STUDIES OF BEAN ANTHRACNOSE IN AUSTRALIA.

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(Plate iii.)

[Read 27th April, 1955.]

Synopsis.

Two sets of studies of the host-parasite relationships shown between *Colletotrichum lindemuthianum* (Sacc. and Magn.) Briosi and Cav. and bean varieties were made. In the first, carried out between the years 1925 and 1928, 12 isolates of the fungus showed that 11 were similar to the U.S.A. beta race, and the remaining one has been designated Aust. *A*.

In the second set of studies, made between 1944 and 1952, 14 isolates studied on the same basis yielded seven races, all different from the two previously determined. Using a different selection of better known bean varieties, they have been sorted into eight races designated Aust. 1 to Aust. 8.

Making use of more than 130 bean varieties, the 14 isolates can be separated into 42 different groupings on the basis of the reactions shown to inoculation: the majority (98) of varieties were resistant to all the isolates.

From the varieties having both rust and anthracnose resistance, parents were chosen (Westralia receiving particular attention) for crossing with susceptible dwarf varieties, in order to incorporate in them the needed resistance. Serious incompatibility problems were encountered.

Introduction.

The disease known as anthracnose of beans, caused by the fungus *Colletotrichum lindemuthianum* (Sacc. & Magn.) Briosi & Cav., was first satisfactorily recorded overseas in 1843, and has been known in New South Wales since 1894 (Noble et al., 1934). In bean-growing countries it is an important disease causing serious crop losses under favourable weather conditions. An extensive bibliography is given by Harter and Zaumeyer (1944) as well as by others.

The studies here reported were commenced in 1925, but only in more recent years have they been intensively carried forward.

Materials and Methods.

In 1921 a set of bean varieties then in use as differentials in sorting out physiologic races of the fungus was brought from Cornell University, U.S.A.; their reactions to the alpha, beta and gamma races were supplied by Dr. L. M. Massey. The original varietal names have been retained, and the beans have since been maintained as single plant—often single pod—selections, with the exception of three which were lost in adverse seasons. Recently many other varieties have been obtained from various sources, thanks to generous responses to requests for material; stocks of them have been maintained in the same way.

Seedlings have been used in plant house tests; in only a few cases has it been possible to check the results on mature plants. Seed treated with spergon was sown in four-inch pots of steamed soil which were kept on plant house benches. After emergence of the true foliage leaves the plants were atomized with a suspension of the inoculum under test, and the pots placed in an incubation chamber for a period of 36 to 48 hours, depending upon the prevailing weather conditions. Since there is the well-known inhibition of disease development at temperatures above the critical point, the work was done at the necessary lower temperature levels. The incubated plants were allowed to develop in the plant house, and when the lesions were clearly developed on the susceptible members in a series (usually after 7–10 days), notes were taken on the whole batch. In some instances where seed was in short supply, the resistant plants were pruned after note-taking, and if after the lapse of a proper period no lesions were showing on the new growth, they were used for the succeeding inoculation.

The inoculum came from various sources. The diseased material was plated in the usual way and pure cultures of the organism obtained; single spore cultures were used in several of the experiments, but this was not general. Individual cultures were maintained on potato-dextrose-agar. Inoculum for use in the plant house was obtained from the abundant fruiting growth made from transfers to sterile bean pods. It was agitated in tubes of sterile water for atomizing on to the plants. Particular series of pots under test were kept in isolated positions in the plant houses. There were cases where unexpected high temperatures made it necessary to repeat the experiment under favourable conditions. In all cases where any doubt existed the work was repeated.

Note-taking presented difficulty. In the case of fully susceptible varieties the seedlings were soon killed, whilst at the other end of the scale there was full immunity to attack. All kinds of intergrading reactions were found. It was finally decided to adopt a notation in which

0 = Immunity: hardly any visible reaction to inoculation.
1 = Resistance: small scattered lesions; plants recovered.
2 = Resistance: lesions obvious but no fructifications; plants recovered.
3 = Susceptible: numerous lesions and severe killing of tissues with abundant development of fructifications; plants died later.
4 = Susceptible: plants wilted and quickly died.

To denote variations in these behaviours, plus and minus signs were sometimes used. Because of the marked effects of changes in the environmental conditions, it is considered that the broad classification into resistant and susceptible classes is all that is desirable. With the variations that occurred in plant house conditions, reaction changes were found within both the resistant and the susceptible classes, but reasonable assurance was felt in regard to the determination that has been set down for one or other of the two classes.

Experimental Results.

Studies of the Pathogen.

Isolates from different sources and at different times showed differences in their behaviour when grown on potato-dextrose-agar under the same conditions. The growth was usually dark and closely appressed to the surface, where the production of acervuli varied greatly. Others gave a somewhat effuse aerial development, with variations in its colour. Sectoring in some cultures was noted.

Clear differences of this sort led to attempts being made to produce the perfect stage of the fungus from combinations of isolates growing on differing substrates under varying conditions.

There were instances in which growth aggregations resembling perithecia developed, but in no case were asci found. This is in accord with other workers' results.

Specialization.

The occurrence of variations in the susceptibility of beans to the disease was reported by Barrus in 1911, and since then many others have demonstrated the presence of physiologic races of the organism. The determinations have been based upon results obtained by using sets of bean varieties which have not always been uniform. Satisfactory comparisons of the results thus become difficult, if not impossible. It has been customary, however, to try to relate the results to those initially reported by Barrus (1918) and Burkholder (1923), who described three races, which they named the alpha, beta, and gamma races.

The work herein reported is conveniently considered as two sets of studies. The first, carried out between the years 1925 and 1928, involved the use of U.S.A. varieties which included differentials used by Barrus and Burkholder, with the addition of two common commercial varieties in use in New South Wales.

Then came a gap during which anthracnose work could not be carried out. The second set of studies covers the period 1944–1952, when work on a more extensive scale was done.

First Set of Studies.

At intervals during 1925 to 1928 diseased beans were obtained from various sources. In a number of cases they came from vegetable markets, and therefore their origin could not be determined. Pure cultures were made and used in the production of inoculum. In all, 12 distinct isolates were obtained.

In the tests it was found that 11 of them behaved similarly, but that the other one was differentiated clearly on one variety. The results are set out in Table 1, in which the reactions reported for the alpha, beta, and gamma races are included for purposes of comparison: cultures of them were not available for side-by-side tests.

TABLE 1.

Reactions Given by Isolates of C. lindemuthianum *on Bean Varieties Compared with those Recorded for U.S.A. Races.*

Accession Number.	Variety.	Reactions of Races.				
		Alpha.	Beta.	Gamma.	11 Isolates (Beta).	1 Isolate Aust. *A*.
B1	Red Cranberry (Low's Champion).	S	S	S	S	S
B2	Large White Marrow.	R	S	S	S	S
B3	Black Valentine.	S	S	S	S	S
B4	Tennessee Green Pod.	S	R	R	R	R
B5	Lazy Wife.	S	S	S	S	S
B6	Wardwell Kidney Wax.	S	S	S	S	S
B7	Red Kidney.	R	S	S	S	S
B8	Kentucky Wonder.	S	R	R	R	R
B9	Scotia.	S	R	R	R	R
B10	Well's Red Kidney.	R	R	S	R	R
B11	Eureka.	S	S	S	S	S
B12	Michigan Robust.	S	R	R	R	R
B13	White Imperial.	R	R	S	R	R
B14	Yellow Eye (Improved).	R	S	S	S	R
B15	Canadian Wonder.	S	S	S	S	S
B16	Epicure.	—	—	—	R	R

The original distinction between the alpha and beta races was made on the reactions shown by many varieties. Amongst them, B4 Tennessee Green Pod, B8 Kentucky Wonder, and B9 Scotia were susceptible to the alpha but resistant to the beta races, whilst B2 White Marrow, B7 Red Kidney, and B14 Yellow Eye were resistant to the alpha but susceptible to the beta races (Barrus, 1918). The gamma race differed from them in that B10 Well's Red Kidney and B13 White Imperial, which were resistant to the alpha and beta races, were found to be susceptible to the gamma race (Burkholder, 1923).

From Table 1 it is seen that the two groups of isolates differ in their behaviour on the variety B14 Yellow Eye (Improved), which also differentiates the alpha on the one hand from the beta and gamma races on the other. One of the two races (of which there were 11 isolates) agrees with the beta race. The other is different, and is here styled Aust. *A*. Both races show the same behaviour on the two N.S.W. varieties, B15 Canadian Wonder and B16 Epicure.

Second Set of Studies.

In this work the same U.S.A. varieties were used as differentials, but a different series of isolates was involved and, in addition, numerous other varieties were tested for their reactions.

The isolates were obtained from diseased material collected by the late Mr. R. D. Wilson, with the exception of No. 1034, which was submitted by Miss D. E. Shaw, and of No. 1026, by Mr. D. W. Reilly; to these thanks are tendered. A culture of the organism sent from New Zealand in 1944 was used in comparison with the others.

Details of the isolates are given in Table 2.

The varieties used included most of those already listed in the first set of studies, but many others also came up for test. The Principal of the Hawkesbury Agricultural College, Mr. E. A. Southee, Mr. Shirlow of the N.S.W. Department of Agriculture, and Mr. P. I. Pryke of the Victorian Department of Agriculture, were particularly helpful in supplying seed, and grateful thanks are tendered to them.

Serious problems connected with the purity of host material soon became apparent. Numerous cases were found in which there was clearly admixture of seed in a particular sample submitted; or seed carrying the same name but coming from two different sources was found to be quite different in colour and/or shape; or apparently similar

TABLE 2.

Details of the Isolates of C. lindemuthianum *Used in the Determinations.*

Accession Number.	Date of Receipt.	Source.
767	10 : 1944	Wamberal, N.S.W.
768	do.	do.
985	7 : 1949	Sandy Creek, Queensland.
986	do.	North Coast, N.S.W.
987	do.	Moruya, N.S.W.
988	do.	Sydney Markets.
989	do.	Bodalla, N.S.W.
990	do.	Lindfield, N.S.W.
1026	3 : 1950	Auburn, N.S.W.
1028	do.	Tenterfield, N.S.W.
1034	do.	Sydney Markets.
1035	7 : 1950	Gosford, N.S.W.
1036	do.	Tenterfield, N.S.W.
1038	10 : 1950	Gosford, N.S.W.
1043	do.	Gosford District, N.S.W.

seed carrying the same name was found to produce quite different types of plant; or seed of a particular variety was found to be heterozygous for its reactions to inoculation. Pedigree work thus became necessary. Even so, it is doubtful whether the results given by a variety bearing a particular name are always comparable with those reported for the "same" variety elsewhere. Strict standardization and retention of genetic purity are essential in work of this nature.

In addition to the varieties listed and classified later, many others came up for tests in which limitations of time and of seed available made it impossible for all the tests to be completed; incomplete results of this sort have not been included.

Specialization.

Each of the isolates was used for race determination on the set of differentials listed on p. 73 under similar conditions to those used in the first set of studies.

The results are set out in Table 3, in which the determinations given on p. 73 are also included. Gaps occur where seed was not available for the tests.

From the isolates, neither the beta race nor the Aust. *A* race was obtained. The New Zealand culture corresponded with the gamma race. The 14 isolates examined were different from these all, and fall into races which are here designated Aust. *B* to Aust. *H*.

The isolates fall into the following categories:

Race Aust. *B* = Isolate 768
Aust. *C* = 767, 1038
Aust. *D* = 985
Aust. *E* = 986, 988
Aust. *F* = 987, 1028, 1036
Aust. *G* = 989, 990, 1026, 1034, 1043
Aust. *H* = 1035

An examination of the geographical distribution of the races gives little information. For example, the two collections from Tenterfield are similar, whilst the two from Wamberal are unlike. The one from southern Queensland is dissimilar to the one from the North Coast of New South Wales.

TABLE 3.

Reactions of Isolates of C. lindemuthianum *on Bean Varieties as well as the Reactions Previously Reported.*

Varietal Accession Number.	Reactions of Races.											
	Alpha.	Beta.	Gamma.	N.Z.	Aust. *A.*	Aust. *B.*	Aust. *C.*	Aust. *D.*	Aust. *E.*	Aust. *F.*	Aust. *G.*	Aust. *H.*
B1	S	S	S	S	S	S	S	S	R	S	S	R
B2	R	S	S	S	S	R	R	R	R	R	R	R
B3	S	S	S	S	S	S	R	S	S	S	S	S
B4	S	R	R	R	R	R	R	R	R	R	R	R
B5	S	S	S	S	S							
B6	S	S	S	S	S							
B7	R	S	S	S	S	S	S	S	S	S	S	S
B8	S	R	R	R	R	R	R	R	R	R	R	R
B9	S	R	R	R	R	S	R	R	R	R	R	R
B10	R	R	S	S	R	S	R	S	R	R	R	R
B11	S	S	S	S	S							
B12	S	R	R	R	R	R	R	R	R	R	R	R
B13	R	R	S	S	R	R	R	R	R	R	R	R
B14	R	S	S	S	R	S	R	S	R	S	R	S
B15	S	S	S	S	S	S	S	S	S	S	S	S
B16				R	R	R	R	R	R	R	R	R

A study of their distribution in time is also of little value. From the Gosford area three races were found in a particular year, whereas some stability is shown in other instances.

For this information a much more extensive survey of the physiologic races in regard to both time and space would be necessary.

TABLE 4.

The Identity of the Races under Consideration Shown in Simplified Form.

Race Designation.	Reactions Shown on Differential Varieties.					
	B1.	B2.	B3.	B9.	B10.	B14.
Alpha	S	R	S	S	R	R
Beta	S	S	S	R	R	S
Gamma	S	S	S	R	S	S
Aust. *A*	S	S	S	R	R	R
Aust. *B*	S	R	S	S	S	S
Aust. *C*	S	R	R	R	R	R
Aust. *D*	S	R	S	R	S	S
Aust. *E*	R	R	S	R	R	R
Aust. *F*	S	R	S	R	R	S
Aust. *G*	S	R	S	R	R	R
Aust. *H*	R	R	S	R	R	S

It will be seen in Table 3 that a number of the varieties do not serve to differentiate the Aust. races, showing either susceptibility or resistance throughout the tests. Thus B7 and B15 are susceptible, and B4, B8, B12, B13, and B16 are resistant throughout. This makes it possible to simplify the race determinations as shown in Table 4, in which the comparable alpha, beta, and gamma results are included. The race designated Aust. *A* in the first set of studies is also set down.

Tests of Varietal Behaviour to Attack.

Using 14 of the same set of isolates, numerous varieties of beans were subjected to test. One of the original isolates (Acc. No. 768) was lost before the tests had been completed.

An extreme range of diversity to attack was shown. The varieties fell into one or other of 42 classes. At one end of the scale the class of varieties showed resistance to all

TABLE 5.

The Classes (or Races) Determined when 132 Varieties were Tested with 14 Isolates of C. lindemuthianum.

Acc. No.	Variety.	Reactions Shown.													
		767	985	986	987	988	989	990	1026	1028	1034	1035	1036	1038	1043
V2	Russia.	R	R	R	R	R	R	R	R	R	R	R	R	R	R
V3	Roger's Stringless Green Pod Refugee.	R	R	R	R	R	R	R	R	R	R	S	S	S	R
V10	Stringless Green Pod Refugee.	S	S	R	S	S	S	S	S	S	S	S	S	S	S
V11	Pencil Pod Black Wax.	R	S	S	R	S	S	S	S	R	R	S	S	S	S
V12	Florida Belle.	S	S	R	S	S	R	S	S	R	S	S	R	S	S
V14	Blue Lake Hybrid 65.	R	R	R	R	S	S	S	R	R	R	R	R	R	R
V20	Brown Beauty (A.T.P.).	S	R	R	R	R	R	R	R	R	R	R	R	S	S
V25	Doppelite.	R	R	R	S	S	S	S	S	S	R	R	R	R	R
V28	Early Pale Dun.	S	S	S	S	S	S	S	S	S	S	S	S	S	S
V32	Tweed Wonder.	R	R	R	R	R	R	R	R	R	R	R	R	S	S
V46	U.S. Refugee No. 5	R	S	S	R	S	R	R	R	R	R	R	R	S	S
V52	Staley's Surprise.	S	S	R	R	S	R	R	S	S	R	S	R	R	S
V65	Top Crop.	R	S	S	R	R	R	S	R	R	S	S	S	S	S
V67	Unrivalled Wax.	R	R	S	R	S	S	S	S	S	R	S	S	S	S
V68	H49.	S	S	R	R	R	R	R	S	R	R	R	R	S	S
S9	Idaho H7696.	R	R	R	R	R	R	R	R	R	R	R	R	R	S
S10	Standard Pink.	R	R	R	R	R	S	S	S	R	R	R	R	S	R
S48	Red Kidney H6454	R	R	R	R	S	R	R	R	R	R	R	R	S	S
S51	Pearl Sugar.	R	S	S	S	S	S	S	S	S	S	S	S	S	S
S70	The Wonder.	S	R	R	R	S	S	R	S	S	S	S	S	S	S
S90	Florida Belle (Asgrow's).	S	R	R	R	R	R	R	R	S	S	S	S	S	S
B1	Red Cranberry (Low's Champion).	S	S	R	S	R	S	S	S	S	S	R	S	S	S
B3	Black Valentine.	R	S	S	S	S	S	S	S	S	S	S	S	R	S
B10	Well's Red Kidney.	R	S	R	R	R	R	R	R	R	R	R	R	R	R
B14	Yellow Eye (Improved).	R	S	R	S	R	R	R	R	S	R	S	S	R	R
B30	Kentucky Wonder.	R	R	R	S	R	R	R	R	R	R	R	R	R	R
B32	Wellington Wonder.	S	S	R	R	R	R	R	R	R	R	R	R	S	S
B38	Prolific.	R	R	R	R	S	S	R	S	S	R	R	R	R	R
B40	Pacer.	R	S	R	R	S	S	S	R	S	S	S	S	S	S
B41	Burbank.	R	R	R	R	R	R	S	R	S	S	R	R	R	R
B43	Yellow Eye.	R	S	R	S	R	R	S	R	R	S	S	R	R	R
B45	Norwegian.	S	S	S	S	S	S	S	S	S	S	R	R	S	S
B46	Habilla.	R	S	S	R	R	R	R	R	R	R	R	R	S	R
B54	Poroto enana.	R	R	S	S	S	S	S	S	S	S	R	S	R	R
B55	Poroto C.P.I. 11443.	R	S	R	R	S	S	R	S	R	S	S	S	S	S
B60	Supergreen.	R	S	R	S	R	S	R	S	R	R	R	R	R	R
B63	Native Bean H7789.	R	R	S	S	S	S	R	S	S	S	S	R	R	R
B67	Florida Belle.	R	S	R	S	R	R	R	R	R	S	R	R	S	S
B73	Scott's Bluff Pinto.	R	S	S	S	S	R	S	S	S	S	S	R	R	R
B74	Startler Wax.	R	S	S	R	R	S	S	S	S	S	R	S	R	S
B78	The Wonder.	R	S	S	S	R	R	S	R	R	S	R	R	S	S
B81	Standard Pink.	R	R	R	S	S	S	R	R	R	S	R	R	R	R

the isolates; at the other, susceptibility to all was shown. In between these two classes were those in which 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, or 13 of the isolates gave rise to susceptible reactions. In each of these cases resistance was, of course, shown to the remaining isolates. Furthermore, there were various groupings within these classes. For example, there were six different groupings within the "3 susceptible" class, five groupings in each of the "4 susceptible", "5 susceptible", and "10 susceptible" classes, four groupings in the "9 susceptible" class, and so on. It is clear that when large numbers of host plants are used as differentials, an extreme range of diversity is exhibited. In this case no one of the 14 isolates examined was the same when subjected to this test.

TABLE 6.

List of Varieties Tested where More than One Fell within the Several Classes.

Class 1.—*Resistant to All the Isolates.*

V2 Russia, V4 Rainy River, V5 Klein Weisse, V6 Pink, V9 Great Northern, V13 Blue Lake, V15 Blue Lake Stringless Pole, V16 Boston Marrow, V18 Burbank, V21 Californian Small White, V22 Cannellini, V23 Case Knife, V24 Case Knife Climbing White Dutch, V26 Hamburger Market, V27 Early White, V29 Emperor William, V31 Frigole Nigros, V34 Java, V35 Michigan Robust, V36 Michelite, V37 Robust, V38 Norida, V40 Navy, Canadian Type, V41 Navy, Ottawa, V42 Northern Star, V44 Purple Pod, V49 Red Mexican U. I. 3, V50 Red Mexican U. I. 34, V53 Zucker Perl, V58 Red Valentine, V61 Roumanian White Pea, V63 Pilot, V64 Bill, V69 Corbett's Refugee, S4 Otenashi, S8 Little Navy, S31 Pinto H6781, S34 Michelite, S36 B2675, S47 Pilot, S57 Small White, S66 Shravni Ghendi, S67 Native Bean H7790, S69 Fullgreen, S71 Cromer, S100 Dwarf Haricot (Comptesse di Chambord), S118 Pilot, S122 Rice, S124 Roger's Refugee 1071, B4 Tennessee Green Pod, B8 Kentucky Wonder, B9 Scotia, B12 Michigan Robust, B13 White Imperial, B16 Epicure, B18 Wiggin's Prolific, B25 U.S. No. 3, B27 Harter's 643, B28 Harter's 650, B29 Harter's 765, B31 Harter's 814, B33 Blue Navy, B35 Cecic's Epicure, B37 Kentucky Wonder, W.A., B44 C.P.I. 11272, B48 Alabama No. 1, B49 Feijao, B51 Poroto C.P.I. 11439, B52 Poroto C.P.I. 11440, B53 Poroto topero, B57 Poroto criollo, B58 Poroto cuarenton, B59 Poroto arroz chilero, B61 Ideal Market, B68 Long White Marrow, B69 St. Fiacre, B70 Resistant Kentucky Wonder, W.A., B75 Roger's Refugee 1071, B76 Medal, B77 Great Northern, B79 Fullgreen No. 1, B80 Fullgreen No. 2, B82 Roumanian White, B83 Early Pink, B84 Russia, B85 Pilot, B88 Westralia, Scarlet Runner, also ten of the original selections from which Westralia was isolated, *Dolichos Lablab* (six isolates), two of them giving "2" reactions.

Class 2.—*Susceptible to All the Isolates.*

V17 Burpee's Dwarf Stringless Green Pod, V28 Early Pale Dun, V54 Surecrop Wax U.S.A., V60 Low's Champion, S53 Granda, S85 Dwarf Pencil Pod Wax, S95 Pencil Pod Wax (Ferry Morse), B7 Red Kidney, B19 Hawkesbury Wonder, B20 Wardwell Kidney Wax, B21 Lazy Wife, B22 Stringless Black Valentine, B24 Clarendon Wonder, B26 Harter's 181 (Bountiful), B34 Stringless Green Pod French Bean, B36 (Clarendon Wonder × Wellington Wonder), B47 Frijol pico de oro, B50 Frijol guarzo rayado, B56 Feijao rayado, B64 Granda, B65 Tendergreen, B71 Staley's Surprise, B72 Red Valentine.

Class 3.

Isolates.

767	985	986	987	988	989	990	1026	1028	1034	1035	1036	1038	1043
R	R	R	S	R	R	R	R	R	R	R	R	R	R

V33 Hidatsa Red, B30 Harter's 780.

Class 4.

R	R	R	R	R	R	R	R	R	R	R	R	S	S

V32 Tweed Wonder, V39 Negro Long Pod, V45 Idaho Refugee, V56 The Wonder, V62 Medal, S17 The Prince, S59 Tweed Wonder.

Class 5.

R	S	S	S	S	S	S	S	S	S	S	S	R	S

B3 Black Valentine, B66 Black Valentine.

The various classes determined are shown in Table 5, where one variety of each is listed.

It will be noted that the variety "Florida Belle" appears in three and "Standard Pink" in two of the categories. In each case the seed came from different sources, but the variety appeared to be the same. Differences in resistance within a given variety are clearly shown.

Where more than one variety fell within a class they are set out in Table 6.

TABLE 7.

Reactions Shown by Nine Bean Varieties when Inoculated with Fourteen Different Isolates of C. lindemuthianum.

Accession Numbers of Isolates.	Race Designation.	Reactions Shown by Varieties.								
		Tweed Wonder.	Wellington Wonder.	Kentucky Wonder.	Black Valentine.	Brown Beauty (A.T.P.).	Staley's Surprise.	Startler Wax.	Hawkesbury Wonder.	Epicure.
767	Aust. 1	R	S	R	R	S	S	R	S	R
985	Aust. 2	R	S	R	S	R	S	S	S	R
986, 989, 990, 1034, 1036 ..	Aust. 3	R	R	R	S	R	R	S	S	R
987	Aust. 4	R	R	S	S	R	R	R	S	R
988, 1035 ..	Aust. 5	R	R	R	S	R	S	R	S	R
1026, 1028 ..	Aust. 6	R	R	R	S	R	S	S	S	R
1038	Aust. 7	S	S	R	R	S	R	R	S	R
1043	Aust. 8	S	S	R	S	S	S	S	S	R

It is seen that judging by these tests there is a wealth of resistant material available. Many of the varieties exhibit the climbing habit, but a number of the dwarf type are included. No association of resistance with any particular seed character could be found. Nothing regarding the real nature of host resistance is known.

TABLE 8.

A Comparison of the Determinations Made by Using the Two Different Sets of Varieties.

Race Designation.	
Second Test.	First Test.
Aust. 1	Aust. *B*
2	*D*
3	*E, F, G*
4	*F*
5	*E, H*
6	*F, G*
7	*C*
8	*G*
1	*B*
7	*C*
2	*D*
3, 5	*E*
3, 4, 6	*F*
3, 6, 8	*G*
5	*H*

In order to relate these results to those in which the smaller set of differentials was used (p. 75), the determinations have been simplified by making an empirical choice from the 132 varieties of a small group of nine of the better known varieties. The varieties Hawkesbury Wonder (susceptible throughout) and Epicure (resistant throughout) do not actually serve as differentials, but are included as useful commercial varieties, as well as types of their respective behaviours.

On this basis the determinations are as in Table 7.

On this basis eight races are sorted out. But they do not correspond with the eight previously determined with the other set of differentials. One of them (Aust. 3) comprises three of the former races (Aust. *E*, *F*, and *G*), and two of them (Aust. 6 and 7) each comprise two of the former races (Aust. *E* and *H*, and Aust. *F* and *G* respectively). A comparison is shown in Table 8.

An examination of the distribution of types on a space and/or time basis again gives no satisfying information.

Discussion.

A knowledge of the nature of the causal organism is essential to success in any attempt to control the disease. These studies were designed to throw some light on the host-parasite relationships that exist in the disease known as anthracnose of beans.

The first set of studies carried out between 1925 and 1928 revealed the presence in Australia of two physiologic races. One of them agreed with that recorded in U.S.A. as the beta race, and was present in 11 of the 12 isolates examined. The remaining one was different in its behaviour on one of the bean differential varieties, and has been styled Aust. *A*. This designation will not conflict with others in the literature where symbols such as Roman numerals are commonly used. From the small number of isolates no information of value could be got in regard to the distribution of the two races in time and space.

In the second set of studies, carried out between 1944 and 1952, 14 isolates were used in race determinations similar to those done previously. One came from Queensland, the rest from New South Wales. The presence was revealed of seven physiologic races, all different from the two found in the earlier work. They have been styled Aust. *B* to Aust. *H*.

During the interval between the two sets of studies there has been no appreciable change in the commercial varieties under cultivation. In other diseases, like the rusts of cereals, a marked change in the popularity of varieties because of their differential resistance has led to a marked change in the physiologic races present: a screening of the races has occurred, leading to the change in the rust flora as determined in the survey (Waterhouse, 1952). In this work on beans the change in the races determined cannot be explained in this way. The pathogen is seed-borne, and it is possible that the "new" races were introduced in seed brought from overseas. No sexual stage of the anthracnose fungus has been demonstrated, and so hybridization is ruled out. Hyphal fusions of differing mycelia could produce "new" races, but this happening has not been proved. Mutation of fungi has been demonstrated many times, and may be the explanation of the present happenings. What is important is that changes in a parasite as determined by its relationship with the host are constantly occurring. Where comparative studies are to be made, it is quite inadequate for morphological features to be regarded as a criterion of identity. Continuous checking of the physiological behaviour is necessary.

In such work the invariability of variation in the host is also of fundamental importance. Retention of genetic purity of the differential varieties used as hosts is essential. And if comparisons of results obtained by different workers are to be made, not only must the environmental conditions under which the tests are carried out be uniform, but the same genetically pure host material must be used as well.

The work reported herein shows clearly the need for these precautions. In a crop like beans, which are so widely grown, and in which seed is often sent from one country to another, confusion of names is not uncommon. In a new locality a local name may be substituted for the former name. A particular selection from imported material which is multiplied and established because of its particular characteristics may still carry the former name, whereas it may be of a different constitution from that of the original variety.

An example may be given. It was reported recently that Westralia beans were attacked by rust in New South Wales. Close examination showed that the "Westralia" crop which was rusted was not the real rust-resistant Westralia, although it appeared to be the same (Cass-Smith et al., 1954). Westralia itself is stated to have its origin

in a natural cross between Golden Harvest and a brown-seeded Kentucky Wonder (Cass-Smith et al., 1951). It was estimated that natural crossing occurred to the extent of 2%.

Our work has shown clearly the occurrence of natural crossing under Sydney metropolitan conditions, although only very limited observations have been possible. In 1954, from a pedigree row of Westralia, pods harvested from two plants yielded respectively mottled purple and light brown seeds. Six plants were produced; all were climbers, but they show clear differences in habit of growth, shape of leaf, and colour of flower. Further pedigree work with them is in progress, and may yield further information on the happening. It was known that several other varieties and crossbreds were growing some 10 to 12 feet away from the Westralia row.

In another instance, in 1953, a plant resembling Westralia was found in a row of this variety, also grown from pedigree seed. It produced rather flat streaked seeds—brownish-black streaks on a dun background—instead of the usual kidney-shaped white seeds of Westralia. Several of these streaked seeds were sown. They developed into strongly growing climbers which showed marked variation in flower colour, from white through pink to dark pink. The pods were long, but some were round, others flat in cross-section. The seed varied in shape and size as well as in colour; some were brown streaked with black, others brown, and two showed brown streaks on a cream background.

In this case it was known that the variety called "Tiger" was growing in close proximity to the Westralia row. It is a climber with dark pink flowers and flat pods bearing seeds which have brownish-black streaks on a dun background. It seems probable that in this case a natural cross between these two varieties had occurred. Numerous attempts have been made to cross these two by hand, but without success.

In areas where seed is produced on a commercial scale and where only one variety is under cultivation, the chances of natural crossing are greatly lessened. But in plant breeders' plots, where many varieties are grown in close proximity, it seems likely that the phenomenon occurs more frequently than is generally supposed.

Variations that are due to mutation must not be ruled out. A number of cases in our work has been noted in which chimaeric conditions affecting chlorophyll development have been present, but none has been shown to be heritable.

Selection of the varieties that are to be used in the host-parasite relationship studies is made on an empirical basis. It is not yet known what constitutes resistance to attack. But because of their genic make-up, some varieties show this character when tested with a wide series of isolates of the pathogen, whereas others are susceptible throughout the tests. Others again show differences in the reactions, and hence may be useful in classifying variations in the behaviour of different isolates. Because of differences in varieties under cultivation and differences in environmental conditions, it may be expected that with the passage of time there will be differences in the physiologic races present in different areas. Hence it is likely that the set of varieties selected as differentials for one country may not have the same usefulness elsewhere. In the cereal rust investigations it has been clearly shown that local conditions will often make it imperative to modify the normally-accepted set of differentials (Waterhouse, 1952).

This has recently been found in studies of bean rust in Australia (Waterhouse, 1954). The race of rust which is now so damaging to dwarf beans is not differentiated on the normally-accepted set of differentials, but is separated clearly when a local variety is added to the set.

Not only does a modified set of differentials give a more accurate picture of the host-parasite relationship that exists, but it generally gives far more assistance to the worker who is breeding for disease resistance.

In this work the normally-accepted set of six bean differentials has been used and eight physiologic races sorted out; they are styled Aust. *A* to Aust. *H*. They differ from the races recorded in U.S.A. as the alpha, beta, and gamma races. Using a totally different set of seven varieties, chosen as a result of testing more than 130 varieties

for their reactions, it happens that again eight races have been determined: they are styled Aust. 1 to Aust. 8. Whilst the results of the two sets of determinations show agreement in the case of three of the isolates, the others do not. Because of the relative ease in maintaining stocks of the second set of differentials in Australia, it is likely that this set will be found to be the more useful here. It may well be that further investigations will lead to modifications in this choice of varieties.

The simplified set of differentials just referred to came from the extended tests of varieties which showed that when the number of varieties tested is large, a very large number of variants of the pathogen may be distinguished. The tests show that there are numerous bean varieties available which were resistant to all the isolates used. A wider selection of isolates may well reduce this list of resistant varieties.

In recent communications (personal communications, 1954 and 1955), Mr. W. P. Cass-Smith, Plant Pathologist of the W.A. Department of Agriculture, states that a new situation has arisen in that State. Anthracnose of beans has recently shown up on Westralia, which on account of its strong rust resistance is now being grown late in the season. The temperatures are then relatively low, and anthracnose has been able to attack these crops of Westralia. In our tests the variety itself, as well as ten families from which it was ultimately selected and named, were quite resistant to all the isolates examined. It seems clear that a different race—or races—of *C. lindemuthianum* is present in Western Australia.

Because of its resistance to rust and its resistance to all the isolates of *C. lindemuthianum* tested, Westralia was selected as a parent in crosses and back-crosses with dwarf beans like Hawkesbury Wonder designed to combine the dual resistance with the commercially desirable characters of the dwarf type. This work is well under way, but the W.A. occurrence of anthracnose may mean that the Westralia resistance will be inadequate. If the anthracnose from Western Australia reaches New South Wales, this seems certain. Several other varieties, like Feijao, Little Navy, Resistant W.A. Kentucky Wonder, Harter's 814, and Scarlet Runner have also been used as parents having the dual resistance, but nothing is known about the basis of their resistance as compared with that of Westralia. Many other varieties also will be seen to combine the rust and anthracnose resistance.

From 200 pollinations of Hawkesbury Wonder with Westralia made between 1951 and 1954, only 10 have been successful. Very generally there is some development of the pod, but it soon stops growing and drops off. This is illustrated in Plate iii, in which the three basal flowers of the raceme were pollinated with Westralia, yielding tiny sterile pods in contrast to the normally-developed pods which were from selfed flowers. In the successful cases the pods developed were small and contained an average of only two seeds each. In one instance the crossed pod yielded seven seeds, but when they were grown, only four were crosses, the other three being straightforward Hawkesbury Wonder plants.

The F1 plants showed very poor development and produced an average of only 15 seeds each, thus curtailing very much the F2 examination; always some plants have been very feeble and have soon died. The segregating plants show marked sterility in seed-setting in some individuals, taking the form of tiny sterile seeds interspersed with normal seeds in a pod. Similar sterility effects have been found in the two crosses, Hawkesbury Wonder × W.A. Resistant Kentucky Wonder, and Hawkesbury Wonder × Kentucky Wonder Hybrid. The W.A. Resistant Kentucky Wonder is the supposed parent of Westralia which gave the latter its resistance. Counts involving 118 pods and 850 seeds gave a 20% sterility occurrence. There is a clear need for cytogenetical studies of these happenings.

The variety Scarlet Runner (*Phaseolus coccineus* L.) has been even more difficult to cross. It is still too soon to evaluate the results.

The late Mr. R. D. Wilson recorded (Wilson, 1950) striking differences between what he called Strain 1, to which the varieties Wellington Wonder and Tweed Wonder were resistant, and Strain 2, to which they were susceptible. The present work fully

substantiates this finding. It is clear that on the basis of the reactions given by additional varieties the two strains can be further split up.

An endeavour has been made to link up with the results reported by Egerton and Moreland (1916), Leach (1923), Rands and Brotherton (1925), Müller (1926), Schreiber (1932), Müller (1941), Reid (1943 and 1945), and Hubbeling (1946). In places some of the varieties used in the current work are included in the results reported, but there are so many differences in the varieties used that no valid comparisons can be made.

The amount of variation in *C. lindemuthianum* which has been so clearly established in Australia may well be further extended if further local studies are made. It is a happening that must always be taken fully into account in any programme designed to yield anthracnose-resistant varieties of beans.

Acknowledgements.

The Principal of Hawkesbury Agricultural College (Mr. E. A. Southee), Mr. N. S. Shirlow, Mr. P. I. Pryke, Mr. W. P. Cass-Smith, and Mr. W. Hartley submitted seed of many bean varieties. The late Mr. R. D. Wilson was most helpful in supplying diseased material, as were also Miss D. E. Shaw and Mr. D. W. Reilly. Miss Shaw did much of the work in the preparation and maintenance of the cultures, and Miss E. M. Dumbrell and Mr. F. Law in the plant house routine. My daughter (E.R.W.) gave invaluable help in making the bean crosses and with the manuscript. Financial assistance was given by the Commonwealth Bank and the Rural Bank of N.S.W. To all grateful thanks are tendered.

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EXPLANATION OF PLATE III.

A and B : Resistant and susceptible varieties respectively, inoculated with *C. lindemuthianum*. $\times \frac{1}{4}$.

C : A raceme of a growing plant of Hawkesbury Wonder three weeks after pollination. The three basal flowers were pollinated with Westralia, and show the typical stunted pod development in contrast to the normal development of the other pods on the raceme from flowers which were self-pollinated. $\times \frac{1}{3}$.