

THE HISTORY OF PLANT PATHOLOGY IN AUSTRALIA

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EARLY EPIDEMICS OF WHEAT RUST

Plant pathology in Australia began in the last century as a result of sporadic rust epiphytotics which blighted wheat crops and devastated part of the vital food supply of the pioneers. Soon after the first settlement was established in Australia in 1788, Governor Phillip devoted all his spare time to the question of providing food for the young colony (84). The first crop of wheat was grown (46) in what is now the Sydney Botanic Gardens (28). Collins was the first to record disease in wheat in 1795 in a crop of bearded cape wheat "which was not worth the labour of sowing" at Petersham Hill, now the site of Sydney University (111). Early settlers referred to disease of wheat crops as blights or accidents, and the disease could not be identified. Joseph Holt, a farmer, gave an accurate description of a rust-infected wheat crop at Dundas, New South Wales, in 1803. After a few days of foggy weather and within 3 weeks of harvest, wheat was reduced in value from £1400 to less than £20. "It covers the whole wheat straw with reddish powder. ..." (84, 90). The early Governors frequently mentioned crop losses in their despatches to the British Government. Governor King in his despatch of 1804 (46) reported: "Our last year's crop was much injured by rusts and smuts." The early records of rust attacks in the Australian colonies have been reviewed by Waterhouse (111), who showed that rust epiphytotics occurred in 1799, 1803, 1805, 1829, 1832, 1860, 1863, 1864, 1867, and 1889. Not long after the founding of Victoria in 1851, the Board of Agriculture (forerunner of the Department of Agriculture) was established. Within 5 years three rust epiphytotics occurred, causing the Board to appoint a committee in 1864 to inquire into the causes and prevention of rust. F. Mueller (later Baron Sir Ferdinand von Mueller), Government Botanist and Director of the Melbourne Botanic Gardens, was chairman. The rust committee (72) determined the effect of agricultural practices on the incidence of the disease and recommended early sowing and careful selection of wheat varieties as a means of control. In Australia this first official scientific inquiry into a major plant disease came at the time when plant pathology was established in Germany as a scientific discipline by de Bary. Following an outbreak of wheat rust in 1867 in South Australia the Government of that colony appointed a similar committee (88).

EARLY AUSTRALIAN PLANT PATHOLOGISTS

William James Farrer graduated from Cambridge University in 1868 and came to Australia the following year. He became a surveyor and, because of his travelling through the country, developed an interest in the problems of the man on the land (91). Farrer (32) later recalled that "The idea of making improvements in the wheat plant was taken hold of me as early as 1882 It was not until 1889 that the first attempts at cross breeding were made." This work was carried out at his own expense on his property near Canberra until he accepted an appointment with the Department of Agriculture of New South Wales in 1898. He was then able to give time to the production of a rust-resistant wheat variety. In this work, Farrer was encouraged by A. E. Blount of the Colorado Agricultural Experiment Station who was at that time producing new varieties of cereals by hybridization and selection. Blount was not concerned with rust resistance, as this disease was not a problem under his conditions. In a letter to

Farrer in 1885, Blount said (91) "I think four to six years' breeding of your standard wheats would almost entirely revolutionize them so that rust, smut and blight would be unknown . . . I will send you several kinds of my crosses to test." This is perhaps the earliest instance of the cooperation in agricultural science between the United States and Australia. According to Large (57), "the greatest single undertaking in the history of applied plant pathology was to be the attack on rust of cereals. The mighty rust investigation soon to be world wide began in Australia with a series of rust in wheat conferences following the epidemic of 1889." A brief history of this first conference has been given (7, 82). Subsequent conferences were held in Sydney in 1891, Adelaide in 1892, Brisbane in 1894, and Melbourne in 1896. Watson (113) stated "that the influence of Farrer's varieties was so great that the area sown to them rapidly increased as the overall production of wheat in Australia expanded. Federation became the leading variety and held that position until 1925 . . . He started his work when fundamental knowledge of the disease was lacking, not only in Australia but in other wheat producing countries as well. He was unaware of the extreme variability that was present in the organism and which was later to upset the breeding programmes of many countries." Daniel McAlpine arrived in Melbourne in 1884 and was appointed lecturer in biology at the University of Melbourne, and in 1890, Consulting Vegetable Pathologist to the Department of Agriculture of Victoria. He was born at Saltcoats, Scotland in 1849 and, like Marshall Ward, studied biology under Huxley, and botany under Thistleton-Dyer, in the Royal College of Mines, South Kensington, England. There is little doubt that his appointment as vegetable pathologist was furthered by the 1889 rust epiphytotic and the program of experimental work approved by the first rust-in wheat conference held in Melbourne in 1890. He was chairman of the final conference in Melbourne in 1896 and, in the report (92), summarized the combined results of all sessions of the conference. McAlpine cooperated with Farrer by testing wheats under Victorian conditions. He published a systematic census of Australian fungi in 1895, and in 1906 a critical monograph on rusts of Australia, followed by a paper on smuts of Australia in 1910. McAlpine published 226 scientific works, papers, and bulletins (62), 56 of which dealt with the fungal flora of Australia. In plant pathology there were three volumes (Diseases of Citrus in 1889, Diseases of Stone Fruits in 1902, and Diseases of Potatoes in 1911) and 137 publications. An investigation into the nature and control of bitter pit of apples was reluctantly undertaken, and the results which were published in five reports between 1911 and 1916 included information on the influence of orchard practices on the incidence of the disease. McAlpine retired in 1916 and died in 1932. Daniel McAlpine has been called "the father of Plant Pathology in Australia" (13, 112). He was a truly dedicated pioneering scientific worker during his 26 active years in Australia. Nathan Augustus Cobb, who was born in Spencer, Massachusetts in 1859, arrived in Sydney in 1889. He had undertaken courses at the University of Jena in zoology under Haeckel, Lang, and Hertwig, and botany under Stahl, obtaining his PhD in helminthology. Cobb worked for one year at the Naples Zoological station before coming to Australia. Blanchard (9), Cobb's daughter, indicated that on arrival in Sydney with his family he had difficulty in finding suitable work, and "started working on a six months' appointment with the New South \Vales Government as Consulting Pathologist. He was given enough time, mostly evenings, to answer letters from farmers and examine specimens, etc., and was paid £2 per week, but soon found that he put in much more time than the salary paid for." The Department of Agriculture of New South Wales was established in 1890, and Cobb was appointed Vegetable Pathologist (112) the same year that McAlpine was appointed in Victoria. Cobb developed a formula for describing the anatomy of nematodes which is still used (18) and produced about 12 papers on nematodes while in Australia. The proof that gumming disease of sugarcane was caused by a bacterium (20) impressed Erwin F. Smith, who later supported Cobb's appointment to the United States Department of Agriculture. Cobb published an index of Australian fungi in 1893 (19). From 1891 to 1903 he described and illustrated many plant diseases present in New South Wales. Before leaving Australia in 1905 he published a monumental work on the nomenclature of wheat varieties. His experimental methods were outstanding. To replace the very indefinite adjectives

previously used, he designed a scale of rustiness which was used by Farrer in connection with field observations on the degree of rust infection in his wheats. He endeavoured to determine the factors of importance in resistance to rust in wheat. He had a keen appreciation of error in field experiments, and lectured on this subject to Department officers. He was a man with great practical outlook, capacity, and versatility who, in addition to his numerous duties, managed the Government experimental farm at Wagga for 3 years. In 1897 he was commissioned to report on agriculture in overseas countries and, on his return in 1901, published on such general agricultural matters as grain elevators and the California wheat industry. In 1905 he went to Honolulu until he was called to Washington by the Bureau of Plant Industry of the US Department of Agriculture. According to Buhner (10) Cobb became the father of American plant nematology-in fact he gave nematology its name. Cobb produced approximately 250 publications (9), 90 of which were produced in the New South Wales Department of Agriculture. He died in 1932 while still actively engaged in nematological studies. A medical man, Joseph Bancroft, was probably the first to carry out a plant disease investigation in Queensland (97). In 1874 he discovered and described Fusarium wilt of bananas, noted the occurrence of varietal susceptibility, and recommended the use of disease-free planting material. He also cooperated with Farrer in his attempt to produce suitable rust-resistant wheats for Queensland. Henry Tryon, who had been Government Entomologist in the Queensland Department of Agriculture since 1894, also became Vegetable Pathologist in 1901, holding the dual position until 1929. Of the 136 papers he published, 30 were concerned with plant pathology, including two on the gumming disease and the top rot of sugarcane. According to Simmonds (97), he described for the first time in 1891 the bacterial nature of bacterial wilt of potato and tomato, which was subsequently confirmed by Erwin F. Smith. Tryon was the first to recognize the presence in Australia of late blight of potatoes. The Biology Branch of the Department of Agriculture of New South Wales was established in 1913 with G. P. Darnell Smith as Biologist, following the reorganization of the Government Bureau of Microbiology. Darnell Smith (26, 27) showed that seed treatment with copper carbonate dust gave better control of bunt than did liquid bluestone-lime treatment, and that this dust treatment had no deleterious effect on the germination of wheat. This method soon became standard practice in Australia and, by 1925, one tenth of the wheat grown in the United States was treated with copper carbonate powder (57). This discovery changed seed treatment methods throughout the world. Darnell Smith, before his retirement in 1927, established a group of plant pathologists in the Department of Agriculture of New South Wales, who specialized on a crop basis, which was unique at that time. Charles Clifton Brittlebank, after assisting McAlpine in Victoria for 5 years, was appointed Vegetable Pathologist to the Department of Agriculture of Victoria in 1913. He carried on this work single-handedly until 1924, and also lectured in plant pathology at Melbourne University from 1923-1928. He published some 25 papers, and established a high-grade plant pathological diagnostic and consultative service for the primary producers of Victoria. Brittlebank became Biologist in charge of the Science Branch following W. E. Laidlaw, who had held this position since 1913. On retirement he was engaged by the Council of Scientific and Industrial Research to produce a host and fungus index for Australia, which was later cyclostyled for limited distribution. He died in 1945 at the age of 82. I worked with him for 3 years before he retired a plant pathologist, artist, naturalist, successful farmer, professional boxer, and no mean golfer-an unforgettable character. F. Maddox demonstrated in Tasmania in 1894 that floral infection takes place in loose smut of wheat. H. M. Nicholls was Microbiologist of the Department of Agriculture of Tasmania from 1913 to 1935, and published on black spot of apples and pears, and root rot of fruit trees. F. Stoward was appointed Botanist and Vegetable Pathologist to the Department of Agriculture of Western Australia in 1911. Up until that time the state had been dependent on outside help for its plant disease problems, particularly on McAlpine. Stoward was followed by H. A. Herbert in 1918, and this marked the commencement in Western Australia of the modern approach to plant disease problems. Herbert was followed by J. C. Campbell. During this era plant pathology began to develop in some of the Australian universities. The

Botany School at the University of Melbourne was founded in 1906 with A. J. Ewart as the first Professor of Botany in Australia (78). Ethel I. McLennan, who was appointed to this school in 1915, published on an endophytic fungus associated with the seed of *Lolium* (64). Between 1890 and 1912, plant pathological material in South Australia was referred to McAlpine and Cobb (112). Professor T. G. B. Osborn's appointment to the Chair of Botany in the University of Adelaide was contingent on an agreement with the Government that he would act as Botanist and Vegetable Pathologist to that state. David Shepherd North joined the Colonial Sugar Refining Company as Sugar Pathologist in 1900, and worked on leaf scald (*Xanthomonas albilineans*) and gumming disease (*X. vasculorum*), and from 1907 to 1916 on Fiji virus disease and downy mildew (48). He was notably successful in controlling these diseases in commercial crops of sugarcane, and his nine publications (76) remain standard works. He retired in 1942. The David North Plant Research Centre at Indooroopilly, Brisbane, is named after him.

DEVELOPMENTS OF AUSTRALIAN PLANT PATHOLOGY IN THE LAST FIFTY YEARS

Plant disease hazards affecting the stability of agricultural production during the 1920s were numerous and serious. Wheat-rust epiphytotics occurred in 1920, 1921, 1925, 1930, and 1934. Flag smut caused losses of up to 70% or more. Take-all and root rot of wheat took their toll. Average potato yields were low because of virus degeneration; tomato crops were being ravaged by a disease later named spotted wilt by Brittlebank. The existence of the tobacco industry was threatened by blue mold. Brown rot and mst of peaches, and apricot scab caused serious losses in the canning industry. Black spot of apples and pears ruined fruit grown for export. Bitter pit was still present, and citrus and grape vines had unknown diseases. Bunchy top of bananas caused the collapse of the banana industry in New South 'Wales and Queensland in 1924. Pineapple and other tropical fruit disease losses occurred, and the sugarcane industry had its disease problems.

ORGANIZATIONAL DEVELOPMENT

Universities.-It was in this atmosphere that the teaching of plant pathology, associated with some research, became established in Australian universities. Locally trained plant pathologists gradually became available to tackle these problems. There was much work to be done by few workers, with minimum facilities and very limited funds. The pioneering work in University teaching of plant pathology and his outstanding contribution to basic and applied research established W. L. Waterhouse of the University of Sydney as the doyen of this field in Australia. Ethel I. McLennan taught mycology and plant pathology in the University of Melbourne from the midtwenties to 1955. During her active professional career some 27 higher degrees were granted, and she and her students published about 100 papers (78). Those of us who received our undergraduate training from McLennan regard her as the doyenne of university teaching and research in mycology and plant pathology in Australia. In the twenties there was no chair of plant pathology in any Australian university. Three chairs were established at the University of Adelaide in 1964 (N. T. Flentje), the University of Sydney in 1966 (N. H. White), and at the University of Melbourne in 1969 (L. L. Stubbs). G. C. Wade, Professor of Agriculture in the University of Tasmania since 1961, is responsible for the teaching and research in plant pathology in his faculty. Plant pathology training at the University of Queensland was provided by D. A. Herbert, 1924-42, R. F. N. Langdon, 1946-69, and A. E. C. Aberdeen, 1950-69. Eight well-known plant pathologists graduated from the University of Queensland in the pre-1945 period and 31 since then, about 20 students completed higher degrees, and 23 papers have been published (56). At the University of Sydney, N. H. White's colleagues are D. M. Griffin and C. D. Blake. P. G. Williams is a member of the Biochemistry Department. Since 1955, 67

publications in plant pathology and cognate fields have come from this teaching and basic research group. At the Waite Agricultural Research Institute, David B. Adam was Head of the Plant Pathology Department from 1934 to 1951, succeeding C. Samuel. He was followed by C. G. Hansford from 1951 to 1957, and N. T. Flentje since 1958. The present group consists of nine plant pathologists. Within 4 years of the establishment of the chair of plant pathology in 1964 some 80 papers were produced by this group. The pioneer plant virologist, R. J. Best, works in the Agricultural Biochemistry Department of the Institute. From 1958 to the present the number of graduate students has risen from one or two to twelve undertaking PhD work, and another five doing Master's Degree work. They include people from Australia, England, Canada, South Africa, India, Ceylon, Pakistan, Ghana, Malaysia, and Burma. At the University of Melbourne, L. B. T. Thrower was appointed lecturer in Mycology in 1957, and in 1961 D. G. Parbery became lecturer in Plant Pathology. Recently L. L. Stubbs was appointed to the chair of Plant Pathology. W. M. Carne established teaching of plant pathology in the University of Western Australia in 1923. State Departments of Agriculture.-The disposition of these forces in relation to the problems of the twenties in the State Departments of Agriculture was as follows: New South Wales-R. J. Noble, appointed Biologist in 1927 (flag smut of wheat and passion-fruit virus) ; H. J. Hynes, 1922 (cereal root rot diseases); E. T. Edwards, 1928 (maize diseases); C. J. Magee, 1923 (bunchy top of bananas) ; F. C. McCleery, 1925 (citrus diseases). Victoria-Co C. Brittlebank, Biologist in charge in 1924; D. B. Adam, 1925 (blue mold of tobacco) ; S. Fish, 1926 (fruit diseases). Queensland-H. Tryon, J. H. Simmonds, 1926 (diseases of tropical fruits) ; R. B. Morwood, 1926 (diseases of cereals). The Bureau of Sugar Experimentations, A. F. Bell, 1923, in charge of the Division of Plant Pathology. Western Australia-W. M. Carne, 1923 (flag smut of wheat and bitter pit of apples). Tasmania.-H. M. Nicholls, 1913 (black spot of apples); W. J. Dowson, 1928 (potato virus degeneration) . Changes have occurred in plant pathology in State Agricultural Departments over the years since the twenties. In the Department of Agriculture, New South Wales, H. J. Hynes was appointed Chief Biologist in 1940 to succeed R. J. Noble, and was followed by C. J. Magee in 1944, W. S. Sutton in 1960, and Lilian R. Fraser in 1968. The Biology Branch, along with two other branches of the Division of Science Services, was transferred to new laboratories at Rydalmere in 1960. C. J. Magee became Chief of the Division of Science Services, and was followed by T. H. Johns in 1968. There were ten plant pathologists in 1960; in 1969 there were nineteen. From 1923 to 1968 this group has produced 150 research papers on a very wide range of plant disease problems of New South Wales. The division of Science Services became the Biological and Chemical Research Institute in 1970. J. H. Simmonds was appointed Plant Pathologist in the Department of Primary Industry, Queensland in 1926. B. L. Oxenham was appointed in 1961, and was succeeded by G. S. Purss, who now heads a team of 21 plant pathologists. A total of 275 papers have been published (96). W. J. Dowson held the position of Plant Pathologist in the Tasmanian Department of Agriculture from 1928 to 1931, J. O. Hendrick from 1936 to 1943, N. H. White from 1944 to 1946, G. C. Wade from 1947 to 1961, and I. D. Geard after 1961. The group now consists of five plant pathologists. H. A. J. Pittman became Plant Pathologist in the Department of Agriculture of Western Australia in 1928, and concentrated on the development of an advisory and extension service. From 1939 to 1949 the staff increased from one to four, and the next decade saw increased specialization with further increase in staff members under W. P. Cass Smith, who retired in 1964. H. L. Harvey was then appointed to lead this group of six plant pathologists. The Plant Pathology Department of the Waite Agricultural Research Institute is legally responsible for providing advisory service in plant pathology to the South Australian Government. It is the only Australian university carrying out this function, which is elsewhere carried out by the plant pathologists of the State Departments of Agriculture. This service was covered entirely by the Waite Institute for the period, 1925 to 1960. After 1960 the Department of Agriculture sent two young graduates overseas to be trained in plant pathology. With three other young graduates the Department of Agriculture of South Australia is now building up a staff in plant pathology to relieve the Waite Institute of much of the advisory work. The Department of Agriculture group and the Department of

Plant Pathology at the Waite Institute are now housed together and work in cooperation on many of the problems of the state. C. C. Brittlebank retired as Biologist in charge of the Science Branch of the Department of Agriculture of Victoria in 1929, but not before a new Plant Research Laboratory had been built at Burnley. S. Fish was appointed Biologist in charge of the Biology Branch in 1935, and continued in this position until 1968, with its designation changed to Chief Biologist. A sound scientific environment was considered to be vital to carry out the basic research required to understand the problems, and then to investigate appropriate stratagems for control. General pathologists for the agricultural and horticultural crops were provided, as well as plant pathology specialists for the various causal agents of disease. The Biology Branch was established as the Victorian Plant Research Institute in 1965 with a staff of 20 plant pathologists. C. R. Millikan became Chief Biologist in 1968, and L. L. Stubbs was succeeded as Principal Plant Pathologist by R. H. Taylor. The Northern Territory Administration in Australia has conducted work on the pathology of rice and other crops. W. Stahl indicated that the most important disease was caused by *Helminthosporium oryzae*, also found on indigenous rice. J. Heaton studied this problem from 1961 to 1968 and showed that the pathogen carried over on seed, and on volunteer and wild rice, and that seed-borne infection was controlled only by hot-water treatment. In the Department of Agriculture, Stock, and Fisheries of the Territory of Papua and New Guinea a group of plant pathologists under Dorothy E. Shaw has worked on the pathology of tropical crops since 1954. The main pathology laboratories are at Port Moresby, with a smaller laboratory at Keravat in New Britain. Since 1955, 48 papers in pathology and related subjects have been published. Shaw in 1965 successfully eradicated coffee rust, and prevented the fungus from reaching the main coffee areas and causing tremendous economic loss (93a). Comm01?wealth Scientific and Industrial Research Organization.-In 1916 the Commonwealth Government set up an advisory Council of Science and Industry. The name was changed to the Institute of Science and Industry in 1919 and a Director was appointed. The Council for Scientific and Industrial Research was established in 1926 (25) and in 1927 was represented at a conference of Australian plant pathologists by T. G. B. Osborn, who was chairman of the conference. It became a corporate body in 1949, and was renamed the Commonwealth Scientific and Industrial Research Organization. The CSIRO established a Division of Economic Botany in 1928 (later renamed the Division of Plant Industry) with B. T. Dickson, a Canadian plant pathologist from McGill University, as Chief. He quickly organized a section of plant pathology with the following staff: H. R. AngeJl (blue mold of tobacco); H. A. J. Pittman (spotted wilt of tomatoes); W. M. Carne (bitter pit of apples); J. G. Bald (spotted wilt of tomatoes and later potato-virus diseases); Miss P. H. Jarrett (flag smut of wheat); W. L. Geach (root rots of wheat). This group was complementary to the staffs of state Departments of Agriculture. It could devote full time to research, whereas plant pathologists in the states were responsible for diagnostic and advisory service in plant pathology for departmental officers and primary producers, as well as research directed at immediate agricultural problems. Subsequent to 1928 B. T. Dickson developed a plant pathology group well balanced in basic and applied aspects of plant pathology. K. O. Muller initiated the formation of a research group in 1953 for the study of the physiology and biochemistry of disease resistance in the Division of Plant Industry in Canberra. It has been shown by the use of model host-parasite systems that plants respond to infection by the formation of host-specific antifungal compounds called phytoalexins. The first of these, pisatin, was isolated in 1960 by I. A. M. Cruickshank and D. R. Perrin. The role of such compounds in disease resistance has been reviewed by Cruickshank (24a, 24b). Three other phytoalexins have since been isolated and characterized. Biochemists in CSIRO isolated the factor in blue-mold-infected tobacco that confers resistance to the leaves, and chemical characterization is in progress. C. J. Shepherd, in charge of the plant pathology group since 1962, has studied the biochemistry of host relations to *Peronospora tabacilla*. K. Helms has also studied the physiology of host-parasite relations. M. F. Day, of the Division of Entomology, did stimulating work on the relationships of viruses and their aphid vectors. He demonstrated the presence of the potato leafroll virus in solutions by injecting virus in solutions into

aphids; the first time aphids had been successfully inoculated in this manner (29a). Rovira and his associates (89a-89c) in the Division of Soils at Adelaide have shown that root exudates largely determine which bacteria and fungi live in the rhizosphere of the roots. These exudates thus play an important role in the ecology of organisms which infect roots. Bowen and Rovira (9a, 89c) have also studied the stimulation of bacteria by plant roots, and the effects of these organisms on root growth. From 1926 to 1945 CSIR published 104 papers in plant pathology and cognate fields; from 1945 to 1969 there have been 217 papers published. In 1966 there were 177 plant pathologists in Australia (probably now of the order of 200), as compared with a total of about 26 in 1929. Most of the plant pathologists in Australia are employed by state Departments of Agriculture, and fewer in the CSIRO, universities, forestry, and industry. The Australian Plant Pathology Society was organized in 1969 with 200 foundation members. N. T. Flentje was elected as the first president.

DEVELOPMENTS IN SUBJECT MATTER Cereal diseases.-

W. L. Waterhouse continued the attack on stem rust of wheat and published 20 papers on it. He showed (114) the marked effect of environment on rust infection type, the significance of the barberry in the origin of new strains of wheat stem rust. This followed the work of Craigie in demonstrating the function of the pycnia ... the group at St. Paul, Minnesota used a culture homozygous for pathogenicity and of course recovered the same pathogenic strain from aecia as they had used in the initial inoculation. Waterhouse used a strain heterozygous ... for virulence and recovered some very spectacular variants. About 1930 Waterhouse began to see more clearly the role of resistant varieties in the control of cereal rust. He had, of course, synthesised wheat lines earlier by crossing cultivars which combined the genes of resistance to the two groups of strains he had recorded. With the arrival of a new rust from Western Australia, combining new genes for virulence with new genes for aggressiveness, all his material became susceptible overnight. The arrival of rust resistant parents from overseas such as Webster, Hope, Gaza (*Triticum durum*) was a great stimulus to the work he proposed on breeding ... With rust in northern New South Wales and Queensland taking 25% to 30% of the crop, W. L. Waterhouse saw the need to intensify this work ... in the north western part of New South Wales where rust is a serious problem and began testing material there ... He was, in common with his associates elsewhere, not aware that breeding disease resistant plants would represent the challenge it turned out to be. It was not anticipated, for example, that releasing commercial wheats with single genes for resistance to rust would result in a steady succession of disappointments for the breeder. However, during the period 1940-1950, in spite of the war ... investigations were made into the value and feasibility of having not one gene but several genes in the material released and this approach has been the basis of the success of the newest releases which combine several types of resistance. It is a great tribute to Waterhouse that during the latter period of his working career we saw in 1947-48 the last serious rust epidemic in New South Wales. Due to his basic approach to this problem it has not been seen in New South Wales for 20 years or more. Upon the retirement of Waterhouse at the end of 1952 the rust work at the University of Sydney was continued by I. A. Watson, Professor of Agricultural Botany. A further outstanding advance was made in 1966 at the University when Williams et al (114a) reported convincing evidence of the growth of the obligate parasite, *Puccinia graminis* f. sp. *tritici*, in culture media. The continuous attack on stem rust of wheat over an 50-year period has been a remarkable contribution to plant disease control and to the welfare of Australia. R. J. Noble carried out fundamental studies on the parasitism of flag smut of wheat (74). In 1924 Carne, who was situated in Western Australia, obtained evidence that Nabawa wheat was resistant to flag smut (12), and within 7 years it was sown on 32% of the five million acres of wheat (14). Breeding for resistance to flag smut was an unqualified success, and the resistance of Nabawa has been maintained for over 40 years (113). Gurka wheat was found in 1934 to be resistant to flag smut in Victoria (68), and a range of derivative varieties resistant to flag smut have since been bred in Victoria and in Western Australia. Farrer released early in this century varieties of wheat (Florence and Genoa) resistant to bunt. Because a cheap and effective fungicidal seed treatment was available for bunt control, most wheat breeders in Australia directed their attention to those

diseases not controlled by fungicides. A. T. Pugsley joined the Waite Agricultural Research Institute, and carried out the most comprehensive and successful breeding work against bunt in Australia (113). He has been Director of the Agricultural Research Institute at Wagga since 1953. He identified races of *Tilletia*, studied the genetics of resistance, and bred the bunt-resistant wheats Heron, Robin, Raven, and Vande (86). Disease-resistant or tolerant varieties have also been developed in sugarcane, potatoes, vegetables, and pasture plants. J. Kuiper found a new race of *Tilletia foetida* in Victoria in 1965 which was tolerant of the organic fungicide, hexachlorobenzene (55). This is perhaps the first example of resistance of a pathogen to a fungicide developed under field conditions. The development of wheat varieties resistant to the smut may overcome this difficulty. Fruit diseases.-Fungicidal protection of fruits, vegetables, and other plants against infection by pathogens was also utilized. Although there was no noninjurious fungicidal cover-spray known at that time which could be used on apricot fruits without causing injury, apricots infected with scab (*Clasterosporium carpophilum*) were reduced from over 70% to 2% with Bordeaux mixture in the autumn and at the pink-bud stage in August (33). It was later found that tetramethylthiuram disulfide could be used on apricot fruits without causing injury, and Wade also assessed it for brown rot control in Tasmania (IOŠa). It was shown in Victoria that dry-mix lime sulfur could prevent an epiphytotic of peach rust on the very susceptible variety, Thiele's Cling, and that it could reduce brown rot loss by about two thirds, but no more. The epiphytotics of brown rot (*Sclerotinia fructicola*), in evidence since the twenties, culminated in 1955-56 with heavy losses to growers of canning peaches. A combined attack on this problem was made in 1957-62 by the Departments of Agriculture of Victoria, New South Wales, and Tasmania, and by the CSIRO and the University of Tasmania (89). Wade (109) noted the possible occurrence of latent infection of brown rot in apricots, and Jenkins & Reinganum (50) showed that it occurred in peaches as well as apricot fruits. Dichlone applied to peaches at the early-full-bloom and early-petal-fall stages reduced the incidence of brown rot at harvest and in storage by eradicant action. Post-harvest thermotherapy (108) developed in Victoria affords substantial control of post-harvest brown rot. Peaches are treated before they are fully mature for 24 hr at 104°F, with ripening then completed at 75°F; they ripen fully without brown rot development and with minimum losses from *Rhizopus* and other rot fungi. Simmonds of Queensland noted in 1941 (94, 95) the existence of latent infection of tropical fruits, as did Adam in 1949. T. B. Kiely of New South Wales found the perfect stage of the causal fungus of the black-spot disease of citrus, and showed that *Guignardia citricarpa* had an unrecognized latent period (53, 54). Hutton (49) discovered that the overwintering ascigerous stage of apple and pear scab could be eradicated by post-harvest spraying of trees with mercurial fungicide. Because of mercury residues, use of this fungicide has not been encouraged, but it has opened up new avenues of research. Fisher (33a) discovered the ascigerous state of the apricot freckle fungus. Tobacco diseases.-The most important single contribution to the Australian tobacco industry was the discovery by Angell et al (5, 6, 88a) that fumigation with benzol vapor controlled blue mold in tobacco seedlings. Seedlings were grown at this time as far as 300 miles from tobacco areas in an effort to protect them from disease. Such precautions were rarely effective, and in the Report from the Select Committee on the Tobacco growing Industry in Australia (1929-30) it is stated that, "The growers have hitherto proved unable to deal with the blue mold disease, which in many cases wipes out the tobacco of a whole district two out of three seasons." Root diseases.-Lilian R. Fraser of New South Wales identified the cause of a widespread citrus disease as *Phytophthora* root rot, and introduced the use of the resistant *Poncirus trifoliata* as a root stock to combat this disease and *Phytophthora* collar rot (34-36). R. N. Hilton of the University of Western Australia is investigating die-back in jarrah (*Eucalyptus marginata*) due to *Phytophthora cinnamomi* which has destroyed 462,000 jarrah trees and is threatening another fifteen million trees (61). G. C. Marks and F. Kassaby, of the Forests Commission of Victoria, are investigating this fungus in nursery trees and shelter belts, and H. T. Hartigan of the Forests Commission of New South Wales is also concerned with it on *Eucalyptus*. Root rots of wheat were first mentioned as occurring in South Australia in 1868 (88). McAlpine in 1902

recognized *Ophiobolus graminis* as a cause of take-all and deadheads in wheat. From the twenties to the end of the Second World War there was much activity in Australia on this problem by Brittlebank 1919, Samuel 1923-33, Fish 1927, Garrett 1933-34, Adam and Colquhoun 1936, White 1939-47, and Angell 1943-51. Hynes in 1935-38, and Millikan in 1940, were concerned with *Helminthosporium* and *Curvularia*. Samuel and Garrett in 1932, and Hynes in 1937, investigated *Rhizoctonia solani* on cereals, while Geach in 1932-33 was concerned with *Fusarium culmorum*. F. C. Butler published a comprehensive world review on the root- and foot-rot diseases of wheat which contains some 70 Australian references (11). Flenjte investigated *Rhizoctonia solani* after 1956. Magee in 1957 recorded *Fusarium graminearum* as a crown- and root-rot pathogen of wheat, and it was later studied, along with *Ophiobolus graminis*, by Chambers (15) and Price (85). Price also recorded *Pythium ultimum* associated with deadheads of wheat in 1964. *Ophiobolus graminis* and barley yellow dwarf virus were the most important pathogens in Victoria, causing losses of 40% to 60% in a few instances. Virus diseases.-During the twenties little was known about virus diseases in Australia. Noble (75) studied the woodiness disease of passion fruit in 1928. In the pioneering work of. Magee in 1927 on bunchy top of bananas it was shown that it was an insect-borne virus disease (58). A scheme based on eradication and replanting with disease-free stock was initiated, and this industry was reestablished (60). Samuel and Pittman carried out a joint investigation on spotted wilt of tomatoes, and Pittman showed that it was caused by a virus acquired only during the larval stage of *Thrips tabaci*, the first record of this type of vector (83). A second thrips vector, *Franklinella insularis*, was soon also found. Dawson in 1928 tried to increase potato yields by eliminating virus diseases (30, 31). Studies by Magee (59) and Adam (1) on potato virus diseases and their control eventually led to the initiation of potato seed certification schemes in the various states. Pugsley and Bald studied the main virus diseases of the potato in Victoria (8). Bald contributed 24 papers on virus diseases of potatoes, symptom expression, reaction of variety, host range, effect on yield, and search for resistance between 1940-50. Tobacco mosaic virus (12 papers) and tomato spotted wilt virus (7 papers) were also studied. C. G. Hughes and D. R. L. Steindl joined A. F. Bell in the Bureau of Sugar Experiment Stations, Queensland, in the mid-thirties. According to Hughes (47), the most important contribution of the Pathology Division was the discovery of ratoon-stunting disease and the working out of a method for its commercial control. Ratoon stunting has no external symptoms ... There are internal symptoms . . . The effects of this disease vary with the variety and the season and on sensitive varieties there may be a total loss of crop. The discovery of this very infectious disease, which was subsequently found in practically every cane growing country, offered one explanation of the well known running out of cane varieties. This disease is controlled by heat treatment of plant material, in water at 50°C for three hours or in air at 54°C for eight hours. The hot water is the more widely accepted method. In Queensland some 2,000 to 3,000 tons of plants are treated annually, but a much larger tonnage of disease-free plants come from special plots propagated from treated setts. According to P. B. Hutchinson, Fiji disease of sugarcane has assumed some importance in New South Wales. Grieve, while with the University of Melbourne, showed that rose wilt and die-back is caused by a virus (39, 41). He also published on the effect of spotted wilt on plant growth (42). He is now Professor of Botany of the University of Western Australia. Rose Mushin conducted serological studies on plant viruses (73). Stubbs & Grieve first recorded carrot motley dwarf in 1944 (100), and Stubbs studied its identification, epidemiology, virus vector relationships, and control in 1948 (101). Stubbs gradually expanded this work to include viruses of strawberry, citrus, grape, pasture, and cereals, while R. D. Anderson extended the work on virus diseases of potatoes. Stubbs & O'Loughlin (103) demonstrated climatic prevention of mosaic spread in lettuce seed crops in the Swan Hill region of the Murray Valley. Cooperative work with R. G. Grogan of the University of California resulted in the elucidation of the previously unrecognized lettuce necrotic yellow virus (104). Detailed studies of this virus, including its purification and characterization by Chambers, Crowley, Francki & O'Loughlin (16, 17, 77) have continued. Work on the strawberry virus complex by Stubbs, and subsequent provision of disease-free planting stocks of the

Victorian Department of Agriculture led to a spectacular increase of five- to tenfold in yield. He has also been concerned with the identification of citrus viruses, and their elimination by heat therapy. His work has involved inoculation with mild strains of the tristeza virus with a view to its protection against severe strains (102). Simmonds of Queensland was one of the first workers to thus use a mild strain against a plant virus-the passion-fruit woodiness virus (94a). Elimination of the viruses affecting fruit trees by heat therapy has been studied by Stubbs in Victoria, R. S. Greber in Queensland, and G. P. Johnstone in Tasmania. There is probably more work on virus diseases of fruit species in Australia than of other crops. Johnstone & Martin have shown that infection of apple with the green crinkle virus markedly reduces the performance compared with virus-free trees (51). Fraser demonstrated the virus nature of scaly butt of *Poncirus trifoliata* which limited the use of root stock, and the previously unrecorded diseases of citrus, seedling yellows, and woody gall (37, 38). Pares studied virus diseases of stone fruits (79, 81), and with Hutton investigated virus diseases of pome fruits (80). In 1957 Smith (98) reported the presence of barley yellow dwarf virus of cereals in Australia. R. H. Taylor worked with W. B. Hewitt of the University of California on grape viruses in 1962-63 and has continued work on serology, virus purification, and electronmicroscopy (105-107). Bacterial diseases.-Work on bacterial diseases of plants in Australia commenced with that of Cobb on the gumming disease of sugarcane in 1895 (20). North in 1926 (76) described and named leaf scald disease of sugarcane caused by *Xanthomonas albilineans*. In 1935 he published on gumming disease of sugarcane caused by *X. vasculorum*, and on its dissemination and control, mainly by using resistant varieties or healthy planting material. H. L. Jensen, who was appointed Macleay Biologist with the Linnean Society of New South Wales in 1929, found that the corynebacteria were a numerically important group of soil bacteria and were active in the decomposition of organic matter in the soil. In a study of saprophytic mycobacteria and corynebacteria, he placed the organisms causing bacterial canker of tomato and bacterial wilt of lucerne in the genus *Corynebacterium*. He also described strains of both *C. michiganense* and *C. insidiosum* isolated from soil under grass (50a,b). Cottrell-Dormer in 1932 described the causal organism of red-stripe disease of sugarcane, *Pseudomonas rubrilineans* (24). An epiphytic of halo blight of beans, caused by *Pseudomonas phaseolicola*, devastated the French bean seed-growing industry in Victoria in 1930-31 (4), severely damaging crops in New South Wales (115) and other states when infected seed was used. None of the seed treatments listed by Adam (4) was effective, and Pugsley demonstrated that the pathogen was under the third seed coat and in the cotyledon, which made effective seed treatment very difficult. The principal variety which was grown at that time was Canadian Wonder on which the bean-seed export had been built. This variety proved to be so susceptible to halo blight that it was no longer grown commercially. A strain of Canadian Wonder which was field-selected from a badly infected crop and had good field resistance was, unfortunately, inferior in its length of pod and other desirable horticultural characters. Varieties with field resistance, such as Richmond Wonder, Hawkesbury Wonder, and Windsor Long Pod, have been developed in New South Wales. Halo blight has also been kept under control by seed certification, a zero tolerance being enforced. Studies by Adam & Pugsley (2) showed colony variation, and phage reactions of the pathogen. They also (3) identified other bacterial diseases. In 1936 Pugsley first used serological techniques for identification of plant-bacterial pathogens in Australia. Wilson's demonstration (115) of improved means for detecting infected bean seed was the basis of the New South Wales bean-seed certification scheme. Grieve (40) studied the relationship of *Ps. solanacearum* to water in plants in 1941. Rose Mushin also published on the physiology of plant pathogenic bacteria in the same year. Harrison (43) reported an atypical strain of *Ps. solanacearum* producing symptoms somewhat similar to those recorded for the ring-rot bacterium, *Corynebacterium sepedonicum*, and Harrison & Freeman (44) found this strain to possess a common antigenic fraction with the ring-rot bacterium. The Victorian isolates proved to be identical with type 11 described by A. C. Hayward of the University of Queensland. *Erwinia atroseptica* has caused severe losses in Sebago and to a lesser extent in Sequoia potato varieties. According to Harrison, seed-piece decay and black leg have

accounted for a loss of up to 50% of some potato crops, particularly in low, poorly drained areas. Two important bacterial diseases have recently been identified in Australia. Lucerne bacterial wilt, caused by *Corynebacterium insidiosum*, was found (99) in Victoria, and a survey (52) showed it to cause early decline in lucerne stands. The Hunter River variety was very susceptible to bacterial wilt. Serology tests at the University of California showed the similarity of Victorian and United States isolates. Resistant American lucerne varieties have been introduced. Peach bacterial spot, caused by *Xanthomonas pruni*, was first recorded in New South Wales on plum in 1929, and on peaches in 1960. Infected peaches are unmarketable, severe defoliation may occur, and severe cankers form on the lateral branches. Other bacterial pathogens in Australia of economic importance include *Pseudomonas syringae*, *Corynebacterium michiganense*, *Xanthomonas juglandis*, *X. campestris*, and *X. plzaseoli*.

Nematode diseases.-After Cobb left Australia, plant pathologists without specialized training in nematology largely passed on information developed elsewhere for nematode control. W. Laidlaw was an early worker on onion rootworm. J. Davidson (29) first described the damage caused by *Heterodera avenae*, now regarded as of major importance in cereals in Victoria and South Australia. Millikan's experiments on the control of nematodes (69, 70) led to the discovery of zinc deficiency in cereals. The finding in 1943 by W. Carter in Hawaii that D-D was effective as a soil fumigant against nematodes stimulated studies on nematode control in Australia. Seinhorst was brought from Holland to report on nematode problems and to conduct a short school. Seinhorst & Sauer (93) indicated the existence in Australia of a nematode complex on grape vines. By 1955 the Departments of Agriculture of New South Wales and Queensland had appointed plant pathologists to specialize in nematology, and work also soon began in South and Western Australia. A Victorian pathologist went to Rothamsted to study in the Nematology Department. The CSIRO established a Section of Nematology in the Division of Horticultural Research in Adelaide. Specialized courses in nematology became available at the University of Sydney under C. D. Blake and at the University of Adelaide under J. M. Fisher. An extensive list of nematodes and their hosts recorded in Queensland (21) showed the range of crops attacked by nematodes apparently introduced into Australia. Recent papers by Meagher (65, 66), Colbran (22, 23), and Sauer have described several new plant-parasitic genera. Most of the new Australian nematodes have not been shown to attack cultivated crops (67). Much work is now in progress in nematology throughout Australia and an unpublished bibliography of Australian literature from 1890 to 1945 shows 104 references and from 1945 to 1969, 232 references.

Plant quarantines.-The outbreak of *Phylloxera* in Victoria in 1875, and subsequently in New South Wales and Queensland, demonstrated the need for an effective Plant Quarantine Service. Legislative action in 1877 limited the spread of this insect. Interstate conferences were held in 1884 and 1886 for the purpose of designing uniform legislation for a Quarantine Bill. This was based on part of the Public Health Statute of 1865 of Victoria, and the original basis can be traced in the form of the existing Quarantine Act of 1908 and 1969 (71). The Federal Quarantine Service was established in 1909 in the Department of Trade and Customs, but in 1921 it was placed in the Ministry of Health with the Director-General of Health as the Director of Quarantine. The Chief Officer administering the Plant Diseases Acts in each of the various states was also appointed as a Chief Plant Quarantine Officer (plants) under the Federal Law. The most important early action in relation to plant quarantine was instituted in 1916 when citrus canker *Pseudomonas citri*, was found in the Northern Territory. Gerald F. Hill (45) supervised the destruction of infected trees, and the disease was successfully eradicated. E. A. MacKinnon was appointed Director of Plant Quarantine in 1927. T. H. Harrison was appointed Assistant Director General of Health, Plant Quarantine, in 1947, and plant quarantine policy in Australia was consolidated, with the 1941 report of the Australian Institute of Agricultural Science as a guide. J. R. Morschel succeeded T. H. Harrison. That Australia is free from such major diseases and pests as citrus canker, fire blight of apples and pears, wart disease of potatoes, golden nematode, European corn borer, and Colorado potato beetle is a tribute to the plant quarantine service of this island continent.

CONCLUSIONS

The many accomplishments in plant pathology in Australia since the mid-nineteenth century were made possible by the sound foundations provided by the pioneers of the science. Today there are many well-organized groups of plant pathologists and a membership of about 200 in the Australian Plant Pathology Society. Some of the discoveries and developments have become landmarks in international phytopathology: the development of rust-resistant wheat varieties by W. J. Farrer after 1889 is one of the earliest examples of successful breeding for disease resistance. The use of fungicidal dusts for seed treatments by G. P. Darnell Smith in 1917 to control wheat smut became a standard control procedure throughout the world for this important disease. The use of a volatile eradicant fungicide (benzol) by H. R. Angell, A. V. Hill, and J. M. Allan in 1935 provided an effective control of downy mildew of tobacco, and added a new dimension to fungicidal studies. The discovery by H. A. Pittman in 1927 that *Thrips tabaci* could spread the spotted wilt virus revealed a new class of insect virus vectors. That the internationally important ratoon stunting disease of sugarcane was transmissible was first demonstrated by D. R. L. Steindl in 1949 in Queensland. His development in 1953, in cooperation with C. G. Hughes, of a successful heat treatment to free the setts of the virus provided the world standard control method for this destructive disease. M. F. Day was able in 1955 to successfully inject aphids with a virus for the first time, using potato leafroll. The importance of root exudates in determining the composition of the rhizosphere microflora was clearly shown in studies of A. D. Rovira and associates, beginning in 1956. These exudates play an important role in the ecology of microorganisms which infect roots, and in root growth itself. The phytoalexin concept introduced by K. O. Muller and H. Boger in 1940 was given firm support by the isolation and characterization of the first of these compounds by I. A. M. Cruickshank and D. R. Perrin in 1960. Subsequently three additional phytoalexins have been purified by this group. What is perhaps the first instance of the selective development under field conditions of resistance by a pathogen to a fungicide was demonstrated in 1965 by J. Kuiper for *Tilletia foetida* against hexachlorobenzene. The culturability of an "obligate" fungus parasite (*Puccinia graminis* f. sp. *Tritici*) was firmly established in 1966 by P. G. Williams, K. J. Scott, and L. J. Kuhl. Achievements such as these must surely be an inspiration for Australian plant pathologists of the future.

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