Fungicidal Control of Rice Diseases*

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INTRODUCTION

RICE is one of the world's most important cereal crops, and its protection from disease is vital to the many millions dependent on it as their staple food. In the pre-war period, diseases of rice were practically unimportant in Tropical Asia where ancient varieties were traditionally grown in soils of relatively low fertility. However, with the recent increasing demand for world rice supplies, there has been an awakening interest to maximize production using improved varieties, high fertilization and other intensive cultural practices. High cultural regimes, therefore, have led to a great increase in the occurrence and severity of diseases affecting rice in several countries, especially in Tropical Asia.

Rice is subject to several destructive diseases for the control of which dependence on host resistance alone has been found to be unreliable and disappointing. It thus seems that chemical control offers greater promise and will constitute an important weapon in reducing crop losses caused by rice diseases. This paper reviews the progress in the development of chemical control of the major rice diseases, namely, blast, sheath blight and bacterial leaf blight, and presents the current outlook on the use of chemicals to control diseases such as brown spot, stem rot and those incited by viruses.

1. RICE BLAST DISEASE

Rice blast caused by *Pyricularia oryzae* is responsible for spotting and blasting of the foliage and for blighting of the panicles. The disease is highly destructive under conditions of monsoon rainfall and high atmospheric humidity.

In the pre-war period, copper compounds, including basic copper silicate, basic copper sulphate, copper oxide, copper oxychloride and Bordeaux mixture were widely used for blast control. Among copper compounds, a differential efficacy of copper oxide and copper oxychloride against the rice blast fungus was

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demonstrated in Ceylon, but experiments in India showed that these compounds were equally effective in reducing panicle infection (1, 20). In more recent tests, low volume application of 0.25 per cent metallic copper has been found to give economic control of the disease in India (21). Copper compounds, nevertheless, give insufficient disease control under epidemic conditions and are phytotoxic to rice resulting in grain yield reduction (11)

The efficacy of organomercuric compounds as foliage fungicides for the control of blast disease was first recognized by Ogawa *et al* in Japan in 1950 (19). They demonstrated the effectiveness of a mixture of phenylmercuric acetate and slaked lime in controlling the disease on *japonica* rice. This discovery led to the commercial production and application of several organomercuric compounds for rice blast control during the past decade. The compounds extensively in use are listed in Table 1.

TABLE 1

Different Organomercuric Compounds Used for Blast Control

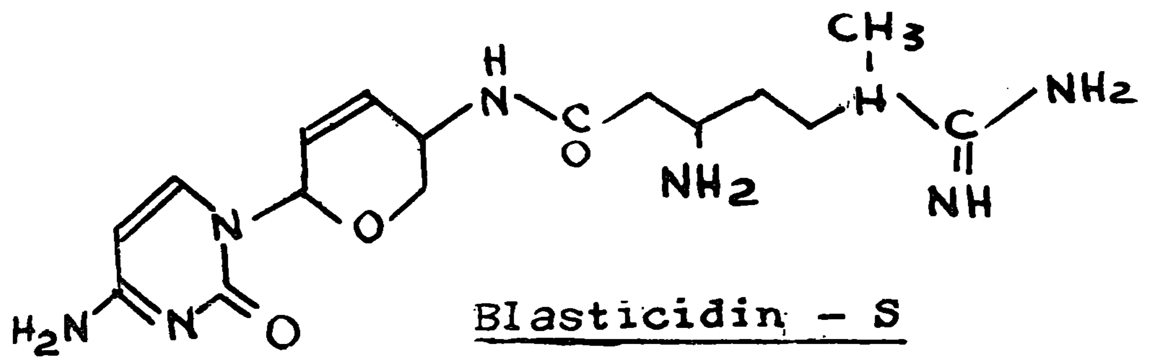
Chemical	*Application*
Phenylmercuric chloride	spray or dust
Phenylmercuric iodide	spray or dust
Phenylmercuric acetate	spray or dust
Phenylmercury-p-toluene sulphonanilide	spray or dust
Phenylmercuric dinaphthylmethane disulfonate	spray or dust
Phenylmercuric urea	spray or dust
Phenylmercuric mercaptobenzothiazole	spray or dust
Phenylmercuric triethanol ammonium acetate	spray
Ethylmercuric phosphate	spray or dust
Ethylmercury-p-toluene sulphonanilide	spray or dust
Ethylmercuric urea	spray or dust
Methoxyethylenemercuric chloride	spray or dust
p-Tolylmercuric chloride	spray or dust
p-Tolylmercury-p-toluene sulphonanilide	spray or dust
2-oxy-2-phenylmercuric oxyhexachloro diphylmethane	spray or dust

Organomercuric compounds are commercially produced as wettable powders, emulsifiable concentrates and dust formulations. Sprays containing 20 ppm. metallic mercury are effective, somewhat eradicative, and their fungicidal activity persist for a period of about two weeks (18). These compounds are known to react with glutathione and other SH—enzymes.

Investigations with organomercuric compounds in Ceylon revealed that phenylmercuric formulations such as phenylmercuric acetate and phenylmercuric-p-toluene sulphonanilide were highly phytotoxic to *indica* rice varieties, the damage reported varying from development of necrotic chocolate—brown spots to severe scorch of the foliage. Ethyl mercuric compounds, on the contrary, were non-phytotoxic and controlled the disease satisfactorily (14). In similar tests in India, organomercuric dusts were found to be phytotoxic whereas phenylmercuric sprays had no adverse effect on *indica* rice (20). Recently, however, the residual toxicity of mercury to man and livestock is widely recognized in Japan, and mercury accumulation in the human body has been attributed to the organomercuric sprays used for blast control. The use of mercuric sprays is now discouraged in Japan and will be prohibited by law in 1968 (16).

One of the most revolutionary developments in blast control is the discovery and commercial use of antibiotics. Yoshi, first reported the inhibitory effect of cephalothecin, a metabolic product of the fungus *Cephalothecium* sp., on the rice blast fungus (28). Several antibiotics, namely antiblastin, antimycin, blastmycin and blasticidin A. B. C. and D effective against the rice blast fungus were developed in rapid succession in Japan, but they were of little or no practical significance because of their chemical instability and high toxicity to fish.

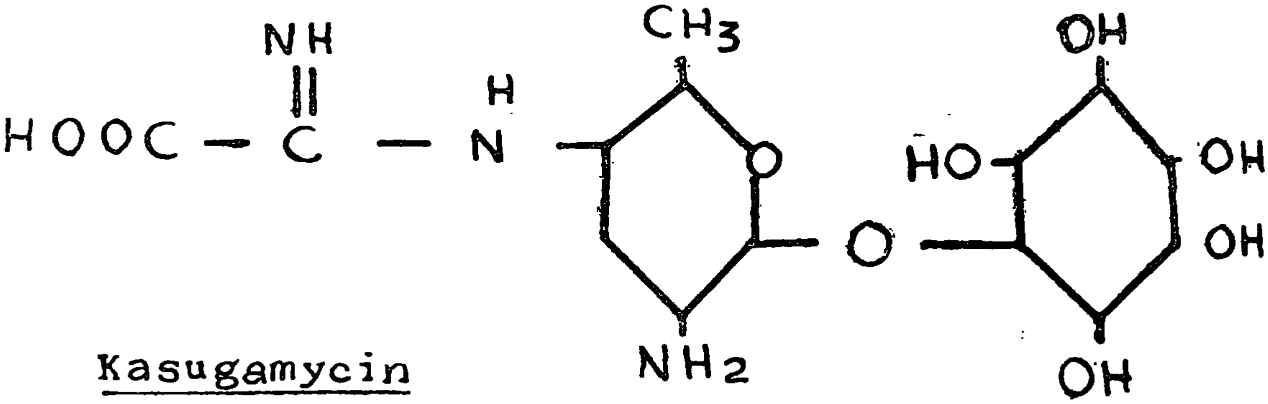
Blasticidin—S, a metabolic product of *Streptomyces griseochromogenes*, was the first antibiotic commercially introduced for blast control in Japan. It has a molecular formu'a of $C_{18} H_{24} O_5 N_8 H_{20}$ and is soluble in water and acetic acid. Its crystals are white, needle-shaped and melts at 235-236°C. Benzylaminobenzene sulfonate of blasticidin—S is insoluble in water and is in commercial use for blast control.



Blasticidin - S

Blasticidin—S is effective at 10-20 ppm. as a spray or 0.2-0.4 per cent as a dust. This antibiotic has excellant curative properties, but its protective action is shorter than that of organomercuric compounds suggesting its comparatively rapid decomposition on rice plants. High concentrations of blasticidin—S is phytotoxic, producing chlorotic or necrotic spots on the foliage of rice plants. It is also known to be hazardous to spray operators causing conjectivitis. The high efficiency of blasticidin—S is thought to be due to its strong inhibitory action on protein synthesis of the fungus (15).

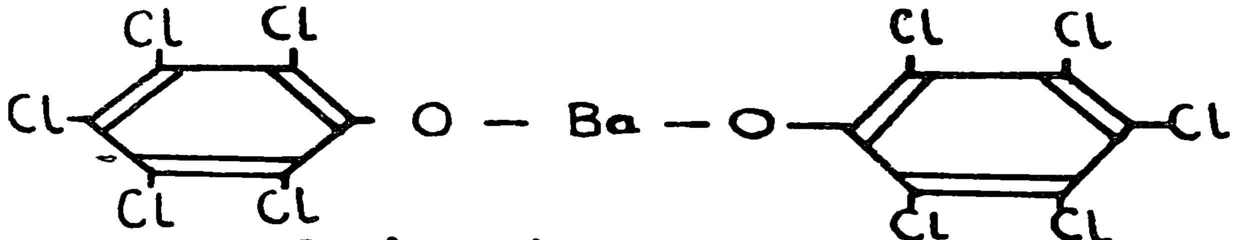
The second significant antibiotic introduced for blast control in Japan is Kasugamycin, a metabolic product of *Streptomyces kasugaensis*. Despite its low in *v tro* activity, it is known to give excellent control of the disease at relatively low concentrations of 20-40 ppm.



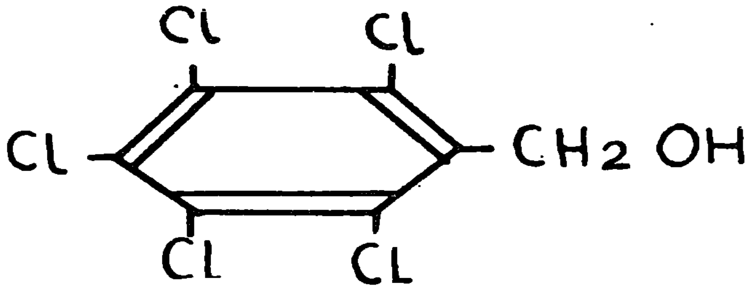
Kasugamycin

Recent investigations with Kasugamycin in Ceylon offer wider prospect in the use of this chemical for blast control on *indica* varieties (3). The efficacy of Kasugamycin is attributed to its inhibitory action on protein synthesis of the pathogen (27). Unlike most antibiotics developed for blast control, Kasugamycin conbines low mammalian toxicity with little or no phytotoxicity to both *indica* and *japonica* rice. However, the possible development of antibiotic resistant strains of the rice blast fungus by continued field application of Kasugamycin cannot be fully overlooked. In laboratory culture, for example, strains of *P. oryzae* tolerant of 100 ppm. of Kasugamycin are already recognized in Japan (16).

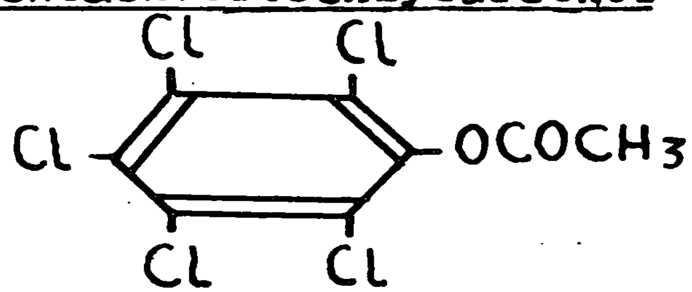
Besides antibiotics, two other groups of chemicals have been developed for blast control in the recent past. They are organochlorine and organophosphorus compounds. The former constitutes several derivatives of pentachlorophenol ; the chief among them are barium pentachlorophenolate, pentachlorophenyl acetate, pentachlorobenzyl alcohol and pentachloromandelonitrile. The first two compounds are phytotoxic and are also toxic to fish. In contrast, pentachlorobenzyl alcohol produced by combination of toluene and chlorine is known to give excellent control of the disease. This compound has no in *vitro* fungitoxicity, but has remarkable preventive action against the entry of the pathogen into the host plant. Plentachloromandelonitrile is also highly effective for blast control. Both these compounds are not phytotoxic and have low toxicity to mammals and fish (16).



Barium di-pentachlorophenolate

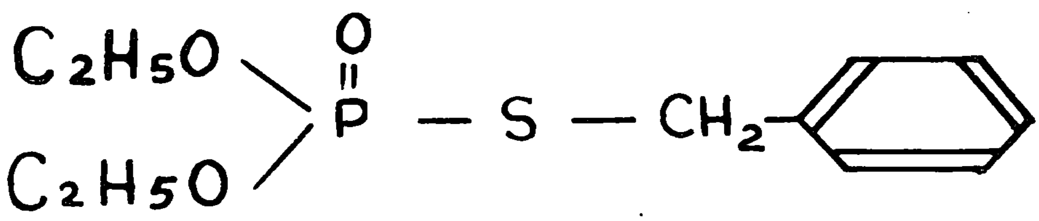


Pentachlorobenzylalcohol



Pentacholorophenyl acetate

Among the organophosphorus compounds introduced for blast control are O, O-diethyl-S-benzylthiophosphate, O-ethyl-S, S-diphenyl-dithiophosphate and O-methyl-O-cyclohexyl S-4 chlorophenyl thiosulphate. They are known to possess excellent curative action against blast, while also exerting certain insecticidal properties. These compounds, therefore, offer greater promise as broad spectrum pesticides in combined disease and pest control of rice. Some of these compounds are phytotoxic to *indica* rice and therefore require improvement and wider testing before they are commercially used for blast control.



O, O-diethyl-S-benzylthiophosphate

The active ingredients, recommended dosages and relative toxicity of the more recent chemicals introduced for blast control are given in Table 2.

TABLE 2

Effective Dosage and Toxicity of Compounds used in Blast Control

Compound	*Effective Dust %*	*Dosage Spray ppm.*	*Toxicity to Mice LD 50 mg/Kg*	*Toxicity to Fish Carp ppm.*
Antibiotics				
Blasticidin S	0·2	10-20	39·5	8·7
Kasugamycin	0·2	20-40	2,000	—
Organochlorine				
Barium pentachloro phenolate	2·5	—	847	—
Pentachloro phenyl acetate	3·0	300-500	5,000	8·6
Pentachloro benzyl alcohol	4·0	300-500	3,600	10
Pentachloro mandelonitrile	3·0	300-500	3,000	48
Organophosphorus				
O, O-diethyl-S-benzylthiophosphate	1·5	400-600	237	5
O-methyl O-cyclohexyl S-4-chloro-phenyl thio phosphate	3·0	400-500	72	72

Reports from several countries show the usefulness of dithiocarbamate fungicides in rice blast control. For example, zineb at 0.25 per cent sprayed once on seedbeds and twice on the transplanted crops has given efficient control of the disease in the United Arab Republic (5). Similarly, ferbam has shown high in *vitro* efficacy in Ceylon, but was only capable of controlling mild to moderate infection in the field (1). Its effectiveness has shown a sharp decline under epidemic conditions of the disease.

2. SHEATH BLIGHT

Sheath blight is caused by the soil inhabiting fungus *Pellicularia sasakii* and has assumed major importance in most rice-growing countries. The pathogen produces numerous sclerotia which constitute the chief survival organs between crops. The disease is usually evident at the tillering stage ; lesions are produced on leaf sheaths, at first greenish-grey in colour but, later become greyish-white with a distinct black margin. Infected leaf-sheaths wither causing severe yield reduction.

In Taiwan, organomercuric fungicides are reported to effectively reduce hyphal growth of *P. sasakii* in *vitro* but were distinctly inferior to organo-arsenic compounds in reducing the severity of field infection (12). High efficiency of organoarsenic compounds on sheath blight has also been demonstrated in several other countries (2,9,10). The compounds in commercial use include ferric methane arsonate, calcium methane arsonate, methyl arsine sulphide, methyl arsine bis-dimethyl dithiocarbamate. Sometimes, a mixture of organoarsenic compound and ziram or urbacid is used for disease control. Most organoarsenic compounds are phytotoxic when applied in excess and cause severe damage to rice leaves.

Recently, a polyoxin component derived from *Streptomyces* sp. has proved to be highly effective in sheath blight control (18). Unlike organoarsenic compounds, this antibiotic is not phytotoxic to rice. In greenhouse tests in Japan, halogenophenylpyrazolone and halogenophenylhydrazine derivative have controlled sheath blight satisfactorily (25). Significant control of the disease has also been obtained in Ceylon with dodecylguanidine and triphenyltin acetate sprays (2).

3. BACTERIAL LEAF BLIGHT

This disease, caused by *Xanthomonas oryzae*, has now gained widespread importance in Tropical Asia. It produces a wilt, also called 'kresek ', of the seedlings and blight of the foliage. The pathogen spreads rapidly through irrigation water.

In the past Bordeaux mixture or a combination of copper and mercury wers suggested for bacterial leaf blight control. During the last five years, howevere several antibiotics and synthetic compounds have been developed for disease control. The present-day practical antibiotics are streptomycin, deoxy, dihydrostreptomycin, streptocycline, chloramphenicol and cellocidin (26). Cellocidin (actylenedicarboxamide), a metabolic product of *Streptomyces chibaensis* is now produced synthetically and is fairly effective at 100 ppm. Higher concentrations are phytotoxic to rice.

Chloramphenicol at 60–120 ppm. gives promising control of bacterial leaf blight and is in commercial use in Japan in combination with organomercuric fungicides. Among the other antibiotics, streptocycline is recommended for the control of the disease in India.

Several synthetic bactericides effective against the bacterial leaf blight pathogen have been developed in recent years. They are nickel dimethyldithiocarbamate, dithianone, phenazine and phenazine-N-oxide. Of these nickel dimethyldithiocarbamate is effective at 1,000 to 1,600 ppm. ; it is stable on rice and is known to have a relatively long protective action. Dithianon, 2, 3 Dicyano-1, 4-dithia-anthraquinone is effective at 750–1,500 ppm. ; it is chemically stable and is not phytotoxic to rice. Better control of the disease is claimed recently with a combination of cellocidin and dithianon. Finally, phenazine and its N-oxide have shown a strong inhibitory effect on *X. oryzae* and have given promising control of the disease in greenhouse studies (23). The effective concentrations of phenazine and its N-oxide are 200 and 100 ppm. respectively. Fenitazon (3-benzylidene amino-4-phenylthiazoline-2-thione) is another chemical which has given effective control of bacterial leaf blight in recent field tests in Japan.

The antibiotics and organic compounds currently used for bacterial leaf blight control together with their effective dosages are tabulated in Table 3.

TABLE 3

Antibiotics and Organic Compounds Currently Used for Bacterial Leaf Blight Control

Chemical	*Effective Dose*
Antibiotics	
Cellocidin	100 ppm.
Chloramphenicol	60–120 ppm.
Organic Compounds	
Nickel dimethyldithiocarbamate	1,000–1,600 ppm.
Dithianone	750–1,500 ppm.
Phenazine	200 ppm.
Phenazine-N-oxide	100 ppm.

CHEMICAL CONTROL OF OTHER RICE DISEASES

Few practical developments exist for the chemical control of diseases such as Brown Spot (*Cochliobolus miyabeanus*), Stem Rot (*Helminthosporium sigmoideum*), Virus diseases (Stripe, Dwarf, Yellow Dwarf, Black Streaked Dwarf and Tungro) and the nematode disease, White Tip (*Aphelenchoides besseyi*). Their control, especially of those caused by viruses, presents an urgent problem in rice growing countries today.

Brown spot control has been achieved in India with copper fungicides or organomercuric dusts, while in British Guiana substantial control is reported with organomercuric sprays (8, 7). In Japan, the disease was reduced substantially with pentachlorophenol and pentachlorophenoxyacetic acid, but these chemicals were highly phytotoxic to rice (6). Systemic control of the disease in India is recently reported with sulphanilamide and griseofulvin ; these chemicals are, however, not in commercial use for brown spot control as yet (24). In Ceylon, field screening of a wide spectrum of commercial fungicides and antibiotics has given disappointing results (4).

Effective and commercially applicable chemicals for brown spot control are yet unavailable. The disease is consistently associated with unfavourable soil conditions and deficiency of plant nutrients, and is generally believed that soil amelioration and correction of nutrient deficiencies would result in profitable control of the disease.

Stem rot caused by the soil-inhabiting fungus *Helminthosporium sigmoideum* is a serious problem of rice in ill-drained soils of Tropical Asia. There had been no intensive work on the control of this disease chemically. It is claimed that organomercuric compounds used for blast control in Japan have simultaneously reduced the severity of stem rot (17).

Virus diseases of rice have become increasingly important throughout the rice-growing world in recent years. Except mosaic reported from the Philippines, they are all transmitted by a variety of leafhoppers and planthoppers and are controlled indirectly by eliminating the vector with insecticides. Several insecticides including benzene hexachloride, carbaryl, diazinon and disyston are widely used for vector control in certain countries (13).

Recently, chemicals capable of directly controlling virus diseases of rice have been investigated in Japan. Laurusin, blasticidin-S, actidione and triazine have established some anti-virus activity. They are, however, not sufficiently effective for commercial control of virus diseases (15).

USE OF CHEMICALS TO CONTROL SEED-BORNE DISEASES

The major rice diseases transmitted through the seed are blast, brown spot, Bakanae (*Gibberella fujikuroi*), bacterial leaf blight and white tip—the last named being caused by the nematode *Aphelenchoides besseyi.*

Copper fungicides were widely applied as seed dressings for the control of seed-borne fungus diseases. Copper is primarily direct in action against surface borne spores and is ineffective against dormant mycelium within the seed. It is also recognized to be phytotoxic to young rice seedlings. Organomercuric compounds, currently in practical use, proved more promising because of their eradicative activity and of their low phytotoxicity.

Control of seed-borne infection of bacterial leaf blight is claimed with copper, organomercuric compounds and antibiotics, or with combination of these chemicals. Similarly, control of seed-borne infection of white tip nematode disease has been obtained by treatment with insecticides ; highly effective control of the disease has been reported in Ceylon by treatment with dimethyl-2, 2, 2-Trichloro-1-hydroxethyl phosphonate.

DISCUSSION

Research in the development of fungicides for rice disease control has been focussed mainly during the last two decades. Copper which was widely used as a general purpose surface protectant on rice has been substituted with other chemicals due to its phytotoxicity, detrimental effect on grain yield and its inability to give sufficient control of diseases under epidemic conditions.

Search for chemicals for rice blast control—against which disease there had been the most dramatic development—has led to the discovery and commercial use of organomercuric, organochlorine and organophosphorus compounds and antibiotics. Among them, organomercuric compounds and antibiotics act as local systemics ; they combined excellent curative and eradicative properties. Recent recognition, however, of mercury accumulation in man and the development of antibiotic tolerant strains are two serious problems that confront their future use. Organochlorine and organophosphorus compounds, on the other hand, might serve wider purposes, possibly with less biological problems associated with their use. The latter group of chemicals while affording systemic activity, combines the possibility of dual control of blast and insect pests. For practical purposes, and under severe conditions of disease, there is a real need for more effective and stable chemicals that would act systemically against the fungus diseases, especially blast and sheath blight.

Antibiotics, namely cellocidin, chloramphenicol and streptocycline have been introduced recently for bacterial leaf blight control. Although encouraging results have been reported with these antibiotics on a restricted scale they require wider testing under more stringent circumstances, especially in the tropics. Besides their detrimental effects on the user and on the biological environment, they require more intensive scrutiny before they are widely recommended. Synthetic organic bactericides, therefore, offer wider scope in eliminating possible biological hazards associated with the use of antibiotics. Thus, it seems, there exists an urgent need for bactericides which will afford better control of bacterial leaf blight under epidemic conditions.

There had been no significant development in chemicals for the control of brown spot, stem rot and virus diseases. Although some control of these diseases have been obtained under experimental conditions, there is scarcely a single material in practical use.

REFERENCES

1. ABEYGUNAWARDENA, D. V. W. and PEIRIS, J. W. L. (1958). Studies on the fungicidal control of rice blast. (1) The fungistatic efficacy of certain organic and inorganic fungicides on *Piricularia oryzae*. *Indian Phytopath.* XI, 116-121.

2. ABEYGUNAWARDENA, D. V. W. and DE SILVA, E. M. B. (1964). Chemotherapeutic Investigations on Sheath Blight of Rice. *Trop. Agric.* CXX, 149-158.

3. ABEYGUNAWARDENA, D. V. W. (1966). A Century of Plant Disease Investigation in Ceylon. Proc. of the 22nd Annual Session (Part II) of the Ceylon Association for the Advancement of Science.

4. ABEYGUNAWARDENA, D. V. W. (1967). Conditions that favour *Helminthosporium* Leaf Spot disease and its Control in Ceylon. *Proc. Symp. on Tropical Agricultural Researches. Trop. Agric. Res. Series No. 1, Ministry of Agriculture and Forestry, Japan.*

5. ABO-EL-DAHAB, M. K. and MICHAIL, S. H. (1967). Studies on Rice Blast Disease in the United Arab Republic with special reference to its control. *Phytopath. Mediterranea.* 5 (2), 109–114.

6. AKAI, S. (1955). Chemotherapeutic application of some compounds to rice plants and the outbreak of Helminthosporium leafspot. *Shokubutsu Byogai Kenkyu* 5, 45–46.

7. ANONYMOUS (1959). *Annual Report of the Director of Agriculture.* British Guiana, 1959.

8. CHATTOPADHYAY, S. B. and CHAKRABARTI, N. K. (1961). Application of fungicides in the control of secondary airborne infection of *Helminthosporium oryzae.* Breda de Haan. *Indian Phytopath.* 14, 88–92.

9. CHU, V. and CHEN, Y. L. (1964). Control of Sheath Blight of Rice by 'K. C. I. 911'. *Acta Phytophylac sin* 3 (i) ; 1–14.

10. FUKUNAGA, K. (1966). Antibiotics and new fungicides for control of rice diseases. *Proc. Symposium on Plant Diseases in the Pacific.* XIth Pacific Science Congress, Tokyo, 170–180.

11. GOTO, K. *et al* (1955). Accumulation of starch around diseased spots. Div. Plant Breed and Cult. Tokai-Kinki *Agric. Expt. Sta. Bull.* 2, 41.

12. HASHIOKA, Y. (1961). Phytopharmacological studies on Rice Disease. VIII. Bioassay of the organic fungicidal substances for the Rice Sheath Spot fungus. Corticium sasakii. *Spec. Publ. Coll. Agri. Taiwan University* 10, 74–81.

13. ISHIKURA, H. (1967). Protection of paddy rice. *Agriculture, Asia.* 11, 31–42.

14. MARKS, G. C. and PEIRIS, J. W. L. (1959). Studies on the control of paddy blast caused by *Piricularia oryzae.* II. A technique of screening fungicides. *Trop. Agric.* CXV, 145–156.

15. MISATO, C. (1961). Blasticidin-S. *Japan Plant Protection Association, Tokyo,* 1–55.

16. MISATO, T. (1967). Fungicides for Rice Blast disease. *Japan. Agr. Res. Quart.* 1, 4, 11–14.

17. MIZUKAMI, T. (1967). Problems of some Rice Diseases in Japan. *Proc. Symp. on Trop. Agricultural Researches. Trop. Agric. Res-Series No. 1, Ministry of Agriculture andForestry, Japan.*

18. NAKAZAWA, M. (1959). Studies on the mechanism of the protective action of organomercuric fungicides, with special reference to their therapeutic action. *Aichi. Agr. Expt. Sta. Bull.* 15.

19. OGAWA, M. *et al* (1953). Studies on blast control by Ceresan lime. *Chugoku—Shikoku Agr. Res.* 3, 1–5.

20. PADMANABHAM, S. Y., GANGULY, D., CHANDWANI, G. H., VEERARAGHAVAN, J. and KRISHNAMURTHY, C. S. (1962). Control of blast disease of rice with fungicides. II. Further trials with copper, organo-sulphur and organo-mercurials. *Indian Phytopath.* XV. 28–36.

1. PADMANABHAN, S. Y. (1967). Blast disease of Rice. *PANS. Section B,* 62-67.

22. SASAKI, S. *et al* (1966). *Ann. Phytopath. Soc.* Japan. 32–99.

23. SEKIZAWA, Y. *et al.* (1965). *Annals Phytopath. Soc.* Japan, 32, 99.

24. SRIVASTAVA, S. N. S. (1966). The systemic control of Brown Spot disease of rice with sulphanilimide and griseofulivn. *Indian Phytopath.* 19, 272–275.

25. SUMINA, I. and KITAMURA, T. (1966). Controlling effect of halogenophenylpyrazolone and halogenophenylhydrazine derivatives on some plant diseases. *Ann. Phytopath. Soc.* Japan. 32, 175–180.

26. TAGAMI, Y. and YOSHIMURA, S. (1967). Forecasting and control of Bacterial Leaf Blight of Rice in Japan. *Proc. Symp. on Trop. Agric. Researches. Trop. Agric. Res. Series No. 1, Ministry of Agriculture and Forestry, Japan.*

27. TANAKA, N. *et al* (1965). *J. Antibiotics Series A. 18* ; 139–144.

28. YOSHI, K. (1949). Studies on *Cephalothecium* as a means of artificial immunization of agricultural crops. *Ann. Phytopathol. Soc.* Japan, 31 (3/4), 37–40.