QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 678

PHYSIOLOGIC SPECIALIZATION AND CONTROL OF BEAN RUST (UROMYCES APPENDICULATUS) IN QUEENSLAND

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SUMMARY

Rust surveys over the period 1954–1970 have shown that eight forms of the bean rust fungus (*Uromyces appendiculatus*) are present in Queensland. None of the forms correspond to the races previously identified overseas. The evidence suggests that Queensland is a centre of local diversification and evolution for the fungus.

Several means of controlling bean rust are under investigation. Resistant varieties have been bred and released but have become susceptible to rust. Regular foliage sprays with fungicides such as maneb have also been recommended. More recently, the systemic fungicides have shown promise as seed dressings and as foliage sprays in glasshouse tests. However, their effectiveness in the field has not yet been tested.

I. INTRODUCTION

Bean rust caused by *Uromyces appendiculatus* (Pers.) Unger is favoured by mild temperatures and a long host growing season. Both conditions are amply fulfilled by the extensiveness of bean growing in Queensland. There is no month of the year when significant numbers of plantings are absent, and for about 9 months of each year beans are extensively grown in one or another Queensland locality. It is interesting to note here the similar longitudinal disposition of growing areas on the Queensland coast and those in Mexico where rust is so common and so proliferated by host heterogeneity (Crispin and Dongo 1962). It seems likely that this State provides ideal conditions for the perpetuation and continuous diversification of the bean rust fungus.

The complete life cycle of *U. appendiculatus* has been described and is known to take place on species of *Phaseolus* in other parts of the world (Andrus 1931). In Queensland, teliospores appear in winter mixed with urediniospores in the same sorus, but mature pycnia and aecidia have not been observed. It seems that they play no part in the disease cycle. Transmission by urediniospores is the rule and *Phaseolus vulgaris* L. is the only known host although infections on other species of *Phaseolus* have been recorded overseas (Laundon and Waterston 1965).

The first study of variation in *U. appendiculatus* in Australia was reported by Waterhouse (1953). His observations and testing extended over the period 1942 to 1953. He recognized two forms which appeared to conform to races 2 and 17 on the North American differential cultivars described by Harter and Zaumeyer (1941). He also distinguished a third form which attacked dwarf 'Wonder' cultivars such as Canadian Wonder, Tweed Wonder, Hawkesbury Wonder and Brown Beauty in addition to the cultivars of the North American set normally attacked by race 17. He called this form race 17A and concluded that it was probably of Australian origin. It was the first form to attack the popular and commercially important dwarf stringed cultivars in this country, and caused much damage. It was identified from New South Wales in 1948, from Queensland in 1949 and from Western Australia in 1950. Its apparent spread to New Zealand in 1951 was reported by Brien and Jacks (1954).

This account is of a study similar to that carried out by Waterhouse (1953) and covers the period 1954 to 1970.

II. MATERIALS AND METHODS

Bean rust collections were solicited from all parts of Australia. The majority of those used, however, were of Queensland origin.

Air-drying of infected leaves as a method of holding rust collections prior to examination was found to be unreliable. In the summer months, urediniospores on drying leaves soon lost their ability to germinate and were often completely nonviable after 10 days. Thus, some collections from remote areas of North Queensland were nonviable on arrival. On the other hand, spores harvested from the leaf surface were stored in good condition in glass containers in a household refrigerator for periods up to 2 years. Dundas (1948) reported the occurrence of mutations in bean rust urediniospores in cold storage. However, during the studies reported in this paper many transfers of the fungus were made in the glasshouse under various conditions and using many sources of inoculum and only typical uredinia have been observed.

When possible, inoculum from the field was transferred to potted plants of the differential set without intermediate multiplication. In many instances, the occurrence of two or more distinct forms in the one collection necessitated some purification by subculturing on selective varieties, followed by repetition of the standard test on the differentials. It was found that air currents within the cooled (forced-draught) glasshouse, including those induced by the routine moving of infected plants, were responsible for a significant dispersal of inoculum. When two collections were tested concurrently, therefore, uninoculated Pinto plants were included and incubated with the test plants so that a better appreciation of the likelihood of mixed occurrences of races could be made. As far as possible, each collection was identified individually so that suspicions of contamination were not aroused. Pustule number as well as pustule size was recorded as the former was an important aid to the detection of race mixtures.

Because pustule size is related to leaf maturity at the time of infection (J. C. Johnson, unpublished data), only primary leaves at the half-expanded stage were used. After 40–48 hr incubation in a high-humidity box, the plants were transferred to a natural light chamber on the glasshouse bench and held at 24 $\pm$ 1·6°C for 14 days, at which time infection ratings were made. In making these assessments, the methods described by Harter and Zaumeyer (1941) and adhered to by Waterhouse (1953) were used. While it was possible to use the 0–10 scale of Harter, Andrus and Zaumeyer (1935) for classing pustule size and type in individual tests, it was not considered that criticial comparisons could be made between tests carried out on different occasions, because of the effects of non-uniform environmental and other factors on pustule size. Nevertheless, the scale was retained in the tables as representing average values. Fortunately, intermediate ratings were few, both in this study and in the literature. An unusual type of reaction that did not correspond with any of the grades in the Harter, Andrus and Zaumeyer (1935) scale was observed on the cultivar Epicure. It appeared to be a pronounced hypersensitive reaction and is designated in the tables by Hy.

Earlier attempts at race identification were made using only the seven differential cultivars of Harter and Zaumeyer (1941) plus Brown Beauty. In the course of this work, however, a large number of different cultivars were inoculated with successive collections of the fungus and it was possible to demonstrate differences not made apparent by using only these eight cultivars. Thereafter, additional differential cultivars were added until the set was expanded to 13 cultivars. Later it was found that all the forms could be distinguished on five cultivars alone. These were (1) No. 643, a strain of California Small White, (2) Golden Gate Wax, a cultivar added to the Harter and Zaumeyer differential set by Fisher (1952), (3) Redlands Greenleaf A, a cultivar released in 1960 by the Queensland Department of Primary Industries (then Department of Agriculture and Stock), (4) No. 888, C.P.I. 26888 from Colombia, also called C.C.G.B. 44 and Costa Rica 2, and (5) Epicure, a green-podded pole bean, grown by home gardeners in Australia for many years. This abbreviated set of differential cultivars was subsequently used in all routine race determinations.

TABLE 1

REACTIONS OF THE EIGHT AUSTRALIAN FORMS OF *Uromyces appendiculatus* ON THE HARTER AND ZAUMEYER AND AUSTRALIAN DIFFERENTIAL CULTIVARS

	Harter and Zaumeyer Differential Cultivars							Australian Differential Cultivars					
Form	White Kentucky Wonder (No. 3)	California Small* White (No. 643)	U.I. Pinto III (No. 650)	Kentucky Wonder Wax (No. 765)	Kentucky Wonder Hybrid W.S. (No. 780)	Kentucky Wonder B.S. (No. 814)	Golden Gate Wax * †	Brown Beauty	Redlands Greenleaf A*	888*	891	Epicure*	120–2B
A	10‡	1	10	1	10	1	10	10	1	1	1	Hy	2
B	9	2	10	1	9	0	3	9	9	2	1	Hy	2
C	9	1	9	2	9	0	2	9	1	1	1	10	2
D	10	1	10	2	9	1	10	10	1	10	1	Hy	2
E	10	1	10	1	9	0	1	9	1	1	1	Hy	0–2
F	10	1	10	0	9	0	2	10	10	10	0	Hy	2
G	10	1	10	1	9	0	10	9	9	2	1	Hy	2
H	10	10	10	10	10	1	2	9	10	2	0	Hy	10

* These varieties form the abbreviated set of five differential cultivars on which the eight Australian forms of bean rust can be adequately distinguished.

† Golden Gate Wax was added to the Harter and Zaumeyer differential cultivars by Fisher (1952).

‡ 0 = immune, 10 = highly susceptible, Hy = pronounced form of hypersensitivity.

III. PHYSIOLOGIC SPECIALIZATION

Eight forms of the pathogen have been distinguished (Table 1). Forms A–G are alike on the Harter and Zaumeyer differential cultivars while form H is virulent on the cultivars California Small White and Kentucky Wonder Wax in addition to the cultivars attacked by forms A–G. None of these forms correspond with any of the 34 races described overseas (Harter and Zaumeyer 1941; Fisher 1952; Sappenfield 1954; Zaumeyer 1960; Goode 1961; Hikida 1962). Genetic homogeneity of these forms was confirmed in glasshouse tests by their uniform reactions on each of a wide range of cultivars.

IV. OCCURENCE AND GEOGRAPHIC DISTRIBUTION OF FORMS

The data in Table 2 show that all eight forms of the fungus have been identified in Queensland, six of the eight in New South Wales and one each in Western Australia and Victoria. Despite the small number of samples from Victorian and Western Australia, the evidence suggests that Queensland is a centre of local diversification and evolution for the fungus.

TABLE 2

OCCURRENCE AND DISTRIBUTION OF THE EIGHT AUSTRALIAN FORMS OF *Uromyces appendiculatus* IN THE PERIOD 1964–1970

Form	First Record		Total Records	Distribution (Numbers of Recordings)
A	Slack's Creek, Qd	5–8–64	59	N.S.W. (18); Qd (40); Vic. (1)
B	Cooroy, Qd.	5–8–64	45	N.S.W. (13); Qd (32)
C	Slack's Creek, Qd	5–8–64	8	N.S.W. (2); Qd (6)
D	Clayfield, Qd	25–2–65	14	N.S.W. (3); Qd (11)
E	Baulkham Hills, N.S.W.	7–4–65	21	N.S.W. (7); Qd (7); W. Aust. (7)
F	Walkamin, Qd	22–7–66	11	N.S.W. (1); Qd (10)
G	Stanthorpe, Qd	24–2–67	3	Qd
H	Nambour, Qd	28–4–70	5	Qd

The earliest Queensland determinations made in 1954 and 1957 indicated, despite the non-germination of several cultivars of the differential set, that the Waterhouse race 17A was still present (Table 3). Attempts to replace nonviable seed stocks from within Australia were unsuccessful, so, in 1964, a fresh supply of the full differential set was obtained from Dr. W. J. Zaumeyer, United States Department of Agriculture. The cultivar Kentucky Wonder Hybrid (No. 780) from this importation reacted in an entirely different manner from the original seed stocks in all subsequent determinations. Whereas all previous tests showed No. 780 to be resistant to rust infection, tests using the new seed line resulted in susceptible ratings. The composition of the New Zealand rust population was analysed in 1956, 1957 and 1958 by Yen and Brien (1960), who used seed of the differentials imported directly (from Dr. H. H. Fisher) and indirectly (in a personal communication, stated to be through Mr. J. Walker, New South Wales Department of Agriculture) from the United States Department of Agriculture. These workers recorded reactions on No. 780 dissimilar to those reported by Waterhouse (1953) but similar to those obtained by J. C. Johnson. Furthermore, Waterhouse (1953) noted that his seed of cultivar No. 780 gave rise to plants of mixed types and from his own observations and reporting it appears probable that his sample was a fragment of a segregating population resulting from hybridization. The identification of the Waterhouse collections with the North American races 2 and 17 is therefore doubtful.

TABLE 3

SUMMARY OF AUSTRALIAN BEAN RUST DETERMINATIONS 1942–1970
Rated from 0 = immune to 10 = highly susceptible

	Differential Cultivar							Rust Race or Form	No. of Determinations
	White Kentucky Wonder (No. 3)	California Small White (No. 643)	U.I.Pinto III (No. 650)	Kentucky Wonder Wax (No. 765)	Kentucky Wonder Hybrid W.S. (No. 780)	Kentucky Wonder B.S. (No. 814)	Tweed Wonder		
Waterhouse (1942–1953)									
	8	8	9	2	1	1	2	2	20
	8	1	9	3	1	1	2	17	59
	8	1	9	3	1	1	9	17A	59
Johnson (1954–1970)									
1954	*	1	10	2	1	1	9	17A	3
1957	..	1	10	2	..	1	9	17A	1
1964–1970	10	1–2	10	2–3	10	1	9–10	A–G	95
1970	10	10	10	10	10	1	9	H	4

* Seed stocks had lost viability.

No other alignment with the North American races of the fungus is possible even after substituting '10' values for '1' values in the No. 780 data of Waterhouse. It appears then that all forms of bean rust so far examined in Australia are different from those described elsewhere.

V. VARIETAL REACTIONS

Some 110 cultivars and lines have been tested for their reactions to the various forms of bean rust in a search for useful resistances for breeding disease-resistant cultivars. The following cultivars have proved susceptible to all known forms of bean rust in Queensland.

Ah Chow (Burnley Selection)
Andersons Wonder
Black Valentine, resistant
Bountiful
Brown Beauty
Bush Blue Lake
California Red Kidney
Choctaw
H.A.C. 18
College Early
College Pride
College Supreme
Corneli 4
Corvette
Diacol Nima
Estrado Rosada
Executive
Extender
Feltham's Prolific
Florida Belle
Goward's Special
Granda

Great Northern U.I. 15
Harvester
Hawkesbury Wonder
Hodgson's Longpod
Hyscore
Idaho Refugee
Kentucky Wonder, white-seeded (U.S. No. 3)
Kentucky Wonder Hybrid, white-seeded (No. 780)
Longval
Michelite
Negro Long Pod
Pea Bean (A.S.L.)
Pearl Green
Pegoraro
Pinto
Processor
Redlands Autumncrop
Red Mexican U.I.–34
Refugee 93a
Royal Princess
Saint Andrews
Saluggia
Sangretoro S–7–3
Startler Wax
Stella
Tendercrop
Tendergreen
Tenderwhite
Tweed Wonder
Windsor Longpod
C.P.I. 26905, Ant. 4 x Peru 5, L. 02230

Cultivars showing differential reactions to the various forms of bean rust are listed in Table 4. Some, such as Burnia, California Small White, Kentucky Wonder Wax and Kerman, were resistant until form H appeared. Others, namely Chiapas 189–D, De Mata, Epicure, Golden Gate Wax, Guarzo, Sezenanto, L. Luis Potosi, Liborini, Nuena Plomo and some of the unnamed accessions, although resistant to form H were susceptible to other forms. Their value in a breeding programme is doubtful because of the possibility that they may select other forms of rust to which they are susceptible so their resistance rapidly 'breaks down'. Perhaps the most promising line is a selection from the cross *P. vulgaris* × *P. coccineus* L. which gives an immune reaction to forms G and H.

TABLE 4

Rust Reactions of Bean Cultivars and Lines
0 = immune; 10 = highly susceptible; Hy = pronounced form of hypersensitivity

Commonwealth Plant Introduction (C.P.I.) or Other No.	Name	Reaction to Rust Form							
		A	B	C	D	E	F	G	H
26952	Actopan	Mix* 1–5	Mix 1–5	Mix 1–10	Mix 1–9	Mix 1–8	Mix 1–10	.. 2	Mix 0–2
26953	Antigua	0	1	2	1	1	1	1	3
	Apollo	..	..	..	..	..	..	10	8
	Beni	10	5 (var)	10	10	10	10	10	10
	Burnia	1	1	1	2	1	1	3	10
No. 643 ..	California Small White	1	1	1	1	1	1	1	10
	Carlos Favorit ..	..	..	..	..	..	..	9	9
26893, Mex. 505†	Chiapas 189–B ..	5	4	3	3	4	4	3	4
26894, Mex 507	Chiapas 189–D ..	1	1	1	10	1	Hy, 9	0	1
	Cornell 49–242A ..	2	1	2	2	0	1	1	0
26899, Ven. 87†	De Mata	1	0	2	10	1	Hy	0	0
26912	Diacol Nutibara ..	1	2	2	3	1	0	1	2
	Epicure	Hy	Hy	10	Hy	Hy	Hy	Hy	Hy
	Fosters Improved ..	..	..	..	..	..	..	10	10
	Gallatin 50	..	10	..	..	..	..	9	10
	Golden Gate Wax ..	10	3	2	10	1	2	10	2

RUST REACTION OF BEAN CULTIVARS AND LINES —*continued*
0 = immune; 10 = highly susceptible; Hy = pronounced from of hypersensitivity

Commonwealth Plant Introduction (C.P.I. or Other No.	Name	Reaction to Rust Form							
		A	B	C	D	E	F	G	H
26886, Cau. 31†	Guarzo	Hy, 9	7	10	Hy	Hy	Hy	8	10
26887, Cau. 39	Guarzo Sezentano ..	2	1	2	9	2	1	1	3
	Idelight	..	..	..	..	..	..	9	..
	Jackpot	..	..	..	..	..	..	9	..
No. 814 ..	Kentucky Wonder, Brown Seeded	1	1	1	1	1	1	1	1
No. 765 ..	Kentucky Wonder Wax	2	3	2	3	1	1	3	10
	Kerman	4	2–4	2	1	1	2	2	10
26890, Mex. 435	L. Luis Potosi 34A–10	2	0	2	10	1	8	0	1
26884, Ant. 23	Liborino	7	4	2	10	4	9	5	6
	Masterpiece ..	..	..	..	..	..	..	9	10
26892, Guat. 14–2†	Nuena Plomo ..	1	2	1	10	2	Mix 1–9	2	0
	Orbit	..	..	..	..	..	..	9	10
	Phaseolus vulgaris x *P. coccineus* ..	seg‡ 1–9	seg 1–9	seg 0–9	seg 1–9	seg 2–10	seg 0–10	seg 0–10	.. ..
	P. vulgaris x *P. coccineus* (Selection)	..	..	..	..	..	..	0	0
	Pink Early	1	2	1	1	1	1	2	6
No. 650 ..	Purple King ..	..	..	..	..	..	..	10	10
	Redlands Beauty ..	0	9	0	1	1	10	9	9
	Redlands Belle ..	9	9	8	10	5	10	9	5
	Redlands Greenleaf A	1	9	1	1	1	10	9	10
	Redlands Greenleaf B	1	9	1	1	0	10	10	10
	Redlands Greenleaf C	1	1	1	1	1	1	2	10
627–1	Redlands Pioneer ..	0	9	0	1	2	10	9	9
	Redlands 120–2B ..	2	2	2	2	2	2	3	10
26885, Ant. 26	Sanchez	3–4	6	4	5	3	6	8	5
	Sanilac	..	..	..	..	..	..	10	9
	Seaway	..	10	..	..	..	10	..	..
	Seminole	..	..	..	..	..	..	9	10
	Stanley's Surprise ..	..	..	..	..	..	..	9	5
26881, Ant. 8 ..	Uribe Redondo ..	3	3	2	2	2	2	2	2
	Valgold	..	..	..	..	..	..	10	..
26891, Mex. 450	Vera Cruz 1–A–6 ..	1	1	2	1	1	0	0	0
	Westralia	2	0	1	1	0	0	2	0
Unnamed Accessions:									
26888, C. Ric. 2†, C.C.G.B.44 ..		1	2	1	10	1	10	2	2
26889, Mex. 11 Variedad 51–1 (probably =CPI26891)		1	0	2	1	1	0	0	0
26895, Ven. 41, S139		0	1	1	1	0	1	1	1
26896, Ven. 49, S249		2	3	2	2	2	0	2	2
26898, Ven. 51, S254		2	3	2	2	2	1	2	3
26906, Ant. 26 x Mex. 11, L. 140§ ..		1	1	1	3	1	0	0	1
26907, L. 140§		1	1	1	3	1	0	0	1
26908, L. 140§		1	0	1	2	1	0–3	0	1
26909, Ant. 10 x Mex. 450, L. 1503 ..		1	2	2	4	1	0	0	2
26910, Ant. 19 x Mex. 120, L. 0687 ..		9	9	9	10	8	1	Hy	3
26911, Ant. 23 x Ant. 8, L. 1330 ..		1	4	2	2	1	2	2	2

* Mix = Cultivar contains plants of differing reaction due to mixing.

† Ant. = Antioquia; Cau. = Cauca; C. Ric. = Costa Rica: Guat. = Guatemala; Mex. = Mexico; Ven. = Venezuela.

‡ seg. = Cultivar contains plants of differing reaction due to segregation following hydridization

§ These lines are probably identical.

VI. BREEDING AS A MEANS OF CONTROL

The most obvious means of control and the one that has been used in the past is the breeding of cultivars with race-specific or vertical resistance. Although breeding for vertical resistance has been extremely successful at times, the nature of the resistance means that, if a race of the pathogen arises possessing the necessary virulence gene or genes for overcoming the resistance gene or genes in the predominantly grown host variety, severe losses may occur under suitable environmental conditions.

The continued replacement of formerly resistant cultivars as they became susceptible is well illustrated by the Queensland experience. In 1958, the rust resistant cultivars Redlands Beauty (California Small White x Brown Beauty strain 17) and Redlands Belle (Florida Belle x Brown Beauty strain 17) were released. Because of their susceptibility to angular leaf spot (*Isariopsis griseola* Sacc.) they were replaced in 1960 by Redlands Greenleaf A (another selection from California Small White x Brown Beauty strain 17) which was resistant to rust, angular leaf spot and common bean mosaic. Redlands Greenleaf B (Redlands Greenleaf A x Brown Beauty strain 17) with superior cold tolerance to Redlands Greenleaf A was relased in 1964 and immediately both cultivars were seen to be susceptible to rust. Forms A, B and D were recorded on these cultivars in 1964 followed in 1965 by forms C and E. In 1966 form F was identified for the first time. Form G apeared in 1967. A white-seeded sister line of Redlands Greenleaf A called 120–2B which had been retained by farmers in the Gympie area because of its superior cold tolerance was resistant to the new forms of rust. Consequently, Redlands Greenleaf B was crossed with 120–2B to give the new variety Redlands Greenleaf C which, in turn, became susceptible to rust in 1970 while undergoing increase under the Queensland Seed Certification Scheme.

Obviously, under local conditions, vertical resistance did not provide long-lasting rust control. However, there are ways in which vertical resistance can be used to provide effective control. According to the rules for the use of vertical resistance proposed by Robinson (1971), the fact that the pathogen is an obligate parasite favours the use of vertical resistance either in the form of multiline cultivars comprising several horticulturally similar lines with different resistance genes, or in the form of alternating patterns, either in time or space, of cultivars with different genes for resistance. Combinations of genes for vertical resistance within the one cultivar may also be effective. Some of these means of utilizing vertically resistant cultivars may be applicable to the Queensland bean industry but they have still to be evaluated.

However, according to Robinson's (1971) rules the following facts operate against the effective use of vertical resistance in this situation—bean rust is a compound interest disase; beans are a genetically uniform crop which is grown in large acreages; the pathogen apparently has a high rate of vertical mutability; beans are grown almost continuously throughout the year; and there is the possibility that after years of breeding for vertical resistance, little or no residual background race non-specific (horizontal) resistance remains.

One alternative to vertical resistance as a means of disease control is the use of horizontal resistance. A high level of horizontal resistance would be required because the pods, which are unmarketable if disfigured with rust lesions, are formed late in the development of the plant and subject to a relatively high inoculum density after the rust has presumably built up on the leaves. It may be possible to use vertical and horizontal resistance together to delay both the onset and the build-up of rust so that it does not develop to serious proportions. Horizontal resistance can also be valuable because it enhances the effectiveness of protectant fungicide sprays.

One of the difficulties associated with the use of horizontal resistance is how it may be best assessed. Any character of the host that reduces the rate of disease development contributes to horizontal resistance. There are definite differences between bean cultivars in such characters. For example, Hawkesbury Wonder develops few pustules compared with Pinto. With an incubation wet period of only 9 hr, rust was able to establish quite well on Pinto but not on Hawkesbury Wonder. When the wet period was extended to 12 hr, the cultivars developed an equal amount of infection. This effect could be observed when the wet period occurred during daylight hours but was absent when the wet period was given at night, suggesting that a factor additional to the wet period was operating (stomatal behaviour, for example). The differing response to 9 hr daytime incubation between Pinto and Hawkesbury Wonder beans was not demonstrated when the test plants were 48 hr younger. Thus, it appears likely that a glasshouse test using a closely controlled period of high humidity during the incubation period and test seedlings at a selected stage of leaf maturity might be used to distinguish cultivars with the Hawkesbury Wonder type of resistance. Much evaluation remains to be done in this area. Cultivars such as Florida Belle, Staley's Surprise and some Brown Beauty types show low levels of resistance in the field and may provide a starting point for further studies.

Another well-known difficulty associated with the use of horizontal resistance is its handling in breeding programmes. However, there is some evidence that resistance governed by a number of genes may be of use in commercial breeding programmes (Lupton and Johnson 1970).

VII. CHEMICALS AS A MEANS OF CONTROL

In experiments conducted in Queensland in the early 1950s sulphur dust applied at weekly intervals from an early stage until flowering gave best results. However, it was observed that considerable rust infection could occur without causing reduction in yield and it was thought unlikely that the amount of rust which occurs on early plantings would warrant spraying. Of course, as the season advanced, the risk of disease became much greater. However, it is difficult to foresee at any time whether or not the additional labour and cost involved will be justified by sufficiently greater returns when the crop is harvested. Consequently, to decrease the rate of rust build-up, a number of cultural practices such as making later plantings as far as possible away from earlier ones, destroying plantings immediately after picking, avoiding excessively close plantings which lead to a very humid microclimate, and avoiding factors such as shortage of fertilizer and exposure to strong winds which seriously retard growth were recommended. When the dithiocarbamate fungicides became available, fortnightly sprays with maneb were found to be reasonably effective in controlling bean rust.

An entirely new approach to chemical control is the use of systemic chemicals applied as seed treatments. Treatment at planting with such materials which suppress primary infections in early stages of crop growth could have considerable value for rust control. The performance of late-season sprays would be improved because the timing of the sprays becomes less critical and the final destructive phase of the epidemic is shortened. Secondly, the terrain in which much of Queensland's beans are grown is not suitable for frequent cutivation or spraying so treatment of the seed with a systemic chemical offers probably the most convenient possibility of control.

Von Schmeling and Kulka (1966) reported that a systemic chemical oxycarboxin ("Plantvax") applied as a seed dressing effectively controlled bean rust. They found that seed or soil treatments alone suppressed rust development for 60–65 days after planting.

Oxycarboxin and benomyl ("Benlate") have been under test in the glass-house in Queensland. Applied to the seed as the wettable powder, at rates as low as 50% of the recommended dosage, both have proved effective in controlling rust. However, reducing the concentration affected the 'stickability' of the fungicide. If this treatment is to be adopted commercially, the fungicides may need to be pelleted. With benomyl, some infection of the trifoliolate leaves occurs but this is not so with oxycarboxin. However, phytotoxic effects have been noticed in some cultivars treated with oxycarboxin. Redlands Greenleaf C was hardly damaged at all, while Pinto was severely affected. This aspect needs further investigation.

One problem associated with the use of seed dressings is that the effective-ness of any seed dressing is influenced by the behaviour of the seed coat. Natti (1970) reported significant differences in the incidence of powdery mildew (*Erysiphe polygoni* DC.) and hypocotyl rot (*Rhizoctonia solani* Kuehl) on bean plants that had grown from benomyl-treated seed planted hilum down and plants that had grown from benomyl-treated seed planted hilum up. He suggested that the differences were associated with the location of the seed coat after germination. The relevance of this observation to the field situation remains to be evaluated.

Oxycarboxin and benomyl can also be used as foliar sprays, in which case their effect is more protectant than systemic. Benomyl applied to the primary leaves does not protect the first trifoliolate leaves from infection, while oxycarboxin is apparently translocated more from the primary leaves and protects the first trifoliolate leaves against infection. Both benomyl and oxycarboxin prevented rust establishment on treated leaves when the spray was applied prior to inoculation. Oxycarboxin applied 72 hr after inoculation had a curative effect but benomyl did not.

To date, the performance of these fungicides either as seed dressings or as foliar sprays has not been assessed in the field.

VIII. DISCUSSION

There are several reasons for conducting rust surveys. Perhaps the foremost is so that plant breeders and geneticists know what forms of the fungus are present in the field and can arrange their breeding programmes accordingly. Secondly, if field rust assessments are to be of any value, the forms of rust present must be known. Thirdly, rust surveys over a number of years show the speed and extent of local evolution of forms. This provides important insights into the behaviour of the pathogen which may influence the control measures adopted. The Queensland rust surveys have fulfilled all three objectives. With a knowledge of the forms present, a breeding and field testing programme has been conducted that has resulted in the release of a number of rust-resistant cultivars horticultur-ally superior to earlier cultivars. Furthermore, the rust surveys have shown that the forms of rust present in Australia at least since 1957 cannot be correlated with races known overseas, and that the bean rust fungus is continuously changing. In the period 1964 to 1970, eight distinct forms of the pathogen have been distinguished. Queensland appears to be the centre of local evolution for the fungus.

In areas such as Queensland where the pathogen is diversifying rapidly and beans are grown almost throughout the year, vertical resistance is unlikely to provide long-lasting rust control. Two of the possible alternatives to vertical resistance, horizontal resistance and systemic chemicals, have only begun to be investigated and many problems remain to be solved. Queensland traditionally supplies beans for fresh vegetable markets in southern States. The swing to processing crops may alter the situation considerably. Overall, the disease problems are somewhat diminished because of the distance which separates processing crops from one another, the lesser degree of successional planting and the tendency of the contracting processor to move his crops out of a traditional growing district into entirely new areas. On the other hand, Queensland has an important and enduring capacity to supply off-season fresh vegetables to the southern States. Thus, we may have to pursue policies in this State different from those followed in other parts of Australia, where the swing to processing crops may be more complete and the problems associated with rust not so great.

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(Received for publication November 5, 1973)

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The paper was prepared by Dr. Ogle after Mr. Johnson's death from notes and tables assembled by Mr. Johnson.