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9. ABSTRACT
Soybean rust is one of the major constraints to growing soybeans in the tropics and some of the subtropics of the Eastern hemisphere. Because of the importance of the rust problem and the values to be gained by cooperative efforts, workers actively engaged in soybean rust research formally organized the International Working Group on Soybean Rust during the regional soybean conference. It was agreed that a systematic, coordianted research, training, and outreach program was urgently needed for many of the Asian and Oceanian countries where the disease limits soybean production. The purpose of this workshop was to discuss the state of knowledge of soybean rust and the biology of the causal agent, P. pachyrhizi, to devise a mechanism to coordinate research efforts, and to seek support for a comprehensive program. Reports are presented on soybean rust and the efforts to combat it through breeding, chemical and biological control or other methods. A bibliography of all known publications about soybean rust is included. The workshop contributes information on the global importance of soybean rust, its suspected geographical distribution, the estimated annual losses by country, and other economic factors. Other data also concerns the state of the art of existing knowledge, areas of research still required, methods of sharing knowledge and seed cultures, and the present resources now being contributed to the study of soybean rust. Countries and people with special expertise in the following areas are identified: pathogen identification, rust nursery, disease screening, host ranges, the environmental effects of seasonal climatic and meteorological factors, the disease resistance mechanism, development of fungicides, and crop management practices.

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Rust of Soybean

The Problem and Research Needs

Report of a Workshop sponsored by the Government of the Philippines, the International Soybean Program (INTSOY), the Asian Vegetable Research and Development Center (AVRDC), and the Philippine Council for Agriculture and Resources Research (PCARRD)

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RUST OF SOYBEAN--THE PROBLEM AND RESEARCH NEEDS

R. E. Ford and J. B. Sinclair, co-editors

Report of a Workshop Held in
Manila, the Philippines, February 28-March 4, 1977

Sponsored by the Government of the Philippines, the International Soybean Program (INTSOY), the Asian Vegetable Research and Development Center (AVRDC), and the Philippine Council for Agriculture and Resources Research (PCARR).

College of Agriculture
University of Illinois at Urbana-Champaign

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Cover: Drawings from original photographs of teliospores (left) and uredospores (right) of *Phakopsora pachyrhizi* (after K. R. Bromfield, U.S.D.A.).

CONTENTS

		Page
Foreword		v
Workshop Participants		x
Opening Remarks		1
Introductory Address	R. E. Ford	3
Welcoming Addresses		
INTSOY	William N. Thompson	5
AVRDC	James J. Riley	6
PCARR	Ramon V. Valmayor	8
The International Working Group on Soybean Rust and Its Proposed Soybean Rust Rating System	S. Shanmugasundaram	11
Soybean Rust - An Overview		15
Studies on the Biology of the Soybean Rust Fungus in the Philippines	Lina L. Ilag	16
Soybean Rust in the Western Hemisphere	James B. Sinclair	18
Soybean Rust in the Eastern Hemisphere	Charles Y. Yang	22
Soybean Rust and the Pathogen - Some Needed Research	K. R. Bromfield	34
Current Research Efforts		41
U.S. Research Effort	K. R. Bromfield	42
Soybean Rust in Australia	J. K. Kochman	44
Soybean Rust in Korea	B. J. Chung and C. S. Park	49
Soybean Rust in Taiwan	Kuo-lein Chan	51
Breeding for Resistance		53
Observations and Theories on Cultivar Resistance of Soybeans to Rust	R. M. Lantican	54
Resistance of Soybean to Rust in Australia	R. McLean and D. E. Byth	58
Breeding for Resistance to Soybean Rust in India	B. B. Singh and P. N. Thapliyal	62
Breeding for Soybean Rust Resistance in Indonesia	R. S. Sumarno and M. S. Sudjadi	66
International Rust Nursery	S. Shanmugasundaram	71
Reaction of Soybean Cultivars and Chemical Control of Soybean Rust in Indonesia	M. S. Sudjadi, M. Amir, and R. S. Sumarno	73
Control of Soybean Rust		79
Chemical Control of Soybean Rust in the Philippines	F. C. Quebral	81

CONTENTS (con't)

		Page
Control of Soybean Rust by Means Other Than Breeding for Resistance	James B. Sinclair	85
Closing Remarks	R. E. Ford	91
Literature Cited and Bibliography		97
Index		107

FOREWORD

Soybean rust, caused by Phakopsora pachyrhizi, is one of the major constraints to growing soybeans in the tropics and some of the subtropics of the Eastern hemisphere. It may be one of the reasons why soybean has not been established as a major crop in this part of the world. Realizing the importance of the rust problem and recognizing the values to be gained by cooperative efforts, workers actively engaged in soybean rust research formally organized the "International Working Group on Soybean Rust" (IWGSR) during the Regional Soybean Conference jointly organized by the International Soybean Program (INTSOY), the Asian Vegetable Research and Development Center (AVRDC), and the Government of Thailand, 23 to 27 February 1976. C. Y. Yang of AVRDC was elected as Chairperson; K. R. Bromfield, USDA, ARS, Frederick, Maryland, as Vice-Chairperson; and S. Shanmugasundaram of AVRDC as Secretary of this group.

It was agreed among those attending the Chiang Mai conference that a systematic, coordinated research, training and outreach program was urgently needed for many of the Asian and Oceanian countries where the disease limits soybean production. A year later the "Asia-Oceania Soybean Rust Workshop" was convened in Manila, the Philippines, 28 February through 4 March 1977, to organize such a program. The intent and purpose of the workshop were to discuss the state of knowledge of soybean rust and the biology of the causal agent, P. pachyrhizi, and to devise a mechanism to coordinate research efforts and to seek support of a comprehensive program.

The workshop was cosponsored by the Asian Vegetable Research and Development Center (AVRDC), the Philippine Council for Agriculture and Resources Research (PCARR), and INTSOY. More than 30 participants from Australia, India, Indonesia, Korea, the Philippines, Taiwan, Thailand and the United States attended. Representatives of these countries presented status reports on soybean rust and the efforts to combat it through breeding, chemical and biological control or other methods.

The first day of the meetings consisted of formal reports from the delegates providing an update on soybean rust and rust research in their respective countries. The next four days consisted of a one-day field trip to study agricultural production in the Philippines and three days in working sessions. The presentations made during the first day of these meetings make up the bulk of this publication.

Soybean rust and its economic impact on soybean production have become of increasing concern to plant pathologists throughout the soybean-growing world. The causal fungus, long thought restricted to the eastern hemisphere, was reported under a variety of synonyms on hosts other than soybeans in Puerto Rico as early as 1913 and on soybeans grown in Georgia in 1922 (unconfirmed). These reports were not appreciated until the summer, 1976, when N. G. Vakili (U.S. Department of Agriculture, Agricultural Research Service, Mayaguez Institute of Tropical Agriculture) found P. pachyrhizi on soybeans in experimental field plots in Puerto Rico. After the rediscovery of this disease in Puerto Rico, the USDA and the University of Puerto Rico, Mayaguez Campus, sponsored the "Workshop on Rust on Soybeans in the Western Hemisphere" at the USDA, ARS Mayaguez Institute of Tropical Agriculture on 15 to 17 November 1976.

INTSOY was prompted to publish information presented in Manila in the INTSOY Series because of the obvious importance of the disease to soybean production throughout the world, the ground swell of requests for information, the interest of workshop participants, and the satisfaction of the INTSOY administration with the outcome of this workshop.

These papers and discussions have been edited and a bibliography of all known publications concerning soybean rust has been included. Some papers invited, but not presented at the workshop for unavoidable reasons, have been included. The draft manuscripts of the working papers and some of the details of the workshop have been collated, mimeographed, and distributed in the Philippines by PCARR as a record of the activities. However, this document will be distributed world-wide, available through many libraries and should be cited as the official source of information resulting from the Asia-Oceania Soybean Rust Workshop.

The sponsors wish to thank all who attended and participated in the workshop. AVRDC, PCARR and INTSOY deeply appreciate the support and hard work of the many persons in the Philippines whose arrangements and hospitality made the visit of all participants and guests such a pleasure. It was resolved at the workshop that: "F. Quebral and his local arrangements committee have done an excellent job; R. Valmayor and PCARR associates hosted us in a kingly and queenly fashion; the PCARR Secretariat provided invaluable services allowing a smooth flow of ideas and work which made our job unusually trouble free; each delegate provided outstanding service during this week; AVRDC be commended for their help and support; and that 'the beautiful brown people' of the Philippines who are so open, friendly, unpretentious, and so sensitive to our needs be praised and thanked."

The sponsors are deeply indebted to the PCARR Secretariat led by Virginia Luis and Mila Barradas; to Arleah Dix, Sheila Welch, and Vicki Toews, Department of Plant Pathology, University of Illinois, who typed manuscript drafts; to Sandie Osterbur who did the final typing; and to Barry J. Shortt for compiling the bibliography.

AVRDC, PCARR, the Government of the Philippines and INTSOY are proud to have been associated with this effort. The editors hope that this publication will stimulate further study, understanding, research and eventual control of soybean rust.

R. E. Ford and J. B. Sinclair, co-editors

Urbana, November 1977

WORKSHOP PARTICIPANTS

Country	Name and Title	Organization
AUSTRALIA	Joseph K. Kochman Plant Pathologist	Department of Primary Industries P.O. Box 102 Toowoomba 4350, Queensland
INDIA	Bir B. Singh Soybean Breeder	Department of Plant Breeding G.B. Pant University of Agriculture and Technology Pantnagar, District Nainital
	Poorna N. Thapliyal Associate Professor	Department of Plant Pathology G.B. Pant University of Agriculture and Technology Pantnagar, District Nainital
INDONESIA	Mas Sudjadi Associate Plant Pathologist	Department of Agriculture Central Research Institute for Agriculture Jl. Merdeka 99, Bogor
KOREA	Bong Jo Chung Chief	Department of Plant Pathology Institute of Agricultural Science Office of Rural Development Suweon, 170
	Chang Seuk Park Junior Researcher	Department of Plant Pathology Institute of Agricultural Science Office of Rural Development Suweon, 170
PHILIPPINES	Federico B. Ballon Chief, Horticulture Section	Bureau of Plant Industry San Andres, Manila
	Isidro A. Domingo Assistant Dir. for Res.	La Granja Agricultural Research Center Bureau of Plant Industry La Carlota City, Negros Occidental
	Nonito Franje Instructor I	Central Mindanao University Musuan, Bukidnon
	John Hubbell Resident Scientist	AVRDC-POP Bureau of Plant Industry Economic Garden Los Baños, Laguna
	Lina L. Ilag Associate Professor	Department of Plant Pathology University of the Philippines at Los Baños College, Laguna
	Ricardo M. Lantican Professor	Department of Agronomy University of the Philippines at Los Baños College, Laguna

Country	Name and Title	Organization
cont. PHILIPPINES	Benjamin B. Legaspi Senior Plant Pathologist	Bureau of Plant Industry Economic Garden Los Baños, Laguna
	Victoria Marfil Research Assistant	Department of Plant Pathology University of the Philippines at Los Baños College, Laguna
	Guia R. Minquez Agricultural Economist	National Food and Agriculture Council Diliman, Quezon City
	William McCluskey Agriculture Advisor Res., Chief, Agric. Res. Div.	U.S. Agency for International Development 1680 Roxas Blvd., Manila
	Eduvigis Pantastico Director	Crops Research Division Philippine Council for Agriculture and Resources Research University of the Philippines at Los Baños College, Laguna
	Amado Piamonte Research Assistant	Department of Plant Pathology University of the Philippines at Los Baños College, Laguna
	Florendo C. Quebral Team Leader/Professor	National Legume Research Commodity Team Department of Plant Pathology University of the Philippines at Los Baños College, Laguna
	Edgardo Quisumbing Deputy Executive Director	National Food and Agriculture Council Diliman, Quezon City
	Ibarra Santos Nuclear Research Superv.	Atomic Research Center Philippine Atomic Energy Commission Diliman, Quezon City
	Jose Soria Associate Professor II	Mindanao Institute of Technology Kabacan, North Cotabato
	Ramon V. Valmayor Deputy Director General for Programs and Operat.	Philippine Council for Agriculture and Resources Research Los Baños, Laguna
TAIWAN	Robert Cowell Communication Specialist	Asian Vegetable Research and Development Center (AVRDC) P.O. Box 42 Shanhua, Tainan, 741
	James J. Riley Assoc. Director (Res.)	AVRDC
	Subramaniam Shanmugasundaram Scientific Associate and Soybean Crop Coordinator	AVRDC

Country	Name and Title	Organization
cont.		
TAIWAN	Charles Y. Yang Plant Pathologist and Legume Program Leader	AVRDC
THAILAND	Arwooth NaLampang Head	Oil Crop Branch Department of Agriculture Bangken, Bangkok 9
	Udom Pupipat Assistant Professor	Department of Plant Pathology Kasetsart University Bangkok 9
UNITED STATES	Kenneth R. Bromfield Plant Pathologist	Plant Disease Research Laboratory ARS-USDA Frederick, MD 21701
	Richard E. Ford Head	Department of Plant Pathology University of Illinois Urbana, IL 61801
	Robert C. Leffel Staff Officer	USDA, ARS, National Program Staff Plant and Entomological Science Beltsville, MD 20705
	James B. Sinclair Professor	Department of Plant Pathology and International Soybean Program (INTSOY) University of Illinois Urbana, IL 61801

Invited but unable to attend

	Kuo-lein Chan Assistant Plant Breeder	Taiwan Agricultural Research Institute Section 4, Roosevelt Rd. Taipei, Taiwan
	Dorothy Shaw Chief	Plant Pathology Department of Agriculture Konedabu Papua, New Guinea
	W. N. Thompson Director	International Soybean Program (INTSOY) University of Illinois Urbana, IL 61801

ASIA-OCEANIA Soybean Rust Workshop participants and observers. Seated left to right; R. Lantican, T. Flores, G. Minguez, R. Valmayor, R. Ford, F. Quebral, Mrs. C. Yang, L. Ilag. Standing left to right; M. Sudjadi, R. Cowell, B. Legaspi, I. Domingo, B. Singh, P. Thapliyal, F. Ballon, J. Kochman, K. Bromfield, J. Soria, R. Leffel, V. Luis, J. Sinclair, B. Chung, C. Yang, A. NaLampang, S. Shanmugasundaram, C. Park, U. Pupipat, M. Barradas.

OPENING REMARKS

A. Introductory Address - R. E. Ford

B. Welcoming Addresses:

William N. Thompson

James J. Riley

Ramon V. Valmayor

INTRODUCTORY ADDRESS

R. E. Ford

Many scientists around the world have been working on soybean rust and did not know each other or have access to data and information about soybean rust from other countries. This is partly the fault of our scientific publication and communication system which tends to be slow and selective depending upon how peer reviewers perceive the importance of a disease. Yet judgments are passed on manuscripts which finally may or may not be published. In-country research data are often accumulated and placed in a file, or on occasion they are analyzed and distributed to local colleagues, some of them not working on this disease. Even less often, data are distributed to other experiment stations in the country and, finally even less often, they are sent to workers in other countries.

The 1976 INTSOY Conference in Chiang Mai, Thailand changed all of that. Soybean rust was a key topic of a symposium and discussion. Both before and after that symposium interested scientists, primarily plant pathologists and plant breeders, gathered together in a bond of common interest asking how to control soybean rust. Out of these two meetings was born the International Working Group on Soybean Rust. Because there had been some precedent set for such other working groups, e.g., the International Legume Virus Workers Group, the suggestion was readily accepted that this group organize informally, that officers be elected, and a communication system be devised either by a newsletter or other means, and that an attempt be made to meet again in the near future. At that point, little was known about when or where this group might be together again. Of course, the expenses of travel pose severe limitations. It was suggested that when other conferences or congresses such as that in Chiang Mai were held the group could gather a few of its scientists to discuss progress since the last meeting.

Fortunately, soybeans have attracted enough international attention because of their importance as a protein food source, that it was deemed nearly mandatory by INTSOY that soybean rust be the subject of its first in-depth workshop to develop guidelines and plans for future research. Even as I write these comments anticipating my trip to the Philippines to work with a group of mycologists, plant pathologists and plant breeders, I cannot quite visualize where this will take us next. To be sure it will not end with this meeting.

The agriculturally developed nations recognize the need to aid agriculturally underdeveloped nations in producing more food either directly or by increased knowledge and technology on the home fronts where food is in short supply. That soybean rust limits yield is recognized by many people other than pathologists and breeders. The results of this conference will at least keep us better informed of the current research technology, the progress that has been made and the job ahead. With the proper organization of research efforts, it is even possible that we can obtain funds to assist each of the participants here, and countries not represented here but, who are in need of research support to accelerate this very vital research area.

The Asian Vegetable Research and Development Center (AVRDC) already has a "rust resistant nursery" that some of you know about or with which you have been involved directly. One of the decisions that might be made here is the need for additional rust nurseries located elsewhere. How do we select the locations, how will they be organized, and how will they be staffed and managed? The deliberations of this select group of scientists will be looked upon and honored as a key to this and other research priority areas. Therefore, we come to this workshop/seminar with a most serious problem to be solved, with the interest of the people of the world at heart, and with the realization that most of our decisions will be momentous.

INTSOY planned and conducted three regional conferences covering the globe (Puerto Rico in 1974, Ethiopia in 1974, and Thailand in 1976) with the intent of stimulating interest and awareness in soybean production. In addition a prime concern is to update all scientists on the state of the art of soybean research. Partly as a result of the awareness created by these conferences, the USDA moved very quickly after discovering P. pachyrhizi in Puerto Rico late in the summer of 1976 to assess its potential danger to the western hemisphere. The USDA, with the cooperation of INTSOY, held a workshop there in November 1976, reviewed all aspects of the disease, conducted extensive field trips, then appraised the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture of recommendations for quarantine measures.

Our task at this workshop/seminar is ominous. Millions of people in this world rely on the judgments of the twenty privileged scientists in this room.

WELCOMING ADDRESS

William N. Thompson
International Soybean Program (INTSOY)

It is my privilege to welcome, in absentia, those participating in this first International Soybean Rust Workshop/Seminar. My absence reflects the nature of this workshop, not a lack of interest in or appreciation for the importance of the topic under consideration during this week.

This is a workshop of scientists carefully chosen for your expertise on soybean rust. I do not qualify. You also were chosen because of continuing interest in doing something, yes and a great deal more, about this disease and the problems associated with it. We of INTSOY, and I personally, do meet this criterion. With our mission in INTSOY of expanding production and use of soybeans, soybean rust has been singled out as the most important topic for intensive study and development of priorities and strategies for the present and future.

This is not "just another international conference." It is a workshop with specific objectives to be reached by Friday. You know of these objectives and will hear more this morning from those who have taken the leadership in the International Working Group on Soybean Rust that was formed as a result of the 1976 Chiang Mai Conference a year ago in which several of you participated. The willingness of you, your organization, and your country to contribute your time and talents is greatly appreciated.

INTSOY is pleased to join with the Philippine Council for Agriculture and Resources Research, the University of the Philippines, Los Baños, and the Asian Vegetable Research and Development Center in sponsoring this Workshop. Our special thanks are expressed to our hosts and to the United States Agency for International Development for most of the financial assistance that is making this Workshop possible. My personal thanks are due R. E. Ford for his many efforts in planning this Workshop and for welcoming you on behalf of INTSOY.

In closing, I wish you well for the week and anticipate the results of your deliberations. These will point the way to solution of a problem that is of vital interest to both present and future soybean farmers throughout the world.

WELCOMING ADDRESS

James J. Riley
Asian Vegetable Research and Development Center (AVRDC)

I bring greetings and best wishes for a successful conference from the Director of the Asian Vegetable Research and Development Center (AVRDC). We are pleased so many scientists have been able to attend - thanks to support by INTSOY and the valuable contributions of so many Philippine organizations, especially the Philippine Council for Agriculture and Resources Research (PCARR), who made the excellent local arrangements; the University of the Philippines at Los Baños (UPLB), and the Bureau of Plant Industry (BPI). Many thanks to PCARR Director General, Joseph C. Madamba and Ramon V. Valmayor, Deputy Director General of PCARR; UPLB Chancellor, Abelardo G. Samonte; Dean Cledualdo C. Perez of the UPLB College of Agriculture; and BPI Director Domingo Panganiban. We are grateful to Secretary of Agriculture, Arturo R. Tanco, for his assistance and encouragement. The imaginative agricultural development program created under his direction is one which any country would be proud to emulate.

It is, I believe, appropriate that this conference convene exactly one year after the conference on "Expanding the Use of Soybean in Asia and Oceania" adjourned in Chiang Mai, Thailand. For it was during that meeting that the International Working Group on Soybean Rust was formed.

Today we shall begin to learn what new developments have occurred in the past year. It is obvious NOW that soybean rust is the single most important disease threatening world soybean production. Once limited to Asia, its occurrence on soybean was rediscovered in the western hemisphere in 1976. This discovery prompted the assembling of world experts in Puerto Rico only 2 months ago, at the "Soybean Rust in the Western Hemisphere Conference."

I believe AVRDC pathologists were the first to recognize the magnitude of the vulnerability of tropical soybean production to the Phakopsora pachyrhizi pathogen. In our first Annual Report in which research results from 1972 and 1973 were presented we stated: "Observations made on Taiwan and elsewhere in Southeast Asia indicate that the most serious disease of soybean is rust." That year nearly 3,000 entries of AVRDC's world soybean collection were screened at the Center and in Pingtung, Taiwan. All were susceptible to some degree.

In our 1974 Annual Report we stated: "Soybean rust is the most serious soybean disease in Asia and Australia and can be regarded as a threat to other soybean production regions." That year AVRDC intensified pathological and breeding studies on this disease and established a nursery to provide a year-around source of inoculum. The cultivars P.I. 200492, P.I. 200451, TK5, KS3, CH1 and CH3, previously reported to be resistant were found susceptible. Weekly records of ambient spore concentration were also initiated. Yield loss was found to range as high as 50 percent. Over 4,000 cultivars from the world collection were screened at AVRDC in 1974 and the first differential response to races was noted. Some hope of finding resistance appeared as several F_3 generation breeding lines were rated as field resistant.

In 1975, nine cultivars out of over 1,000 screened showed moderate resistance to the soybean rust pathogen. I believe I am correct in saying that only two of them were still rated moderate in 1976. These lines already have been used as parental materials in the AVRDC hybridization program and F_2 progenies are being evaluated in the field.

The 1976 Chiang Mai soybean conference was a milestone for soybean research and development. More than 200 delegates from 19 countries met and a truly international cooperative program for soybean improvement in the tropics was initiated.

This meeting is evidence of the further development of the international cooperative approach to soybean research. We meet to form a comprehensive program to mount an all-out assault on soybean rust. The proposal emanating from this conference will bind together the international program efforts of INTSOY and AVRDC, with those of the USDA, PCARR and other national programs into a single coordinated worldwide effort. The effectiveness of this joint program will depend upon the vigor with which the delegates of this conference apply themselves to this important task.

After departing we must all continue to work together. AVRDC will do its utmost to advance the proposal, and I am certain that INTSOY Director Thompson will pledge INTSOY to do likewise. I recommend that a steering committee should be formed to insure continued post conference progress. I would like to nominate R. E. Ford to chair the steering committee and provide it the same leadership he has so ably demonstrated he is capable of in coordinating the assembling of this conference.

The challenge to the delegates of this conference is clear. I believe you are capable of meeting it and I trust you will.

WELCOMING ADDRESS

Ramon V. Valmayor
Philippine Council for Agriculture and Resources Research (PCARR)

Distinguished Participants to the Asia-Oceania Soybean Rust Workshop/Seminar, Honorable Guests, Ladies and Gentlemen.

It is my distinct pleasure to welcome, on behalf of the Philippine Council for Agriculture and Resources Research (PCARR), all the international delegates and Filipino participants and guests to the Soybean Rust Workshop/Seminar. PCARR is happy to co-sponsor a workshop, the output of which, could lead to the solution of an important problem in the production of soybeans in Asia and Oceania.

Soybeans are an important ingredient of the poultry and livestock feed industries of the Philippines. Large quantities are imported yearly contributing to the depletion of precious foreign exchange. To encourage local production, the Philippine government has included soybeans in the national food campaign program. Assistance to soybean farmers comes in the form of easy-term, non-collateral, supervised credit. This scheme offers the farmers opportunity to supply all the production inputs including improved seed, adequate fertilizers and the necessary pesticides. During the last three years, soybean production increased considerably but productivity remained low. One problem is soybean rust.

Our researchers have been engaged in research projects aimed at solving this particular problem. The research workers of our neighboring countries in Asia have done the same. But success has defied us. Perhaps our soybean breeders were constrained to work with limited germplasm resources. Inadequate funding is no doubt a major problem to many of us. But pooling our resources together will enhance the opportunity to succeed. I look forward to a concerted multinational effort in solving the soybean rust problem.

This workshop/seminar is action oriented. PCARR solicited the participation of the private sector and junior researchers with the hope of acquiring part of their renowned efficiency, pragmatism and candor. We would like to see their ideas imprinted along with the suggestions of the leading soybean rust researchers of the world assembled here this morning. We look forward to a stimulating and fruitful workshop.

Once again, allow me to extend a warm Filipino welcome to all of you. Mabuhay!

THE INTERNATIONAL WORKING GROUP ON SOYBEAN RUST AND ITS PROPOSED SOYBEAN RUST RATING SYSTEM

S. Shanmugasundaram

THE INTERNATIONAL WORKING GROUP ON SOYBEAN RUST AND ITS PROPOSED SOYBEAN RUST RATING SYSTEM

S. Shanmugasundaram

The officers of the International Working Group on Soybean Rust are: Chairman C. Y. Yang (AVRDC), Vice Chairman K. R. Bromfield (USDA-ARS) and Secretary S. Shanmugasundaram (AVRDC).

Soybean Rust Newsletter

The first issue of the "Soybean Rust News" (SRN) is in preparation. The success of SRN depends entirely upon your interest, enthusiasm, and participation. Research articles, reports, notes, announcement of resistant or tolerant germplasm, and any other news item related to soybean rust are requested, and they will be accepted until April 1, 1977. Address all correspondence regarding the SRN to:

S. Shanmugasundaram
Soybean Coordinator
Soybean Rust News
AVRDC, P.O. Box 42
Shanhua, Tainan 741
Taiwan, R.O.C.

RULES FOR CONTRIBUTORS

1. Information in the SRN will be informal to stimulate the exchange of ideas and information among soybean rust scientists. SRN articles may be preliminary in nature and speculative in content, and should not be regarded as equivalent to papers published in formal scientific journals. Even so, such reports can be very valuable and helpful, if viewed in the proper perspective. Data presented in the SRN are not to be used in other publications without the consent of the respective authors.

2. Contributions should be in English, typed double spaced and not more than 8½" by 11" pages. You may send as many separate contributions as you wish. Send two copies for each article.

3. Correspondence regarding an article should be on a separate page.

4. Photographs should be glossy black/white prints of high quality with good dark and light contrasts. Drawings for graphs and charts should be prepared with India ink on good quality tracing paper. Typewritten matter is not usually acceptable on graphs and charts. A good size for photographs is 5" by 7" and for drawings is what will fit on a 8½" by 11" page.

5. Except for possible minor editing, manuscripts will be published as received from contributors.

6. Title your report, place your name(s), name of university, institution or

company under the title. Please give complete address. (For contributors outside Taiwan (R.O.C.), please send reports by airmail.)

.. Citations of recent publications are most welcome.

Soybean Rust Rating System

In order to standarize soybean rust evaluation, a rating system containing a three-digit scientific notation was adopted by the International Working Group on Soybean Rust at the 1976 Chiang Mai conference. It will be used universally to rate infections observed both in the field and in the greenhouse by soybean researchers. When examining for rust infections, one should proceed in the following sequence: 1) examine the entire above-ground soybean plant, from bottom to top; 2) if rust lesions are found, record their locations and examine their intensity; and 3) carefully distinguish the type of pustules of the rust lesion with a 20x hand lens. The rating notation is explained as follows:

A) First digit - denotes examined leaf position of the soybean plant

1 - bottom third soybean leaves measured from ground level
2 - middle third soybean leaves measured from ground level
3 - upper third soybean leaves measured from ground level

B) Second digit - denotes the density of rust lesions on the examined leaves (see attached figure).

1 - no lesion
2 - light lesion density
3 - medium lesion
4 - heavy lesion density

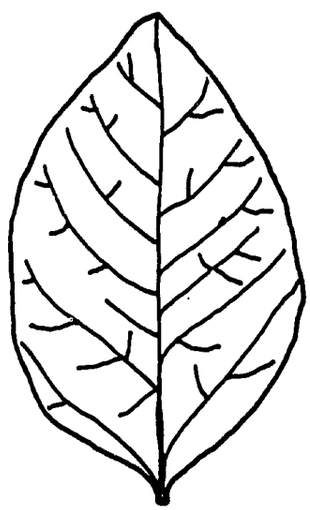
C) Third digit - denotes the reaction to rust

1 - no pustules
2 - non-sporulating pustules
3 - sporulating pustules

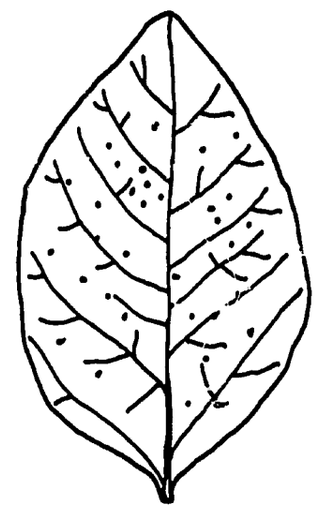
Examples:

A) 323 - upper third leaves infected with a few sporulating rust pustules
B) 143 - bottom third leaves heavily covered with sporulating rust pustules
C) 111 - bottom third leaves show neither rust lesions nor rust pustules
D) 311 - upper third leaves show neither rust lesions nor rust pustules

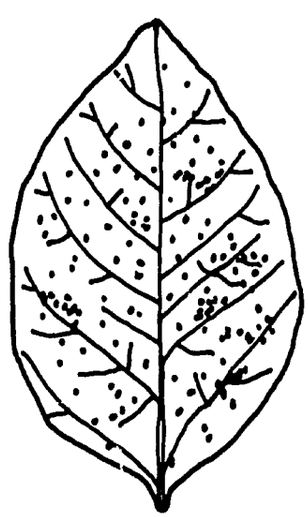
Figure 1. Assessment Key for Estimating the Density of Rust Lesions on Soybean Leaves Infected by *Phakopsora pachyrhizi*



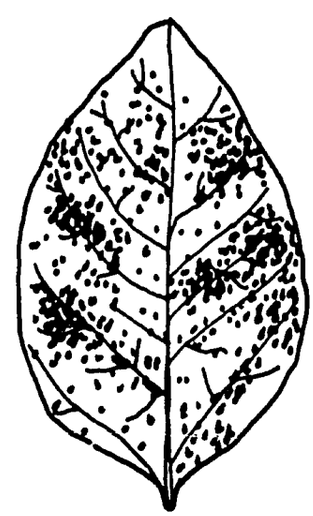
1. No Lesion



2. Light



3. Medium



4. Heavy

SOYBEAN RUST: AN OVERVIEW

Studies on the Biology of the Soybean Rust Fungus in the Philippines - Lina L. Ilag

Soybean Rust in the Western Hemisphere - James B. Sinclair

Soybean Rust in the Eastern Hemisphere - Charles Y. Yang

Soybean Rust and the Pathogen - Some Needed Research - K. R. Bromfield

STUDIES ON THE BIOLOGY OF THE SOYBEAN RUST FUNGUS IN THE PHILIPPINES

Lina L. Ilag

Rust is the nemesis of soybean in this part of the world. It occurs not only in Southeast Asia but also in Australia, China, India, Indochina, Japan and Korea (95). The rust pathogen was recently reported in the Caribbean and in Eastern Africa (unconfirmed) (12).

Its occurrence in the Philippines was first noted by Baker in 1914 (14). However, the disease was literally forgotten for the next 50 years. It was not until the mid-1960's that rust once again caught the attention of Filipino scientists. This long delay is unfortunate because the disease reduces bean yield in the country by 30 to 80 percent (7). The disease is most severe during the dry, cool months of October through March.

Studies on soybean rust in the Philippines have centered on cultivar screening for resistance and on chemical control. Documented biological studies on the disease and its causal organism in the Philippines are practically nil.

This paper will summarize the results of our studies on soybean rust at the University of the Philippines at Los Baños during 1976-77. I also will mention some research areas that deserve investigation.

We studied the effect of temperature and photoperiod on germination and germ tube elongation of P. pachyrhizi uredospores. Freshly harvested spores from diseased leaves were plated on 1.5 percent water agar and stored at 0, 5, 10, 15, 20, 25, 30 and 35°C. The plates at 20 and 30°C were incubated under four different light periods: continuous light for 24 to 48 hours, continuous darkness, 15-hour light followed by 9-hour darkness, and 15-hour darkness followed by 9-hour light. Plates at the other temperatures were kept in continuous darkness. Some spores on water agar were kept under room conditions 13-hour darkness, 11-hour light at 23 to 30°C.

Germination percentages and germ tube lengths under each of the above conditions were determined after 24 to 48 hours. No germination occurred at 0°C. Normal germination was observed from 10 to 30°C. Short germ tubes emerged from uredospores incubated between 5 and 35°C but these did not attain normal length even after 48 hours. High germination rates and long germ tubes were noted in uredospores kept at temperatures between 15 to 30°C. The various light periods did not appreciably affect the percentage germination of uredospores kept at 20 to 30°C. However, after 48 hours incubation, germ tubes were shortest (380 microns) under continuous light or continuous darkness at 30°C, and were longest (950 microns) when exposed to 15-hour darkness and 9-hour light at 20°C.

The problem of pathogen survival also intrigued us. Although various rust fungi have been grown in axenic culture during the last decade, P. pachyrhizi, is still known as an obligate parasite. Thus, when soybean plants are not present in the field the fungus is viable presumably only when transferred to

another living host. Indeed, various plants can be infected by this pathogen, among which are Adzuki bean, asparagus bean, blue lupine, common bean, common purple nutsedge, green gram, kidney bean, Kudzu, wild soybean and yam bean (11, 76, 88, 91).

We were curious to know whether the uredospores survived (in resting or dormant state) in dried or decayed tissues or in the soil. Thus, in preliminary studies we determined how long uredospores may remain viable in diseased leaves or in soil under various conditions. Diseased leaves were collected from the field. Some leaves were dried between newspaper folds and kept in the laboratory while others were placed in a desiccator over calcium chloride. Uredospores also were dislodged from diseased leaves by tapping the leaves and these uredospores were mixed with soil. Some portions of the uredospore soil mixture were kept dry in the laboratory, some were watered once a day in the laboratory and still others were exposed to natural outdoor conditions. The viability of the uredospores was tested by periodically plating spore samples from the various storage conditions on 1.5 percent water agar and determining the percentage germination after 24 hours. Spores that did not germinate within 24 hours were kept longer to observe for possible delay in germination.

Uredospores did not germinate after 8 days in any of the above storage conditions. The shortest period of viability, less than 2 days, was observed in uredospores mixed with soil and watered daily. This was followed by soil exposed under natural outdoor conditions where the soil was rained on on the fourth day, after which time the uredospores ceased to germinate. Thus, there appeared to be a relationship between exposure to water and uredospore germination. These results suggest that the pathogen does not persist for any appreciable period in diseased leaves and in the soil.

The importance of alternative hosts in the survival of the fungus in the field is the next logical question. It would be very useful to know whether or not the rust fungus also infects the weeds that abound in the field in addition to various other crop plants.

SOYBEAN RUST IN THE WESTERN HEMISPHERE

James B. Sinclair

Phakopsora pachyrhizi, known to occur on a wide variety of wild and cultivated legumes, has been reported in the literature under a number of synonyms (21, 152). A summary of this information is presented elsewhere in this publication in the section titled: "Soybean Rust: An Overview." Also, the soybean rust uredium, appears to the unaided eye much like the pustule caused by Xanthomonas phaseoli (E. F. Smith) Dowson sojensis (Hedges) Starr (Synonym: X. apelina), the causal agent of bacterial pustule disease of soybean (131). These facts have contributed to the confusion surrounding the occurrence of "soybean rust" in the western hemisphere.

The rediscovery of soybean rust in Puerto Rico was summarized by Vakili and Bromfield (152). Material presented in this review was freely adapted from this report and two presently unpublished reports: the first by P. L. Melendez (University of Puerto Rico, Mayaguez) titled: "History of Phakopsora Rust in Puerto Rico"; and the second by N. G. Vakili (USDA, ARS, Mayaguez Institute of Tropical Agriculture) titled: "Observations and Host Range of Soybean Rust, Phakopsora pachyrhizi, in Puerto Rico."

The soybean rust fungus was first collected and reported in the Caribbean on the island of Puerto Rico by F. L. Stevens in 1913 on the wild legumes Dolichos lablab L. and Teramnus unicinatus L. growing near Jayery (8). It has been reported since that time on at least 12 other hosts under several synonyms in seven other island nations or countries in the Caribbean as well as Central and South America (Table 1). When the various locations are plotted on a map of the area, the fungus is shown to be widespread in the tropics and subtropics of the Americas (Figure 2).

At this writing, only the urediospores of the fungus are known to be infective. Although the suspected telial stage of the fungus has been observed in soybean leaf tissues, teliospores have not been observed to germinate (K. R. Bromfield, personal communication). An aecial stage of the fungus on an alternate host has not been recorded although there is suspicion that it occurs in Taiwan (C. Y. Yang, AVRDC, Taiwan, personal communication).

P. pachyrhizi has been most frequently reported in the western hemisphere from Puerto Rico probably because the island has been visited and studied more by mycologists and plant pathologists than other areas in the region. The fungus was reported from Brazil in 1940; Costa Rica in 1976; Cuba in 1926; Georgia (U.S.A.) in 1922 (unconfirmed); Guatemala in 1940 and 1941; Puerto Rico in 1913, 1916, 1917, 1918, 1926, 1963, 1975 and 1976; St. Thomas in 1926; and other islands of the West Indies in 1926 and 1975 (Table 1) (8, 9, 39, 115, 125, 134, 135, 146, 152).

The fungus initially was collected in Puerto Rico on D. lablab and named Uredo concors by Arthur (8). Arthur (9) in 1916, after studying the fungus from new collections from D. lablab, transferred it to the genus Physopella and named it P. concors (Arth.) comb. nov. In 1917, Arthur (10) listed P. concors as a

Table 1. The hosts of *Phakopsora pachyrhizi* reported in the western hemisphere with country and the year reported.

Host	Location, year reported and literature citation ( )
Canavalla villosa	Guatemala, 1940-41 (39)
Centrosema pubescens	Puerto Rico, 1976 (152)
Crotalaria stricta	Brazil, 1940 (146)
Dolichos lablab	Costa Rica, 1976 (C. Y. Yang, AVRDC, Taiwan, personal communication); Puerto Rico, 1913 (8), 1916 (9), 1917 (10), 1918 (134), 1926 (125), 1963 (115), 1975 (134) and 1976 (152); St. Thomas, 1926 (125); and West Indies, 1975 (134)
Glycine max	USA (Georgia), 1922 (D. Phillips, University of Georgia, Athens, personal communication) (unconfirmed), and Puerto Rico, 1976 (152)
Phaseolus coccineus	Puerto Rico, 1976 (152)
P. lathyroides	Puerto Rico, 1976 (152)
P. longepedunculatus	Puerto Rico, 1976 (152)
P. macrolepis	Guatemala, 1940-41 (39)
P. lunatus	Puerto Rico, 1917 (9), 1918 (144), 1926 (125), 1963 (115), 1975 (135) and 1976 (152)
P. vulgaris	Puerto Rico, 1963 (115) and 1976 (152)
Teramnus uncinatus	Puerto Rico, 1913 (8), 1917 (9), 1926 (125); St. Thomas, 1926 (125); and West Indies, 1975 (135)
Vigna lutea	Puerto Rico, 1917 (9)
V. mungo	Puerto Rico, 1976 (152)
V. unguiculata	Puerto Rico, 1976 (152)
Host not known	Cuba, 1926 (125) and Trinidad, 1926 (125)

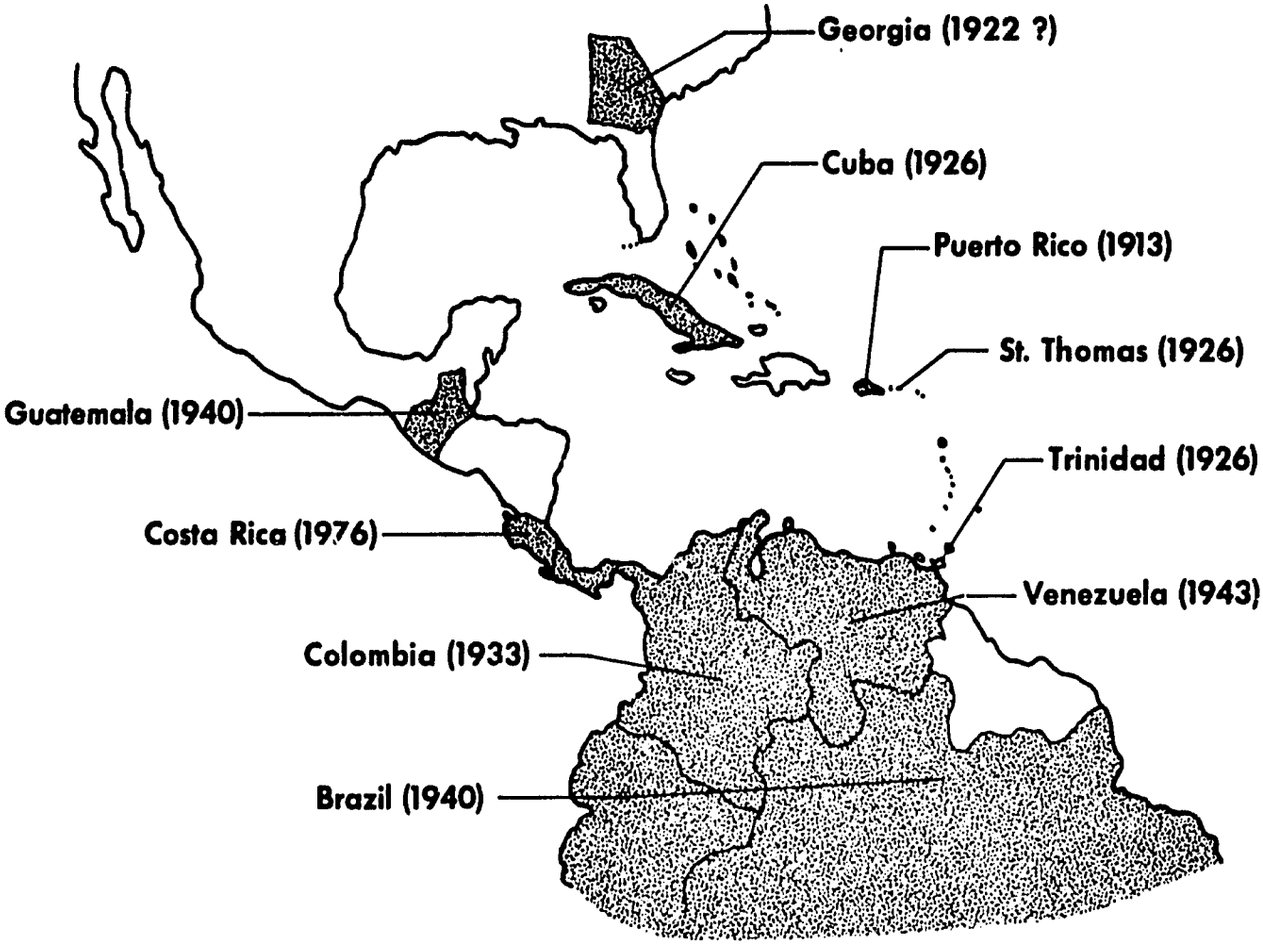


Figure 2. Map of countries in the western hemisphere and earliest years in which soybean rust was reported either on soybean or other host species

synonym of Phakopsora vignae Bres. The fungus was reported on lima bean (Phaseolus lunatus L.) by Thomas (144) in 1918 as U. concors; and in the same year Stevenson (135) reported it as Physopella concors on D. lablab. Seaver and Chardon (125), in 1926, reported Phakopsora vignae from Puerto Rico and St. Thomas. Roure (115), in 1963, listed D. lablab as well as P. lunatus and P. vulgaris as hosts of Physopella vignae in Puerto Rico. In 1975, Stevenson (135) listed the following synonyms of P. pachyrhizi: Phakopsora vignae, Physopella concors, Physopella vignae, U. concors, and U. vignae; and D. lablab, P. lunatus and T. uncinatus as hosts in Puerto Rico and the West Indies. In 1976, Vakili and Bromfield (152) listed four cultivars of soybean (Glycine max (L.) Merr) as hosts: Biloxi, Hardee, Santa Rosa and Williams as well as a number of wild and cultivated legumes (Table 1). Phakopsora crotalaria, recorded on Crotalaria stricta in Brazil (146) in 1940, was considered by J. R. Kochman, Department of Primary Industries, Queensland, Australia (personal communication) as a synonym of P. pachyrhizi.

It seems safe to speculate that the fungus is more wide spread in the tropical Americas than the literature would indicate. A concerted effort must be made by plant pathologists and mycologists in the Americas to determine the true geographical distribution and host range of this pathogen in order that the potential threat to soybeans and other cultivated legumes might be better understood.

SOYBEAN RUST IN THE EASTERN HEMISPHERE

Charles Y. Yang

Occurrence

Soybean rust, incited by P. pachyrhizi, is the most serious soybean disease in Asia and Australia and is a potential threat to other soybean production regions (11, 20, 23, 147). Considering the importance of soybean in the Americas, it is obvious that the rediscovery of P. pachyrhizi on soybean in Puerto Rico in 1976 is a justifiable concern to those involved in the production and protection of the crop in the Americas (152). An historical account of the occurrence of soybean rust in the western hemisphere was made by P. L. Melendez (99) at a workshop on "Rust on Soybean in the Western Hemisphere," held at Mayaguez, Puerto Rico in November 1976.

Symptomology

The disease develops on leaves, petioles, and sometimes stems of soybean plants. The first symptoms are small grayish-brown spots or lesions which gradually change to brown or dark-brown. Rust lesions appear before the pustules erupt. The lesions are angular in appearance, being delimited by the vascular bundles adjacent to the point of infection. At later stages of soybean development, after flower initiation, those lesions become larger or sometimes coalesce and become darker brown or even black. As a rule, rust symptoms appear on the lower leaves first, gradually progressing up the plant. The lesions, though generally on the underside of the leaf, can occur on both surfaces, i.e., both epiphyllous and hypophyllous. Uredosori formed on stems and petioles are more elongate than those on leaves, probably due to their development being confined or delineated by the shape of these organs. The rust fungus can infect cotyledons and leaves long before flowering and produces uredosori on them. The color of the uredospores of P. pachyrhizi is quite variable (71, 76, 166), ranging from opaque-white, buff-yellow, or brown to pinkish-brown depending upon the plant age and on such environmental factors as light, humidity (71) and temperature. Premature defoliation occurs on heavily infected plants.

Distribution and Host Range

The geographical distribution and movement of soybean rust is of considerable interest (Table 2). P. pachyrhizi or soybean rust has been recorded in Australia (20, 71), northeastern, central, and southwestern provinces of China (23, 41, 58, 76, 89, 112, 142, 148, 154, 158), Cambodia, India, Indonesia, Japan, Korea, the Malayan Peninsula, Okinawa, Papua New Guinea, the Philippines, Sarawak, Sri Lanka, Taiwan, Thailand, the USSR (81, 100, 103) and Vietnam (11, 18, 38, 55, 56, 62, 69, 90, 106, 109, 114, 120, 121, 141, 145).

Rust was first reported in Japan in 1902, but did not reach epidemic proportions until the late 1940's. Kitani and Inoue (76, 78) conducted studies dealing with soybean rust in Japan which started in 1948 and concluded in 1952 with a statement that both Aso No. 1 and Iyo soybean cultivars were resistant, and Tamanishiki and Shirodaizu and their relatives were susceptible to the soybean rust. In Taiwan, the pathogen was found in 1914 and rust is presently considered

Table 2. Geographical, chronological and seasonal distribution of soybean rust caused by Phakopsora pachyrhizi in the eastern hemisphere.

Country	First reported or epiphytotic year	Seasons (months)
Australia	1934; 1971	Apr.-May
Cambodia	1962	--
China	1940 or earlier	Aug.
Ethiopia	(1976)	--
India	1906; 1970	Apr.-May; Aug.-Sept.
Indonesia	1960	Apr.-May; Oct.-Dec.
Japan	1902; 1948	Aug.-Oct.
Korea	1935 or earlier	July-Sept.
Okinawa	1948	Mar.-May
Papua New Guinea	1914; 1958	--
Philippines	1914;1966	Aug; Dec.-Jan.
Sri Lanka	1951	--
Taiwan	1914	Mar.-May; Sept.-Jan.
Thailand	1966	Mar.-Apr; Sept.-Oct.
USSR	1957 or earlier	--
Vietnam	1948 or earlier	Aug.-Sept.

the most serious soybean disease. It has caused economic losses since the early 1960's. In Thailand, rust, first reported in 1966, is considered the most serious soybean disease. In the Philippines, P. pachyrhizi was first recorded in 1914 (14) and soybean rust became especially serious in 1970. In India, the rust pathogen was first collected at Poona in 1906 but rust was observed for the first time on soybeans at Pantnagar in 1970. Soybean rust also has been observed during the rainy season in Uttar Pradesh and West Bengal. Soybean rust did not become a serious problem in Indonesia (137) until 1961 and 1962, when great crop losses occurred. In Australia, the pathogen was first collected from soybean in 1934 but it was not serious in Queensland until 1970-71 (71).

P. pachyrhizi has an extremely wide host range since it infects large numbers of dicotyledonous plants. At AVRDC, we have been successful in infecting other leguminous hosts, such as the common bean (Phaseolus vulgaris), wild soybean (Glycine ussuriensis), and yam bean (Pachyrhizus erosus), both in the field and in the laboratory, with P. pachyrhizi uredospores.

Keogh (71) has made a rather thorough study of the host plants indigenous to Australia. A list of the hosts for P. pachyrhizi Syd. compiled from Keogh (71), Kitani and Inoue (76), Lin (88), N. G. Vakili (USDA, ARS, Mayaguez Institute of Tropical Agriculture, personal communication), Yang et al. (164), and K. R. Bromfield (USDA, ARS, Plant Disease Laboratory, Frederick, Maryland, personal communication) is presented in (Table 3).

Table 3. Hosts for the uredial stage of Phakopsora pachyrhizi, causal agent of soybean rust reported by various workers[a/].

Cajanus	Lespedeza	Pueraria
Canavalia	Lotus	P. lobata P. phaseoloidea
Crotalaria	Lupinus	P. thunbergiana
Desmodium	Macroptilium	Rhynchozia
Dolichos	Mucuna	Teramnus
D. lablab	M. capitata	T. ucinatus
Glycine	Pachyrhizus	Vigna
G. max G. formosana G. hispida G. soja G. ussuriensis G. wightii	P. bulbosus P. erosus	V. mungo V. radiata V. repens V. sesquipedalia V. sinensis V. unguiculata
Hardenbergia	Phaseolus	
Kennedia	P. coccineus P. lunatus P. vulgaris	
	Psoralea	

a/ In this compilation, P. vignae is considered to be a valid synonym for P. pachyrhizi.

Economic importance and disease losses

World soybean production, in 1973, was estimated to be at an all time high of 58.2 million tons, of which the U.S. produced 43.5 million tons. In recent years there have been marked declines in soybean production in mainland China and Japan; moderate increases in Canada, Indonesia, and South Korea; and substantial increases in Brazil, Colombia, Mexico and the USSR.

Owing to soybean's versatility in meeting the manifold requirements for food nutrition and industry, there is a strong tendency for agricultural policy makers of many countries to encourage soybean breeders to develop cultivars adapted for production in the tropics and subtropics. Undoubtedly, in time, the soybean industry will expand in the warmer regions and the soybean rust may become more serious since the causal organism *P. pachyrhizi* has long been a member of the ecological niche of tropical and subtropical pathogenic fungal flora.

One of the most difficult of plant disease studies is to accurately relate disease incidence to subsequent crop losses. To determine yield loss within a country or region requires that well designed plant disease surveys be conducted with standardized assessment methods at a sufficient number of sampling sites. Although such complete surveys have not been made for soybean rust, some data on losses due to soybean rust are available showing conclusively that this disease is capable of causing serious damage on crop yield and monetary losses to the farmers (11, 118, 164, 166).

An example of one such experiment performed at AVRDC clearly indicates that soybean rust can cause substantial yield losses (Table 4).

Table 4. The impact on yield of fungicide[a] application on four cultivars of soybeans[b] naturally infected with *Phakopsora pachyrhizi*.

Cultivar	Disease index (ρ)		Yield (t/ha)		%Reduction[d]	
	w/[c]	w/o	w/	w/o	Total wt	100-seed wt
Shih-shih	1.03	2.09	1.58	1.22	23	13
Wakajima	2.39	2.76	2.00	1.36	32	15
Kao-hsiung#3	1.11	2.68	1.77	0.88	50	19
Tainung#4	0.99	2.28	2.07	1.57	24	8
LSD 5%	0.71		0.34			

[a] Fungicide: Dithane M-45 400X

[b] Plant density: 4×10^5/ha

[c] Spray schedule: bi weekly
w/ : with fungicide
w/o : without fungicide

[d] Measurement taken-the total seed weight, the 100-seed weights, and the disease index (ρ)
Correlation coefficient between rust disease index and soybean yield r = -0.87.

Comparing treated and nontreated plots, a 50 percent yield reduction resulted when soybean cultivar, Kao-hsiung#3, was not sprayed. Comparable reductions in yield for the nonsprayed Shih-shih and Wakajima cultivars were 23 and 32 percent, respectively. Wakajima had relatively fewer pustules and maintained a greener appearance than the other three cultivars throughout the growing season.

Pathogen Morphology and Taxonomy

In the early literature, mostly Japanese, the name of the causal organism of the soybean rust was changed several times (76). The first identification of soybean rust fungus was made by Nakanishiki in Japan in 1902. He classified this fungus as *Uredo sojae*. In 1903, Yoshinaga sent his rust specimen which was collected from wild grown soybean (*Glycine soja*) in Japan to Hennings of Europe for further identification. Hennings confirmed the fungus as *Uredo sojae*, similar to the one discovered earlier on cultivated soybean by Nakanishiki. In 1906, while working in India, Sydow and Butler discovered the teliospores of the soybean rust. They named the fungus, *P. pachyrhizi*, instead of *Uromyces sojae*. In 1908, Kawakami and Miura, owing to their unsuccessful attempt to find the teliospore of the soybean rust in Japan, suggested that *Uromyces sojae* should be used in describing the Japanese isolate of rust in order to distinguish it from *P. pachyrhizi*. In 1919, Fujikuro found both the uredospores and the teliospores on the same leaves infected by soybean rust in Taiwan. He agreed with Sydow and Butler in classifying this fungus as *P. pachyrhizi*. He considered also that the uredospores obtained earlier in Japan might have been indentical to those collected in Taiwan. In 1931, Sawada discovered another rust parasitizing soybean in Japan. He named this fungus, *P. sojae*. However, later studies made by Hiratsuka, in 1932, showed that this fungus was morphologically identical to *P. pachyrhizi*. Therefore, Hiratsuka finally concluded in the same year that there is only one fungus causing the rust disease on soybean; *P. pachyrhizi*. All the other species of fungi which were previously called *Uredo sojae*, *Uromyces sojae*, or *P. sojae* proved to be the same species, and thus synonyms of *P. pachyrhizi* (55,76).

Sathe (121), who compared the holotypes of *Uredo sojae*, *Uromyces sojae*, and *P. pachyrhizi* with a collection on soybean from India, concluded that they were similar and belonged to *P. pachyrhizi*. Thus, Sathe's research supported that of Hiratsuka. The synonyms of *P. pachyrhizi* Syd. are as follows:

Uredo sojae P. Henn.

Uromyces sojae (P. Henn.) Sydow nom. nud.

Phakopsora sojae (P. Henn.) Sawada nom. nud.

Uromyces sojae Miura non. Sydow

Phakopsora vignae Arthur

Uredia of this fungus are both epiphyllous and hypophyllous. They are light brown to brown, and 100 to 200 nm in diameter. Paraphyses are united at the base, forming a dome-like covering over the uredium. Paraphyses are incurved, clavate or clavate-capitate, and hyaline to straw colored with a narrow lumen. They measure 7.5 to 15 nm at the tip and are 20 to 47 nm long. Uredospores are short, hyaline to yellowish-brown subglobose, ovate or oblong, 15 to 24 x 15 to 34 nm in diameter, with a finely echinulate hyaline wall 1 to 1.5 nm thick.

Teleutosori are hypophyllous, sparse or aggregated, irregular, erumpent, minute, 0.15 to 0.25 nm in diameter, dark and brown; teleutospores are 4 to 6 in a row, variable, mostly clavate, oblong or angular, yellow to brownish, smooth,

20 to 35 x 8 to 15 nm, with an epispore of 1.5 nm, often gradually thickened and darker toward the apex. No report of teliospore germination has been published. No one positively identified the alternate host for soybean rust.

Rust Nursery

Since the soybean rust fungus is an obligate parasite, it cannot be cultivated on an artificial cultural medium. It grows only inside the plant tissues of its living host. A simple rust nursery was established at AVRDC (11, 162) to provide a year-round supply of rust inoculum for field screening trials. The nursery area was 180 m^2, and divided into four sections. One section was planted each month in rotation with a susceptible soybean cultivar such as Shih-shih (or TK 5). To encourage rust development, a high population density of plants was used (400,000 to 600,000 plants per hectare).

Young seedlings in the nursery are artificially inoculated twice with uredospore suspensions at a concentration of 20,000 spores/ml prepared from infected older plants elsewhere to accelerate the development of rust. The first inoculation is made 3 weeks after emergence, and the second, 10 days later. After the first inoculation, the plants are watered twice a day for 10-minute periods using a surface perforated pipe system. Rust symptoms are usually evident on soybean leaves 10 days after the first inoculation. The yield losses of heavily infected soybean plants in the nursery generally were more than 80 percent, with yields as low as 0.3 tons per hectare.

Disease Development

Keogh (71), in Australia, made a detailed study on the pre- and post-penetration stages of P. pachyrhizi uredial infection on soybean. Marchetti (93), Marchetti et al. (94,95) and Melching and Bromfield (98), studied the uredial development and the effect of temperature and dew period on germination and infection by urediospores of P. pachyrhizi under containment conditions in the United States. We have studied the development of soybean rust (11,12,162) under experimental conditions in the field and in the greenhouse at AVRDC.

Infection of soybean can take place when the plants are young, if there is an abundance of freshly released uredospores and weather conditions for the initiation of infection are favorable. Six to 8 days are required for the primary rust infection to become apparent at temperatures between 19° and 30° C (with an optimum temperature of 25° C) and with a high relative humidity (over 90 percent R.H.) in the early morning hours. Temperatures below 19° and above 32° C, or continuous rainy days, will prolong the time required for rust development in the field.

The secondary spread of the rust in the field may require a similar length of time. However, in a rust nursery, where the soybean plants were artifically inoculated with uredospore suspensions of 20,000 uredospores/ml (much higher concentrations than those provided by nature), the spread of rust was more rapid. Six to eight cycles of uredospores can be produced within a single soybean growing season. Any number of these cycles might occur on the same leaf depending on the length of time it survives.

P. pachyrhizi has been observed to go from the uredial (asexual) stage to the telial (sexual) stage in the later phases of its life cycle. As a result of this transition, the number of teliosori formed on the infected leaves increased greatly compared with the number of uredosori. Other factors also may cause this

change, such as temperatures above 32° or below 19° C, or metabolites secreted by both the pathogen and the soybean leaf or their interaction also may contribute to the transition. We have isolated some self-inhibitor-like compounds from the uredospores that were collected from freshly infected soybean leaves in the field (158, 163, 164). Whether these compounds are similar to those produced by other rusts (47) is still under investigation. The finding of spore self-inhibitors may offer great opportunities to critically examine the primary physiological and biochemical events in germination of P. pachyrhizi uredospores and the resultant infection processes.

When air temperatures go below 15° C, accompanied by strong northerly winds, most of the uredospores that developed later in the soybean growing season are dislodged. However, laboratory studies indicate that the production rate of rust pustules on the infected leaves decreases in cold weather, yet fresh colonies of uredospores are still being generated. This suggests that both self-inhibitor and stimulator-like compounds may be operating in the uredospore system of the soybean rust fungus.

Rust Surveys and Screening for Resistance

Information on the prevalence and severity of soybean rust over large areas, i.e., countries or even continents, is needed to estimate the relative economic importance of the disease. Worldwide cooperative research efforts are needed to control or eradicate soybean rust. Surveys have been made by AVRDC scientists to: (i) ascertain their geographical distribution and if different races of P. pachyrhizi exist, (ii) record and determine the occurrence of alternative rust hosts or to observe other possible secondary hosts, and (iii) determine the geographical limits and incidence of the soybean rust pathogen.

Extensive surveys were made of Taiwan farmers' fields and this worldwide collection of soybean germplasm planted at various localities in Taiwan. Our results revealed that all cultivars or accessions of the soybeans surveyed are susceptible.

During the surveys, we found that currently used cultivars of soybean, previously reported as rust resistant (29), are now susceptible, including P.I. 200492, P.I. 200490, P.I. 200451, T.K. #5, KH #3, CH #1, and CH #3. Tainung #4 was more field tolerant to the rust, as determined by the number of rust pustules, than were other cultivated soybean varieties. The failure of the former "resistant" cultivars to maintain disease tolerance, indicates that mutations or new, more virulent rust strains may have developed in the field. A host and parasite reaction similar to that which we observed in Taiwan was reported by Sumarno (137) who stated: "Breeding for disease resistance, especially rust, has many difficulties. There is no variety of soybean in the collection which is resistant to rust. Some introduced varieties with noted rust resistance, such as Tainung #3, P.I, 200451, P.I. 200492, P.I, 368037, and Wayne, are susceptible to the Indonesian rust strains."

All of the important U.S. commercial soybean cultivars, when planted in Taiwan, were either susceptible or highly susceptible to rust (Table 5).

Table 5. Rust reactions of leading U.S. soybean cultivars grown in Taiwan, 1975.

Cultivar	Reaction[a/]	Cultivar	Reaction
Amsoy	S	Harosoy 63	VS
Anoka	VS	Hill	S
Bonus	S	Hood	S
Bossier	S	Kanrich	S
Bragg	VS	Lee	VS
Calland	S	Lee 68	VS
Chippewa	VS	Magna	S
Chippewa 64	S	Merti	VS
Clark	VS	Mukden	VS
Clark 63	S	Norman	VS
Clay	VS	Portage	VS
Corsoy	VS	Provar	VS
Custer	S	Semmes	VS
Cutler	S	Tracy	VS
Cutler 71	S	Verde	S
Davis	VS	Wayne	VS
Disoy	VS	Williams	S
Dunn	S	Wirth	S
Hardee	S	York	S
Harosoy	VS	PI 200492	VS

[a/] S = susceptible
VS = very susceptible

In the fall of 1975, in cooperation with the USDA Delta Branch Experiment Station, 1,080 soybean cultivars were sown in two separate fields at AVRDC, one of which was protected with a fungicide. Only nine cultivars, less than 1 percent of the total screened, were classified as moderately resistant (Table 6).

Table 6. Soybean cultivars identified moderately resistant to rust in a screening of 1,080 cultivars, 1975, AVRDC.[a/]

AVRDC acc. no.	Cultivars	Origin	Rust[b/] rating
7985	PI 60273	China	323
7988	PI 62204	China	323
8260	PI 90406	China	323
8268	PI 94159	Japan	323
8283	PI 159322	Korea	323
8316	PI 181561	Japan	323
8377	PI 371609	China	323
8586	PI 230970	Japan	323
8587	PI 230971	Japan	323
8529 (susceptible control)	PI 200492	Japan	343

a/ 1,080 soybean cultivars were sown on Sept. 16; inoculated on Oct. 21 and 29 and evaluated on Nov. 21, 22, Dec. 10, and 22, 1975.

b/ Rust rating was devised by IWGSR and is explained later in the text.

These nine cultivars were tested further in two successive screenings in 1976. Both PI 230970 and PI 230971 continued to exhibit moderate resistance to the soybean rust fungus.

Evaluation - IWGSR soybean rust rating system

The new IWGSR rating system described elsewhere in this publication was used and evaluated to determine its ease of use and interpretation.

A color guide helpful for estimating the density of rust lesions on soybean leaves was included in the 1975 AVRDC Soybean Report (12). By using the IWGSR evaluation system, the final classification of disease reactions of soybean hosts to the pathogen can be established (Table 7).

Table 7. Relationships between disease reactions and IWGSR ratings for soybean rust.

Disease reaction	IWGSR rating
Immune	111
Resistant	122, 123, 132, 133, 222, 223
Moderately resistant	142, 143, 232, 233, 242, 243, 322, 323
Moderately susceptible	332, 333
Susceptible	343

In supplementing the screening methods used in the field, a detached-leaf technique was devised at AVRDC (11, 12, 164) to assist in the evaluation of the soybean varietal resistance to rust. This technique also can be adapted for studies of soybean rust uredospore germination and the efficacy of fungicides against it (45, 63).

Epidemiology

The epidemiology of soybean rust is not well understood. Without knowledge about an alternate host for *P. pachyrhizi* and the nature of germination of its teliospores, the real source of the primary inoculum for soybean rust infection is only speculative. Since this rust pathogen has wide host range, any one of these alternative hosts could serve as the source of primary inoculum if its growing season were somewhat out of phase with that of soybean. In locations such as Indonesia, the Philippines, Taiwan and Thailand where yam bean, *Pachyrhizus erosus*, is grown *P. pachyrhizi* on this plant is common and probably serves as a source of primary inoculum for soybean.

Control of Soybean Rust by Fungicides

Early studies (64, 68, 77, 78, 91, 118, 153) on preventive measures indicated that soybean rust could be controlled by the application of suitable fungicides. In a search for more effective fungicides against soybean rust, AVRDC has maintained a fungicide screening program (11, 12, 63, 164). A rust-susceptible cultivar, TK 5, was used to test the effect on yield of four fungicides: Dithane M-45, Plantvax, Saprol, and Sicarol. All plants were inoculated with rust uredospores. The yields and 100-seed weight of plots protected by the four fungicides were compared to those of the nontreated control (12). Dithane M-45, a preventive fungicide, provided better control of rust, as shown by higher yields, than did the three systemic fungicides with spray schedule (A) (Table 8). However, with spray schedule (B), the yields of all four treatments were similar, except for Plantvax, which provided significantly better control. The delayed action of the systemic fungicides in arresting rust development was partially attributed to their "curative effect." Other fungicides screened for effectiveness in controlling soybean rust will be reported in AVRDC annual reports.

Table 8. Effect of four fungicides and two spraying schedules (A, B) on the yield of soybean cultivar, TK 5, under rust epiphytotic conditions; 1975, AVRDC[a].

Treatment	Rate (kg/ha)	Calculated yield in t/ha[b] A	Calculated yield in t/ha[b] B	100 seed weight in g A	100 seed weight in g B
Dithane M-45	2.0	3.2*	2.4	17.4*	16.8*
Plantvax	2.0	2.4	2.6	15.2	15.3
Saprol	1.5	2.2	2.4	16.3*	16.8*
Sicarol	1.5	2.1	2.4	15.1	16.0*
Control		2.0		14.4	
LSD 5%		0.6		1.0	

a/ Sown, Mar. 12; inoculated, Apr. 17; and harvested June 23 to 26. Spray schedule A: began Mar. 27; Plantvax, every 3 weeks; final spraying June 10. Spray schedule B: began Apr. 18; Plantvax, every 18 days; the other 3, every 10 days, final spraying June 10.

b/ Plot size, $9m^2$; 3 replications; population density, 400,000 plants/ha.

*The difference between the actual yields (LSD 5% = 0.55) and 100-seed wt (LSD 5% = 1.03) of TK 5 were significantly different from those of the control.

Future Research on Soybean Rust

The initiation and undertaking of intensified research on soybean rust are of paramount importance in view of the economic and nutritional importance of soybean, the great yield loss caused by rust, the spread of the disease, the threat to the major temperate soybean growing areas and our inadequate knowledge of the pathogen. A concerted research effort involving many scientific disciplines should be undertaken and directed toward the following goals:

1) Search for rust resistant soybean cultivars through field screenings in many localities.

2) Among those cultivars rated moderately resistant, efforts should be made to identify morphological, physiological, or biochemical factors that are associated with host resistance.

3) Study the chemical control of soybean rust, particularly testing new systemic fungicides and biological control methods.

4) Develop reliable massive screening techniques under controlled environmental facilities to supplement screening for resistance in the field.

5) Study the rust pathogen to learn the regulatory mechanism of rust infection process(es) and the disease development in the host, i.e., the host-parasite interrelationships.

6) Identify the physiological races of the rust pathogen and the alternate host, or secondary hosts, or both.

7) Apply innovative approaches and new techniques for rust resistance breeding; establishment of international and regional soybean rust testing programs and exchange of resistant breeding materials.

8) Study the epidemiology of the soybean rust fungus.

SOYBEAN RUST AND THE PATHOGEN - SOME NEEDED RESEARCH

K. R. Bromfield

Soybean rust is classically a disease of economic importance in the Orient. With the exception of the People's Republic of China (PRC), the distribution of the disease on soybeans in the eastern hemisphere is known in general. Until soybean rust distribution and severity within PRC is made known to the world, however, plant pathologists in neighboring countries will be somewhat at a disadvantage in attaining understanding of many epidemiological aspects of the disease.

The lack of adequate information about soybeans and soybean rust in the PRC is further regrettable because that area of Asia is the probable center of origin of the soybean. As such, it would most likely be a center of diversity for soybean genotypes and, by analogy, genotypes of the rust pathogen, P. pachyrhizi.

The soybean rust pathogen can be found throughout an area exceeding the area in which it causes economic crop loss, but detailed knowledge of the geographical distribution of the pathogen currently is inadequate. In part, this is because detailed information on the geographical distribution of the nonsoybean species that may function as supplementive hosts for the pathogen is fragmentary and data on the natural occurrence of the rust on them are minimal.

Host distribution and pathogen distribution data are needed for lifecycle studies of P. pachyrhizi and to ascertain the role that wild or nonsoybean legumes play as reservoirs or primary sources of inoculum that initiate epidemics on soybean crops following a period in which soybeans are absent from the fields. Surveys made for pathogen and disease distribution on soybean and on nonsoybean hosts should be structured to provide information both on geographical and seasonal distribution. Eventually the accumulation of distribution data should make possible the construction of maps graphically presenting detailed information for regions, countries, and smaller physiographic or political subdivisions. The current work of Keogh (72) in New South Wales, J. K. Kochman (personal communication) Department of Primary Industries, in Queensland and Vakili and Bromfield (151) in Puerto Rico will provide good information on the host range of the pathogen, the distribution of supplementive hosts and pathogen distribution, but it represents only a beginning and must be broadened by others to include wider areas of the globe.

Turning now to areas other than the major Oriental center of soybean rust, there have been at least two unconfirmed reports of the pathogen in the Middle East. In 1939, Reichert (113) reported the occurrence of Uromyces sojae (a synonym of P. pachyrhizi) on soybean in the area then known as Palestine. More recently, in 1975, S. Abdul Axix Saleh reported to J. B. Sinclair, University of Illinois, Urbana (personal communication), (unconfirmed) soybean rust in INTSOY variety trials at Wadi Jizan, Saudi Arabia.

In Africa, in another INTSOY trial in 1975, soybean rust was reported at Jimma, Ethiopia, (J. B. Sinclair, University of Illinois, Urbana, personal communication). This report also remains to be confirmed. Interestingly, P. pachyrhizi has been identified by mycologists at the Commonwealth Mycological Institute, Kew, England, on leaves of cowpea (Vigna unguiculata) from the African countries of Ghana, Sierra Leone, Sudan, Tanzania, and Uganda, (R. J. Williams, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, personal communication).

In the Americas, Phakopsora vignae, now generally considered a synonym for P. pachyrhizi, has been known on a number of legume hosts since the early 1900's (125). Countries in which P. vignae has been reported include; Colombia, Costa Rica, Cuba, Guatemala, Puerto Rico, St. Thomas, Trinidad, and Venezuela (39, 73, 74, 125).

Rust on soybeans was reported for the first time in the western hemisphere in 1976. The pathogen, subsequently identified as P. pachyrhizi, was observed and collected by N. G. Vakili on experimental plantings of soybean cultivars Biloxi, Hardee, Santa Rosa, and Williams at the Adjuntas Agricultural Substation (elevation 500 m) in the Limani Valley in the western highlands of Puerto Rico (151).

In August 1976, N. G. Vakili and K. R. Bromfield (unpublished) collected leaves of common bean, hyacinth bean, lima bean, scarlet runner bean and soybean infected with Phakopsora rust at Limani, and elsewhere in Puerto Rico. Specimens then were transported under quarantine permit to the Plant Disease Research Laboratory (PDRL) at Frederick, Maryland. Spores from each of the several collections were used to inoculate sets of Wayne soybean.

Distinctive lesions were apparent on all inoculated plants 7 days after inoculation. Fourteen days after inoculation, sporulating uredia were present in most lesions. No difference in symptom expression could be detected among any of the Wayne plants inoculated with spores from the several hosts. The lesions were characteristically reddish-brown, about $0.4mm^2$ in area, and had none, one, two, or very rarely three uredia within them on the lower surface of the leaf. Only an occasional uredium was observed in the lesions on the upper surface of the leaf. Spore production in the uredia was minimal and remained so with time.

Under similar conditions in the greenhouse at PDRL, cultures of P. pachyrhizi from the Orient produced tan-colored lesions that are more productive of uredia and uredospores than are the Puerto Rican cultures.

More than 30 U.S. commercial soybean cultivars were inoculated with the Puerto Rican culture. All reacted as did Wayne. In my opinion, the interaction between the cultivars tested and the Puerto Rican culture was that of incompatibility and indicates a degree of specific rust resistance in U.S. cultivars to the Puerto Rican culture.

Of course, it is recognized that the rust collections made and tested to date comprise a small sample. In view of the possible existence in the Americas of strains of the organism with enhanced virulence to soybeans, the scope of soybean rust surveys in the western hemisphere should be broadened and the pace of research on the pathogen accelerated.

The species P. pachyrhizi is probably quite complex in composition. It would not be surprising -- as we learn more about the fungus, its host range, and its virulence characteristics on various hosts -- to find that it comprises several distinct "varieties" or "formae speciales" differing in minor morphological characters but differing especially in the kinds of plants that each can attack. Within each variety for forma specialis probably there will be physiologic races that look alike but differ in their ability to attack certain cultivars of their host. We have this situation with many fungi. Especially well known in this regard is that of the intensively investigated stem rust of wheat organism, Puccinia graminis.

The scientific evidence for formae speciales within P. pachyrhizi has not been compiled or documented, but evidence for races among P. pachyrhizi cultures virulent on soybean has accumulated. In 1966 Lin (88) showed that P. pachyrhizi collected from soybeans varied in pathogenicity and virulence among various nonsoybean hosts. Somewhat later Yang (11) differentiated two races in Taiwan on the basis of lesion type produced on soybean accessions. In 1976, McLean and Byth (96) reported the presence of at least two races at Redland Bay, Australia. There, Race 1 is virulent on Wills and avirulent on P.I. 200492; Race 2 is virulent on both P.I. 200492 and Wills.

At PDRL, an Australian culture of rust from Redland Bay (AUST-72-1) induces two distinct infection types intermingled on each of the following genotypes provided by B. B. Singh, G. B. Pant University of Agriculture and Technology, Pantnagar, India: Ankur, UPSL-18, UPSL-85, UPSM-91, UPSM-168, PK-71-39, PK-73-84, and PK-73-94. One infection type consists of a reddish-brown lesion with few uredia, the other a tan lesion with many uredia. The results are interpreted as evidence of at least two races in culture AUST-72-1.

On accessions P.I. 230970 and P.I. 230971, culture AUST-72-1 produces only one kind of infection type -- reddish-brown lesions with few uredia. These two soybean accessions apparently exhibit uniformly a specific resistance to the Australian culture.

Although no standardized scheme for the identification of physiologic races of P. pachyrhizi has as yet been developed, a valid need for such a scheme exists. Its use would permit us to determine the range of virulence within rust populations and plot the geographic distribution of genes for virulence. This knowledge, in turn, would permit rational deployment of specific resistance genes within soybean populations.

Specific resistance in soybean is uncommon but it has been observed in the field and confirmed in the greenhouse in Australia, observed in the field in India, and observed at PDRL. In Australia, McLean and Byth (96) observed immunity among certain race-host cultivar combinations and also discolored necrotic lesions with no sporulation or limited sporulation on certain accessions, one of which is HY2217 from the Philippines. In India, B. B. Singh (Pantnagar, India) and colleagues have observed reddish-brown lesions with no or limited sporulation on at least 13 accessions in their germplasm holdings. Among them is the recently released cultivar Ankur (132). Ankur and certain other accessions from India and P.I. 230970 and P.I. 230971 showed specific resistance to our culture AUST-72-1. We have not as yet had the opportunity to test these materials to other cultures in our collection. Currently no accessions are known that have specific resistance to the predominant race of P. pachyrhizi in Taiwan.

Specific resistance is generally thought to be conditioned by one or few major genes and inherited in rather simple fashion. It is relatively easy to manipulate in breeding programs. Experience in many crops indicates, however, that specific resistance is often only temporary.

Observations made by workers in many countries indicate that accessions growing in close proximity may vary in the intensity of rust that develops among them during a season, even though they all are subjected to the same inoculum load and to the same environment. The differences in rust severity are attributed to differences in general or nonspecific resistance among the hosts. Nonspecific resistance is generally thought to act against all races of a pathogen, to be strongly influenced by environment, and is usually inherited polygenically. It also may be masked if conditions are especially favorable for development of the disease. Because general resistance differs in degree, it is difficult to manipulate genetically with traditional breeding techniques and has, up to quite recently, been rather neglected. The benefits to be gained by utilizing general resistance are many. A strong program for incorporating and enhancing this kind of resistance into high-yielding adapted soybeans with appropriate agronomic characteristics would be highly desirable.

Soybean rust pathologists will have to identify and quantify general resistance mechanisms that retard development of rust. If this is done, then it is reasonable to expect that suitable and convenient screening techniques for identifying lines or individuals with nonspecific resistance will be devised.

Pathologists working with the cereal rusts have already pioneered in this area. Some of the identified components of general resistance are: (i) a reduction in the number of uredospores produced per lesion, (ii) a reduction in the length of time a lesion produces spores, (iii) a reduction in number of lesions produced per unit of inoculum applied, and (iv) an increase in generation time. It is highly probable that these factors will also operate in the soybean-soybean rust system.

Referring again to work done with cereal rusts, it has been observed that the yield of certain cultivars of wheat appears not to be reduced even though the cultivar is heavily rusted. The term "tolerance" has been applied to this phenomenon. Plants cannot be classified for tolerance by visual observation, but only by measuring the effect of the rust on yield. Tolerance may be regarded as a type of general resistance. To my knowledge, experiments designed and executed specifically to detect tolerance in the soybean-soybean rust system have not been made.

The lack of a standardized rust assessment method has led to some confusion in field identification of lines with usable degrees of general resistance. This topic was addressed at the Chiang Mai Conference in 1976 where an assessment scheme was formulated and adopted. Additional research on appropriate assessment methods is needed.

Turning now to the pathogen, we know in some detail from published results the effect of temperature on uredospore germination and penetration. Our information is less adequate in regard to the effect of temperature on colonization and the production, maturation, and release of a new generation of spores. It is generally thought that sporulation is impaired by temperature above 30°C and below 10°C, but experiments made to determine quantitatively the effect of temperature on sporulation apparently have not been reported in the literature.

The requirement for liquid moisture on the leaf surface to permit spore germination and penetration is recognized and it is generally accepted that penetration can occur in about 6.5 to 7 hours on a wet leaf when temperature is in the range 18 to 21°C. The effect of liquid moisture and/or atmospheric humidity on postpenetration phases of the pathogen, however, is obscure.

In recent work by Bonde et al. (19) the number of penetrations observed was the same for leaves kept wetted 9, 10, 12, or 16 hours after inoculation. The number of resulting lesions, however, progressively increased as the period of leaf wetness was increased stepwise from 9 to 16 hours. Thus, although penetration was completed by 9 hours, colonization success was apparently enhanced when the period of time that water was on the leaf was extended. The mechanism of this apparent enhancement is now known and it is not known whether high atmospheric humidity in the absence of liquid moisture is effective.

The soybean rust fungus seems to develop best under conditions of abundant and frequent rainfall, and least well under conditions usually described as "hot and dry." In order to define more precisely the effects of important environmental factors on the fungus and the resulting disease, carefully controlled experiments are required. The simplest of these would be experiments in which only one factor at a time is varied -- temperature alone, atmospheric humidity alone, etc. Eventually, however, experiments to study the interaction of the major environmental factors must be made to provide a satisfactory understanding of the pathogen and the disease it causes. Knowledge of these factors is needed to identify times and places favorable for the appearance and development of rust, for the rational development of effective chemical control procedures, and for the development of cultural methods for disease control.

Although P. pachyrhizi has been known to science for some 70 years, the role of the teliospore in the life cycle of the fungus has not been demonstrated.

In southern Japan, Kitani and Inoue (76) observed that teliospores were not present in the field in the period May to September but they were present after mid-October. They further commented that teliospores were more likely to form on leaves densely covered with uredial infections and just before abscission.

Koegh (71), in Australia, has reported the collection of telia of P. pachyrhizi on Crotalaria linifolia and Desmodium rhytidophyllum but, to my knowledge, there are no reports on telia on soybean in Australia. Yang (AVRDC, Taiwan, personal communication) reported the appearance of telia in Taiwan. There may be reports of the appearance of telia on soybeans, but I am not aware of them.

In December-January 1972-73, abundant telia developed in the greenhouse at PDRL on Wayne soybean inoculated with a culture of P. pachyrhizi from Taiwan. This did not occur in following years although greenhouse conditions were similar.

We have attempted to induce teliospore formation by modification of the environment in growth chambers -- modifying day and night temperature, reducing day length and temperature concurrently, etc. -- but as yet without success. R. C. French (PDRL, personal communication) has been attempting to "switch" the fungus from uredospore production to teliospore production by use of volatile chemicals with biological activity for fungi, but no telia have developed. As far as I know, no one else is doing this sort of work with Phakopsora spp.

There are no published reports on teliospore germination. Consequently we know nothing about sexual reproduction and the recombination of genes that could lead to the formation of new physiologic races.

Inability to germinate teliospores has hindered determining whether P. pachyrhizi is autoecious and completes its life cycle on soybean, or whether it is heteroecious and requires an alternate host to complete its life cycle.

Until the entire life cycle of P. pachyrhizi is known and until the other gaps in our knowledge of the pathogen and the disease are closed, those of us charged with protecting soybean crops from soybean rust will be in an uncomfortable position.

CURRENT RESEARCH EFFORTS

U. S. Research Effort in Soybean Rust Pathology	- K. R. Bromfield
Soybean Rust in Australia	- J. K. Kochman
Soybean Rust in Korea	- B. J. Chung and C. S. Park
Soybean Rust in Taiwan	- Kuo-lein Chan

U.S. RESEARCH EFFORT IN SOYBEAN RUST PATHOLOGY

K. R. Bromfield

Suggestions and opinions presented in the following summary represent a personal view and are not to be construed as official positions or views of the U.S. Department of Agriculture.

Current and Visualized Status

Within the U.S., direct research with P. pachyrhizi is underway solely at the Plant Disease Research Laboratory (PDRL), Frederick, Maryland. This research is being conducted under strictest quarantine within a specially designed and operated containment facility. Of necessity, the work is restricted to laboratory and greenhouse investigations.

PDRL, a unit of the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA), has been assigned general responsibility for investigating nonendemic plant diseases that appear to have the potential for serious damage on major U.S. agricultural crops. Soybean rust is in this category. Other nonendemic diseases currently under investigation at PDRL include downy mildews of maize and other cereals, rusts of maize, virus diseases of maize and soybeans, and various leaf spots of maize.

Recognition of the damage potential of soybean rust, the scarcity of known resistance in the world's soybean germplasm collections, and the ever-present possibility of introduction of soybean rust prompted USDA's investigation of this disease and its pathogen beginning in 1971. In addition to the work at PDRL, USDA also is supporting, under contractual arrangements, work on the epidemiology of soybean rust at the University of Sydney and on the genetics of rust resistance at the University of Queensland in Australia.

With the discovery in 1976 of P. pachyrhizi on soybeans in an experimental planting in Puerto Rico, study of the pathogen and disease has begun at USDA's Mayaguez Institute of Tropical Agriculture (MITA), Mayaguez, Puerto Rico in cooperation with PDRL. The University of Puerto Rico also will cooperate with MITA and it is anticipated that cooperative arrangements will develop between the U.S. and other countries in the Americas as research on P. pachyrhizi in the western hemisphere evolves.

In general, universities and state experiment stations in the U.S. are not directly involved with P. pachyrhizi because it has not been reported in this country. Joe Hennen, Curator of the Arthur Herbarium, Purdue University, Indiana, is developing a monograph on the genus Phakopsora. The mycological and taxonomic information acculumated and systematized in the monograph should be of direct value to researchers. Those universities with programs in the Far East, such as the University of Illinois through its INTSOY program, are investigating the disease by establishing various cooperative arrangements with scientists and educators in countries where soybean rust is endemic. The INTSOY nurseries widely planted under the International Soybean Variety Evaluation Experiment (ISVEX) program, provide information on the occurrence of soybean rust and will serve as an early warning system for the appearance of the rust in areas previously free from the disease.

Organizations and universities with programs that utilize breeding and/or seed increase nurseries in Puerto Rico, e.g., Iowa State University, are now faced with the rust and are reacting to the presence of Phakopsora. The dimensions and directions the responses will take remain to be seen. The USDA will survey for rust in the U.S., particularly along the Gulf Coast and in Florida, during the summer of 1977. If soybean rust is found, a rapid response on the part of scientific personnel in land-grant colleges, state governmental organizations, and USDA would occur, particularly in those states in which the rust was found.

The following U.S. personnel with percent full-time equivalent are currently engaged in soybean rust pathology research: USDA, PDRL, C. H. Kingsolver (10), K. R. Bromfield (75), J. S. Melching (10) and M. R. Bonde (25); USDA, MITA, N. G. Vakili (10); University of Illinois, INTSOY, Urbana, R. E. Ford (1) and J. B. Sinclair (2).

Envisioned Support

Within an international program, PDRL could effectively: (i) assist in the study of physiologic specialization and development of a physiologic race identification scheme, (ii) compare the characteristics of Phakopsora collections from various legume hosts to determine taxonomic and pathogenic relationships and to assess their virulence to soybean, (iii) assess the effects of environmental factors on the pathogen and the disease by means of carefully controlled growth chamber and greenhouse experiments, (iv) function as a repository for the liquid nitrogen preservation of research cultures of P. pachyrhizi collected globally, and (v) function as a supplementary facility for the screening for rust reaction of elite breeding lines and newly developed cultivars about to be released for production.

PDRL could provide office, laboratory, and greenhouse space for visiting scientists (and possibly graduate students) but no support funds for salary, travel and living expenses. PDRL's current soybean rust research program will continue to investigate the biology of the organism; host range; induction of the telial stage; teliospore germination; physiologic specialization; environmental effects on germination, penetration, colonization, sporulation, and dissemination; components of field or general resistance to the rust pathogen; quantitative methods of disease assessments; and quantitative methods for yield loss estimation. Findings, of course, will be made generally available through publication in scientific journals.

USDA research at MITA will include pathogen biology, host range, seasonal occurrence and geographical distribution studies.

SOYBEAN RUST IN AUSTRALIA

J. K. Kochman

The Soybean Industry in Australia

Soybeans were regarded as a minor crop in Australia until there was a major increase in cultivation of the crop in the early 1970's. However, in comparison to many other countries, the area of soybean cultivation is small, estimated at about 40,000 hectares for 1976-77. All cultivation of soybeans, of commercial importance, occurs in two states - Queensland 25-30,000 hectares and New South Wales - 10-15,000 hectares (Fig. 3). Soybeans are normally planted from mid-November to early January and harvested in April to May. Although some winter crops have been grown, the normal situation is to produce one crop per year during summer.

Soybean Rust in Australia

The first report of rust in Australia came from Queensland in 1934 (128). It was found also on *Glycine clandestina* in 1954 (R. F. N. Langdon, Department of Botany, Queensland, personal communication). Rust was first recorded in serious proportions on experimental soybean plots at the University of Queensland Redland Bay research farms in 1970-71 (97). Since then rust has been recorded in most of the soybean growing areas of Queensland, including the St. George area (450 km west of Brisbane). However, in New South Wales (72) it has been recorded only in coastal and subcoastal areas. At present, rust cannot be considered a major disease of Australian soybeans, except in coastal areas and in the Atherton Tableland area of North Queensland. However, this situation could change.

Soybean Rust Research in Australia

Soybean rust research is being conducted by members of three institutions: the Department of Agriculture, University of Queensland; the Department of Primary Industries, Queensland; and the Department of Plant Pathology and Agricultural Entomology, University of Sydney.

The following are personnel engaged in rust research at Queensland University: D. E. Byth, Reader in Agriculture; R. F. N. Langdon, Reader in Botany; R. McLean, Research Scholar; H. Ogle, Senior Research Assistant; and P. de Jabrun, Research Assistant.

Initial studies demonstrated that none of the soybean accessions available in the germplasm collection at the University was immune to the disease. However, three reaction types were identified in progeny of crosses involving the imported lines: Tainung 3; Tainung 4 and P.I. 200492. These reaction types were: immunity (I), necrotic lesion formation but no sporulation (R); and necrotic lesion formation with sporulation (S) (97).

Preliminary investigations indicate the field studies of inheritance of different reaction types is unsuccessful and all inheritance work is now conducted in the glasshouse with controlled inoculations. It appears that P.I, 200492 type

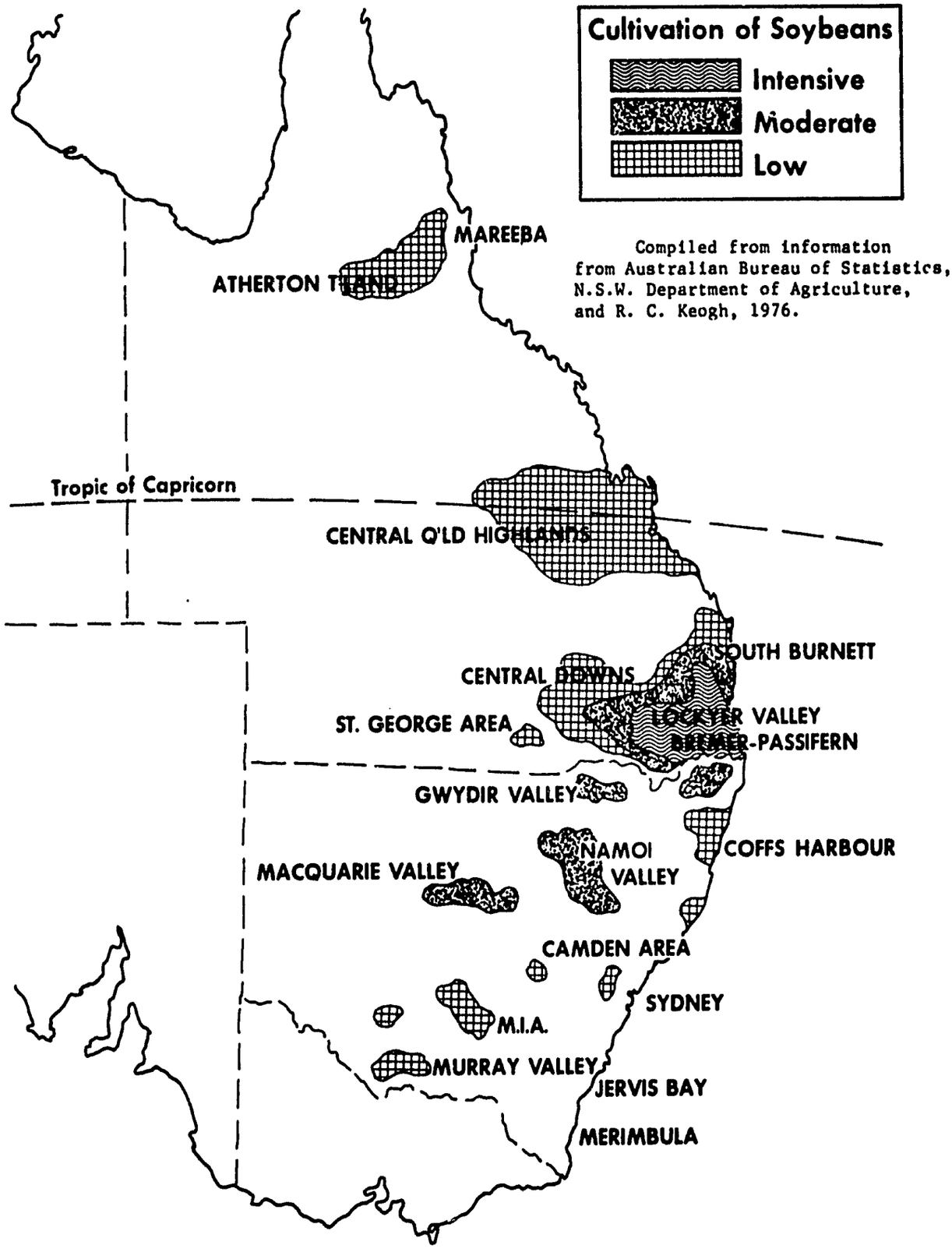


Figure 3. Approximate Distribution and Intensity of Soybean Cultivation in Australia

resistance is relatively simply inherited, and histological studies indicate that this type of resistance prevents fungal proliferation into the mesophyll tissue of the leaf. However, because of the occurrence of a new rust race the P.I. 200492 is unlikely to be useful in further breeding programs to produce rust resistant lines (97). Further crosses and testing of material are continuing.

Currently, the research is directed towards study of: the inheritance of the different types of resistant reactions; the histology of the disease in lines showing different reactions to infection; the physiological impact of the pathogen on susceptible hosts with a view towards chemical control strategies; and the diversity of the pathogen in Australia.

Other work has shown that soybean yield may be reduced by over 60 percent by certain levels of rust severity. The reduction was mainly attributable to a decrease in seed weight. It was found during this experiment that the rust rating system adopted by the International Working Group on Soybean Rust (IWGSR) was unsatisfactory because it was not quantitative. Hence ratings, based on a percentage leaf cover, were used.

As a result of the yield reduction caused by rust, trials will be conducted this season with new chemicals to evaluate their rust control potential.

Several publications have arisen from the research at Queensland University (see literature cited nos. 25, 26, 96, 97). The following are personnel currently involved with rust research within the Department of Primary Industries: J. K. Kochman, Plant Pathologist stationed at Toowoomba; a technical assistant and a laboratory assistant.

Initial work on soybean rust was conducted by officers in the Athberton Tablelands area during the early 1970's. Following damage to trial plots, a number of chemicals; (oxycarboxin at three rates, mancozeb and chlorothalonil) were screened for effectiveness against P. pachyrhizi. The results indicated that both mancozeb and chlorothalonil provided good control of soybean rust.

In 1974, a survey was initiated to determine in which of the soybean areas of Queensland the rust occurred. Although rust was found in most of the soybean growing areas, P. pachyrhizi did not develop within crops until late summer or early autumn, i.e., when crops began to mature. However, rust was found on soybeans and native legumes throughout the year. P. pachyrhizi overwintered on G. clandestina during 1974 and 1975 and occurred throughout 1975 in a trial where soybeans were sown monthly. The rust was often difficult to find during the summer months. As a result it was decided to investigate the effect of temperature on rust development.

Inoculated plants were placed in dew conditions suitable for infection and then placed into one of four temperature regimes. The following data were recorded: time between inoculation and flecking; time between inoculation and sporulation (generation time); and percentage of pustules which had sporulated at 14 days after inoculation. Differences were significant among the data obtained under different temperature regimes (Table 9).

Table 9. The effect of four temperature regimes on the development of *Phakopsora pachyrhizi* on the soybean cultivar Wills.

Temperature regime °C night/day	Days from inoculation to flecking	Generation time (days)	Percent of pustules sporulating at 14 days after inoculation[a/]	
7/17	10.8	13.8	0.96	(5.33)
12/22	6.8	11.0	85.91	(69.0)
17/27	4.8	9.0	94.33	(77.0)
22/32	7.0	11.0	70.75	(57.35)
Necessary Difference for Significance				
5%	0.2959	0.2153	4.3793	(4.1303)
1%	0.3941	0.2867	5.8319	(5.5002)

[a/] Values in brackets are percentage values transformed to arcsine (percentage).

The shorter generation time and increased sporulation observed in the 17 to 27°C would increase: (i) the number of rust generations within a crop and (ii) the number of pustules within a crop per rust generation. Under these conditions the rate of disease development would increase and reach epidemic proportions more quickly than in the other temperature regimes. Field observations on rust incidence in Queensland support the laboratory findings.

Temperature also may affect other aspects of disease development. The viability of spores and the longevity of pustules may be either enhanced or adversely affected. Spore survival also may be affected by other factors and we will study these when time and facilities permit. Control measures can be utilized most effectively when conditions for rust development are known.

There is close cooperation between the department and the University of Queensland.

Personnel involved with soybean rust research at the University of Sydney are B. Deverall, L. Burgess, R. Keogh, and P. Casey. These scientists investigate three main areas of rust research, namely: host-pathogen relationships; biochemical studies; and epidemiological studies. The host-pathogen relationship work involves study of the behavior of rust on native legumes as well as investigations into histochemical changes in leaves infected with rust. The biochemical studies include investigations on the production of phytoalexins within infected soybean leaves and, on the separation and characterization of several phytoalexins produced within rusted leaves. The epidemiological studies were commenced in 1974 to 1975 in collaboration with the Plant Disease Research Laboratory, Frederick, Maryland. It involves study of spread and development of rust in relation to prevailing environmental conditions. Work also is being conducted on the relationship between infection density and yield. Field occurrence of rust within New South Wales also is being studied (72).

Future Research and Needs

Much more information is required on the epidemiology of the disease, particularly factors affecting rate of development. This information is required by breeders so that conditions for effective screening of resistant material can be defined. This is particularly important as it appears that the relatively simply inherited immune type of resistance will be short lived and the possibly more complicated forms of resistance such as "slow rusting" will need to be screened and tested. Still many factors concerning host, pathogen and environment effects, need study. There also is a need for basic genetic studies on the inheritance of resistance.

Funds for soybean rust research from within Australia are generally short. A levy on oilseed producers may be introduced within the next 12 months and a small portion of the monies raised in this way might be provided for soybean rust research. However, there is no definite information on this levy at present.

D. E. Byth indicates that soybean rust research could cease at the University of Queensland by mid-1978 for a number of reasons. Ogle will be resigning in June 1977 and R. McLean will be completing her studies in 1978. It is unlikely that new funds will be allocated for rust research from Australian sources so new staff and research students will not be appointed.

Work on soybean rust within the Department of Primary Industries will proceed as priorities of work and funds permit.

Information on future work and needs was not supplied by the University of Sydney group.

Extension and Educational Activities on Soybean Rust Control

Extension activities are limited because many soybean growing areas do not have a rust problem. In coastal areas, local advisers from the Department of Primary Industries provide farmers with information on chemical control.

SOYBEAN RUST IN KOREA

Bong Jo Chung and Chang Seuk Park

Soybean rust disease is not a major problem with the cultivation of soybeans in Korea.

A rust was collected for the first time at Wonsan (North Korea) in 1935 and identified as P. pachyrhizi (56). This disease has not occurred significantly elsewhere in Korea. As a result, there has been little research on soybean rust in Korea.

Recently, soybean is an increasingly important crop in Korea, not only for foodstuffs but also as an industrial crop. Consequently, investigations on the soybean diseases and pests have intensified. The Department of Plant Pathology of the Institute of Agricultural Sciences has made intensive annual field surveys on soybean diseases throughout the country since 1972. Soybean rust was not widespread until 1975 when field surveys indicated that soybean rust was found at a large number of locations although the infection rates were very small (84). Subsequently the disease is occasionally found in places where it was reported previously.

Distribution

It is presumed that soybean rust is distributed throughout the Korean peninsula (Fig. 4). It was found at Wonsan (North Korea), on Jeju Island (South-most of Korea), and it also was reported in Manchuria (North of Korean peninsula) (76). In general, severity of soybean rust disease is very small except in southern parts of Korea, especially Jeju Island, where damage often occurs.

Host Range

Soybean (Glycine max) and Kudzu vine (Pueraria thunbergiana) are natural hosts of rust in Korea (75, 104). Kudzu vine, a common perennial plant, is found widely distributed in hills and mountains. Kudzu vine appears to be more susceptible to rust than soybean because Kudzu vine infected with rust is readily found anywhere in Korea (75). We did not make artificial inoculations of soybean rust to leguminous plants or other hosts.

Damage

Soybean rust usually occurs after maturation stage (mid-September) in Korea (37), thus not affecting yield significantly. However, certain parts of infected plants often showed heavy infection at a given location (Table 10).

Table 10. Occurrence of soybean rust at several locations in Korea (1975)

Location	Cultivar	Infection rate
Suweon	Kwangkyo	±
Pygentack	Kwangkyo	+
Iri	--	±
Chinju	--	+
Jeju	Hill	++

± : trace
+ : little
++ : moderate

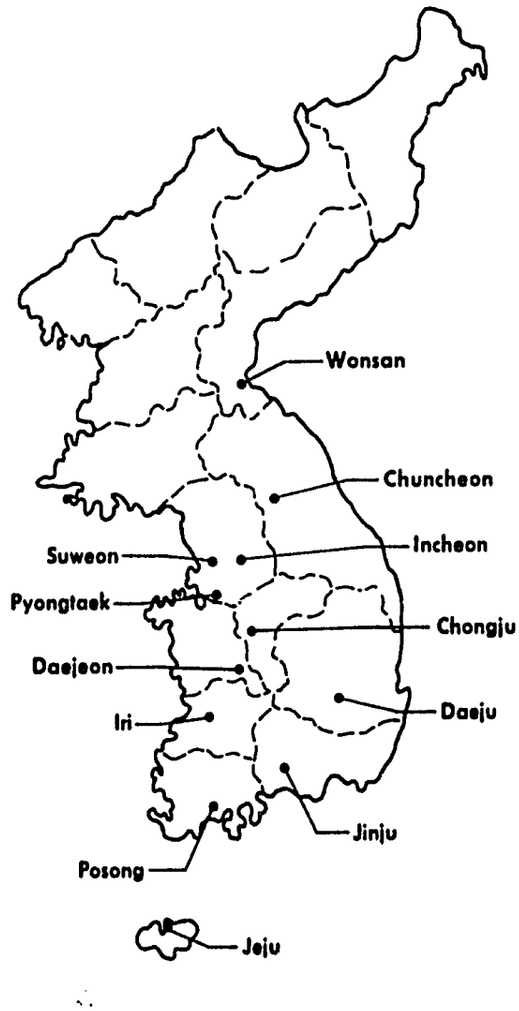


Figure 4. Locations Where Soybean Rust Fungi Were Collected in Korea

SOYBEAN RUST IN TAIWAN

Kuo-lein Chan

Soybean rust has long been considered the most serious problem in soybean production in Taiwan. Up to 50 percent in yield loss caused by rust disease is not unusual, especially in spring and autumn crops. Although chemical control of soybean rust is successful, and the farmers in Taiwan use it, it is still laborious and costly.

Leaf-Petiole in Soybean Rust Research

Immersing leaf-petioles has great potential as a new approach to rust research for the purpose of maintaining *P. pachyrhizi*. A whole leaf may be severed at the bottom of the petiole, and two-thirds of the petiole immersed immediately into a small tube full of water. Roots may emerge at the end of the petiole after 7-10 days. There are several advantages of such a technique: (i) large numbers of immersed petioles can be handled, (ii) this technique can be done throughout the year if a growth chamber is available, and (iii) it reduces labor and other costs.

Control of Soybean Rust by Resistant Cultivars

Control of *P. pachyrhizi* through host resistance has been emphasized for more than twenty years throughout the soybean breeding sections in several government agricultural research organizations. It led to the release of three moderately rust-resistant cultivars, Kaohsiung No. 3 (KS 3), Tainung No. 3 (TN 3) and Tainung No. 4 (TN 4), and in recent years by the use of P.I. 200492 as the resistant parent. P.I. 200492 was a selection from the soybean germplasm introduced from the U.S. Regional Soybean Laboratory, Urbana, Illinois, and maintained by the Taiwan Agricultural Research Institute. Since P.I. 200492 is not highly rust resistant, the rust problem cannot be solved solely by breeding until a more highly resistant or immune cultivar is available. A set of 27 rust resistant entries donated by S. Shanmugasundaram of AVRDC will be further tested in a 1977 screening.

BREEDING FOR RESISTANCE

Observations and Theories on Cultivar Resistance of Soybeans to Rust	Ricardo M. Lantican
Resistance of Soybeans to Rust in Australia	R. McLean D. E. Byth
Breeding for Resistance to Soybean Rust in India	B. B. Singh P. N. Thapliyal
Breeding for Soybean Rust Resistance in Indonesia	R. S. Sumarno M. S. Sudjadi
International Rust Nursery	S. Shanmugasundaram
Reaction of Cultivars and Chemical Control of Soybean Rust in Indonesia	M. S. Sudjadi M. Amir R. S. Sumarno

OBSERVATIONS AND THEORIES ON CULTIVAR RESISTANCE OF SOYBEANS TO RUST

Ricardo M. Lantican

Soybean rust is a very destructive disease of soybeans in Asia and Australia. Cultivar resistance has been exploited and is actively pursued in the Asian Vegetable Research and Development Center (AVRDC), Australia, India, Indonesia, the Philippines, Taiwan and Thailand. The Taiwan Agricultural Research Institute (TARI) initiated its breeding work as early as 1961, culminating in the release of rust-resistant cultivars, Kaohsiung 3, Tainung 3 and Tainung 4. These cultivars, especially Tainung 4, have been used as sources of resistance in other breeding programs such as those in the Mae Jo Experiment Station near Chiang Mai, and University of the Philippines at Los Baños.

A number of breeding institutions in Asia and Australia have made use of the original sources of resistance, namely, P.I. 200451, P.I. 200490 and P.I. 200492. These were Japanese cultivars introduced to the U.S. in 1952, from the Chugoku-Shikoku Experiment Station, Shikoku, Japan, which carried the cultivar names Amakusa Daizu, Kiwami and Komata, respectively. P.I. 200492 was the main source of resistance in the Taiwan breeding program.

Since then, other cultivars and newly bred lines observed resistant to rust have been reported by different workers in the AVRDC; University of Queensland Australia; G. B. Pant University of Agriculture and Technology, Pantnagar, India; Bogor Agricultural University and Ministry of Agriculture, Indonesia; Mae Jo Station, Thailand; and the University of the Philippines at Los Baños (UPLB).

Observations on the Host-Parasite Relationship

Present observations and knowledge on cultivar-disease relations point to a wide diversity in the infective nature of the rust organisms occurring in Asia and Australia and the transitory and unstable nature of cultivar resistance. Cultivars that manifest resistance to the indigenous strains of rust in one country may not necessarily exhibit the same degree of resistance when introduced and exposed to the disease populations in another. For example, cultivars observed as highly resistant in Australia and India were found susceptible when grown in the Philippines and Taiwan.

Our experience with the rust disease in the Philippines suggests that these disease populations must be very dynamic. I suspect that the organism can continuously develop into new strains probably due to its close and continued association with the host plants since it is an obligate parasite. Shifts in the population from one strain to the other can happen at any time. This makes our cultivar evaluation work difficult and it may explain why cultivar resistance is transitory. For example, TK-5, a cultivar from Taiwan, and Wayne, a U.S. cultivar, were originally highly resistant to our indigenous rust. Naturally, they were used immediately in our crossing program with the bacterial pustule-resistant cultivars. For a while, it was thought that our breeding efforts to combine rust and bacterial pustule resistance had paid off, but soon the resistance of our selections to rust was completely lost, including that of TK-5 and

Wayne. Apparently, a shift to a new strain of the rust organism, which was capable of attacking the resistant cultivars had occurred. Since then, TK-5, Wayne and all our selections have been susceptible, yet these cultivars still have the genes for resistance to some earlier specific strains of rust. When Kochsiung 3, Tainung 3, Tainung 4 and the P.I. series were first grown in 1973, they showed a remarkable level of field tolerance to soybean rust, but through several generations of exposure to the Philippines rust disease, these cultivars have gradually lost all resistance.

From among these rust-tolerant cultivars, we made a total of 54 crosses in combination with the cultivars resistant to bacterial pustule since 1974. In addition, we obtained 12 segregating populations from the AVRDC. The shift to susceptibility was rapid resulting in a high mortality rate of our breeding materials. From the initial 66 different bulk populations, only 41 proved worthy of further selection after one growing season. From these 41 populations, 992 different selected families were extracted. In one more season, only 217 families survived the screening process and after one more season, only 21 survived. These 21 selections are represented by the following crosses: (i) P.I. 200451 x Lincoln, (ii) P.I. 200451 x CES 16-103, (iii) P.I. 200451 x Hill, (iv) Sankuo x Lincoln, (v) P.I. 200492 x Lincoln, and (vi) Tainung 4 x Hill. Without knowing how long these selections can be maintained, we have undertaken another round of intercrossing among these selections to recover the resistance genes at higher dosages. We hope to further intensify these resistance genes by maintaining our breeding populations through two or three more cycles of repeated selection and recombination following the recurrent method of breeding.

We have observed also that Clark 63 and Lincoln, cultivars formerly highly susceptible, have improved in their tolerance reaction to the Philippine rusts.

Cultivar reaction to rust infection may be expressed at any stage of development of the plant, starting from the seedling stage when the pair of unifoliolate leaves are still intact to any time before flowering, after flowering and early-pod development. Infection begins with the lower or older leaves. The early appearance of disease symptoms in the seedling stage, if it can be induced, may be used to advantage in maximizing time and space in mass screening work.

Under the conditions in the Philippines, rust is most serious beginning in early-pod development stage. In some resistant cultivars, rust pustules may develop but at a slow and gradual rate and the green matter of the leaves may remain unaffected, rendering the leaves still capable of sustaining the developing seeds. By the time the infected leaves fall off, seeds have already developed normally. This seems to be the case with the cultivars Clark 63 and Lincoln. The tolerance reaction may not be all genetic but partly due to an escape mechanism by virtue of the fact that pod-filling and development in these cultivars occur quickly.

In susceptible cultivars, pustule formation is rapid and the chlorophyll of the leaves is lost. The leaves wilt, then turn brown and assume a burned-up, crinkled appearance. Soon the leaves drop off, even at early-pod development stage. As a result, the pods do not develop any further and seeds remain malformed and shrivelled. We have observed a 46 percent reduction in seed weight between the susceptible and resistant cultivars. The susceptible, highly determinate cultivars, such as Bragg, are more seriously affected than the indeterminate types which somehow manage to carry on with photosynthesis in the young, less-affected terminal leaves.

At the time when genes for resistance expressed themselves to the particular strain of the rust organism (when TK-5 demonstrated absolute resistance), inheritance of resistance was simple and dominant, following a monogenic ratio. Since the difference between the resistant and susceptible plants was clear-cut and easily distinguishable, resistance to a particular strain of the rust should be easy to fix. This is called "vertical resistance" which is complete but specific only to a single biotype of the rust organism. When a new strain of the organism develops, this resistance may be completely lost.

If we could only identify the various predominant ecologic or specialized substrains of our indigenous rust populations through the use of differential host cultivars and then maintain them in pure cultures for inoculation work and genetic studies, I am certain that we can, in time, fill in the gaps of information and ultimately establish a matching gene-for-gene or lock-key relationship between the organisms and the differential host cultivars, through an intensive screening process of our germplasm collection and breeding materials. Thus, for each known strain of the rust organism, we can find the corresponding sources of genes for resistance. The next step would be relatively simple, that of assembling as many of these different genes together into a line or "multi-line" to constitute a "horizontal" or broad-spectrum type of resistance that would be more stable over a wide range of infective conditions. Such lines will be released as commercial.

Doing this is difficult insofar as maintaining pure cultures of known strains of the organism is concerned, because the rust organism, an obligate parasite, does not lend itself to artificial rearing. This is a great handicap to the breeding program. Our plant pathologists are working on this aspect of artificial rearing of the organism.

In our screening procedure for disease resistance, we do not do artificial inoculations but rely on natural occurrence of the disease in the field which occurs naturally and regularly. Each season, we plant about a dozen cultivars as indicators or differentials, and observe their reaction to rust, in an attempt to characterize which particular biotype of the rust organism was naturally predominant. However, under controlled field conditions and where populations of the organism form one complex, the procedure has not served the purpose.

Another safeguard in our screening work is that whenever we have observed breeding populations or families showing resistance to a naturally occurring rust population, such populations are not discarded but kept in cold storage even if they are susceptible in some other season. As I have indicated earlier, these materials may have some latent genes for resistance to some strains that may become important in the future. We need not start over again searching for gene sources and recombining them in crosses; this can save valuable time.

In the past, the rust disease appeared under the cool, dry conditions only in December, January, February and March. Now, the disease occurs year-round, even during the hot humid months of June, July and August. Rust also can be epidemic in newly established plantations of soybeans. The organism must have a number of alternate hosts.

A Call for Greater Collaborative Efforts

Experimental evidences on the nature of host-parasite relations and the genetics of cultivar resistance are scanty. More precise information is needed.

To fill these information gaps which are basic in framing sound approaches to cultivar resistance development, the following requisities have to be met: (i) the important strains or biotypes of the disease organisms indigenous in the country must first be identified, (ii) a practical system must be found by which the different biotypes can be maintained and multiplied for subsequent inoculation work. A breakthrough in artificial rearing of the organism into pure cultures would greatly facilitate the cultivar screening work, and (iii) the respective sources of genetic resistance for each biotype must then be identified.

Where a precise host-parastic relationship can be established, the ultimate objective of breeding programs would be to put these different resistance genes into a multiline composite, through a series of backcross breeding with each donor of genes for resistance. However, this breeding procedure will entail much time and effort before benefits can accrue. Meantime, a short-term solution is needed to overcome the extensiveness of the rust disease. We need not wait till all the refinements in handling the rust organism have been attained.

A breeding program can be designed which relies on the naturally occurring disease complex as the chief source of infection. The simple recurrent selection for disease resistance is proposed which will consist of selection for resistance and immediate recombination in diallele crosses in each generation. The process is repeated in three to four cycles. The final product will be individual pure lines or composites of pure lines, that will eventually constitute the commercial cultivar.

The success of cultivar resistance development programs hinges, likewise on the refinements of screening techniques. Screening of breeding materials for genetic resistance should be done both in the field under natural or induced infection and in the laboratory where conditions can be controlled. A fast, intensive and reliable varietal screening technique must be worked out through pathologic manipulations or bioassay work. For the latter reason, the assistance of the biochemists must be enlisted in establishing the biochemical nature of varietal resistance. A look at the isozyme patterns of say, catalase, peroxidase and a few other catalytic enzymes known to be associated with disease resistance may be worthwhile. Elaboration of the bioassay technique will follow.

It is only through this alliance among the plant breeder, geneticist, pathologist and biochemist that we may be able to keep pace with or be ahead of the dynamism of soybean rust. Let us remember that the organisms do not work in an 8-hour-day or 5-day-week shifts but continuously with the capability to mobilize a superstrain at any time.

International cooperation, through exchanges of information on techniques and breeding materials and cooperative testing will go a long way in establishing a common line of defense against this scourge of the soybean industry.

RESISTANCE OF SOYBEANS TO RUST IN AUSTRALIA

R. McLean and D. E. Byth

Previously no immunity or high degree of resistance to soybean rust has been reported. The tests described have demonstrated that strong resistance to rust does exist in soybean genotypes, and in particular in one accession of P.I. 200492 (Q 12956) and the cultivars derived from it (Tainung 3 and Tainung 4) and in lines P.I. 227268, P.I. 227687 and HY 2217.

However, these resistances may not be effective against the whole rust population, as evidenced by the identification of a second race of rust which is virulent on the previously immune line P.I. 200492.

Rust of soybeans, caused by P. pachyrhizi, is reported widely distributed throughout Asia from China south to Australia (21, 76, 116). The rust causes premature defoliation of plants, with a subsequent increase in the numbers of unfilled pods per plant. Losses have not been accurately determined, but available data show that soybean rust can cause serious yield loss. In Taiwan, it is estimated that, due to rust, production is reduced by 20 to 30 percent (91), while in individual fields as much as 70 to 80 percent of potential yield may be lost (62). In Japan, losses of 15 to 40 percent in individual fields are reported (82), and in Thailand losses are estimated to range from 10 to 30 percent in individual fields (91). No accurate measures of yield loss have been reported for Australian crops.

Screening tests of soybean accessions have been carried out in several countries where the rust is indigenous to identify sources of resistance to rust. The tests have shown that accessions differ in the severity of rust development that occurs on them and show varying amounts of field resistance. However, no soybean lines which are immune to the rust or which show a high degree of resistance have been reported (21).

Accession P.I. 200492 was shown to have a high degree of field resistance to rust when tested in Taiwan (29, 33), though it was infected and sporulation occurred readily in glasshouse tests made in the U.S.A. using a Taiwanese isolate (95). P.I. 200492 was used subsequently as a parent to breed cultivars Tainung 3 and Tainung 4 which show degrees of rust resistance in Taiwan (29, 33).

Soybean Rust in Australia

In 1970, soybean rust was first recognized in Australia in serious proportions on soybeans at the University of Queensland Research Farm at Redland Bay, Queensland. All Australia soybean cultivars were susceptible as well as a large collection of accessions of soybean. Since 1970, a much wider distribution of the rust has been shown in Eastern Australia, with P. pachyrhizi being identified in all major soybean growing regions, except the Narrabri region. Aspects of the distribution of the pathogen and of the host range in Australia were discussed by Keogh (71).

Chemical control using regular applications of Dithane M 45 and Benlate has proved effective but expensive. Investigations into genetic sources of resistance

were commenced, since this appeared to offer the most promising and economical means of disease control.

In 1971, three soybean accessions (P.I. 200492, Tainung 3 and Tainung 4) were introduced for testing and hybridization. Initial tests of the three introductions and bulk F3 progeny of four crosses (P.I. 200492 x Ogden, Tainung 3 x Ross, Tainung 4 x Gilbert and Tainung 4 x Ross) were made under epiphytotic conditions at Redland Bay in the 1973-74 season. Varying degrees and types of plant reactions to rust within these populations were observed. The plant reactions can be classified into three types: Type 1 (plants immune, no macroscopic signs of infection), Type R (necrotic lesions, no sporulation), and Type S (necrotic lesions, with sporulation). The three introductions gave a Type 1 reaction, Ogden, Ross and Gilbert Type S, and the four F3 populations each segregated for all three reaction types.

In the 1974-75 season, over 600 single-plant progenies of F3 plants of the four crosses were grown in an attempt to confirm the reactions observed in the F3. The F4 lines confirmed the reaction types. The lines were either pure Type 1, Type R or Type S, or segregating for these reaction types.

Glasshouse tests were made on a number of lines using 6-week old plants inoculated with freshly collected uredospores of the Redland Bay isolate (Table 11). Those lines which exhibited infection Type I to R in field trials were either pure Type I, Type R, or Type S, or segregating for these reaction types.

Glasshouse tests were made on a number of lines using 6-week old plants inoculated with freshly collected uredospores of the Redland Bay isolate. Those lines which exhibited infection Type I or R in field trials show the same reactions to rust in the glasshouse.

These data indicated that P.I. 200492 is a source of genetic resistance to the soybean rust isolate from Redland Bay. Various different reactions to rust have been reported for lines identified as P.I. 200492 in other countries (21, 29, 33, 95). However, this is the first record of an immune reaction. The origin of these differences is unknown. Investigation is required to determine whether these differences are due to variation in the pathogen populations of the various countries, misidentification of the line, to genetic variation within the accession, or differences in the test conditions imposed. Some misidentification of the line has occurred, since two accessions to Australia from different sources both identified as P.I. 200494, have been found to be of different reaction type (Table 11).

Twenty-one other accessions of soybean (*Glycine max*) and of a related species *G. ussuriensis* reported to have some degree of resistance to rust, have been evaluated for reaction to the Redland Bay isolate in glasshouse and field trials during 1975-76 (Table 11). Most were found to be susceptible, but in glasshouse tests five showed some degree of rust resistance. P.I. 224268 and P.I. 227687 exhibited a Type I reaction, HY 2217 Type R and P.I. 219653 and P.I. 229358 showed only a low level of sporulation. In field tests, P.I. 227687, HY 2217 and P.I. 219653 showed the same reaction to rust as they did in the glasshouse tests, while P.I. 229358 was fully susceptible and P.I. 200490 showed a much slower spread of rust from lower to upper leaves compared with other more susceptible lines. P.I. 227268 was not field tested.

Table 11. Results of glasshouse and field evaluation of rust resistance of some *Glycine max* and *G. ussuriensis* accessions.

		Species	Immediate origin	Test Glasshouse	Test Field
P.I. 200492(a)	(Q 12956)(b)	*G. max*	AVRDC Taiwan	I(d)	I
Tainung 3	(Q 12957)	"	"	I	I
Tainung 4	(Q 12958)	"	"	I	I
P.I. 366119		G. ussuriensis	Germ plasm resources Lab. USDA Washington, D.C.	S(e)	
P.I. 245331	(Q 15623)	"	"	S	-
P.I. 245331	(Q 15990)	"	USDA Maryland	S	-
P.I. 171451	(Q 15723)	*G. max*	USDA Stoneville, Miss.	S	S
P.I. 200465	(Q 15724)	"	"	S	S
P.I. 200466	(Q 15725)	"	"	S	S
P.I. 200490	(Q 15726)	"	"	S	LR
P.I. 200492	(Q 15727)	"	"	S	S
P.I. 219653	(Q 15728)	"	"	LR(f)	LR
P.I. 224268	(Q 15729)	"	"	I	I
P.I. 227687	(Q 15730)	"	"	I	-
P.I. 229358	(Q 15731)	"	"	LR	S
HY 2217	(Q 15991)	"	USDA Maryland	R(g)	R
Americana	(Q 15992)	"	"	S	S
AVRDC 2051(c)	(Q 15994)	"	AVRDC Taiwan	S	S
AVRDC 2053	(Q 15995)	"	"	S	S
AVRDC 2054	(Q 15996)	"	"	S	S
AVRDC 2055	(Q 15997)	"	"	S	S
AVRDC 2056	(Q 15998)	"	"	S	S
AVRDC 2057	(Q 15999)	"	"	S	S
AVRDC 2058	(Q 16000)	"	"	S	S

(a) United States Department of Agriculture plant introduction number.
(b) Queensland Department of Primary Industries plant introduction number.
(c) Asian Vegetable Research and Development Center (Taiwan) accession number.
(d) I - infection Type I
(e) S - infection Type S
(f) LR - low level of resistance
(g) R - infection Type R

It is apparent that in addition to P.I. 200492 and its progeny, six soybean accessions are of immediate interest in soybean rust resistance investigations. They are P.I. 200490, P.I. 200653, P.I. 224268, P.I. 227686, P.I. 229358 and HY 2217. Studies of the inheritance of the resistance in P.I. 200492 are proceeding, as is genetic study of the other possible source of resistance.

Since it showed such a high degree of resistance, accession P.I. 200492 was of interest for use as a parent in breeding for resistance to rust. However, late in the 1975-76 season at Redland Bay P.I. 200492 showed a low frequency of sporulating rust lesions. At the end of the season, lesions were still present at only a low level, one lesion per 10 leaves.

Rust was isolated from the lesions and multiplied in the glasshouse. When the rust was inoculated back to P.I. 200492, that line was heavily infected and exhibited Type S (fully susceptible) reaction. This showed that there are at least two physiologic races of P. pachyrhizi present at Redland Bay. These two races may be identified using a uniformly susceptible cultivar, such as Wills, and P.I. 200492 as differential hosts. Race 1 is virulent on Wills and avirulent on P.I. 200492, while Race 2 is virulent on both Wills and P.I. 200492. At present Race 1 makes up the greater proportion of the Redland Bay rust population.

In view of the occurrence of a rust race virulent on P.I. 200492, this line is of limited use in a rust resistance breeding program. Tainung 3, Tainung 4 and the six other accessions showing resistance to rust are being tested with rust Race 2, and further accessions are being obtained and screened for resistance.

Acknowledgments

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BREEDING FOR RESISTANCE TO SOYBEAN RUST IN INDIA

B. B. Singh and P. N. Thapliyal

Soybean rust was first noticed at Pantnagar in September 1970 and subsequently it was observed also at Kalyani (West Bengal) and in the low hills (4000') of Uttar Pradesh. The disease was severe in 1970, 1971 and 1974 and mild in 1972 and 1973. The attack always came in mid-September to early October when temperatures were mild and humidity was high. This coincided also with the pod filling stage of the crop causing drastic reduction in seed size and yield. Typical symptoms were development of many pustules on the dorsal side of the leaves which after rupturing released powdery spores, followed by rapid drying of the leaves and then senescence of the leaflets leaving petioles attached to the stem. The crop died 15 to 20 days before its normal maturity with consequent reduction in yield of up to 66 percent. Cultivars Bragg, Hardee and Semmes yielded up to 40 quintals per hectare in 1967-68, but only 12 to 15 q/hectare in 1970-71 during a severe rust epidemic (Table 12). Thus, rust is considered one of the most devastating diseases of soybean in northern India.

Table 12. Yields and days to maturity for soybean cultivars grown in no-rust and severe rust years in Uttar Pradesh, India.*

	1967		1968		1970		1971	
Cultivar	Days to maturity	Yield kg/ha	Days to maturity	Yield kg/ha	Days to maturity	Yield kg/ha	Days to maturity	Yield kg/ha
Bragg	120	4051	121	3883	104	1799	100	1298
Hardee	127	4518	129	4050	116	2333	107	1429
Semmes	121	4601	121	3287	106	1599	102	1211

* No rust in 1967 and 1968, severe rust in 1970 and 1971.

Sources of Resistance to Rust

Soybean germplasm consisting of over 3,300 lines was screened in the field in 1971 (132). Rust was very severe which permitted identification of resistant lines. Based on symptoms, the germplasm lines were classified into the following three groups:

Resistant: These lines did not develop any rust pustule even though adjacent to severely infected susceptible lines. P.I. 200465, P.I. 200466, P.I. 200477, P.I. 200490, P.I. 200492 and P.I. 224268 were rated as resistant.

Moderately Resistant: These lines developed necrotic spots at the point of contact with fungal spores which is typical of a hypersensitive

reaction. There was very little or no further development of the fungus on those spots and the plants looked as healthy as resistant ones. No premature senescence of leaves was observed in such lines: E.C. 11695 (UPSM-91), E.C. 50081 (UPSM-168), P.I. 88816-S, P.I. 181567, P.I. 200455, P.I. 200474, P.I. 200476, P.I. 224270, P.I. 200487, P.I. 285089, P.I. 341352, E.C. 22694 (UPSL-18), E.C. 36956 (UPSL-85), Ankur, and PK-71-39.

Susceptible: These lines developed large numbers of pustules which were full of powdery spores. All such lines dried prematurely. Except for the lines mentioned above and the very early ones which escaped the disease, all the germplasm lines screened were highly susceptible to rust.

Development of Rust Resistant Breeding Lines

Based on the superior agronomic characteristics and tolerance to yellow mosaic, some of the rust resistant lines were selected and crossed with high yielding but susceptible cultivars such as Bragg, Clark-63 and Hardee. From the segregating populations a number of high-yielding rust-resistant breeding lines were developed and evaluated in 1974 (Table 13).

Table 13. Performance of some rust-resistant breeding lines of soybean.

Line	Parentage	Days to maturity	Yield kg/ha	Reaction to rust[a]
PK-73-84	UPSL 85 x Hardee	132	4335	MR
PK-73-94	UPSL 85 x Hardee	135	4181	MR
PK-73-109	UPSL 85 x Hardee	135	4279	MR
PK-73-148	UPSS-3[b] x Clark 63	127	3853	MR
PK-73-156	UPSS-3 x Clark 63	125	4129	MR
Bragg	Jackson x D49-2491	111	2261	S

[a] MR = moderately resistant; S = susceptible

[b] UPSS-3 is a sisterline of Ankur

Thus, the new rust-resistant breeding lines have restored the prerust yield levels. The resistance of these breeding lines was further demonstrated by artificial inoculation in greenhouse and checking the spore development. The susceptibility index (number of pustules/leaflet x number of urediospores/microscopic field) of these breeding lines ranged from 0 to 8 as compared 2 to 6 for Bragg.

Inheritance of Rust Resistance

Genetic data on segregation for resistant and susceptible plants were obtained in 1971 from $3F_2$ populations which involved resistant and susceptible parents (Table 14).

Table 14. Segregation for rust resistance in F_2 populations of soybean.

F_2 populations	No. of plants Resistant	Susceptible	X^2 (e:1)	Probability
UPSL 18 x Bragg	357	58	20.4	.01
UPSL 85 x Hardee	287	65	8.1	.01
UPSS-3 x Clark 63	314	89	1.8	.10- .20

The data fit a 3:1 ratio in only one population. In the other two populations the data did not fit to 3:1 ratio but were closer to a monogenic than a digenic ratio. In general, the number of susceptible plants was less than expected which might have been due to escapes of otherwise susceptible plants. Although not conclusive, these data suggested that rust resistance was a simply inherited trait. To confirm these ratios, individual resistant and susceptible plants were harvested separately and planted in 1972 for progeny testing. A large number of newly made F_1s also were planted. Unfortunately, the incidence of rust came very late in the season after most of the materials had matured and no screening could be done. Also in 1973 rust came very late and in mild form. Thus, due to erratic appearance of rust, it has not been possible to carry out further genetic studies.

Chemical Control of Rust

In order to identify suitable chemicals for rust control, a trial was conducted in 1971 using Bragg soybean and four fungicides: Dithane M-45, Dithane Z-78, Benlate and Plantvax. Each chemical was sprayed three times at an interval of 10 days with the first spray applied as soon as the disease was noticed (Table 15).

Table 15. Effect of fungicides on soybean rust.

Treatment	Rate kg/ha	Rust incidence	Yield kg/ha
Dithane M-45	2.5	Light	18.6
Dithane Z-78	2.5	Light	18.6
Benlate	0.5	Moderate	16.0
Plantvax	0.2	Moderate	12.3
Control	-	Severe	12.2

These data indicate that Dithane M-45 or Dithane Z-78 provided partial disease control. Further studies on chemical control of rust could not be conducted due to late and mild appearance of rust in subsequent years. Also, we were not able to maintain the fungus in the greenhouse.

Disappearance of Rust from India

Even though soybean rust was fairly severe and widespread in India from 1970 to 1974, it was not observed in either 1975 or 1976. The summer of 1975 was very hot with temperatures ranging from 40 to 44 C in several parts of north India. Probably the fungal spores were killed due to hot and dry weather in 1975 and since then there has not been sufficient buildup of fungal spores to cause disease. This observation is in consonance with the report of Marchetti *et al*. (94) that the Indian rust isolate is more temperature sensitive than others.

BREEDING FOR SOYBEAN RUST RESISTANCE IN INDONESIA

R. S. Sumarno and M. S. Sudjadi

Soybean leaf rust, caused by P. pachyrhizi, is considered the most serious disease problem in Indonesia (Sutakaria, 1964 and Oka, 1975 personal communications). Dahro (personal communication) had observed soybean rust in Bogor since 1956. In 1962 soybeans in Bogor were badly attacked by rust (Sutakaria, 1964 personal communication). Sutrisno Hadi who conducted surveys in 1964 found that rust occurred in all soybean regions of Java. Yield loss data are not available although Dahro (1964 personal communication) estimated an average of 20 percent yield loss caused by rust, mainly due to reduction in seed size. The soybean yield trials conducted in the rainy season 1974 in Bogor and Cirebon failed to produce seed, due to a rust epidemic (CRIA, unpublished data).

Yields were reduced as much as 81 percent for susceptible cultivars (TK_5), and 36 percent for the rust tolerant cultivar, Orba (Table 16). The data were average seed yields from 5,000g of matured dry plants and they were compared in the same location in both the rainy and dry seasons of 1974. The major difference between the two plantings was heavy rust infection in the rainy season and light rust in the dry season. High relative humidity enhances the severity of the disease which causes leaf defoliation and retards seed development. It appears that serious yield losses occur when there is a heavy rust infection during the pod filling period.

Most of the recommended Indonesian cultivars are susceptible to rust, with the exception of the field tolerant Orba. We feel that using resistant cultivars is the most effective method in controlling the disease because it is inexpensive for the farmers and nonpolluting. Breeding for rust resistance in Indonesia was begun in 1974.

When 50 cultivars at four locations were screened in the field in both the rainy and dry seasons, eight varieties were found moderately resistant to rust (Table 17).

Table 16. Average seed yield of soybeans obtained from 5,000g of mature dry plants harvested in the same location following both the dry season when no rust was present and the rainy season when rust was abundant.

Cultivar	Seed yield in grams[a]		Estimation of yield loss (%)
	No rust (dry season)	Rust (rainy season)	
TK_5	1283	252	81
Sumbing	1317	358	73
Shakti	1455	437	70
Amerikana	1108	331	70
Taichung E 32	1113	607	46
Orba	1516	971	36

[a] Insects controlled both in dry and rainy season.

Table 17. Reaction of soybean cultivars to soybean rust under natural infection in Indonesia (after Sudjadi 1974).

Cultivar	CRIA Acc. No.	Reactions[a]	Days to maturity[b]
San kuo	943	MR	95
Arosoy	1039	MR	98
LS_1D_2	1288	MR	95
--	778	MR	102
Jagus	966	MR	95
Bilomi-1	928	MR	100
Klungkung	767	MR	108
Ohito Okidaizu	842	MR	102
Ringgit	317	S-HS	85
Sumbing	452	S-HS	88
TK-5	1291	S-HS	83
Merapi	520	S	88

[a] MR = moderately resistant; S = susceptible; and HS = highly susceptible.

[b] Most of those moderately resistant cultivars were medium to late maturing, i.e., 95 to 100 days.

In another screening trial in Bogor, two seeds were planted in each pot, then beginning with 20-days-old plants inoculations of rust spores were made once a week for 8 weeks. Rust reactions were noted 6 days after each inoculation. Reaction type was determined by the highest degree of infection observed.

Three cultivars (Nos. 835, 986 and 1312) were resistant, 14 were moderately resistant, and 65 were susceptible or highly susceptible (Table 18). San kuo was resistant both in the field and the pot test, while Ringgit was highly susceptible in both tests. The resistant cultivars were medium to late-maturing, while most of the early-maturing cultivars were susceptible.

In late 1974, crosses were made between some recommended Indonesian cultivars and rust resistant cultivars No. 986, No. 1312 and San kuo.

The F_2 plants segregated for rust reaction under natural (field) infection. Individual plants with rust resistance and more than 100 pods per plant were selected. Crosses between Orba/No. 986 and Orba/San kuo gave 70 F_2 lines with more than 125 pods per plant. Those lines will be planted again the next season.

The resistant cultivar No. 986 was crossed with the two susceptibles TK-5 and Ringgit. F_1 plants were resistant demonstrating that resistance is dominant. The segregation ratio for the F_2 population was 9:7 between resistant or moderately resistant to susceptible (Table 19) showing that two major genes control resistance. Both genes must be present to condition resistance (epistatic). This is a preliminary study. More populations will be observed next season.

There are undoubtedly different races of the organism. Cultivars resistant in Bangladesh and Taiwan are susceptible in Indonesia. Much more work is needed to help understand rust resistance.

Table 18. Reaction of soybean cultivars to soybean rust after artificial inoculation in Indonesia (137).

Cultivar	CRIA Acc. No.	Reactions[a]	Days to maturity
	986	R	100
PI-HS/2	1312	R	97
Matsu-ura	935	R	95
Local variety	1630	MR	90
Orba	1343	MR	85
San kuo	943	MR	95
Rikuwa No. 8	840	MR	85
Pu-nu	875	MR	85
Hampton	993	MR	87
Hernon	1005	MR	106
Tainung No. 3	1327	MR	82
Line Americana	1400	MR	90
Ringgit	317	HS	83
CES 4-14	1609	HS	95
Local variety	1628	HS	85
AVRDC 2040	1649	HS	
Genjah Slawi	887	HS	80
York	1320	HS	80
Shi-shi	1326	HS	80

[a] R = resistant, MR = moderately resistant, and HS = highly susceptible.

Table 19. Number of rust-resistant and rust-susceptible F_2 plants from crosses between soybean cultivars No. 986/Ringgit and No. 986/TK-5 in Indonesia.

F_2 population	Number of plants R+MR[a/]	Number of plants S	Chi square (X2) value	Probability of accepting 9:7 fit (%)
Ringgit/986-1	8	10		
" -2	9	4		
" -3	7	13		
Total for population	24	27	2.00	15
TK-5/986-1	19	18		
" -2	12	8		
" -3	16	9		
Total for population	47	35	0.05	80
Total for both populations	71	62	0.49	50

a/ R = resistant; MR = medium resistant; and S = susceptible.

INTERNATIONAL RUST NURSERY

S. Shanmugasundaram

Soybean rust has been identified as a serious disease only since 1960. Now, it has been identified in a number of Asian countries from India through Japan. Sources of resistant germplasm have been reported in Australia, India and Taiwan. The resistance reported until recently are all from two plant introductions identified P.I. 200490 and P.I. 200492. In Taiwan several cultivars have been developed using resistance from P.I. 200492. A few of them are Kaohsiung No. 3 and Tainung No. 4. Tainung No. 3, Tainung No. 4 and P.I. 200492 also have been reported either immune or resistant to soybean rust in Australia. Utilizing the resistant germplasm Australia has developed breeding populations and are selecting for rust resistance. Field resistance to soybean rust based on natural infection also was reported from India. However, when most of the reported resistant soybeans were carefully screened in a field rust nursery and in the greenhouse at Asian Vegetable Research and Development Center (AVRDC), all of them were susceptible.

At AVRDC, in cooperation with the USDA Delta Branch Experiment Station, Stoneville, Mississippi, 1,080 soybean accessions were screened with and without fungicide in two separate fields. Multiple soybean rust readings were taken and only nine cultivars were found to be moderately resistant.

Interest was expressed by the breeders and pathologists in establishing an International Soybean Rust Nursery (ISRN) during the conference in 1976 at Chiang Mai, Thailand, with the following objectives (i) to identify sources of soybean rust resistance; (ii) to determine the race pattern of the fungus in the soybean growing areas of the individual countries; (iii) to identify the germplasm potentially available as international differentials; and (iv) to enable the participating countries to choose the best available resistant source for breeding.

In May 1976, 27 soybean entries (Table 20) with reported resistance to soybean rust were sent to 16 scientists in nine countries including: Australia, India, Indonesia, Malaysia, Philippines, Sri Lanka, Taiwan, Thailand, and U.S.A. Instructions were provided for inoculation and soybean rust rating. Results will be published.

Table 20. Soybean cultivars in the First AVRDC International Soybean Rust Nursery, Tainan, Taiwan.

Acc # or BM #	Designation or P.I. No.	Pedigree or Name	Country or origin
BM 27	S - 3	P.I. 200492 x CH - 3	Taiwan
BM 28	S - 4	P.I. 200492 x CH - 3	Taiwan
BM 29	S - 6	P.I. 200492 x CH - 3	Taiwan
BM 30	S - 13	P.I. 200492 x CH - 3	Taiwan
BM 31	S - 15	P.I. 200492 x CH - 3	Taiwan
BM 32	T - 3	P.I. 200492 x CH - 3	Taiwan
BM 33	T - 8	P.I. 200492 x CH - 1	Taiwan
BM 50	AnKur		India
BM 51	PK - 71 - 39		India
BM 52	UPSL - 18		India
BM 53	UPSL - 85		India
BM 54	UPSM - 91		India
BM 55	UPSM - 168		India
BM 98	X 74 - 853001		Australia
BM 99	TN #4	Tainung No. 4	Taiwan
BM 100	TN #3	Tainung No. 3	Taiwan
BM 101	P.I. 200492		Australia
G 7985	P.I. 60273		China
G 7988	P.I. 62204[a]		China
G 8260	P.I. 90406		China
G 8283	P.I. 159322		Korea
G 8293	P.I. 170891		South Africa
G 8375	P.I. 368039	Tainung No. 4	Taiwan
G 8377	P.I. 371609	VV 3	China
G 8529	P.I. 200492	Koma Ta	Japan
G 8586	P.I. 230970[b]		Japan
G 8587	P.I. 230971		Japan

[a] Moderately resistant to Mexican bean beetle in Maryland.

[b] Green cotyledon.

REACTION OF SOYBEAN CULTIVARS AND CHEMICAL CONTROL OF SOYBEAN RUST IN INDONESIA

M. S. Sudjadi, M. Amir and R. S. Sumarno

Soybean (Glycine max) is grown in two seasons in Indonesia, most in Java, Madura, Nusa Tenggara islands and some in Sumatra. Soybean cultivation will be gradually intensified from 75,000 hectares in 1974 to 270,000 hectares in 1978. The current yield potential is low about 6.89 qt/hectare in 1966, to 7.68 qt/hectare in 1975 (136, 138). Of several diseases encountered, rust caused by P. pachyrhizi is considered the most destructive disease, especially during the wet seasons. Yield losses are as high as 100 percent in cases where severe rust develops on susceptible cultivars with total defoliation.

Since cultivars of soybean react differently to the rust fungus, the search for resistant cultivars or lines under natural field conditions has been in progress for three years. As in any breeding program for disease resistance, the first step is to screen all available materials against the disease. The need for determining sources of resistance has been emphasized. Although some chemicals are now effective in reducing the disease incidence, breeding for resistance is the only economical way of fighting the disease.

Twice a year field screening is done in three locations, May to September for dry seasons and October to March for wet seasons, at CRIS's experimental station at Muara or Cikeumeuh, Bogor (West Java), Mertoyudan (Central Java) and Muneng or Genteng (East Java).

Although most germplasms are highly susceptible, there are certain lines or cultivars which are more tolerant or resistant. The Hinojosa and Mazzani's method for rust scoring has been used. The disease severity is rated into five groups, i.e., 0 = highly resistant (HR), 1 = resistant (R), 2 = moderate resistant (MR), 3 = moderate susceptible (MS) and 4 = susceptible (S). Disease ratings are conducted in a microplot with planting disease 30 x 20 cm; 2 and 3 meter in length with 3-row plots. Susceptible and resistant check plants (Ringgit and San kuo, respectively) are interplanted among five plots and bordered with a susceptible check around the block.

Screenings of 100 cultivars and lines for rust resistance under natural conditions at Muara, Muneng and Genteng were conducted during dry season 1974 to dry season 1975 (Table 21). There were only four cultivars and lines showing MS to HR reaction in the three locations, especially in the 1974/1975 wet season in which severe infection occurred at Muara, Bogor (all with MS reaction).

Similar screenings of 100 selected cultivars and lines were conducted at Muara and Muneng substations during 1975 dry season and 1975/1976 rainy season (Table 22). There were clear indications that cultivar reactions differ from place to place or from season to season. There are apparent races of the rust fungus. Otherwise, the weather conditions vary from season to season in the country and rust spore density at infection time may have influenced the severity of disease incidence. No spore counting was done.

Screening of 220 lines, 50 at Muara, 85 at Mertoyudan and 85 at Muneng was conducted during wet season 1976 (Table 23) where Ringgit and San kuo cultivars were used as susceptible and resistant checks. Only 3 lines were resistant to rust in Muara, 11 lines in Mertoyidan and 10 lines in Muneng. The data show less resistance at Muara. High humidity (varies from 81 to 91 percent yearly) and temperature (varies from 23.5 to 25.0°C yearly) may have enhanced the rust infection. The last 3 years' observations in Muara show more cultivars or lines with severe rust infection.

Twenty-five selected F_6 lines were screened against P. pachyrhizi in the field (Table 24). The data indicated that higher yield potentials were obtained over the improved cultivar ORBA and they show a resistant reaction to rust infection. These results show that prospects for the future are good and that there are possibilities for attaining high yield potential through a breeding program for rust resistance.

Control of Soybean Rust by Foliar Fungicides

The use of foliar fungicides may be one plausible means of combating rust. During the 1976 dry season, five fungicides, i.e., Bavistin, Benlate, Daconil, Dithane M-45 and Topsin M were tested for rust control under field condition at the Cikeumeuh substation, Bogor. Foliar applications with Triton sticker following recommended dosage for each fungicide were applied in 10-day intervals started 25 days after seeding (Table 25). The data showed the treatments in order of effectiveness to be Dithane M-45, Daconil, Topsin M and Benlate, all of which reduced disease severity significantly over the nonsprayed control. No phytotoxicity was observed for any fungicide. Leaf defoliation was significantly less in the Benlate treated plots. There were no significant differences in yields.

The results of these trials bring out the possibility of controlling rust through foliar sprays of fungicides. Among the fungicides tried, Dithane M-45 and Daconil gave good control to the disease. We plan to retest the promising fungicides in the 1976/1977 wet season to determine their efficacy since a heavier rust incidence will occur then.

Cooperative Research on Soybean Rust

With respect to the control of rust disease on soybean, the use of field (horizontal) resistance on soybean to rust is undoubtedly the most logical, practical, efficient, effective and long lasting. This method makes use of the natural defense mechanism of the plant itself. This also is especially suitable for developing countries since their research facilities, manpower, and finances are limited. Since field (horizontal) resistance is polygenic in general this method also is increasing the genetic diversity of the crop with respect to resistance.

The need for regional cooperation is obvious and it is hoped that this workshop will incite further cooperative efforts for solving problems of host resistance.

Table 21. Soybean cultivars (of 100) screened for rust resistance in Indonesia at Muara (Mu), Muneng (Mn), and Genteng (Gt) in the 1974 dry season, the 1974/1975 rainy season and the 1975 dry season[a/].

Cultivars CRIA Acc. No.	Reaction to rust						
	1974 dry		1974/75 rainy			1975 dry	
	Mu	Gt	Mu	Mn	Gt	Mu	Gt
Lumajang (1456)	HR[a/]	R	MS	HR	MR	MR	HR
Pressi (1458)	HR	MS	MS	HR	R	MR	HR
Bilomi-1 (928)	HR	MR	MS	HR	R	MR	HR
1248x945/0/0/4 (1338)	HR	MS	MS	HR	MR	MR	R
Ringgit (317)	S	S	S	S	S	S	S

a/ HR = highly resistant, R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.

Table 22. Soybean cultivars (of 100) screened for rust resistance in Indonesia at Muara (Mu) and Muneng (Mn) in the 1975 dry season and the 1975/1976 rainy season.

Cultivars/lines CRIA Acc. No.	Origin	Reaction to rust			
		1975 dry		1975/76 rainy	
		Mu	Mn	Mu	Mn
Bantul (1389)	Indonesia	MR[a]	R	MR	HR
Klungkung (767)	"	MR	R	MS	MR
Lampung (1460)	"	MS	R	MR	R
Pasuruan (1457)	"	MR	HR	MR	HR
Tegineneng (1454)	"	MR	HR	MR	HR
Mitsugoro (1464)	"	MR	R	MS	HR
Sambas (961)	"	MS	HR	MR	HR
Kal.Bar (1587)	"	MR	R	MR	HR
Sukoharjo (1465)	"	MS	HR	MR	HR
Lumajang (1456)	"	MR	HR	MR	HR
Madiun (520)	"	MR	HR	MS	HR
Sumbing (452)	"	MR	HR	MR	HR
Shakti (945)	"	MR	HR	MS	MR
Kepet (1401)	"	MS	HR	MR	S
Jagus (966)	"	MR	R	MS	MR
TK-5 (1291)	IRRI	MR	HR	MS	HR
Davros (1248)	Indonesia	MR	R	MS	MR
Eco. Gardens (1289)	IRRI	MR	R	MS	HR
Americana (1400)	Indonesia	MR	HR	MR	HR
Mark (1425)	"	MR	R	MR	HR
D.N.S. (1390)	"	MS	HR	MR	HR
N.B.B. (1397)	"	MS	HR	MR	R
16 B.B. (1396)	"	MS	HR	MR	HR
S.S. 33 (1037)	"	MR	HR	MR	HR
S.T.K. (1395)	"	MS	HR	MS	MR
Stongara (816)	"	MS	HR	MR	HR
Pressi (1458)	"	MR	HR	MS	HR
Black Manchuria (1306)	"	MR	HR	MS	HR
Pop (980)	"	MS	HR	MS	HR
F-94 (467)	"	MS	HR	MS	HR
Taichung E-30 (1290)	IRRI	--	MR	MR	HR
Clark-63 (1293)	"	MR	R	MS	MR
Bilomi-1 (928)	the Philippines	MR	HR	--	S
Calmetto (1329)	Taiwan	MR	HR	MS	HR
Otan (16)	"	MR	HR	MR	HR
Ohito Okadaimo-2 (842)	Japan	MR	R	MS	HR
CPI-15939 Avoyelles (903)	Australia	MR	HR	MR	HR
Burdette-19 (742)	U.S.A.	--	HR	--	HR
Wilson Black (951)	Venezuela	MS	HR	MR	HR
Yellow (832)	Tanganyika	MR	HR	MS	HR
San Kuo (R check) (943)	Taiwan	MR	HR	MR	MR
Ringgit (S check) (317)	Indonesia	S	S	S	S

[a] HR = highly resistant, R - resistant, MR - moderately resistant, MS = moderately susceptible, S = susceptible.

Table 23. Soybean lines resistant to rust from tests in Indonesia during the 1976 rainy season conducted at Muara (50 lines), Mertoyudan (85 lines) and Muneng (85 lines).

Lines resistant to rust		
Muara	Mertoyudan	Muneng
1291/986-1-7	1312/317-8-17	1291 987-3-3
1291/986-2-6	1312/317-8-19	1291/986-3-6
317/986-4-1	1551/1312-2-9	1312/317-3-11
	1551/1312-2-10	1312/317-3-16
	1551/1312-2-22	1312/317-5-11
	1551/1312-2-23	1312/317-
	1312/1551-3-6	1312/317-7-8
	1609/1343-1-4	317/986-6-5
	1551/1312-1-5	1312/317-5-1
	1551/1312-1-7	1312/317-7-8
	1551/1312-2-	-

1312 = PI-HS/2 (resistant, 317 = Ringgit (susceptible),

1609 = CES 4-14 (highly susceptible), 986 (resistant),

1551 = Wayne (susceptible)

Table 24. Selected rust resistant soybean lines of F_6 generations screened in Indonesia at Cikeumeuh during the 1976 dry season.

Lines[a/]	Crossing	Yield (kg/ha)	Rust[b/] reaction
943/1343-5-4-0	San kuo x ORBA	2.416	R
943/1343-1-3-0	"	2.427	R
943/1343-4-2-0	"	2.335	R
943/1343-3-2-0	"	2.421	R
1343/986-20-0	ORBA x a line	2.826	R
1343/986-22-0	"	2.422	R
1343	ORBA	1.883	MR

a/ 25 lines were tested; 943 - San kuo; 1343 ORBA; 986 (resistant) - a line of 5015/62/28/0/0/0/0.

b/ R = resistant, MR = moderately resistant

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Table 25. Foliar fungicides used for rust control on Ringgit soybeans during the 1976 dry season at Cikeumeuh substation, Bogor, Indonesia.

Fungicides	Dosages kg ai/ha/apl[a/]	Rust infection (%)	Leaf defoliation (%)	Yield gr/plot
Daconil	1.250	2.02**	32.9	408.5
Topsin M	0.735	4.37**	33.1	391.0
Dithane M-45	1.792	1.70**	33.2	374.3
Benlate	0.235	9.90**	31.5*	358.3
Bavistin	0.140	16.71	34.8	434.0
Check/untreated		35.20	36.9	444.3
	HSD 0.05 = 19.67		4.27	200.8
	0.01 = 24.80		5.39	253.2
	C.V. (%) = 48.14		5.28	21.7

a/ Five applications at 10-day intervals in plots 4 x 5 m2 in four replications.

* Significant at the .05 level.

** Significant at the .01 level.

CONTROL OF SOYBEAN RUST

Chemical Control of Soybean Rust in the Philippines — F. C. Quebral

Control of Soybean Rust by Means Other Than Breeding for Resistance — James B. Sinclair

CHEMICAL CONTROL OF SOYBEAN RUST IN THE PHILIPPINES

F. C. Quebral

In the early 1960's, two leading research institutions, the University of the Philippines at Los Baños (UPLB) and the Bureau of Plant Industry (BPI) initiated a sustained research program on field legume cultivar improvement and development, emphasizing soybeans. Just like any other economic crop, the improved and high yielding cultivars were threatened by injurious pests and diseases, soybean rust caused by P. pachyrhizi being among them.

The first record of the control of soybean rust by chemicals was published by BPI in 1965. The findings indicated that copper fungicide (copper Lonacol) at the rate of 363 grams per 379 liters of water applied a total of five times at 7- to 10-day intervals controlled soybean rust.

As newer fungicides became available, further testing and field trials were conducted. Two field trials, one during June to September 1974 (wet season) and another during November 1974 to February 1975 (dry season) compared the effectiveness of five fungicides for soybean rust control of two soybean cultivars; Clark 63 and T.K. #5. The fungicides were: Benlate, Dithane M-45, HOE 6052 50 WP, HOE 13764 and Plantvax 75 W. Spraying was done weekly with five applications during the wet and four during the dry season. Dithane M-45 was the most effective in reducing rust infection with significant yield increases of 64 and 24 percent in T.K. #5 and Clark 63, respectively (Table 26).

During the dry season of 1976, a paired plot experiment was conducted at the Central Experiment Station at UPLB. The treatment consisted of protecting one plot of each pair with a combination of Dithane M-45 and Plantvax 75 W at the rate of 0.91 kg/379 liters and 91 gms/379 liters of water, respectively, and leaving the other plot nonsprayed. Two soybean cultivars, Clark 63 and T.K. #5, were used. The fungicides were applied at weekly intervals five times. After the third application, the plants in the nonsprayed plots showed severe rust infection, leaves were turning yellow and defoliation was evident.

The mean disease rating using the three-digit scheme in the sprayed plots of T.K. #5 was: 133 for the bottom third leaves and 311 for the upper third leaves measured from ground level (Table 27). On the other hand, the nonsprayed plots had an average rating of 142 and 333 for bottom and upper third leaves, respectively. On Clark 63, the upper third leaves of the sprayed plots showed no rust pustules. These results show that Dithane M-45 and Plantvax 75 W applied in combination could check the development of P. pachyrhizi. Control of soybean rust invariably results in increased soybean yields (Table 28).

Table 26. Means for a rust index and yields from two cultivars of soybeans[a] nonsprayed and sprayed with fungicides during the wet and dry seasons in the Philippines.

Cultivar	Fungicide treatment	Rate per 379 liters	Means[b]			
			Rust index[c]		Yield (kg/ha)	
			Wet[d]	Dry[d]	Wet	Dry
T.K. #5	HOE 6052 50 WP	272 g	6.0	4.31	465.50	635.00
	HOE 1374	0.45 liter	5.75	5.75	610.25	523.75
	Benlate	454 g	5.75	4.61	724.75	683.25
	Plantvax 75 W	181 g	6.0	5.23	492.50	660.50
	Dithane M-45	907 g	3.87	4.32	1,138.25	650.25
	Nonsprayed		6.0	5.53	698.00	570.25
Clark 63	HOE 6052 50 WP	272 g	4.47	3.80	1,273.25	628.25
	HOE 1374	0.45 liter	5.66	4.18	1,699.50	722.75
	Benlate	454 g	3.75	3.88	1,793.75	758.50
	Plantvax 75 W	181 g	3.75	3.60	1,727.50	816.25
	Dithane M-45	907 g	2.74	3.40	1,997.50	764.75
	Nonsprayed		4.77	5.57	1,608.75	752.50

[a] Clark 63 and T.K. #5.

[b] Average of four replicates.

[c] Rust Index: no rust pustules; 1 = less than 10% of leaf area infected; 2 = 10 to 25% of leaf area infected; 3 = 26 to 50% of leaf area infected; 4 = 51 to 75% of leaf area infected; 5 = 76 to 90% of leaf area infected; 6 = 91 to 100% of leaf area infected.

[d] Wet season = June to September 1974; dry season = November 1974 to February 1975.

Table 27. Disease rating of two soybean cultivars infected with *P. pachyrhizi*, treated and not treated, 1976 (dry season) [a].

Cultivar	Treatment[a]	Plant location	Disease rating[b]
Clark 63	Treated	Upper	311
		Middle	211
		Bottom	123
	Not treated	Upper	333
		Middle	233
		Bottom	143
T.K. #5	Treated	Upper	311
		Middle	222
		Bottom	133
	Not treated	Upper	333
		Middle	233
		Bottom	142

[a] Paired plot experiment; treated with 0.91 kg of equal parts Dithane M-45 and Plantvax 75 W mixed in 379 liters water; average of 15 plants per treatment.

[b] IWGSR rating system.

Table 28. Influence of rust control on the yield of soybean in the 1976 (dry season).[a]

Cultivar and treatment		Pods per plant[a]	Seeds per plant[b]	Seed weight per plant (gm)	1000 seed weight per treatment (gm)[c]	Yield-kg/ha
T.K. #5						
	Treated	14.48	24.71	3.42	151.50	1072.45
	Not treated	12.49	18.73	1.46	82.00	568.79
Clark 63						
	Treated	28.54	50.77	7.09	136.25	1910.52
	Not treated	22.44	36.66	3.46	125.50	1162.44

[a] Five weekly treatments with Dithane M-45 and Plantvax 75 W at 0.91 kg mixed in 379 liters water.

[b] Average of 4 replications, 15 plants per treatment.

[c] Average of 4 replications.

CONTROL OF SOYBEAN RUST BY MEANS OTHER THAN BREEDING FOR RESISTANCE

James B. Sinclair

The eventual control of soybean rust will come through the development of a "pest-management system" rather than through the use of a single method or strategy. The development of resistant cultivars is the ideal means for control but at present there are few commercially acceptable cultivars resistant to P. pachyrhizi. Those cultivars now available have restricted use and are not resistant in all soybean-producing areas where rust occurs. A discussion on the progress and problems of breeding for resistance to the soybean rust fungus is in the "Breeding for Resistance" section of this publication.

Control with Fungicides

Information for the development of a well-planned program for the chemical control of soybean rust is not available. As an example, the economic threshold of soybean rust is not known. The occurrence and severity of soybean rust varies among regions, from season to season, and even within regions in the same season. The epidemiology of P. pachyrhizi is not understood and forecasting of soybean rust epidemics is not possible with the present knowledge. It would be ideal to have this information in order to develop an effective, cost-saving fungicide spray program for the control of soybean rust that would use the minimum amounts of pesticides and labor.

All of the work on the use of fungicides for the control of soybean rust has been done in the Far East where the disease has been a problem for many years. Most of the information published up to 1970 on the chemical control of P. pachyrhizi was abstracted by Sinclair and Dhingra (130). A number of systemic and nonsystemic fungicides used as sprays or seed dressings, alone or in combination, have been tested and the data published. A summary of the compounds most widely used and the sources of the data are presented (Table 29).

The fungicides or combinations used as sprays that have offered the most promise are: Benlate (68, 143), Bordeaux mixture (64, 68, 153), copper (153), Dithane M-22 (64), Dithane M-45 (68, 130), Dithane Z-78 (130, 152), Dithane Z-78 + sulphur (64), Karathane WD (153), lime-sulphur (7), o-methyl-benzoic acid acetate (68), Phygon XL (153), Plantvax (68, 118), Plantvax + Benlate (118) and Sankyo (68). Two reports (68, 143) stated that Benlate was effective while another report (118) stated that it was not effective. The rates used were often not stated in the source material. Dithane M-45 at 2.2 kg of 80% w/w per 200-400 liters per hectare for spray application and 2.2 kg of 80% w/w per 50 liters per hectare for aerial application is suggested for control of soybean rust in Australia (J. K. Kochman, Department of Primary Industries, Queensland, Australia, personal communication).

Fungicide sprays can be used to control rust, but additional research must be done. Fungicides that have been found effective must be compared with those that show promise to find the most efficient compound or combination of materials. Fungicides that have been used for the control of rust disease on crops other than soybeans need to be evaluated. Some of those that might be considered are: EL-222, mitram (Polyram), triforine and thiram (used for the control of the apple rust fungus) and BAY MEB 6446 and 6447, and BAS 31709 (used for the control of rust diseases of small grains).

Table 29. Fungicide sprays used for the control of soybean rust, country tested, and literature citation.

Fungicide[a]	Country tested and literature citation
Benlate (benomyl)	Taiwan (68), India (143)
Brestanol (triphenol tin chloride)	India (143)
Bordeaux mixture or copper	Taiwan (64, 68, 153)
Difolatan (captafol)	India (143)
Dithane M-22 (maneb) + wettable sulphur	Taiwan (64)
Dithane M-45 (mancozeb)	India (143), Taiwan (68)
Dithane Z-78 (zineb)	India (143), Taiwan (153)
Dithane Z-78 + wettable sulphur	Taiwan (64)
Karathane WD (dinocap)	Taiwan (153)
Lime-sulphur	Japan (7, 76, 77, 78)
o-methylbenzoic acid acetate	Taiwan (68)
Phygon XL (dichlone)	Taiwan (153)
Plantvax 75 W (oxycarboxin)	India (142), Thailand (118), Taiwan (68)
Plantvax + Benlate	Thailand (118)
Sankyo	Taiwan (68)
Six fungicides and five combinations (not specified)	Taiwan (36)

[a] The mention of these compounds here and in the text does not constitute an endorsement or recommendation by the author.

In general, it appears that for effective chemical control of soybean rust, with any of the materials so far tested, at least three to five or more fungicide applications are required on a weekly or 10-day basis. Thus spraying with fungicides for control of soybean rust is time consuming and expensive. Some of the yield loss data from the endemic areas of soybean rust show that in certain areas where losses of 80 percent reductions have been recorded that use of fungicides might be warranted. However, when losses are 10 or 15 percent, it may be difficult to justify the cost of the more expensive fungicides. Much more work must be done on timing, rates, number of applications, plant age and other factors affecting the use of fungicides for control of this disease.

Fungicide sprays can be used to determine the "economic injury threshold" for soybean rust, as well as protecting breeding lines. The use of fungicides may well be part of a "pest-management system," which could use moderately resistant cultivars and a few fungicide sprays to obtain reasonable control of soybean rust.

Seed Dressings

The use of fungicide seed dressings can be effective in controlling a wide variety of seed-borne microorganisms of soybean (130, 131). The only research on soybean seed dressings for control of rust was done in India, where it was reported that two systemic compounds, Benlate and Plantvax, were effective compounds (143). These results may indicate the influence of unknown factors in the epidemiology of soybean rust and need further investigation. Results from studies at the USDA, ARS Plant Disease Laboratory, Frederick, Maryland, and the Department of Plant Pathology, University of the Philippines at Los Baños, College Laguna discussed by K. R. Bromfield and L. L. Ilag, respectively, elsewhere in this publication, have shown that *P. pachyrhizi* is not seed-borne in soybean, suggesting that other means are involved in the long-range dissemination of the pathogen. In addition, the aeciospores live for only a few hours away from host tissue (K. R. Bromfield and L. L. Ilag, personal communication). Thus, seed dressing per se cannot be considered as an effective means for direct control of this fungus on soybean seeds.

Control with Methods other than Chemicals or Disease Resistance

A number of other methods are available for the control of soybean rust and need further study. Any one or a combination of these methods should be used in the development of a complete system for the management of the disease.

1. Date of planting: Soybean rust occurs at certain times of the year in different regions. This needs to be precisely understood and the information used to determine planting dates to avoid severe losses from this pathogen.

2. Early- and late-maturing cultivars: If the disease appears late in the growing season, crops may "escape" severe losses if they mature before the fungus can become fully established.

3. Spacing: Little is known about the effect of spacing on the epidemiology of soybean rust. However, observations suggest that this should be further studied as a potential means of reducing losses due to this pathogen.

4. Control of wild weed hosts: The host range of *P. pachyrhizi*, presented in the "Soybean Rust: An Overview" section of this publication, includes a number of wild legume species. Control of noncrop hosts with herbicides or other means in the vicinity of soybean production areas should be practiced. Until more is known about the aerial transport of the spores of this fungus, the extent of the area in which weed hosts must be controlled will be based on observation and good judgment.

5. Control of alternate hosts: It is still not clear whether or not *P. pachyrhizi*, like many other rust fungi, has an alternate host. There is some indication that it may have; if so, control of the alternate host near soybean production areas must be practiced.

6. Control of cultivated crops hosts: *P. pachyrhizi* has a host which includes a number of cultivated legume species, such as common bean (*Phaseolus vulgaris*) and lima bean (*P. lunatus*). These crops should be avoided near soybean production areas in regions where the pathogen is endemic.

7. Crop rotation: This practice has been effective for the control of other plant diseases and, because of the short-lived nature of the aeciospores, it is presumed that crop rotation may be an effective means for control of this disease. However, field studies should be done to determine the feasibility of this practice.

8. Intercropping: There is no evidence that intercropping will provide disease control but studies need to be made to test this possibility.

9. Transport of host material: The long-range transport of host plant material, other than seeds, whether wild host species, cultivated host species, or alternate hosts should be forbidden until proof is accumulated that the fungus is not carried in these tissues. The long-range transport of seeds of the various hosts should be regulated, except in the case of soybeans for which there is evidence that fungus is not seed-borne.

10. Planting of nonhost barriers: In endemic areas, nonhost plant barriers should be planted around soybean fields or larger production areas to reduce the amount of air-borne inoculum (if this is shown in time to occur) from one area to another.

11. Sanitation measures: All plant debris of hosts of this fungus should be destroyed after harvest either by burning, plowing under, chemical treatment or other such means, until it is known the extent to which this fungus can overseason in the tissues of its various hosts.

12. Surveillance and inspection: Constant surveilence of endemic areas and inspection of exported and imported host materials, including seeds, is necessary for local, regional and international control of this pathogen.

13. Biological control: There is little known about the potential use of biological methods for control of *P. pachyrhizi*. If and when this practice becomes available, it should be used in an all-over control program.

CLOSING REMARKS

R. E. Ford

CLOSINC REMARKS

R. E. Ford

May I be philosophical before getting specific? It has surprised many of us in the western world how quickly an emphasis can change. We have been accustomed to seeing world influence or power expressed in various ways such as numbers of people, territorial land mass, or military prowess. Then technology became the controlling influence. Many of us who read George Orwells' 1984 thought it utterly impossible that computerization and sound transmission technology would catapult us into a "big-brother-is-watching-you" era exemplified by Watergate.

Then almost overnight energy became the big word. Just stop and think, you who enjoy a mild climate year round, what would happen if all we northerners, because of the lack of energy, would move into the tropics for survival, and commute to raise our crops. What kind of sociological rules will guide us? We have a joke phrase in the U.S. for more affluent farmers - they have a "corn-soybean - Florida rotation" because they can afford to travel south annually to enjoy the winter warmth. When energy runs low it will cease to be a joke, rather it will be a matter of survival. Size of land mass suddenly has less influence than the energy to be tapped under it or over it.

Most importantly food now has become a new "power base." Food was taken for granted when there was ample room on this globe for migration. There are now precious few corners left in this world for such population expansion. Suddenly everyone is aware of weather patterns and how they influence the bread baskets of the world. Suddenly agriculture, which was the literal step-child or door mat, now can attract headlines on page 1 rather than page 12 of a 12-page newspaper. For instance, we all notice coffee and tea prices, as well as wheat, rice and soybean prices.

Some say "in the face of starvation we have a moral commitment to feed everyone; so it is amoral to use food as a political power base." Not many countries can afford to hold the same high ideal unless centers of influence such as UN, UNESCO, FAO, etc. can solidify the world politic.

Suddenly protein has more positive impact and more constructive potential than the destructive potential of TNT or splitting the atom. It is a nutritional fact that the lack of protein causes unending human grief; adequate protein in a diet allows people to be healthy, clear-thinking and vital, full of life.

Suddenly the soybean is now recognized as a unique food package in most of the world. The nutritional qualities of soybeans have been recognized in the Orient for years. Education and research have helped us understand the requirements for human nutrition, a balanced protein and carbohydrate intake. In the western world, until a few years ago, soybeans were primarily protein for animal feed and only the oil was used for human consumption. Oil is now often the secondary product and the demand for protein will be the key to the future of soybean production success.

We have been dealing this week with a difficult problem, a disease called soybean rust caused by P. pachyrhizi, purported to be the key limiting factor to soybean production in an area of the world capable of growing this crop. Rust is just one component, yet by many it was deemed so important that an elite few scientists were asked for advice. It is not unlike President Marcos in his televised speech on 25 February 1977 to his people who had just completed civil service training. Your President was speaking about the Mindanao situation and he gave rebels amnesty. He also told these new employees "You are the elite leaders. You will provide a new kind of leadership. We'll use a new kind of weapon - education and social improvement of the masses - not destructive devices."

Likewise you are an elite few scientists in the world who know more than anyone else about soybean rust. As with food, knowledge is also power and you can use this power for doing good in your own country. I am not so naive to think a funding agency will suddenly rise up out of their chairs when they read our request for help even though it be such a worthy cause as aiding in the solution of more protein for more people. It will require yet more work than was put forth this week. Our job is to go back home and sell it to our own peers and administrators, the very people on your own soil who understand. I believe with a unified and coordinated approach we will succeed in attracting support for our efforts.

The attached outlines developed by the various working groups are the backbone of our proposal. Unexcelled judgments have gone into this document.

I may have erred earlier in the week by not providing some of you with information about INTSOY and its mission. It is a variant of the international center concept. You know the centers such as IRRI, ICRISAT, CIMMYT, IITA and others. INTSOY is a research education and outreach program with the resource base centered in a developed country, and at two universities. A major purpose is to do research on the soybean because we believe the high protein content of this crop is one of the answers to world food needs. The concepts underlying INTSOY continue to develop and its exact future administrative structure may be different. But that is not the important thing to remember. The important thing to remember is our mission to expand the use of soybeans, especially for human food and assembly of world expertise on soybean in all phases of production, processing and use.

The state of Illinois and even the U.S. will not see a large change in amount of land devoted to soybean production. We have essentially no more land to be brought under cultivation without some drastic events such as opening up new land with irrigation or denuding forests. Therefore, the main thrust of INTSOY is to assist any country interested in learning how to grow and use soybeans, or how to do it better.

This group has responded by contributing information and data concerning:

A. The global importance of soybean rust, its suspected geographical distribution, estimated annual losses by country, and other economic factors.

B. The state of the art of existing knowledge, published (and more important, unpublished) information; areas of research still required; methods of systematically sharing relevant knowledge and seed cultures; the present resources now being contributed to the study of soybean rust; and the willingness of participants to contribute greater resources through the program.

C. Each country's interest in developing a coordinated, cooperative strategy for soybean rust work.

D. Local research in progress.

E. Local interest in expanding additional research needs for soybean rust studies.

F. The need for a "coordinating mechanism" for a comprehensive soybean rust program.

G. The formulation of plans to send seed of elite breeding materials to researchers at sites throughout the Asian area for rust screening.

H. Agreement on method for evaluating and recording rust severity on genotypes in the field.

I. The need for a "joint research committee" to recommend Asian, Australian and U.S. scientists for an exploratory visit to countries where rust epidemics limit soybean production, and

J. The need for the "joint research committee" to develop a proposal for a long-term coordinated program for the study of soybean rust, which would be considered for funding from foundations and other national and international funding agencies.

In addition, the participants have identified countries and people who have special expertise in one or more of the following areas of research and have listed research thrusts in priority order including, but not restricted to the following:

A. Pathogen identification:

To isolate and identify and characterize *P. pachyrhizi* isolates or strains that cause soybean rust under different ecological and climatic conditions of the regions from each participant.

B. Rust nursery:

1. To have a complete picture of the relative incidence of soybean rust in growing areas that are representative of the wet, humid tropics and subtropics.

2. To study the etiology and reaction of soybean cultivars to *P. pachyrhizi* in the nursery.

3. To develop control measures, both biological and chemical, for soybean rust.

C. To study the biology and life cycle, including possible alternate hosts, of the rust pathogen and the disease development of the rust.

D. To study the host-parasite interrelationship and determine the environmental factors of each stage from host infection through the disease outbreak (secondary and subsequent infection processes).

E. Disease screening and resistance breeding.

F. Studies on the host ranges and their identification.

G. Identification of the races and their differential hosts.

H. Study the environmental effects of seasonal climatic and meteorological factors which influence rust outbreaks in various geographic regions and devise a rust forecasting system.

I. Study the global dissemination and distribution of the pathogen and its races.

J. To establish international soybean cultivars trial nurseries to evaluate the performance on rust resistance of advanced soybean lines contributed from each cooperator.

K. To establish a long-term rust resistance breeding program and invoke a standard rust evaluation system to assess uniformly this disease in all soybean-growing areas of the world.

L. To study the disease resistance mechanism, broaden the genetic base of soybean and its inheritance against the rust disease.

M. To devise systems for standard yield-loss estimates and potential economic impact of rust on soybean production of the world.

N. Study control of soybean rust through development and applications of fungicides.

O. Study crop management practices as they influence soybean rust control.

Long-Term Objectives

The following long-term objectives for the proposal (5 years) are to:

A. Improve understanding of current and future practices in soybean rust control and their applicability in all tropical and temperate regions. (A coordinated team effort is necessary among all cooperators.)

B. Develop mechanism to effect interdisciplinary research, advisory and extension capabilities relating to soybean rust control of the tropical and subtropical regions.

C. Improve education capabilities for university students and staff to acquire greater knowledge of the principles and practices of controlling soybean rust and other problems of soybeans in the tropics and subtropics.

D. Develop comprehensive knowledge, expertise and experience on major problems of rust control of soybeans for tropical and subtropical areas, and prevent the possible spread of this rust to major soybean production areas of the world.

E. Establish soybean rust nurseries in different ecological or geographical areas in Asia and Oceania to detect the disease presence and study the etiology and reaction of soybean cultivars to rust and to develop biological or chemical control measures for the disease.

F. Initiate and expand graduate and production training programs in control of soybean rust.

G. Screen local rust resistant varieties and advanced breeding lines for their performance under natural and artificially created rust epiphytotic conditions in rust nurseries.

H. Establish research and information linkages with U.S. universities, countries of Asia, Oceania and international centers to inform about the progress on soybean rust research around the world.

Some objectives and research approaches will change as new information is gathered, as new technology emerges, and as more new scientists devote their energies to solving this problem. It is imperative that each country where rust is present devote resources to its solution. Furthermore, it is essential that all soybean-growing countries be aware, and ready to devote resources to the solution of the soybean rust problem.

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INDEX

INDEX

	Page
Aecia	18
Aeciospores	16, 17, 47, 87
Alternate Hosts	17, 31, 56, 87, 88, 93
Amir, M.	73
Axenic Culture	16, 57
Bas Compounds	85
Bay Compounds	85
Bavistan	74, 78
Benlate	See Benomyl
Benomyl	58, 64, 74, 78, 81, 82, 85-87
Biological Control	88
Biotypes	34, 36, 57, 61, 68, 93
Bordeaux Mixture	85, 86
Brestanol	86
Bromfield, K. R.	11, 27, 34, 42, 43
Byth, D. E.	44, 48, 58
Cajanus sp.	24
Canavalia sp.	24
Canavalia villosa	19
Captafol	86
Centrosema pubescens	19
Chan, K. -L.	51
Chemical Control	25, 31, 32, 46, 48, 58, 64, 81-88
Chlorothalonil	46
Chung, B. J.	49
Control	25, 31, 32, 58, 64, 74, 78, 30-90
Copper	85, 86
Copper Longcog	81
Crop Rotation	88
Crotalaria sp.	24
Crotalaria stricta	19, 21
Crotalaria linifolia	38
Daconil	74, 78
Desmodium sp.	24
Desmodium rhytidophyllum	38
Detached Leaf Culture	3, 51
Dichlone	86
Difolatan	86
Dinocap	86
Dithane M-22	85, 86
Dithane M-45	25, 31, 32, 58, 64, 74, 78, 81-86
Dithane Z-78	85, 86
Dithane + Zinc	46
Dolichos lablab	18, 19, 21, 24
Economic Importance	7, 23, 25, 34, 42, 46, 47, 49, 51, 58, 62, 63, 64, 66, 73, 92
EL 222	85
Epidemiology	31, 32, 37, 38, 42-44, 46-48, 56, 66, 73, 85, 87, 93
Ford, R. E.	3, 5, 7, 43, 91
Fungicides	25, 31, 32, 58, 64, 74, 78, 80-87
Genetic Control	See Resistance
Geographic Distribution	16, 18, 19, 20-23, 31, 34, 35, 43-46, 49, 50, 58, 62, 73, 92-94
Glycine clandestina	44, 46
Glycine formosana	24
Glycine hispida	24
Glycine soja	24, 26
Glycine ussuriensis	24, 59, 60
Glycine uightii	24
Hardenbergia sp.	24
HOE 6052 WP	80, 82
HOE 13764	80, 82
Host Range	17, 21, 24, 31, 34, 35, 43, 44, 46, 49, 50
Ilag, L. L.	16
Inhibitor (self)	28
Intercropping	88
International Rust Nursery	71
International Working Group on Soybean Rust	3, 30, 31, 46
Karathane WD	85, 86

	Page
Kennedia sp.	24
Keogh, R. C.	27, 34
Kochman, J. L.	21, 34, 44, 46
Lantican, R. M.	54
Lespedeza sp.	24
Lime-Sulphur	86
Losses	See Economic Importance
Lotus	24
Lupinus sp.	24
Maneb	25, 31, 58, 64, 74, 80, 83-86
Macroptilium sp.	24
Mancozeb	46
Marchetti, M. A.	27, 65
McLean, R.	44, 48, 58
Mitram	85
Moisture Effects	38, 73
Mucuna capitata	24
Nursery	4, 71, 93, 94
O-Methylbenzoic Acid Acetate	85, 86
Oxycarboxin	31, 46, 64, 81-86
Pachyrhizus bulbous	24
Pachyrhizus erosus	24, 31
Park, C. S.	49
Phakopsora crotalaria	21
Phakopsora sojae	26
Phakopsora vignae	21, 24, 26, 35
Phaseolus coccineus	19, 24
Phaseolus lathyroides	19
Phaseolus longepedunculatus	19
Phaseolus lunatus	19, 21, 24, 88
Phaseolus macrolepis	19
Phaseolus vulgaris	19, 21, 24, 88
Photoperiod Effects	16, 38
Phygon	85, 86
Physiologic Races	33, 34
Physopella concors	18, 21
Physopella vignae	21
Plantvax	31, 32, 46, 64, 81-87
Plantvax 75W	82, 86
Polyram	85
Psoralea sp.	24
Pueraria lobate	24
Pueraria phaseoloidea	24
Pueraria thunbergiana	24, 49
Quebral, F. C.	81
Races	See Biotypes
Rating System	11, 12, 13, 30, 31, 32, 81, 83
Resistance	7, 28-32, 36, 37, 42-44, 46, 48, 50, 52-80, 93
Rhynchozia sp.	24
Riley, J. J.	6
Sanitation	88
Sankyo	85, 86
Saprol	31, 32
Seed Dressings	87
Self-Inhibitor	28
Shanmugasundarum, S.	11, 56, 71
Sicarol	31, 32
Sinclair, J. B.	18, 34, 35, 43, 85,
Singh, B. B.	36, 62
Soybean Cultivars	22, 25, 28-30, 35, 36, 46, 51, 52-81, 93
Sujadi, M. S.	66, 73
Sulfur	85, 86
Sumarno, R. S.	66, 73
Susceptibility	7, 28-32, 36, 37, 42-44, 46, 48, 50, 52-80, 93
Symptoms	18, 22, 35
Taxonomy of Phakopsora pachyrhizi	18, 21, 26
Telia	18, 27, 38
Teliosori	26, 27, 38
Teliospores	18, 26, 38, 39
Temperature Effects on Soybean Rust	16, 28, 37, 38, 46, 47, 56, 93
Terannus unicinatus	18, 19, 21, 24
Thapliyal, P. N.	62
Thiabendazole	74, 78
Thiram	85
Thompson, W. N.	5, 7
Topsin M	74, 78
Triforine	85
Uredo concors	18, 21
Uredo sojae	26

	Page
Uredo vignae	21
Uredosori	22, 26, 27, 35-37, 46, 47
Uredospore Germination	17, 27, 87
Uromyces sojae	26, 34
Valmayor, R. V.	8
Varietal Resistance	See Resistance
Vigna lutea	19
Vigna mungo	19
Vigna radiata	24
Vigna repens	24
Vigna sesquipedalia	24
Vigna sinensis	24
Vigna unguiculata	19, 24, 35
Xanthomonas apelina	18
Zanthomonas phaseoli var. *sojensis*	18
Yang, C. Y.	11, 22
Zineb	86