 (1.95%), U.N. race 10 (1.68%) and U.N. race 4 (1.35%). The other fifteen U.N. races had less than one percent of the total isolates. In this period seventy five standard races were identified, proving the potential for variability of the pathogen. Countries in Asia and Africa did not show much difference in composition and prevalence of races compared with Europe, confirming the epidemiological relation between regions.

In this period leaf rust nurseries were tested in most European and Mediterranean countries, Asia and Africa, and some countries of the Near and Middle East. The nurseries contained sources of resistance and the best results with leaf rust and other diseases have been reported elsewhere (Boskovic, 1972).

Browder (1971) first stated that the classic pathogenic race concept was inadequate and may, particularly in relation to breeding cultivars for specific resistance, be better served by other means. Information on pathogen genotypes was conveyed only to the extent of one's knowledge of the genetic make up of the hosts in the differential set. However, it is genes, not

arbitrarily chosen gene combinations, which are the functional, segregating units; genes for pathogenicity singly are the inherited units. Thus, a direct method was needed to relate information about genes for pathogenicity in pathogen populations to genes for resistance in host plants and about gene association in both organisms.

Pathogenic race names were inadequate since the variation in the P.recondita: Triticum aestivum system is so extensive that it would be impossible to describe and name all the races if all the existing variation was included in the taxonomic system (Loegering and Burton, 1974).

International pathogencity surveys from1970 to 1974 were carried out using near-isogenic wheat lines with different genes for low reactions (Boskovic, 1976). Virulence frequencies are presented in Table 1.

Table 1. Virulence frequencies to twelve near-isogenic wheat lines with different genes for low reactions to Puccinia recondita f.sp.tritici in 1970-1974 International pathogenicity surveys.

Lr line	Virulence frequencies by years				
	1970	1971	1972	1973	1974
LR1/TC.x Centenario/	53.26	32.35	97.24	100.00	100.00
LR2A/TC.x Webster/	52.34	32.35	96.35	98.59	98.35
LR2D/PL x Loros/	99.34	77.75	100.00	97.18	99.45
LR3A/TC.x Democrat/	90.46	94.11	100.00	98.59	98.35
LR10/TC.x Exchange/	99.21	99.81	100.00	85.91	100.00
LR16/TC.x Exchange/	98.30	99.81	87.88	87.88	100.00
LR17/TC.x Kl.Lucero/	94.12	100.00	99.81	100.00	98.90
LR18/TC.x Africa 43/	99.47	96.13	77.19	66.90	96.70
LR3B/TC.x Aniversario/	64.05	43.35	93.98	78.84	99.09
LR14b/TC.x M.Escobar/	99.85	99.76	98.83	91.61	100.00
LR9/TC./	1.39	0.23	0.58	0.00	0.00
LR19/TC./	19.16	3.49	0.97	0.64	0.00

Very high virulence frequencies were found throughout the period on the Lr10, Lr16 and Lr17 lines, while on Lr18, lower percentages were detected in 1972 and 1973. In the first two years rather lower virulence frequencies can also be observbedf on the Lr3B line. On the strong resistance genes Lr9 and Lr19 in each year only a few single susceptible reactions were found. More susceptible reactions were detected in 1970 and 1971 on the variety Agatha possessing Lr19, which was used in the first two years instead of single gene Lr19 backcross line in variety Thatcher.

Thirty-one virulence formulae were identified in 1970, 12 in 19 in 1971, 1972, and 11 in 1973, but only 8 in 1974, with almost complete susceptibility of all eight Lr lines to 92 isolates, 30 percent of the total. The collections from 41 countries which were analysed during this period were sent mostly from Europe, Asia and Africa, and the number of countries varied in individual years, from 13 to 28. The adult plant reactions of these Lr lines in the nurseries were mostly susceptible. Greater resistance in several localities was recorded only on the Lr 18 line.

In a separate paper details were given for 1972 of the considerable differences on the same basic Lr lines between the populations of Puccinia recondita f.sp. tritici of the European-Mediterranean area, U.S.A. and Canada (Boskovic and Browder, 1976). Virulence frequencies for samples from each of the three areas are shown in Table 2.

Table 2. A comparison of virulence frequencies to nine near isogenic wheat lines having different genes for low reaction to Puccinia recondita f.sp. tritici in samples of P.recondita taken in European-Mediterranean countries, the United States and Canada in 1972.

Line name	Line No.	Virulence frequency in samples from: Europe[a]	United States[b]	Canada[c]
LR1(TC)	RL6003	97.2	34.6	6.5
LR2A(TC)	RL6000	96.4	17.3	2.4
LR2D(PL)	RL6001	100.0	26.8	11.2
LR3A(TC)	RL6002	100.0	89.4	96.4
LR10(TC)	RL6004	100.0	67.6	46.7
LR16(TC)	RL6005	87.9	5.0	4.7
LR17(TC)	RL6008	99.8	15.4	5.9
LR18(TC)	RL6009	77.2	4.5	23.1
LR3B(TC)	RL6007	94.0	11.1	-

[a]Data from 545 isolates collected in 24 European and Mediterranean countries.
[b]Data from 809 isolates collected in 32 States.
[c]Data from Samborski, D J, 1972. Leaf rust of wheat in Canada in 1972. Can.Plant Dis. Surv. 52, 168-170.

Pathogenicity of Puccinia recondita tritici to nine near-isogenic lines of Triticum aestivum was determined by assaying samples from 24 European and Mediterranean countries, and 32 States of the United States in 1972. These lines carried Lr1, Lr2A, Lr2D, Lr3A, Lr10, Lr16, Lr17, Lr18, or Lr3B. Data from these studies were compared with each other and with data from a similar study in Canada the same year in which eight of the same nine lines were used. Virulence frequencies to all the lines were very high in the European-Mediterranean sample, whereas virulence frequencies were high to only two of the lines in the samples from the United States and Canada. Sixty-three percent of the 545 isolates in the European-Mediterranean sample had combined virulence to all eight lines, but none of the isolates from the United States or Canada had virulence to more than seven lines. These data indicate that the host lines used are of limited value in survey studies of pathogenicity in the European-Mediterranean countries. These lines have no value to plant breeding for leaf rust resistance in the European-Mediterranean countries; however, there is value in knowing of pathogenicity to them in epidemiological studies.

After this period it was essential to include some other experimental differential wheat lines in the international survey. Two sets, each with the experimental host differentials, were established and used in 1977 and 1978. The first set contained differentials with poorly known genetic background. In the second, most of the lines were better known genetically. These lines were selected from material received and recommended by Australian scientists (personal communication). The results have been reported (Boskovic, 1980).

Total virulence frequencies of Puccinia recondita f. sp. tritici in the seedling stage and field reactions in the nurseries on the first set of those differentials are presented for two years in Table 3. The countries from which collections were received differed in the two years. Eighteen countries were represented in both years.

The wheat lines or varieties listed in the table were selected after several years of preliminary testing. Only the first variety Arthur was replaced in 1978 by Arthur 71. It is known that Agent has the Lr 24 gene for which there were low virulence frequencies and satisfactory field reactions. For field data from the nurseries it should be mentioned that severity of leaf rust was higher in 1978 than in 1979. Differential nursery reactions (D) with average MS or S response but with low severity could be valid, but where the average susceptibility was of high severity would not be reliable. This is because high severity would be more likely to fluctuate with time even though the variety might be completely susceptible to all races.

Tobari 66 contains two weak genes Lr1 and Lr20 and may be some other resistance genes. These genes in mutual interactions are quite differentially valuable at the seedling stage, followed by good field reactions. In Canada for the first time in 1977 some virulent cultures were found on Tobari 66 (Samborski, 1978). Waldron with several known genes (Lr1,2A,10) and Jaral gave good results, but there was an increased virulence for Jaral in 1978 although it still retained satisfactory field reactions.

Virulence for the wheat lines ND-138-1xPa^5 and Gaba 56xBacka^6 was at quite high frequencies and was indicated by differential nursery reactions with medium or high severity. Two other lines, Purdue 5119xBo-5^6 and NS-4R were better at both growth stages. Kavkaz should have two unclassified resistance genes (Ionescu-Cojacaru et al., 1974). May be these genes would be valuable only when combined. Using these ten differential cultivars it was possible to identify 46 virulence formulae for 1977 and 44 for 1978. The results with another set of differential lines are presented in Table 4.

Table 4. Virulence frequencies of Puccinia recondita f. sp. tritici on a second set of ten experimental wheat lines in 1977 and 1978 International pathogenicity surveys and average field reactions in the nurseries.

Diff. variety/line		Total vir. frequencies in 1977	Total vir. frequencies in 1978	Average reactions in nurseries, 1979
CS/KF 1A	Lr10	2.50	35.10	D(R,MS-L.sev.)
Kenya 1483	Lr15	99.17	76.90	D(R,S-H.sev.)
Thew	Lr20	52.20	99.20	D(R,S-H,sev.)SEG
Tc^6 x Lr.21	Lr21	99.17	89.70	R-MR
Tc^6 x Lee	Lr23	13.33	64.90	D(R,MS-M.sev.)
Agent,CI 13523	Lr24	0.83	18.80	R
Transec	Lr25	5.83	61.60	D(R,S-H,sev.)SEG
Tobari 66	Lr1,20	68.33	50.40	R
Waldron	Lr1,2A,10	11.67	9.40	R
CS/KF 7D		59.17	85.40	R

Legend: D - differential reactions in different nurseries
R - resistant, MR - moderately resistant,
MS - moderately susceptible
S - susceptible
L - low, M - medium, H - high severity
SEG - segregation

The first essential in a study of variation in pathogen virulence is to establish the most effective set of differential genes. It will be most useful to have a wide selection of isolated, identified genes that can be manipulated to produce different kinds of resistance as required. At the same time, testing both lines with single genes and with several genes for resistance leads to a more complete analysis of the population. After preliminary testing of some single gene lines and other resistant material provided and recommended by Australian colleagues, some were selected for inclusion in the second experimental differential set. Several of the differentials with one or more known resistance genes, already used in the first set, were included in the second one, in order to have more complete composition of the known effective genes for the analysed population. The first seven lines carry the known genes Lr10, 15, 20, 21, 23, 24 and 25 the next two, as already explained, have a combination of weak single genes. In the last line CS/KF 7D probably another resistance gene or genes are involved.

The diversity of total virulence frequencies in the table on these ten lines is quite evident. Increased virulence frequencies in 1978 were expressed on the lines with Lr genes 10, 20, 23, 25 and the line CS/KF 7D. Of these only Lr10 and CS/KF 7D had good field resistance in the nurseries. The greater resistance of Lr10 (CS/KK 1A) than of Lr10 in the line TC x Exchange (RL 6004"L") is remarkable. Lr21 showed good

field resistance and the others have already been explained. High segregation was noted in Thew and Transec. Twenty-seven virulence formulae were identified in 1977 and 41 in 1978.

The named Lr genes have been shown to occur on 13 different chromosomes in all three common wheat genomes. As has been shown, Lr genes and their corresponding genes for pathogenicity are the basis for storing and retrieving information about specificity in the P.recondita: Triticum system. Browder (1980) summarised information on thirty-five genes for low reaction to Puccinia recondita tritici (Lr genes), origin, chromosome location, characteristic low infection types, relative environmental sensitivity, synonymy and reference host lines and cultures. Five Lr genes, Lr 12, Lr13, Lr22 a, Lr22 b and Lr26 can be detected only by inoculating adult plants with an avirulent culture. Post-infection temperature influences the expression of all Lr genes, but some, Lr11, Lr12, Lr13, Lr14a and Lr18 are especially sensitive to high temperatures.

The value of Lr genes is ultimately to control leaf rust by manipulating Lr gene frequency in commercially grown wheat cultivars through breeding methods. Meanwhile, it is evident from knowledge of the gene-for-gene relationship that Lr genes protect plants from portions of pathogen populations having the corresponding Lp genes. On the other hand, in recent years some national surveys and other testing have shown good resistance especially at the adult stage among Lr lines possessing only Lr9, 25, 28, Lr19 and Lr24 (Casulli and Siniscalco, 1984; Rizvi et al., 1984; Boskovic, 1976).

SOURCES OF RESISTANCE AND NEW INTERNATIONAL SURVEY APPROACH

The narrow effective genetic base within Lr lines, particularly for breeding for resistance, has stimulated breeding for new efficient genetic combinations transferred into one wheat background.

Years ago we started screening an extensive wheat germplasm for genetically different sources of resistance to be included in a scheme of recurrent selection aimed at the development of diverse resistances. During the last three years, the progenies of these crosses have been screened for resistance to a number of typical cultures of Puccinia recondita tritici in order to gain knowledge of the genetic constitution of their resistance. The recurrent parents Princ and Starke were backcrossed twice with the donors.

The backcrosses were analysed for the presence of resistance genes by two cultures of the pathogen (Boskovic and Momcilovic, 1984). Even from the same crosses genetically different resisances were obtained. Eighteen donors were used, selected and numbered from International rusts nurseries.

Comparative testing using different cultures of the crossing progenies and 26 Lr lines were performed. Only different progeny lines numbered 66, 77, 5, 172, 438 and 496, with the same reaction pattern of homozygous high resistance with Lr19 were selected and crossed with Lr9, Lr19 and Lr24 to see if these genes were present in these hybrid lines. Their F2 progenies, together with the parental components and a susceptible control were screened for reaction to a Puccinia recondita tritici culture. The results are presented in table 5 (Boskovic and Momcilovic, 1986).

The resistance frequency above 0.75 was quite prominent, indicating that hybrids possess more than one pair of resistance genes. The only exception was the hybrid 66/1 x Lr9 due to non-homogeneity for Lr9. It was also quite evident that the resistance donors used do not possess any one of the three Lr genes (Lr9, Lr19 and Lr24). The effects of the donor's resistance were complementary, dominant or recessive genes. These produced high resistance by recombining the known or unknown weak resistance genes. The hybrids will continue to be screened by several pathogen cultures to select new genetic resistances in the lines possessing different combinations of donor's genes and Lr9, Lr19 and Lr24.

More than ten years ago Day (1974) suggested that in studies of pathogenic specialisation the most important information is the frequency of certain virulence genes in the pathogen population, as well as combinations of virulence genes. These ideas suggested that a population genetics approach to the study of pathogenic specialisation may be more useful than a taxonomic approach. The major objective of pathogenicity surveys should be to adequately describe pathogen populations, so that the information can be used effectively in breeding programs rather than attempting to name all the variants present in the fungal population.

Similar to these ideas is our new objective in the international pathogenicity survey of P.recondita tritici - to provide genetically diverse sources of resistance to wheat leaf rust for use in European-Mediterranean regions and to search for and document pathogenicity of P.recondita tritici cultures useful in differentiating sources of resistances. Emphasis will be placed on sources of resistance and their usefulness rather than on description of pathogenicity of fungus populations.

A Regional Field nurseries approach will involve testing a uniform set of winter and spring wheat lines, genetically different and highly resistant to P.recondita tritici. This set will be exposed to the naturally occuring pathogen populations at many sites of the European-Mediterranean regions. The material in these nurseries will also provide a basis for collecting uredial cultures which are virulent to some or all of the wheat lines. These cultures will then be used in further

greenhouse and laboratory studies of the genetic relationships of the sources of resistance and to search for other sources of resistance. The cultures to be used will be selected in such a way as to maximise probability of showing genotype differences in the wheat lines.

In this study logical analysis of infection - type data, aegricorpus phenotypes which indicate aegricorpus, pathogen and host genotypes will be applied according to Loegering (1984). Browder's (1985) considerations of the parasite: host: environment specificity will be included in the methods of analysis. Ultimately we manipulate the host; then information about P:H:E systems can best be conveyed in relation to host units. Emphasis in data analysis will be on reporting useful sources of resistance and indications that given sources of resistance are different.

When virulence to a given line is found and confirmed by greenhouse tests, that line will be removed from the field nursery and replaced by another line with potential value. This procedure is based on the concept of maximising the number of sources of resistance to be studied. It is assumed that once virulent cultures are available, these cultures can be used to separate that line from other sources of resistance. Analysis of infection - type data will be done to distinguish between sources of resistance and to evaluate the usefulness of the different sources of resistance in various places of the European-Mediterranean regions.

REFERENCES

Basile, R.A. (1957). A diagnostic key for the identification of physiologic races of Puccinia rubigo-vera tritici grouped according to a unified numeration scheme. U.S. Dept.Agr. Plant Dis.Reptr. 41, 508-511.

Boskovic, M.M. (1971). Effect of leaf rust and powdery mildew on the yield of several wheat varieties in Yugoslavia. Savremena poljoprivreda, 19, No.4, 81-87.

Boskovic, M.M. (1972). European and Mediterranean Wheat Leaf Rust Project. Proc. of the European and Mediterranean Cereal Rusts Conference, Prague, 35-59.

Boskovic, M.M. (1974). International Leaf Rust of Wheat Research. I Unified Numeation Races and Standard Races Puccinia recondita f. sp. tritici Rob. ex Desm. from 1967 to 1970 Year. Contemporary Agriculture, No. 3-4, 41-64.

Boskovic, M.M. (1976). International Pathogenicity Survey of Puccinia recondita f. sp. tritici. Proc. of the fourth Europ. and Mediter. Cereal Rusts Conf., Interlaken, 75-78.

Boskovic, M.M. (1980). The use of some new differentials in international pathogenicity surveys of Puccinia recondita f. sp. tritici. Proc. of the fifth Europ. and Mediter. Cereal Rusts Conf., Bari, Italy, 185-190.

Boskovic, M.M. and Browder, L.E. (1976). A comparison of pathogenicity of Puccinia recondita tritici in Europe, The United States and Canada. Plant Dis. Reptr. 60, 278-280.

Boskovic, M.M. and Momcilovic, V. (1984). Genetically different host-leaf rust parasite interaction in wheat crowses. VI-th Europ. and Med. Cer. Rusts Conf. - Les Colloq. de l'INRA, No. 25, 37-45.

Boskovic, M.M. and Momcilovic, V. (1986). New genetically different sources of resistance to wheat leaf rust (Puccinia recondita tritici). Proc. of the International wheat conference, Rabat, Morocco, (in press).

Browder, L.E. (1971). Pathogenic specialisation in cereal rust fungi, especially Puccinia recondita f. sp. tritici: Concepts, methods of study and application. USDA Tech. Bull. 1432, 51.

Browder, L.E. (1980). A compendium of information about named genes for low reaction to Puccinia recondita in wheat. Crop Sci. 20, 775-779.

Browder, L.E. (1985). Parasite: host: environment specificity in the cereal rusts. Ann. Rev. Phytopathol. 23, 201-222.

Casulli, F.A. and Siniscalco. (1984). Physiologic specialisation of wheat leaf rust in Southern Italy in 1982-83 and effectiveness of some Lr. genes VI-th Europ. and Med. cer. rusts conf. - Les Colloq. de l'INRA, No. 25, 157-161.

Conzales, B.R. (1966). Effecte del ataque del polvillo de la hoja (Puccinia recondita Rob. ex Desm.) en el rendimento de varietades del frigo. Agricultura etc. 26(1), 16-21.

Day, P. (1974). Genetics of host-parasite interaction W.H. Freeman and Co., San Francisco.

Dinoor, A. and M. Levi (1971). Long Distance dissemination of rusts along the East African-West Asian rift valley, In: Advance study institute Epidemiology of Plant Diseases. Wageningen, The Netherlands, Vo.III. 230.

Guyot, L., G Malencon and Massenot, M. (1956). De l'existance d'un foyer montagnard ed rouille noire du ble (Puccinia graminis tritici) sur certaines graminees indigenes due moyen et du Haut-Atlas Marocains.C.R. hebd. Seanc.Acad.Agric.Ft., P-y.Seanc.20-2-1957.

Ionescu-Cojocaru, M. and Negulescu, F. (1974). The complementary effect of at least two genes for resistance to Puccinia recondita f.sp. tritici operating in the winter wheat cultivars Aurora and Kavkaz. Cereal Rusts Bulletin, Vol. 2, Part 1, 16-19.

Johnston, C.O. (1956). Unified Numbers for races of Puccinia triticina. Robigo, 1, 2.

Loegering, W.Q. and Burton, C.H. (1974). Computergenerated hypothetical genotypes for reaction and pathogenicity of wheat cultivars and cultures of Puccinia graminis tritici. Phytopathology, 64, 1380-1384.

Loegering, W.Q. (1984). Genetics of the pathogen-host association. In: The Cereal Rusts. ed W.R. Bushnell, A.P. Roelfs, pp.165-192. Academic Press, New York/London.

Mehta, K.C. (1952). Further studies on cereal rusts in India. Part II. Sci. Monogr. No. 18, Indian Counc. Agric. Res. 365.

Nagarajan, S. and Singh, H. (1975). Indian stem rust rules-an epidemiological concept on the spread of wheat stem rust. Plant Dis. Reptr. 59, 133-136

Rizvi, S.S.A., Hussain, M., and Aslam M. (1984). Leaf rust of wheat in Pakistan during 1983. VI - The Europ. and Med. Cer. rusts conf. - Les Colloq. de l'INRA, No. 25, 181-188.

Samborski, D.J. and Peturson, B. (1960). Effect of leaf rust on the yield of resistant wheat. Can. J. Plant Sci. 40, 620-622.

Samborski, D.J. (1978). Leaf rust of wheat in Canada in 1977. Canadian Plant Disease Survey, 58(3), 53-54.

Stakman, E.C. (1942). The field of extra-mural aerobiology. In: Aerobiology (editor: F.R. Moulton) Amer.Assoc.Adv.Sci.Pub.No. 17, Washington D.C.1087.

Watson, I.A. and Cass Smith, W.P. (1962). Movement of wheat rusts in Australia. J.Aust.Inst.Agric.Sci. 28, 279-287.

Zadoks, J.C. (1967). Intenational dispersal of fungi. Neth.J.Plant Path. 73, Suppl.1, 61-80.

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Table 3. Virulence frequencies of Puccinia recondita f. sp. tritici on ten experimental wheat lines in 1977 and 1978 international pathogenicity surveys, and average field reactions in the nurseries.

Diff. variety/line	Total vir. frequencies, 1977	Average reactions in nurseries, 1978	Total vir. frequencies,1978	Average reaction in nurseries,1979
Arthur(77)/Arthur71(78)	54.17	*D(R,S-L.sev.)	11.11	R
Agent (Lr24)	0.83	D(R,MS-L.sev.)	18.80	R
Tobari 66 (Lr1,20)	68.33	-	50.43	R
Waldron (Lr1,2A,10)	11.67	D(R,S-L.sev.)	9.40	R
Jaral	11.67	-	72.65	D(R,MS-L.sev.)
ND-138-1xPa^{5} (Yu)	77.60	D(R,MS-M.sev.)	53.85	D(R,MS,S-M.sev.)
Gabo 56xBacka^{6} (YU)	69.17	D(R,S-H.sev.)	68.38	D(R,S-M.sev.)
Purdue 5119xBo-5^{6} (YU)	35.00	-	14.50	D(R,MS-Tr.)
NS-4R (Yu)	15.83	D(R,S-H,sev.)	9.40	D(R,S-L.sev.)
Kavkaz	87.50	-	27.35	D(R,S-H.sev.)
No. of virulence formulae	46		44	

*Legend: D - differential reactions in different nurseries
R - resistant, MS - moderately susceptible, S - susceptible
L - low, M - medium, H - high - severity, Tr. - trace

Countries from which collections were made for virulence analysis

1977 and 1978			1977 only		1978 only	
Algeria	France	Switzer-	Belgium	Jordan	Equador	Italy
Austria	India	land	Bulgaria	Luxembourg	Spain	Madagaskar
Bangladesh	Yemen	Thailand	China	Paraguay	Upper Volta	Mexico
Chile	Kenya	Zambia	Cyprus	Saudi Arabia	Greece	Portugal
East Germany	Nepal	Yugoslavia	Czechoslo-	Tanzania	Iraq	Turkey
Egypt	Pakistan		vakia	West Germany	Iran	
Ethiopia	Poland		Holland			

Table 5. The frequencies of resistant plants in F_2 of the crosses between six sources of leaf rust resistance with Lr9, Lr19 and Lr24.

Crosses	No. of Plants	R	S	f(R)	Expected f(R)	P	Expected res. genotype	
							From Lr	From Lines
66/1 x Lr9	181	110	71	0.60				
66/1 x Lr19	182	138	44	0.76	0.77	0.75-0.90	A - OR	bbcc
66/1 x Lr24	169	141	28	0.38	0.89	0.05-0.01	A - OR	B - C -
66/2 x Lr9	155	125	30	0.80	0.77	0.25-0.50	A - OR	bbcc
66/2 x Lr19	143	125	18	0.87	0.89	0.90-0.75	A - OR	B - C -
77 x Lr9	118	102	16	0.86	0.89	0.50-0.25	A - OR	B - C -
77 x Lr19	129	108	21	0.84	0.89	0.10	A - OR	B - C -
77 x Lr24	150	125	25	0.83	0.89	0.05-0.01	A - OR	B - c -
5 x Lr9	137	133	4	0.97	0.94	0.10-0.05	A - OR	B -
5 x Lr19	101	92	9	0.91	0.94	0.25-0.10	A - OR	B -
5 x Lr24	176	136	40	0.77	0.81	0.25-0.10	A - OR	bb
143 x Lr9	199	163	37	0.81	0.77	0.05-0.01	A - OR	bbcc
143 x Lr19	83	79	4	0.95	0.89	0.05-0.01	A - OR	B - C -
143 x Lr24	140	128	12	0.91	0.89	0.50-0.25	A - OR	B - C -
438 x Lr9	71	67	4	0.94	0.89	0.10-0.25	A - OR	B - C -
438 x Lr19	140	131	9	0.94	0.89	0.10-0.25	A - OR	B - C -
438 x Lr24	167	159	8	0.95	0.89	0.05-0.01	A - OR	B - C -
496 x Lr9	155	142	13	0.91	0.89	0.50-0.25	A - OR	B - C -
496 x Lr19	134	116	18	0.87	0.89	0.50-0.25	A - OR	B - C -

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INHERITANCE OF RESISTANCE TO *Puccinia hordei* IN SEVERAL BARLEY LINES

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SUMMARY

Six barley cultivars/lines with resistance to leaf rust were crossed with susceptible parents. Number of genes and gene action were determined by inoculation with several isolates of the fungus originating in the USA, the Middle East and north Africa. In addition to the gene Pa3 in the line 386-16-2 several new genes, some of them recessive, were discovered.

INTRODUCTION

In the past, leaf rust resistance has been restricted to a small number of genes. The genes Pa to Pa9 have been described for a number of varieties (Roane and Starling 1967, Clifford 1974, Nover and Lehmann 1974, Tan 1977a, 1977b). Some of these were used successfully in breeding programmes. As with other diseases virulence developed rapidly, eroding the newly introduced resistances (Walther and Lehmann 1986). A notable exception is the gene Pa7 which has been used in several North American cultivars (Starling et al. 1980). This illustrates the need for more resistance sources for breeders' programmes.

A number of cultivars/lines have been described as possible resistance sources to *Puccinia hordei* (Sharp and Reinhold 1982). The genetic background of these resistance sources however remained unknown. This paper is an attempt to investgate the number of genes and the mode of inheritance for some of the described lines.

MATERIALS AND METHODS

The cultivars and lines used in this investigation are listed in Table 1, together with their reactions to several isolates. Crosses were done in the field. F1 plants were grown in isolation in Arizona. Between 100 and 200 F2 plants were evaluated for each cross. Procedures have been described earlier (Reinhold and Sharp 1982).

RESULTS AND DISCUSSION

Ford 1203

One dominant and one recessive gene were found when this line was inoculated with the isolates Tel Aviv and Tu. 82. Only one recessive gene was effective against the isolate from Merchouch, whereas two dominant genes gave resistance to the Tel Hadia isolate.

CCIM - 13

Resistance to the isolates from Tel Aviv and Merchouch was conferred by one dominant gene. A recessive gene was effective against the isolate from Tunisia.

CI 4974

One dominant gene gave resistance to the isolate from Merchouch, whereas resistance against the isolate from Tel Hadia was due to one recessive gene.

386 - 16 - 2

The resistance in this line was obtained from one dominant gene which segregated freely from the gene in Cebada Capa (PA7) and appeared to be identical or allelic with the gene PA3 in Estate.

Menelik

Only recessive genes were detected in this cultivar from North Africa. One or two recessive genes were effective against the three isolates used in this study.

CI 11577

One dominant gene was found when this line was inoculated with the isolates from Tel Hadia and Merchouch, respectively. The resistance to the isolate from Tel Aviv was caused by a recessive gene.

Modjo

Two recessive genes effective against the isolate from merchouch were detected in this cultivar.

All cultivars and lines described in this study were earlier tested with a number of isolates (Sharp and Reinhold 1982). With the exception of 386-16-2, the resistance patterns seemed to be different from the known Pa genes. The detected recessive genes represent certainly new sources of resistance to Puccinia hordei. The described cultivars/lines were incorporated into the recurrent selection population "Composite Cross XLI" (Bockelman et al. 1983).

Table 1: Leaf rust reaction of cultivars/lines used in the investigation

Cultivar line	*Puccinia hordei* Isolate	Reaction type
Ford 1203	Tel Aviv (Israel)	R
	Tu. 82 (Tunisia)	R
	Merchouch (Morocco)	I
	Tel Hadia (Syria)	I
CCIM-13	Tel Aviv	R
	Tu. 82	R
	Merchouch	R
	Tel Hadia	R
CI 4974	Merchouch	R
	Tel Hadia	R
386-16-2	Tel Hadia	R
Menelik	Tel Hadia	R
	Mercouch	R
	Sidney (USA)	R
CI 11577	Tel Aviv	R
	Tel Hadia	R
	Merchouch	R
Modjo	Merchouch	R

Moore, Egypt and Austral = susceptible parents

REFERENCES

Bockelman, H. E., Reinhold, M., Sharp, E. L., and Eslick, R. F. 1983. Registration of leaf rust resistant barley composite cross XLI germplasm. Crop Sci. 23, 1224-1225.

Clifford, B. C. 1974. The choice of barley genotypes to differentiate races of Puccinia hordei Otth. Cereal Rust Bull. 2(1), 5-6.

Nover, I., and Lehmann, C. O. 1974. Resistenzeigenschaften im Gersten-und Weizensortiment Gatersleben 18. Pruefung von Sommegersten auf ihr Verhalten gegen Zwergrost (Puccinia hordei Otth.). Kulturpflanze 12, 25-43.

Reinhold, M., and Sharp, E. I. 1982. Virulence types of Puccinia hordei from North America, North Africa, and the Middle East. Plant Dis. 66, 1009-1011.

Roane, C. W., and Starling, I. M. 1967. Inheritance of reaction of Puccinia hordei in barley. II. Gene symbols for loci in differential cultivars. Phytopathology 57, 66-68.

Sharp, E. L., and Reinhold, M. 1981. Sources of genes resistant to Puccinia hordei in barley. Plant Dis. 66, 1012-1013.

Starling, T. M., Camper, H. M., Jr., and Roane, C. W. 1980. Registration of Monroe barley. Crop Sci. 20, 284-285.

Tan, B. H. 1977a. A new gene for resistance to Puccinia hordei in certain Ethiopian barleys. Cereal Rusts Bull. 5, 39-43.

Tan, B. H. 1977b. Evaluating host differentials of Puccinia hordei. Cereal Rusts Bull. 5, 17-23.

Walther, U., and Lehmann, C. O. 1980. Resistenzeigenschaften im Gersten- und Weizensortiment Gatersleben 24. Pruefung von Sommer- und Wintergersten auf ihr Verhalten gegenueber Zwergrost. (Puccinia hordei Otth.) Kulturpflanze 28, 227-238.

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