INTRODUCTORY
PLANT PATHOLOGY

By

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PLEASE GO THROUGH DEEPLY

To my wife

Mrs LAXMIBAI M KAMAT [redacted]

[redacted]

Whose life of service & sacrifice
has provided great inspiration
for this compilation

M N K.

PREFACE

This book, second in the series, primarily aims at the treatment of the fundamental aspects of the science of plant pathology which is basic to the proper understanding of this subject in its applied aspects It does not deal with specific diseases and their description The latter aspect has been dealt with by the writer in his earlier book entitled "*Practical Plant Pathology*" published in 1953 The phenomenon of disease in plants and the various events that lead to it have been the main theme of the book It supplements the author's earlier book and is intended to complete a course, both theoretical and practical, in plant pathology at the B Sc level as sponsored by Indian Universities

Although mainly written for Indian students, the book has been so planned as to be useful elsewhere Many of the examples given in the text to illustrate the subject matter are borne of practical experience gained by the writer while engaged in research and extension work for a period of over 25 years The outline and general plan of the book are based on the experience gained through a course of lectures delivered by him to the B Sc and M Sc students of Agriculture and pure botany during this long period

The book comprises of 28 chapters, self contained in themselves the first fifteen of which are devoted to the discussion of events, as they occur in natural sequence leading to the complex phenomenon of disease Although the basic principles of plant pathology do not vary from region to region, every attempt has been made to cite examples and illustrate the text from Indian material as far as possible so as to make the topics specially intelligible to Indian students, for whom the text is mainly compiled The references at the end of each chapter have been specially selected to guide the students to a more detailed discussion of the topics under reference and represent only the classical and more recent citations on the subject

The main inspiration for the compilation of this work came from the brilliant lectures of Dr E C Stakman until recently Head of the Division of Plant Pathology, University of Minnesota, U S A and now Professor *Emeretus*, under whom the writer had the privilege to work during 1931–32 and to whom, therefore, must belong the major credit for this compilation The author wishes to express his sincere appreciations and gratitudes to him for this inspiration and encouragement He is also indebted to Dr J J Christensen of the same University for his assistance, interest, helpful suggestions and for the supply of the recent portrait of Dr E C Stakman appearing in the text

It will be only in the fitness of things to mention here some of the works, which have also greatly inspired the writer in this task Gaumann and Brierley's "*Principles of Plant Infection*", Chester's "*The nature & prevention of plant diseases*", Stevens and Steven's "*Disease in plants*", Butler and Jone's "*Plant Pathology*", to mention only a few, have been of great assistance in the present compilation, along with many others cited in the body of the text Gaumann's unique treatise on the theory of plant pathology has been of special significance in this matter, as it has greatly helped the writer in presentation and marshalling of facts and figures occuring in the present text Sincere acknowledgements are due to these authors and their publishers for the same

The author also wishes to express his deep sense of gratitude and thankfulness to the late Prof S L Ajrekar, Dr M J Thirumalachar, Dr N R Bhatt, Dr Kisan Singh Bedi, and Dr S P Capoor for valuable assistance, helpful suggestions and interest during this compilation Dr N R Bhatt, Dr S P Capoor and Dr K S Bedi deserve my special thanks for critical reading of several chapters Mr S G Abhyankar of the Plant Pathology Department, College of Agriculture, Poona, undertook critical reading of the entire manuscript from the point of view of students, who ultimately are the best judges of the usefulness of this compilation Special mention must also be made of the valuable help that I received from Miss Kumud Lad, who made a large number of line drawings for the book and to my brother Mr V N Kamat for his ready assistance in typing, reference work and preparation of index Dr M J Thirumalachar was good enough to supply me with the original photograph of Professor Gaumann appeaing in the text My thanks are also due to Miss Shirin Irani for the supply of excellent photographs appearing in Chapter Six of the book My sincere appreciations and gratitudes are due to all these friends for the deep interest they have taken in this compilation, but for which it would have been difficult to bring forth this volume All the same, responsibility for any shortcomings and errors, factual or otherwise and interpretations, in this compilation, however, must entirely belong to the author

Since economic considerations were an important guiding factor in this compilation, the author has made special efforts to condense the discussion of the topics, covering all important aspects of the subject under discussion and avoiding details, which, the student will do well to obtain from the references appended to each chapter The present compilation must, therefore, be considered more of an introductory nature, seeking to acquaint the student with this important science and arouse in him interest and inquisitiveness for the subject matter This has been made possible by the inclusion of a large number of figures and illustrations specially prepared and selected for depicting important phenomena described in these pages

The author wishes to express his thanks to the proprietors of Prakash Printing House, Poona, for their efforts in speeding up the printing work and general help rendered in proof reading

In conclusion, I must say that the work of compilation of this book is borne of an innate and sincere desire to help the cause of Indian students, who, in the absence of a suitable Indian text, were greatly handicapped in their studies Above all, it has been a "labour of love With the completion of the two volumes, the "Five Year Plan set forth before him by the author since his retirement in 1952 has been amply fulfilled I must, however, leave the question of the actual measure of success and usefulness of this compilation to my readers, both teachers and students, who I trust will show their indulgence and appreciation for the humble efforts made therein to fulfill the urgent needs of Indian students by providing them with a text in this important phase of Agriculture

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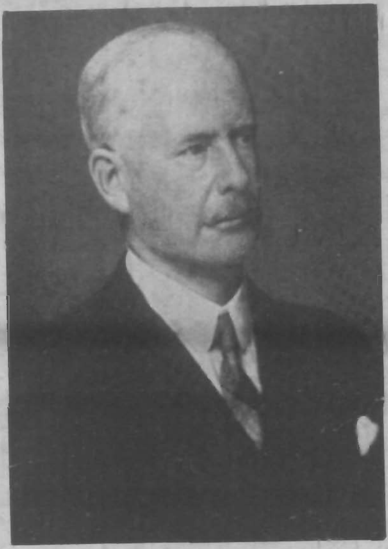

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(1874–1943)

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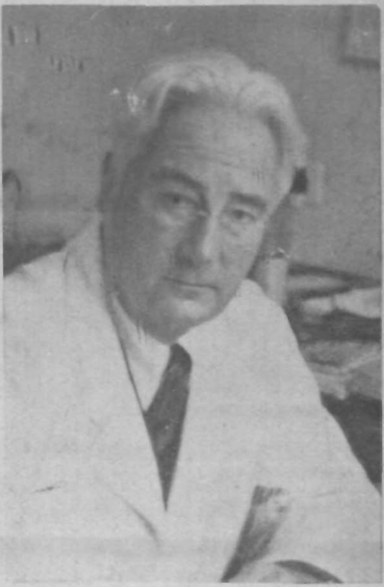

E. GAUMANN

clamps. The two nuclei remain in pairs and divide as such (conjugate) and only fuse prior to formation of spores. No special sex cells are produced. The mushroom fungi are characterized by this process. Insects play an important role in the process of "diplodization" in *heterothallic* forms of mushroom fungi (Fig. 9).

It will be seen from the above discussion that while the sexual process has a fixed pattern in the lower groups of fungi, it is highly flexible and labile in the higher fungi. A single sexual act gives rise to a single sexual spore in the lower groups, while it is followed by the production of many sexual spores in the higher fungi, where in addition, the sexual phase is prolonged, over long periods often lasting several years, so characteristic of the mushroom fungi (Fig. 10).

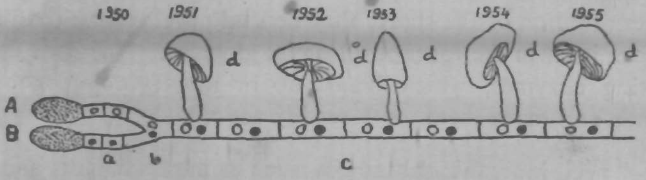

FIG. 10. Sexual reproduction in a mushroom fungus. A & B. gametes, a. haploid mycelia, b. plasmogamy, c. dikaryophase, d. annual recurrence of fruit bodies.

[Modified from Gaumann.

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CHAPTER 1

INTRODUCTION

Phytopathology (*Phyton* = plant + *pathos* = disease + *logos* = discourse) deals with diseases of plants Man has concerned himself with these diseases since times immemorial, as they affected vitally the interests of his agriculture and thus his welfare Ignorance and superstition, however, shrouded the true concept of disease, until the development of the compound microscope and more accurate micro-techniques Romans, Greeks, Hebrews and the Chinese people interested themselves in the well-known fungi, the mushrooms, as they were amenable to vision and were useful as food In the absence of rational knowledge, diseases in general were considered to be the visitations of deities and ghosts, the wrath of gods and goddesses and the result of evil influences of the planets Festivals and public worships, thus, formed the order of the day and were mainly aimed at propitiation of these elements The relics of such superstitious practices persist even today The subject was one of discussion by philosophers, like Aristotle and Theophrastus, rather than of scientific investigation based on observation and experimentation

The discovery of printing in the 15th century and the invention of the microscope by Loewenhoek in 1683 had a profound effect on the rapid progress of this subject and gradually brought in order and reality in place of ignorance and superstitious dogmas, culminating in the publication by great scientists like Robert Koch, Louis Pasteur and Anton de Bary of their brilliant and epoch-making observations and researches, which ultimately established, beyond doubt, the pathogenic nature of disease (Pathogenic theory) discrediting the deeply-rooted dogmas of " autogenesis " and spontaneous generation (Unger, 1833)

DEFINITION OF DESEASE

Disease is a complex phenomenon and according to modern conception, is an interaction among the host, the parasite and the environment It can be aptly defined as a disturbance in the rhythmical equilibrium of a host in respect of structure or physiology or both, and may lead to the death of a part of or the entire host or reduce the economic value of its products. A broad, agricultural concept of disease, however, should include such of the phenomena, as directly or indirectly affect economy and the economic performance of the host and reduce the market value of such products Disease thus may have an individual and an agricultural aspect The latter directly affects agriculture and naturally has to be considered in relation to the various factors, such as variations of host, seasons and soil, cultural practices and the nature of the pathogen, which profoundly influence it The following account relates to this sociological and economic aspects of disease, which constitute the modern science of **Phytopathology**

ECONOMIC IMPORTANCE

The study of this science is of vital importance to agriculture and ultimately to mankind Diseases in plants and agricultural crops have taken heavy toll resulting in wide-spread damage to and ruin of agriculture, our mainstay Serious epiphytotics of these diseases have brought in food scarcities of unprecedented nature and jeopardised the welfare of humanity and even the political status and economic policies of a nation The disastrous outbreaks of citrus canker, the white pine blister rust, the Dutch Elm disease and the Chestnut blight in North America, the introduction and ultimate epiphytotic nature of late blight of potatoes (1845), the wart of potatoes (1918), the downy and powdery mildews of grapes (1845), the gooseberry mildew in Europe and England (1900), the notorious and destructive epidemics of coffee rust in Ceylon (1870–86), of downy mildew of grapes (1928–30), the black stem rust of wheat (1947), the blast of rice (1949) and the disastrous outbreak of the *papaya* mosaic of virus origin in parts of India (1947), to mention only a few, are well known examples of epiphytotic diseases, which have ruined the various agricultural, horticultural and silvicultural industries all over the globe, and have caused in many countries, total famines and have become a serious menace to national economy

The estimated loss caused by the 1947 outbreak of stem rust in India was Rs 50 crores The smuts of sorghum are equally destructive and are responsible for an annual loss of Rs 10 crores to the Indian exchequer Annual crop losses due to various diseases were estimated at 3 billion dollars in recent years in U S A and at 10% in Germany in 1929 The serious epiphytotic of late blight of potatoes (1914–18) is said to have played a decisive role in the defeat of Germany during World War I

The enormous losses caused by the *koleroga* of arecanuts, the *Phytophthora* wilt in betelvine, the *Fusarium* wilts of cotton and banana, the bunchy top of banana, the powdery mildews of mango, peas, cumin and many vegetable crops, the leaf rust of coffee, the virus diseases of potato, the "*Katte*" disease of cardamoms, the bacterial ring of potatoes, the black rot of cabbage and many others in parts of India are too well-known and have been largely responsible for food shortages and entailed misery and privation to millions The following table will give an approximate idea of the magnitude of the losses sustained by the Bombay State alone in respect of the outbreaks of diseases in the case of a few crop plants

Table 1

*Estimated crop losses caused by disease in the Bombay State**

Crop	Area in acres	Disease	Estimated loss in rupees
Sorghum	85,31,500	Smuts	200,00,000
Cotton	14,16,000	Fusarium wilt	14,16,000
Sugarcane	1 64,000	Red-rot	550,00,000
Citrus	21,000	Gummosis	21,00,000
Arecanut	20,300	Koleroga	5,00,000
Grapes	1,000	Mildews	1,35,000
Piper betel	400	Phytophthora wilt	1,80,000
Lathyrus	50,000	Fusarium wilt	2,00,000

* Compiled from crop reports of Bombay Department of Agriculture

DISEASES AND THEIR CLASSIFICATION

Diseases could be classified on the basis of (1) groups of host, (2) parts of plants affected, (3) gross effects produced on host (symptoms), (4) pathological effects on host and (5) etiology Diseases of such plant groups like cereals, citrus, vegetables, narcotics, legumes, fruit trees belong to the first category, while diseases of roots, stem, leaves, flowers, fruits etc constitute the second group Root-rots, wood-rots, fruit-rots, dry-rots, leaf spots, blights, foot rots, canker, anthracnoses, wilts and others constitute the third group of diseases Diseases can also be classified under the fourth category according to the pathological effects produced in plant tissues Those involving destruction of tissues may be termed **necrotic** diseases, those bringing about reduction in growth and structure, the **hypoplastic** diseases, while those involving overgrowth may be known as **hyperplastic** diseases Under the necrotic diseases can be grouped such common maladies like wilts (destruction of vascular tissue), leaf-spots (destruction of lamina), canker (destruction of parenchyma) and so on The hypoplastic diseases involve reduction of tissues, parts of plants and even entire plant, such diseases as mosaics, yellowing, small-leaf, little-leaf, dwarfing, atrophy, belong here, while hyperplastic diseases include formation of galls, tumours, witches broom, blisters, bunchy top, etc The classification of diseases according to their nature, is based upon the consideration of their cause and etiology and naturally is more rational, as it helps the plant pathologist in basic understanding of disease and to devise scientific methods of avoiding, preventing and controlling such diseases.

The last category of disease, thus, can be recognised under three heads, viz parasitic, non-parasitic and virus In parasitic diseases, the causal agent is a living entity and the disease is infectious in non-parasitic diseases, no living organism is involved and they are non-infectious The exact position of the causal agent of virus diseases in the scheme is problematical and occupies an intermediate place, combining living and non-living characteristics (Burnet, 1945) A detailed scheme of such a classification is given below —

DISEASES

Parasitic		Virus	Non-parasitic
Animal	*Plant*		
(i) Animals	(i) Phanerogams		(i) Environment
(ii) Birds	(ii) Algae		(ii) Deficiencies
(iii) Insects	(iii) Fungi		(iii) Accumulation of injurious chemicals
(iv) Nematodes	(iv) Bacteria		
(v) Protozoa	(v) Slime-moulds		

While the role of the various agents, living and non-living, outlined above, in inducing disease cannot be minimised, the field is so wide that it would be impossible to cover it in a small space, and must, therefore, be abandoned for a more restricted scope of study Since fungi and closely related organisms form the bulk of the parasitic agents in plant disease, the scope of these pages will be restricted to the consideration of these organisms and the role they play in the phenomenon of disease

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CHAPTER 2

HISTORY OF PLANT PATHOLOGY

Diseases in plants, have been known since ancient times Rusts, blights, mildews, smuts were familiar to the ancient Greeks, Romans, Hebrews and the Chinese, as they affected man indirectly by the extensive damages caused by them to their crops and thus lowered their food value While their observations on the occurrence of these diseases and their environmental relations were remarkably accurate, their conceptions of the nature and cause of these phenomena were shrouded in mystery, religious dogmas and superstition, which were then the order of the day

The rise and development of plant pathology is closely linked up with progress of botany As a science, phytopathology had its beginnings in the middle of the 19th century Until then, the early philosophers and scientists concerned themselves with mere observations and systematic arrangement of diseases The two great inventions, that stimulated critical studies, were those of printing (1440) and the development of the compound microscope (1683) The increasing realization of the role of micro-organisms in inducing disease was also mainly responsible for the phenomenal growth of this science The epoch-making researches of Robert Koch (1876) in respect of bacterial origin of Anthrax, those of Louis Pasteur (1860–64) in the protozoan nature of the silk-worm disease and his convincing demonstrations about the true nature of fermentations, the brilliant discoveries of Anton de Bary regarding the fungus nature of late blight of potatoes (1853) and the heteroecious nature of black stem rust of wheat (1864) were the true beginnings of a new era in the advancement of this science – the well-known **Pathogenetic period** The earlier period, called by Whetzel (1918) the **Autogenetic** period, was dominated by dogmas, religious superstitions and the theory of spontaneous generation about origin of micro-organisms and a general conception of their origin from diseased tissues Micro-organisms, then, were considered as the result and not the cause of disease The credit for laying the true foundations of this science on a secure basis, belongs, therefore, to the three great pioneers mentioned above and a host of others that immediately followed them

The modern era, which began in 1850, was characterised by a series of researches and experimentations by a large number of workers in different countries, and mainly related to the study of the phenomenon of disease in its various aspects Some of the outstanding scientists in the field, are listed overleaf —

GERMANY	de Bary Kuhn, Brefeld, Hartig, Soraurer, Schroeter, Von Tubeuf Klebahn
FRANCE	Tuslanes, Millardet, Delacroi and Prillieux
ITALY	Savastano, Berlese
SWEDEN	Eriksson, Henning
DENMARK	Rostrup, Jensen
RUSSIA	Woronin
BRITAIN	Berkeley, Ward, Biffen
U S A	Burrill, Farlow, Freeman, Duggar, Smith, Jones, Stakman
AUSTRALIA	McAlpine, Waterhouse
INDIA	Butler E J, Mehta, Mundkur
JAPAN	Tikami
CANADA	Buller, Graigie
SWITZERLAND	Gaumann E

MILE-STONES IN THE PROGRESS OF PLANT PATHOLOGY

300B C	Earliest observations on plant diseases by Theophrastus
100A D	Descriptions and observations in plant diseases by Pliny
1440	Invention of printing
1676	Discovery of bacteria by Loewenhoek
1683	Invention of the microscope by Loewenhoek
1773	Systematic classification of plant diseases by Zallinger
1807	Copper sulphate seed treatment for grain smut by Prevost
1821	The use of sulphur as fungicide by Robertson
1853	Fungus origin of late blight of potatoes by Anton de Bary
1858	The first book on plant pathology by Juleus Kuhn
1864	Heteroecious nature of wheat rust by *Anton de Bary*
1873	Teaching of plant pathology at the University of Illinois by Burrill
1876	Bacterial nature of anthrax by Robert Koch
1876	Independent course of Plant Pathology at Harward by Farlow
1880	Bacterial nature of fire blight of apples by Burrill
1881	Development of the " plate method " of isolation of bacteria and fungi by Robert Koch
1882	Discovery of Bordeaux mixture by Millardet.
1886	Infectious nature of tobacco mosaic by Meyer
1887	Development of hot water treatment for smuts by Jensen
1888	Filterable nature of viruses by Iwanowski

1894	Demonstration of biologic races in cereal rusts by Eriksson
1902	Insect transmission of rice virus by Takami
1905	Mendelian inheritance of rust-resistance by Biffen
1907	Bacterial origin of crowngall by Erwin F Smith
1909	Establishment of American Phytopathological Society
1909	Development of disease-resistant varieties by Orton
1911	Demonstration of parasitic strains in anthracnose fungus by Barrus
1917	Demonstration of physiologic forms in stem rust of wheat by Stakman
1918	Barberry Eradication Campaign in U S A
1926	Studies in soil-borne diseases by Jones L R and his associates
1927	Function of pycnia in the rust fungi by Craigie
1909-34	Studies in physiology of fungi by A H R Buller
1931	Solar heat treatment of loose smut of wheat by Luthra
1935	Nucleoprotein nature of tobacco mosaic virus by Stanley
1950	Publication of a book "Principles of plant infection' by Gaumann (Translated by Brierley)

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CHAPTER 3

The Role of Micro-organisms in nature

SYSTEMATIC POSITION

All organisms are either plants or animals, although forms of an intermediate nature do occur, such, for example are the slime-moulds, also known as *mycetozoa* (*Mykes* = fungi+*Zoon*=animal) meaning animal-fungi Since the present treatment precludes the consideration of the animal group, the only other group that will be considered here is the plant kingdom The plant kingdom is divided into two well defined *phyta* the *spermaphyta* or the seed plants, and the *sporophyta*, the spore plants, the former are also known as flowering plants (Phanerogams) and the latter n o n - f l o w e r i n g (Cryptogams) The vast majority of the disease-producing organisms belong to the latter group, although a few of the former, such as *Lorathus*, *Orobanche*, *Cuscuta* and *Striga*, are also known to cause diseases in plants The Cryptogams or the sporophyta have a characteristic method of propagation by spores and constitute three distinct phyta, on the basis of the progressive development of the thallus The *Pteridophyta*, the ferns, the *Bryophyta*, the mosses and the *Thallophyta*, the algae The position is indicated in the following key

PLANT KINGDOM

- Phanerogams (Seed-plants)
- Cryptogams (Spore-plants)
  - Pteridophyta (Ferns)
  - Bryophyta (Mosses)
  - Thallophyta (Algae)
    1 Chlorophyta
    2 Schizomycophyta
    3 Myxomycophyta
    4 Eumycophyta

The true fungi, thus, constitute the *Eumycophyta* under the *Thallophyta*, the primitive group of the Sporophytes The *Chlorophyta* the *Schizomycophyta* and the *Myxomycophyta* respectively represent the algae, bacteria and the slime moulds The algae are the only group under the Thallophyta that possess chlorophyll and have thus an independent metabolism; others lack chlorophyll and have thus a dependent nutrition-either saprophytic or parasitic The bacteria are the smallest of the micro-organisms, exclusive of viruses, which have a problematical position The slime moulds, also known as *mycetozoa* have a naked thallus, the *plasmodium* and constitute a link between the animal and plant groups A simple key to the four important classes of the thallophyta is given below

THALLOPHYTA
(*A simple key to classes*)

A	Chlorophyll present, aquatic	*Chlorophyta* (algae)
B	Chlorophyll lacking —	
	BB Unicellular, dividing by fission	*Schizomycophyta* (bacteria)
	CC Thallus, naked, a plasmodium, saprophytes	*Myxomycophyta* (slime moulds)
	DD Filamentous, propagation by budding	*Eumycophyta* (true fungi)

THE FUNGI AND THEIR NATURE

The fungi, thus, constitute the Thallophyta, propagating by buds and are devoid of chlorophyll, they have, therefore, a dependent metabolism, feeding upon living or dead organic matter, they depend upon ready-made food material, resembling in this respect, the animals, they may be either parasites or saprophytes depending upon the nature of source of their food

The greyish filamentous growth that grows in jams, jellies, pickles, stale bread, rotten fruits, on discarded shoes in humid weather, the umbrella shaped mushrooms that grow on manure pits and on ground, the shelf-like fleshy, leathery brackets that grow on trunks of trees in the forests, the slimy growth that spoils the syrups, the wines and the beaverages, the ring-worm that affects the human body and, above all, the mildews the rusts and the smuts that damage our agricultural crops, are all well-known examples of fungi

The bacteria are the germs that abound in nature and are responsible for the much-dreaded diseases of man, the tuberculosis, the diptheria, the cholera and the plague and several others

ECONOMIC IMPORTANCE

Human life is intimately linked up with that of micro-organisms, which play a double role, both beneficial and harmful, they are friends as well as foes, they all play an important role in agriculture, industry and medicine, they are responsible for much of the disintegration of organic matter, making it available to higher plants, they play the role of scavengers and have greatly helped man to keep his living conditions clean and sanitary

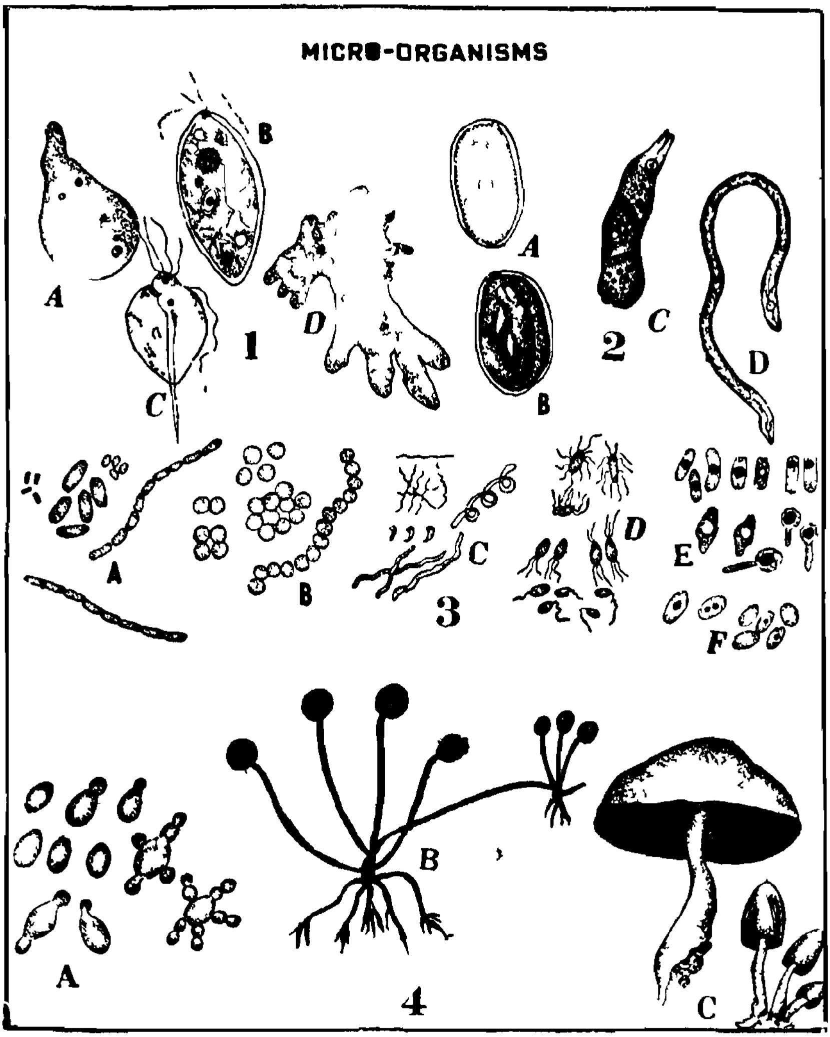

FIG 1 Types of micro organisms 1 *Protozoa* various types 2 *Nematodes* A egg B-larva in egg, C female, D male 3 *Schizomycetes* (Bacteria) A Rods B Cocci C-Spirilla, D Flagellate E Spores F-Capsules, 4 *Eumycetes* (Fungi), A Yeast B Bread mold C Mushrooms [Kamat 1953

The bacteria abound in all parts of the globe air, soil and water and even the human body While several of them are human, animal and plant pathogens, many are beneficial and carry on varied activities in nature, they are important in silage (acetic acid bacteria), in dairy (lactic acid bacteria), in breweries, in vinegar manufacture (acetic acid bacteria), in soil (nitrogen-fixing bacteria) and in splitting up complex organic compounds to simpler ones for the benefit of higher plants The group known as Actinomyces have been successfully used in obtaining important anti-biotics such as *Streptomycin*, *Aureomycin* and *Chloromycetin* which have revolutionised medical science and have been a boon to man (Waksman, 1947)

Some of the important antibiotics and their sources are listed below

	Antibiotic	Source	Reaction
1	Streptomycin	*Streptomyces griseus*	*Anti-bacterial*
2	Chloromycetin	*S Venezuelae*	-do-
3	Aureomycin	*S Aureofaciens*	-do-and anti-viral
4	Penicillin	*Penicillium chrysogenum* / *P notatum*	Anti-bacterial
5	Patulin	*P patulum*	-do-and anti-fungal
6	Viridin	*Trichoderma viride*	Anti-fungal
7	Ergonovine	*Claviceps purpurea* (Ergot)	Alkaloid used in uterine troubles

The harmful activities of bacteria are disastrous to man, animals and plants Apart from their harmful activities in the fermentation of foods, preserved or otherwise, they are directly responsible for many of the dreaded diseases The typhoid fever, the tuberculosis, diptheria, cholera, dysentry, pneumonia in man, anthrax and the foot and mouth disease in animals are important examples of such diseases

This is not all Bacteria are a menace to agriculture, causing serious diseases in crop plants The citrus canker, the black-rot of cabbage, the ring disease of potato, the black arm of cotton, the crowngall of apples, the fire blight of apples and many other diseases of bacterial origin have caused wide-spread destruction and jeopardised human life and welfare

The role of fungi has been admirably described by Dodge, B O thus "The fungi are not degenerate organisms, on the contrary, they are progressive, ever-changing, evolving rapidly and becoming readily adapted to every condition of life" They are friends as well as foes

(Parke-Rhodes, 1950). Being microscopic, they have escaped notice of the common man and naturally their varied activities have not been fully realised. Fungi have been known to man from times immemorial. The ancients had intimate knowledge of the mushrooms, because of their usefulness as food in their diet. The slow but numerous chemical changes brought about in the world are the result of the enzymic activities of these and other micro-organisms. Most saprophytic fungi are scavengers and break up complex organic matter into simpler compounds, and thus make them available to plant life; they have been very successfully used in industry in the manufacture of organic acids and vitamins, in the seasoning of cheese, the ripening of wines and other beaverages and in the making of bread. The utilization of fungi in obtaining life-saving antibiotics, such as **Penicillin** and alkaloids like *Ergotin* and *Ergonovine* has opened up a fertile field and has revolutionised medical science. These seemingly innoceous micro-organisms have been employed to the lasting benefit and service of mankind. Fig. 2 illustrates the phenomenon which, ultimately, led to the discovery of **penicillin** by Fleming in 1929.

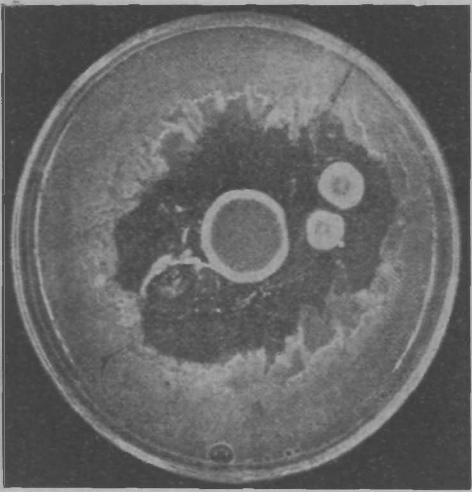

FIG. 2. Antibiotic effect of *Penicillium notatum* (centre) on bacterial growth.
[Courtesy : Merk & Co.

This is not all ; the well-known mushrooms growing on dunghills and in manure pits in moist weather, provide food and nutrition and have consequently, been utilised in developing a new fascinating and lucrative industry of mushroom culture, so widely practised in Europe and the U. S. A.

The picture is not complete without brief mention of their nefarious activities. Many fungi are parasites and dangerous enemies ; they have been known to destroy fabrics, leather, jams, jellies, pickles, bread, butter, wooden posts, railway rafters and lamp-posts and other manufactured goods. Wood-rotting fungi have been dangerous and their activities are so wide-spread in the United States, that millions of dollars are spent annually for keeping these wooden posts and rafters free from such destruction; the manufacture of wood preservatives has, consequently, grown into a big industry. The destructive activities of fungi as disease-producers, are a great menace to agriculture and ultimately to man They cause serious diseases in plants, animals and even man The danger caused by fungi to plants and crops all over the world, is staggering bringing in their wake wide-spread misery, starvation and even economic ruin A casual glance at Table 1 will show the magnitude of the losses caused by these organisms in a single State in India The rusts, the smuts, the mildews, the blights and the wilts are familiar examples of plant diseases The role of fungi in causing diseases in animals and man has been admirably discussed by Dodge C W in *Medical Mycology* Some of the important types of micro-organisms are depicted in Fig 1

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CHAPTER 4

THE FUNGI

Fungi belong to the lowest rung of the ladder of Cryptogamic plants They have, normally, a filamentous body (thallus), a definite cell-wall, and a true nucleus, they lack chlorophyll, and divide by budding They resemble animals in their metabolism, and plants in the manner of multiplication and chemical composition of their cell walls, they are, however, traditionally classed under the plant kingdom The true nature and taxonomic position of these micro-organisms have been discussed in chapters 1 and 3 respectively

VEGETATIVE STRUCTURE

Fungi produce various types of vegetative organs, which are chiefly concerned with nutrition and growth

MYCELIUM (Hyphae)

- Ectophytic
- Endophytic
  - Intercellular (Haustoria)
  - 1 Intra-cellular
  - 2 Vascular
- Dormant
- Sclerotia Rhizomorphs

The body (*thallus*) of a typical fungus plant consists of filamentous **mycelium**, which is made of branching **hyphae** (sing *hypha*), the mycelium may be **non-septate** (continuous), typical of the lower fungi or **septate** (multicellular) with cross partitions, characteristic of the higher **fungi** The cell-walls of many fungi chiefly contain cellulose, although "chitin" has been found to be a constituent in higher fungi The multinucleate nonseptate mycelium is known as **coenocytic** and is characteristic of the Phycomycetes (Fig 3, 1 & 2)

Modified vegetative structures such as **stromata** (fungus tissue) **sclerotia** (fungus tubers) and **rhizomorphs** (fungus cords) are of common occurrence in higher **fungi** and constitute the resting stages (Fig 3, 9-11)

The mycelium is **endophytic** (inside the tissues) in the vast majority of cases, it is **ectophytic** (on the surface) in such fungi that cause powdery mildews and sooty moulds The endophytic mycelium may be either **intercellular** (between the cells) or **intra-cellular** (within the cells), special structures, known as **haustoria** (drinkers) are produced by intercellular and ectophytic mycelia and help in obtaining nourishment from host cells (Fig 3, 3-8)

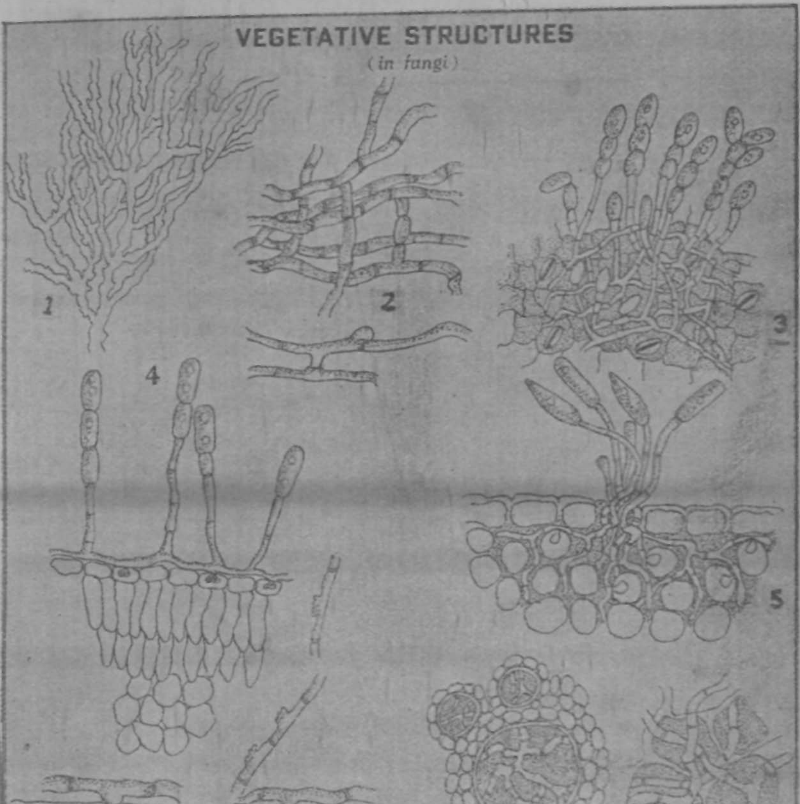

FIG. 3. Vegetative structures of fungi. Mycelium
2. Septate; 3. Ectophytic (Surface view);
5. Endophytic, (intercellular); 6. Types of hausto
Intracellular mycelium; 9. Sclerotia, various types
11. Rhizomorphs (10. after de Bary, 11 Butler, F

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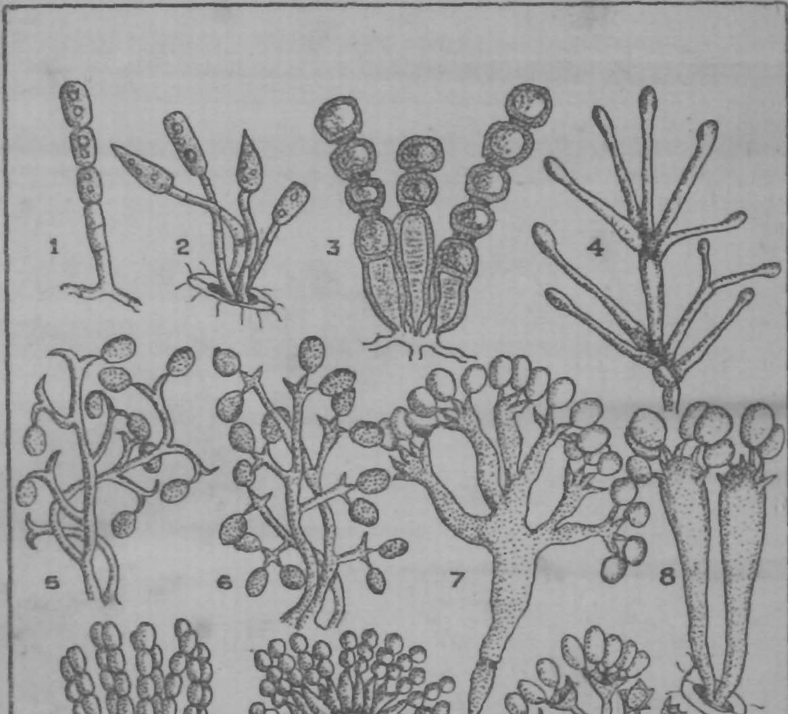
CONIDIOPHORES IN FUNGI



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...nidiophores in Fungi. 1 & 2. Simple; 3. Club-Shaped; ... & 6. Branched; 7. Dichotomous; 8. Clubs; 9. Brush-like; ...d; 11. Branched with discs; 12, 13 & 14. Variously [Kamat, 1953.

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REPRODUCTIVE STRUCTURES

Fungi reproduce by buds or spores, which in turn, are produced in three ways asexual, sexual and vegetative Spores are specialised cells, one or more-celled, set apart for reproduction, they may arise as buds on specialised hyphae (exogenous) or may be borne in special receptacles, the spore-fruits (endogenous)

The following is a simple key to the various types and manners of formation of spores

SPORES

- Asexual
  - Exogenous
    - Conidia
  - Endogenous
    - Motile (*Zoospores*)
    - Non-motile (*Aplanospores*)
- Sexual
  1. Zygotes
  2. *Oospores*
  3. Zygospores.
  4. Ascospores
  5. Basidiospores
- Vegetative
  - Chlamydospores

***Conidia** are asexual spores borne on special spore-bearing* hyphae, the conidiophores, they may be borne *singly in* chains or in cluster, they have various forms and sizes varying from unicellular to *multicellular* with pigments ranging from light olive to deep black, and are characteristic of *terrestrial fungi They are well adapted* for efficient dissemination through wind (Fig 5, 1-3)

***Conidiophores,** also known as* sporophores, are *special* spore-bearing hyphae, they may be s*imple* or branched *in* various *fashions* and are generally produced on the surface of the host They have an erect position and help in the dissemination of spores by bringing them *in direct contact with* various agencies such as wind, rain and insects Some of the *common types met with in fungi are depicted* in Fig 4

Sporangia are the sacs containing spores, which may be motile (zoospores) or non-motile (aplanospores) Zoospores are typical of aquatic fungi and aplanospores of terrestrial moulds such as *Mucor* and *Rhizopus*, the typical bread-moulds The zoospores have one or two *flagella by means of which* they are capable of movement and are disseminated through water (*Fig 5, 4 & 5*)

Sexual spores of fungi are *variously* known as **zygotes, oospores, zygospores, ascospores** and **basidiospores** depending upon the *manner* of their formation and the classes of fungi to which they belong Essentially they are the result of fusion between two gametes of

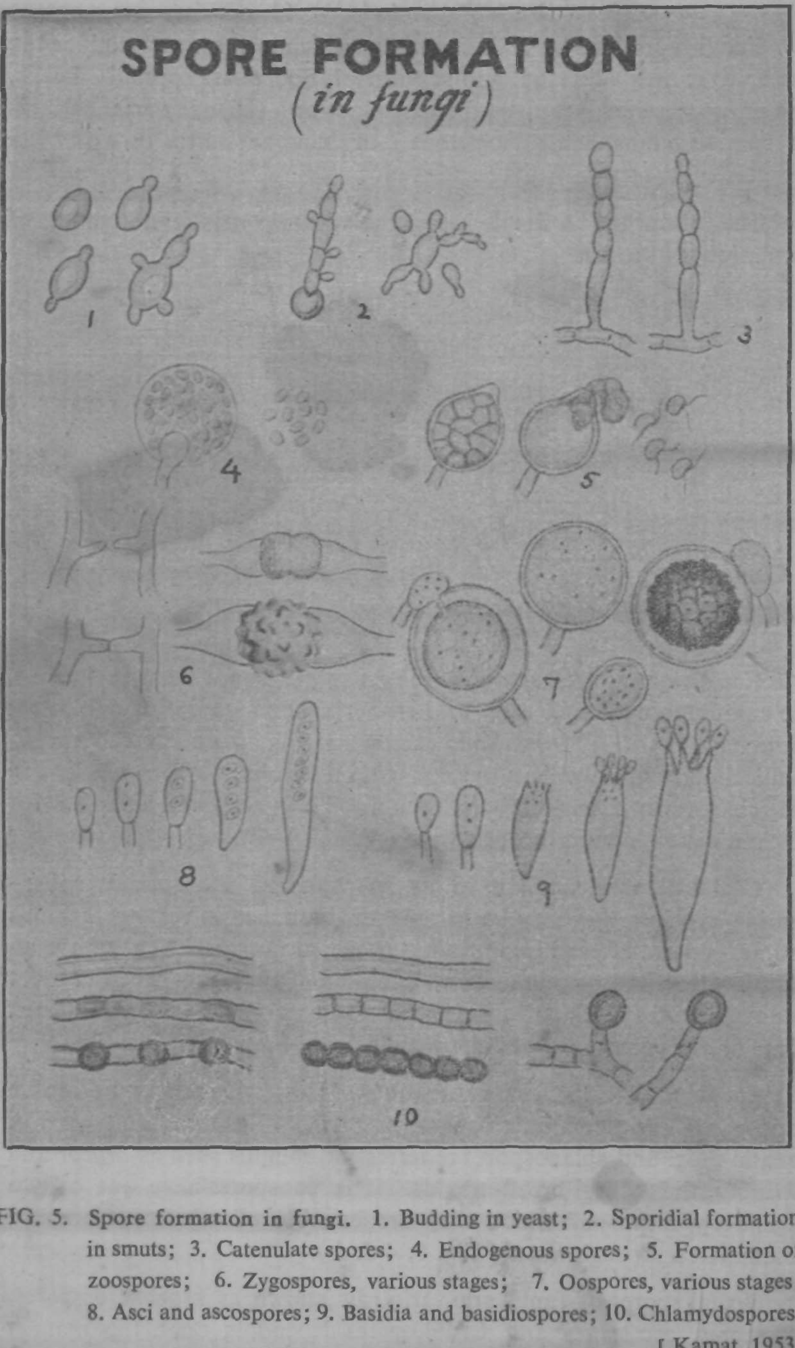

FIG. 5. Spore formation in fungi. 1. Budding in yeast; 2. Sporidial formation in smuts; 3. Catenulate spores; 4. Endogenous spores; 5. Formation of zoospores; 6. Zygospores, various stages; 7. Oospores, various stages; 8. Asci and ascospores; 9. Basidia and basidiospores; 10. Chlamydospores.
[Kamat, 1953.

opposite sex Zygotes belong to the lower group, the Archimycetes and result from copulation of two motile gametes The oospores are sexual spores produced by members of the Oomycetes, the zygospores by Zygomycetes, the ascospores by the Ascomycetes and basidiospores by the Basidiomycetes The sexual spores function as resting spores and must pass through a dormant period before resumption of activity, they, thus, help the fungi in over-summering or over-wintering A detailed account of the sexual processes occurring in fungi will be found in Chapter 5 Fig 5, 6-9 show some of the common types of sexual spores of fungi

Chlamydospores are vegetative in nature and are produced by direct modification of hyphal cells, they may be *terminal* or *intercallary*, they are thick-walled, rich in contents and serve as resting stages of the fungus, and as such have the same function as the sexual spores, described above These spores are of special significance and of common occurrence in Fungi Imperfecti, which have no sexual stages (Fig 5, 10)

SPORE-FRUITS IN FUNGI

Spore fruits are an organization of spores and spore-bearing hyphae, rarely naked, but frequently enclosed in various types of containers or receptacles The fruits have a thick covering the *peridium* which protects the spores within and are, thus, well adapted as hibernating or resting stages Spore-fruits are of common occurrence in higher fungi and are rare or absent in lower groups (Fig 6)

Sorus (*pl* sori) is a 'little heap' and thus limited in structure, naked or covered by a thin false membrane, as in smuts, or protected by the epidermis as in rusts These structures break open at maturity and release the spores within, in the form of a dust, which is characteristic of these diseases (Fig 6, 10 & 11)

Acervulus is a modified sorus provided with thorn-like deep brown to black structures, the setae (*sing* seta) (Fig 6, 6)

Pycnidium is a sperical or ovoid receptacle with short conidiophores lining its inner wall and bearing conidia, it may be entire or provided with an opening, the **Ostiole**, through which the conidia are released in a serpentine fashion (Fig 6, 12 & 13)

Ascocarp is a fructification of the Ascomycetes and takes various forms, spherical, flask-shaped, cup and saucer shape and pod shape, closed in some, and provided with a narrow or a wide opening in others, these bodies contain the **asci** and **ascospores**, and are, in general, of three types

(a) **Cleistothecium** is a closed ascocarp and has no ostiole It is deep brown to black in colour more or less spherical and is many

SPORE-FRUITS IN FUNGI

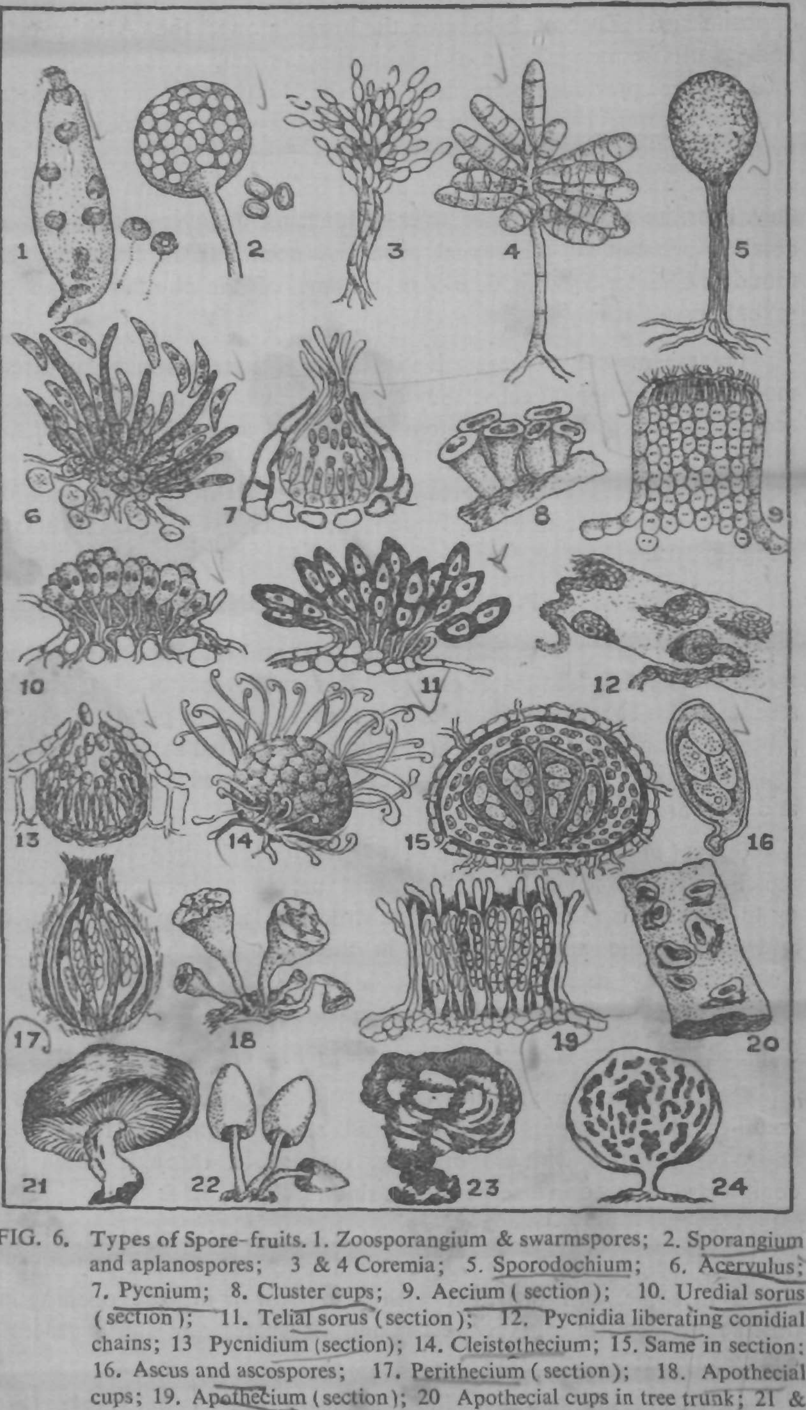

FIG. 6. Types of Spore-fruits. 1. Zoosporangium & swarmspores; 2. Sporangium and aplanospores; 3 & 4 Coremia; 5. Sporodochium; 6. Acervulus; 7. Pycnium; 8. Cluster cups; 9. Aecium (section); 10. Uredial sorus (section); 11. Telial sorus (section); 12. Pycnidia liberating conidial chains; 13 Pycnidium (section); 14. Cleistothecium; 15. Same in section; 16. Ascus and ascospores; 17. Perithecium (section); 18. Apothecial cups; 19. Apothecium (section); 20 Apothecial cups in tree trunk; 21 & 22. Mushrooms; 23. Bracket-fungus; 24. Puffball (section).

[Kamat, 1953.

times provided on its body, with **appendages** of various types, which serve as organs of anchorage and help in dissemination, they break open at maturity by the process of wear and tear (Fig 6, 14 & 15)

(b) **Perithecium** is a flask-shaped ascocarp provided with a narrow ostiole and may possess a short or a long neck, through which the asci are released at maturity The asci are arranged in a regular manner and line the inside wall, the asci are intermingled with sterile structures, the **paraphyses,** which help the asci in nutrition and dispersal (Fig 6, 17)

(c) **Apothecium** has a broad opening and is either cup or saucer shaped, with asci arranged in a palisade layer within, it is usually fleshy or leathery in nature (Fig 6, 18–20)

Basidiocarps are functifications of the Basidiomycetes and consist of **mushrooms** (umbrella shape), **toadstools** (bracket or shelf–like) or **puff balls** (spherical), they are highly developed and have compound structure, they may be fleshy, leathery, woody or waxy in nature and bear the basidiospores in special structures, variously known as ' gills ', ' pores ', ' needles ' and ' chambers The puff balls have a characteristic ' puffing ' action and release their spores in the form of a cloud (Fig 6, 21–24)

The special structures referred to above bring about phenomenal increase in the spore–bearing surface and thus enable these fungi to produce millions and billions of spores on a relatively small area

The spore–fruits, described above, are of great importance to fungi, not only in tiding over conditions of desiccation and freezing, but have vital significance from the point of view of multiplication of inoculum and maintenance thereof These, ultimately, determine the efficiency of these micro-organisms as disease–producers Besides, they have also been utilised as taxonomic characters in determining the broad outlines of various groups of fungi This feature has been discussed in chapter 21 under " Taxonomy and Nomenclature "

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CHAPTER 5

SEXUALITY IN FUNGI

Sexual reproduction in fungi is effected through a fusion between two **gametes** of opposite sex. A gamete is unisexual and, therefore, haploid (1n). The spore resulting from the sexual fusion is bisexual and, therefore, diploid (2n). Gametes may be naked and motile, as in the lower fungi (Archimycetes), and are designated as **planogametes**; they may be carried in special cells and are non-motile, as in higher groups of fungi. In the latter case, the cell carrying the gamete is designated as a **gametangium**. The fusing gametes or the gametangia may be undifferentiated. In that case the sexual process is known as **isogamy**, and the mating gametes as (+) and (—) for compatibility. They are differentiated as male (**Antheredium**) and female (**Oogonium**) in others, and the process of fusion is known as **heterogamy**. These two processes are also sometimes known as **conjugation** and **fertilization** respectively. Various modifications of the essential processes, outlined above, occur among fungi and have been described in detail in standard books on mycology and summarised by Whitehouse (1949).

The gametes or gametangia are produced on the same thallus in some and on different thalli in others ; in a third case, the two sex cells may be produced *in the same receptacle*. The terms **homothallism**, **heterothallism** and **hermaphroditism** are applied to the respective conditions. The first two terms correspond to the phenomena of **monoecism** and **dioecism** found in higher plants. The hermaphroditic forms may be self-fertile or self-sterile. The first demonstration of such sexual compatibility was given by Blakeslee (1904) in the well-known bread mould fungus (Fig. 7) and is now of general occurrence in many fungi. Fig. 7a is a diagrammatic representation of nuclear segregation in homothallic and heterothallic forms of an Ascymyceteous fungus.

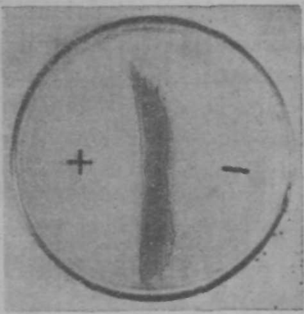

FIG. 7. Demonstration of heterothallism in the bread mold fungus; + and — strains meeting to produce a dark line of zygospores (centre).
[Courtesy: Abhyankar S. G.

Some of the important methods that fungi employ in bringing together compatible nuclei in the process of sexual reproduction may be summarised as follows :

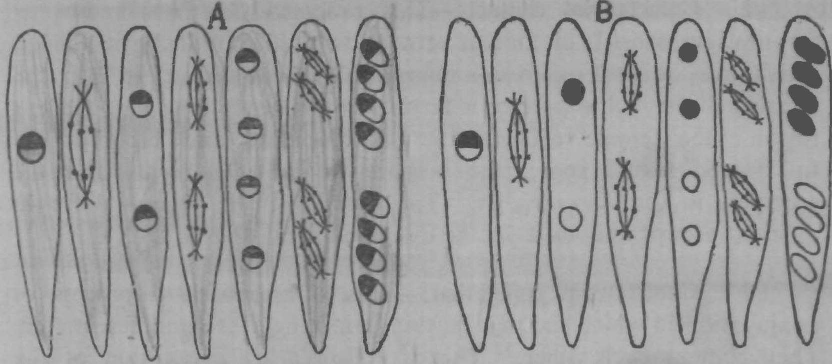

FIG. 7a. Diagrammatic representation of homothallism (A) and heterothallism (B) in an Ascomycetous fungus. [Modified from Dodge.

(1) **Planogametic copulation**:—This is a fusion between two naked gametes, one or both of which may be motile (Planogametes); the mating gametes may be **isogamous** or **heterogamous** in character, depending upon their size, shape and motility. The process and its modifications are a special feature of the members of the lowest group of fungi (Archimycetes), specially suited to aquatic habit and result in the formation of a sexual spore known as **zygote**, which may be either motile or non-motile (Fig. 8, A.-C.).

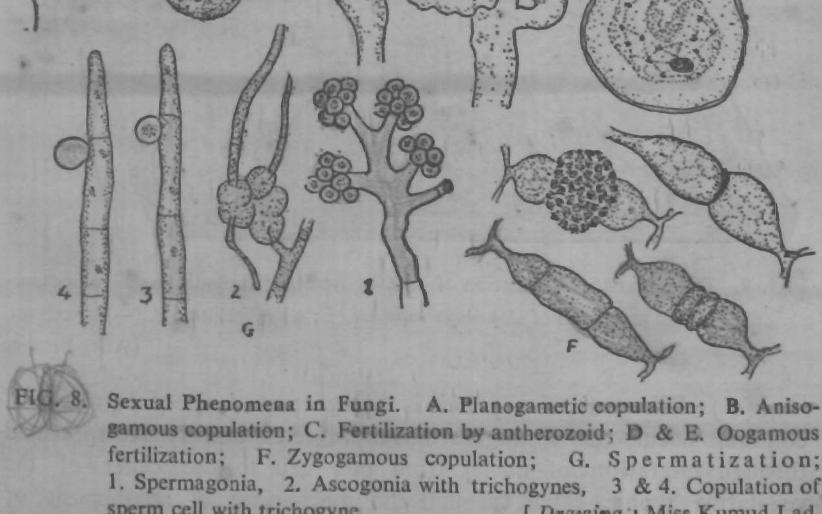

FIG. 8. Sexual Phenomena in Fungi. A. Planogametic copulation; B. Anisogamous copulation; C. Fertilization by antherozoid; D & E. Oogamous fertilization; F. Zygogamous copulation; G. Spermatization; 1. Spermagonia, 2. Ascogonia with trichogynes, 3 & 4. Copulation of sperm cell with trichogyne. [*Drawing*: Miss Kumud Lad.

(2) **Gametangial contact**:—This process, sometimes known as fertilization, consists of contact between two differentiated gametangia, which press on each other with migration of the male nucleus into the female cell through a pore or a fertilization tube, followed by nuclear fusion ; the female cell resumes development and becomes the full-fledged sexual spore, the **oospore** in the *Oomycetes* and the **ascospore** in the *Ascomycetes*. The details of the process differ in different groups and need not be discussed here (Fig. 8, D–E).

(3) **Gametangial copulation**:—This is essentially a process of conjugation in which the two mating gametangia are undifferentiated. They contact each other. This is followed by dissolution of the intervening walls, the migration of a part of cytoplasm and fusion of nuclei from each of the two cells into a separate cell (partitioned off from the two parent gametangia), which ultimately grows into a sexual spore, the **zygospore** (Fig. 8, F). This process is typical of the Zygomycetes.

(4) **Spermatization**:—This is a special process commonly found among higher fungi and is typical of rusts and consists of contact between specialized male cells, the **spermatia**, and **receptive hyphæ** or **trichogynes**, the passage of the male nucleus of the sperm cell into the female cell through the receptive hypha or trichogyne followed by nuclear fusion (Fig. 8, G.). The spermatia are produced in special receptacles, the **spermagonia** or **pycnia** and are carried to the compatible hyphæ through the agency of insects, water and wind.

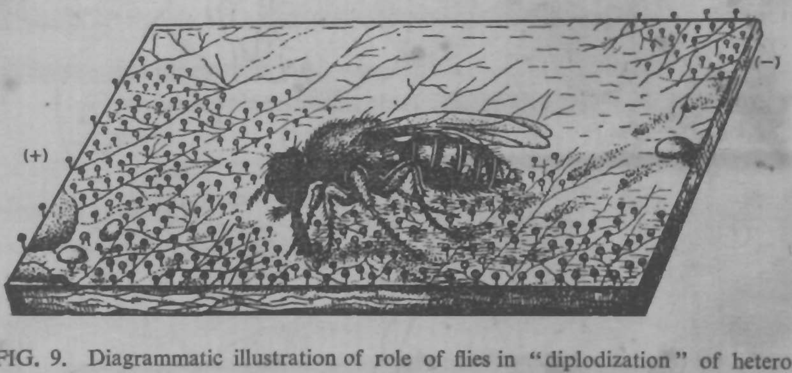

FIG. 9. Diagrammatic illustration of role of flies in "diplodization" of heterothallic mycelium of *Coprinus lagopus*. L:(+) mycelium, R:(—) mycelium. [After Brodie.

(5) **Dikaryotization**:—This is a degenerate type of sexuality of common occurrence in higher Basidiomycetes and is accomplished through migration of nuclei from one cell to the other of the vegetative hyphæ, often through the mechanism of **anastomosis** or

clamps The two nuclei remain in pairs and divide as such (conjugate) and only fuse prior to formation of spores No special sex cells are produced The mushroom fungi are characterized by this process Insects play an important role in the process of "diploidization" in *heterothallic* forms of mushroom fungi (Fig 9)

It will be seen from the above discussion that while the sexual process has a fixed pattern in the lower groups of fungi, it is highly flexible and labile in the higher fungi A single sexual act gives rise to a single sexual spore in the lower groups, while it is followed by the production of many sexual spores in the higher fungi, where in addition, the sexual phase is prolonged, over long periods often lasting several years, so characteristic of the mushroom fungi (Fig 10)

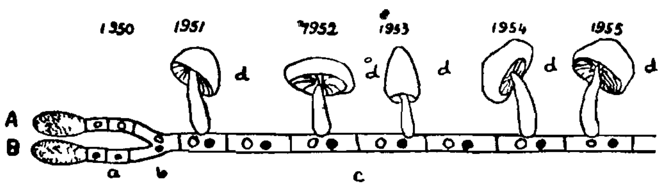

FIG 10 Sexual reproduction in a mushroom fungus A & B gametes, a haploid mycelia, b plasmogamy c dikaryophase, d annual recurrence of fruit bodies

[Modified from Gaumann

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CHAPTER 6

PHYSIOLOGY OF FUNGI

Fungi lack chlorophyll , their metabolism is, therefore, catalytic they are unable to synthesise their own food from the simple inorganic substances, nor can they build up carbohydrates by photosynthesis from the atmospheric carbon-dioxide, in this respect they resemble animals, they feed and grow on ready-made food, which, however, must be in solution because of their inability to assimilate solid particles, their mechanism of nutrition is "absorption", which takes place by osmosis through the permeable cell walls In the early stages of the germination of the spore, they depend upon reserve food stored in the spore itself in the form of oil or fat globules They are capable of secreting enzymes, which break up or modify complex organic compounds and make them more readily assimilable

Fungi need inorganic substances, such as minerals, salts and other minor elements in much the same manner as green plants and animals, these are obtained from the organic food on which fungi feed Nitrogen, phosphorus and potash are essential Sulphur, magnesium, iron and copper are required in small amounts Calcium, which is so essential for higher plants and animals does not appear to be essential for fungi, although evidence so far presented is conflicting on this point

Fungi require free oxygen for their growth and reproduction and behave in this respect like other plants They respire and replace oxygen with carbon-dioxide Free oxygen is essential for the germination reproduction and other life processes of many fungi which are designated as *aerobic*, others which are *anaerobic*, grow without free oxygen, but obtain it from other nutrients present in the substratum in the process of fermentation A strictly anaerobic condition is not met with in fungi but is of common occurrence in bacteria

Like animals, fungi need 'vitamins' and other growth-substances for their development It has been found that reproduction in fungi is stimulated by a supply of vitamins Fungi are able to synthesise such substances and have been utilised in industries for the manufacture of these substances on a commercial scale

Since fungi lack chlorophyll, they are either saprophytes or parasites, depending upon the nature of their food source

Saprophytes obtain their food from dead organic matter, which once formed part of plant or animal tissues This may be considered to be the original life condition of all organisms and the primitive stage in their evolution Such organisms abound in nature, in the atmosphere, soil, humus, and other dead organic material , they are also found as contaminants in the laboratory, where they seriously hamper the pure culture work of the amateur They are in the nature of scavengers, as they, like many bacteria, split up decaying organic matter, releasing simpler substances, like CO_2 and hydrogen for the benefit of higher plants Saprophytes are, thus, friends

Parasites obtain their nutrition from the living tissues of either plants or animals Parasitism is an evolutionary process and is the culminating point in the series beginning from primitive saprophytism, with intervening, symbiosis, mycorhizal associations and facultative parasitism Parasites are, thus, foes of man, animals and plants A few exceptions are, however, encountered The entomogenous fungi, which attack and feed upon insects, are beneficial and have been recently utilised in 'biological control' of pests

Several modifications of the above associations are found in nature Those which pass their entire life on or in living hosts are known as **obligate parasites** and those feeding on or in non-living substances as **obligate saprophytes** Fungi causing downy mildews, powdery mildews and rusts belong to the former category, the moulds, like *Rhizopus*, *Mucor*, *Aspergillus*, and *Penicillium* to the latter **Facultatism** is a mode of life developed by these organisms, and is a clever device for their perpetuation This denotes a capacity to change life habits at will

Facultative saprophytes normally lead a parasitic life but are capable of switching over to a temporary saprophytic mode, which is an adaptation to a change of environment The smut fungi are a well known example They spend a part of their life (sporidia) as saprophytes and other part (chlamydospores) in living plants

Facultative parasites, conversely, are those which are originally saprophytes but adapt themselves to a parasitic mode of life, when they contact living plants in nature Species of *Pythium* and *Phytophthora* causing the damping off and foot-rots, *Fusariums* causing wilts are examples of such a mode of life

Weak-parasites, wound parasites, epiphytes are other modifications encountered in nature and are only in the nature of adaptations to suit the particular situations

Symbiosis and **mycorhiza** are in the nature of co operative associations, which mutually benefit each other and are not antagonistic The lichens, the root nodule bacteria and the root fungus associations (*mycorhiza*) in forest trees and orchids, represent such associations

ENZYMIC ACTIVITY OF FUNGI

Enzymes are products secreted by fungi and other micro-organisms and are either in the nature of *endoenzymes* or *exoenzymes* ; they have been recently isolated as chrystalline proteins (Stanley, 1935) ; their reactions are chemical and are known to initiate chemical changes and even cause disturbances in plant and animal life. Various types of these substances are produced and act on starch, cellulose, pectin, lignin, sugars, tannin and other complex products, reducing them to simpler substances ready for easy absorption and assimilation by the fungus. *Amylase, Cellulase, Pectinase, Ligninase, Diastase, Invertase, Tanninase, Pepsinase, Emulsin, Maltase* and many others are of this type. The capacity of fungi to secrete enzymes varies widely and has been utilised in industries for commercial manufacture of organic acids, such as citric and galic. They have also been utilised in bakeries, breweries, dairy industry and seasoning purposes and in fermentations.

ENVIRONMENT IN RELATION TO GROWTH

Like all other organisms, fungi too are subject to the influence of external environment, chief among them being temperature, water requirements, light, æration, oxygen supply, reaction of the medium and stimuli.

Nutritional requirements of fungi have already been discussed above. Fig. 11 shows the comparative growth and sporulation of a fungus on a synthetic and non-synthetic medium.

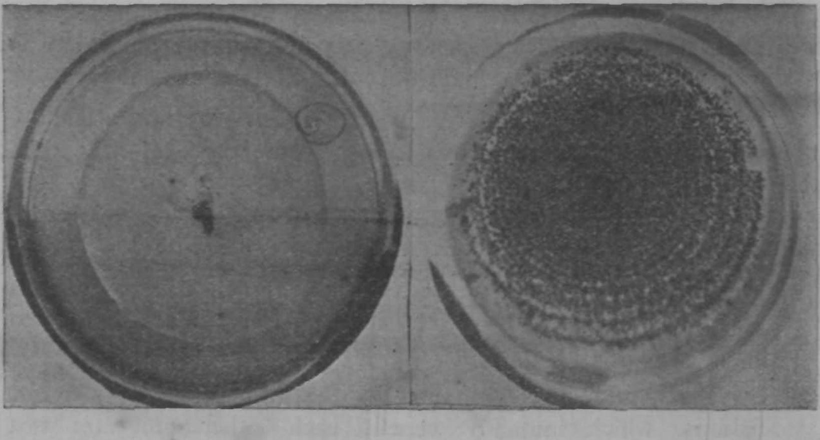

FIG. 11. Effect of nutrients on pycnidial formation in *Phyllosticta papayae*
L : Brown's agar. R : Potato-dextose-agar.

[Courtesy : Miss Shirin Irani.

Water requirements of fungi are difficult to investigate. Influence of relative humidity, however, has received some attention, specially on spore germination and on the course of ultimate picture of disease. The only example of water requirement is provided, in an indirect manner, by the evolutionary series, beginning with purely aquatic fungi (water moulds) intervening semi-aquatic forms (amphibious) and culminating in purely terrestrial forms, familiar in the Phycomycetes. Fungi, however, as a rule, grow well on solid substrata although high humidity is absolutely essential for rapid growth and development. Moisture content of the medium is. however, an important factor in the growth of wood-rotting fungi and moulds that stain and damage fabric and other preserved organic substances. Low moisture content, in general, inhibits the growth of these fungi.

The influence of *temperature* on the growth of the fungi has been extensively studied, both in culture media (Fig. 12) and in living plants. This factor exerts a profound effect on growth, in vegetative as well as reproductive phase. Like other plants, a fungus has its cardinal temperatures for growth—a minimum, an optimum and a maximum. Most fungi are able to grow at a wide range of temperature (5°C to 40°C). Some are tropical in their relations (25° to 30°C), and others are of temperate habit (18° to 22°C). The process of growth and reproduction are distinct and subject to differential effect by temperature and other factors.

Fig. 12. Effect of temperature on growth of *Fusarium lini* (in culture).

[After W. H. Tisdale.

Light has differential effect on the growth of the fungi. It favours growth in some and retards it in others. In general, light favours reproductive growth, although no generalizations are possible, since opposite reactions have been noticed in several instances. Direct light, diffuse light and even ultra-violet light influence growth and reproduction differently (Fig. 13). While diffuse light favours reproduction in some as in downy mildew fungi, direct light favours development of pycnidia and perithecia in others. Prolonged exposure, however, to direct sunlight and ultra-violet rays inhibits growth and is even harmful.

Fungi are capable of growth on a wide range of hydrogen-ion concentration. Some like *Spongospora subterranea* favour alkaline reaction, while *Plasmodiophora brassiceae* flourishes under the influence

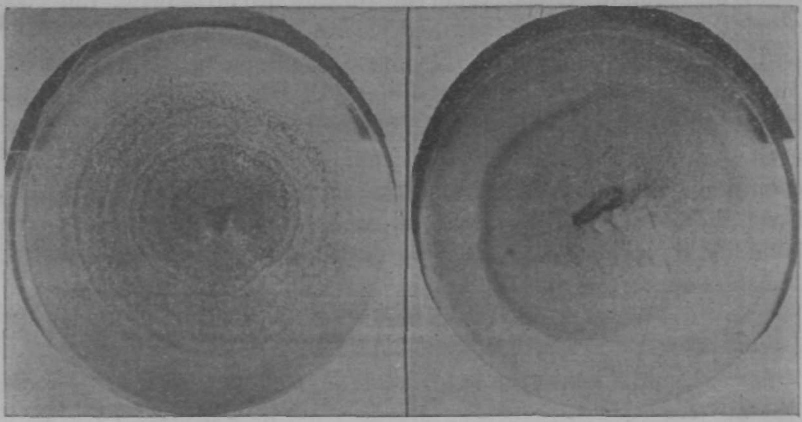

FIG. 13. Effect of intensities of light on pycnidial formation in *Phyllosticta papayae*. L : Diffused light, R : Darkness.

[Courtesy : Miss Shirin Irani.

of acid reaction. *Sclerotinia americana* tolerates acid reactions and ceases growth at 6·6 pH. The American strain of *Fusarium oxysporum f. vasinfectum* (cotton wilt) favours acid medium, while the Indian strain develops best in alkaline soils. Similar observations have been made in many other cases.

Many parasitic fungi, when grown in artificial media, do not produce their reproductive stages, although these stages are of common occurrence in their respective hosts. Most smut fungi, for instance, produce only the sporidial stage in culture but not the chlamydospores. Similar is the case in the "Ergot" fungus, which does not produce the sclerotial stage in artificial culture, but forms its sugary stage (conidia) abundantly under these conditions. Continuous artificial culture tends to produce sterility in some fungi, which regain fertility when grown on the respective hosts or with addition of host tissue to the culture.

The influence of stimuli, physical as well as chemical, has been profound and has differential effects on growth and reproduction. Some of the common stimuli, so affecting these processes are (1) host tissue, (2) metabolic products, (3) nitrogen source, (4) carbon source, (5) alternate desiccation and freezing, (6) freezing, (7) desiccation, (8) vitamins, (9) micro-elements, (10) ultra violet light, (11) wounding and many others. Fig. 14 shows the profound influence of host tissue on sporulation in fungi.

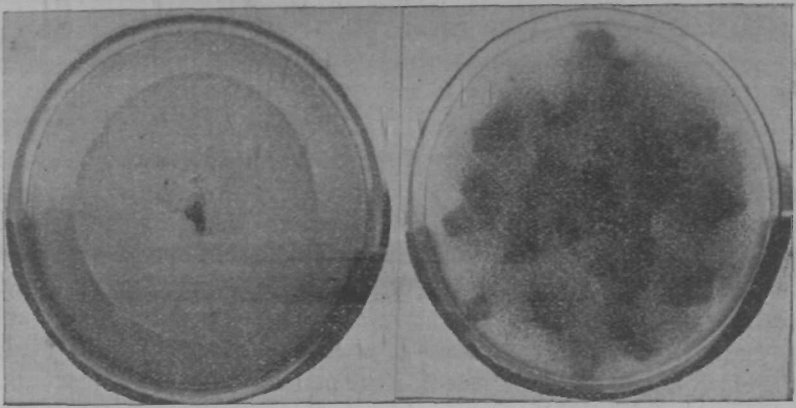

FIG. 14. Effect of host tissue on pycnidial formation in *Phyllosticta papayae*
L : Brown's agar, R : Brown's agar with host tissue.

[Courtesy : Miss Shirin Irani.

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CHAPTER 7

LIFE CYCLES OF PLANT PATHOGENS

The typical life cycle of a pathogen normally has two patterns **continuous and discontinuous** The continuous phase is rarely met with among the plant pathogens and is more common in animal pathogens, where the organism maintains itself from host to host as in highly infectious diseases, like plague, diphtheria, foot and mouth disease, anthrax and so on Such, however, is not the case with plant pathogens, whose life cycles are of a discontinuous type and must, therefore, devise ways and means of maintaining themselves in nature, where they continually meet with changing conditions, sometimes adverse and at other times favourable The question that primarily concerns the plant pathologist, therefore, is as to how the plant pathogens maintain themselves in nature, in the face of such conditions? What are the various devices and mechanisms they employ for the purpose?

Before we attempt to answer these questions, it would be well for the student to critically examine the normal life cycle of a plant pathogen in its true perspective Fig 15 represents the life cycle pattern of two types of fungus parasites, perfect and imperfect It follows, in general, the following cyclic events

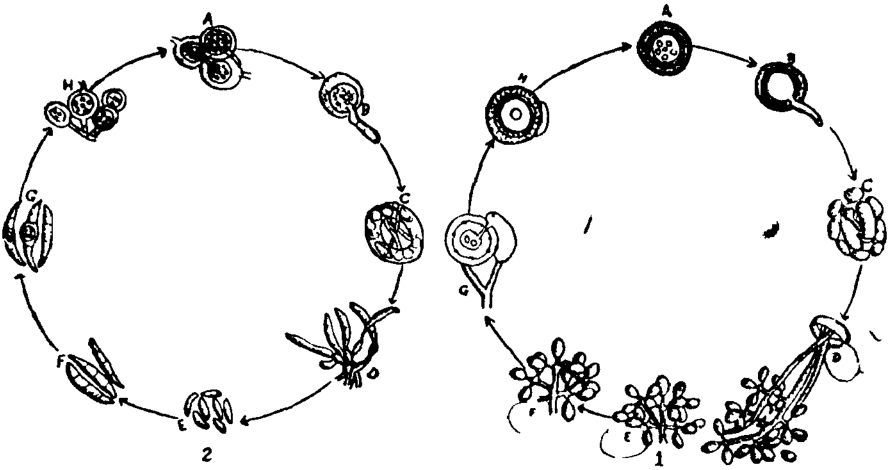


FIG 15 Life cycles of plant pathogens showing perfect (1) and imperfect (2) stages ABC Infection stage DEF active stage, GH Resting stage

[Drawing Miss Kumud Lad

A spore comes in contact with a suitable host, where it germinates, enters it, establishes parasitic relations and grows into ectophytic or endophytic mycelium, the mycelium, at maturity, gives rise to conidiophores, which bear the conidia, this completes the asexual phase, which may be repeated over and over again under favourable environment, in the form of successive crops of conidia This represents the active parasitic phase

With the ushering in of winter (in the temperate zones) or summer (in the tropics), the parasite initiates a new phase, the passive or resting phase with the formation of gametangia, which fuse in pairs to produce the sexual spores (in perfect forms) and resting vegetative bodies such as sclerotia and chlamydospores (in imperfect forms), depending upon the type of the pathogen These are the hibernating stages On the return of favourable conditions of life, these bodies resume activity and carry on the life cycle in the pattern already described in Fig 15

It will be observed from the life cycle pattern, outlined above, that the most critical period is the one that intervenes between two active phases, the winter or the summer, as the case may be, when not only the environmental conditions are unsuitable but there is generally, an absence of a suitable host for the pathogen and the life cycle necessarily becomes interrupted or discontinuous

Micro-organisms employ various kinds of devices to enable them to perpetuate themselves under the adverse conditions, in which they find themselves in nature Some of the most important devices, so employed, are discussed below

1 **Facultatism** —Fungi are either saprophytes or parasites Several fungi, however, have developed the ability to modify their mode of life at will and thus succeed remarkably in dodging over adverse situations *Phytophthora parasitica, Pythium de Baryanum,* various species of *Fusarium, Rhizoctonia and Sclerotium,* which normally lead a saprophytic life in soils, resume active parasitic phase in the presence of their respective hosts and thus contrive to keep up the infection chains Such is the case in the wilt diseases of cotton, banana, betelvine, gummosis of citrus, damping off of seedlings, foot-rot of ginger and root-rot of cotton The fungi are normally saprophytic, but resume parasitic activity with the return of favourable conditions of life

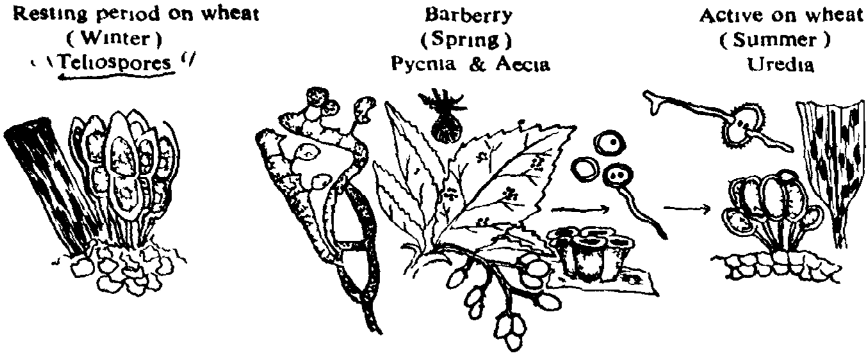
Similar phenomena occur in many bacterial pathogens such as those causing the ring rot of potatoes (*Phy solanacear' m*) and the black-rot of cabbage (*Xanthomonas campestris*)

2 **Heteroecism** —Heteroecism is a phenomenon where an organism needs more than one host to complete its life cycle The cereal

rusts are well-known examples of such a mode of life The organism has two hosts on which it can carry on its life-cycle, one phase alternating with another, so that it can persist on one host in the absence of the other and resume active growth with the return of favourable conditions In stem rusts of cereals (*Puccinia graminis*), leaf rust of *bajra* (*Puccinia penniseti*), rust of corn (*Puccinia sorghi*) and many others like blister rust of pines and cedar rust of apples, the alternate hosts, on which usually the pycnial and aecial stages are produced, provide congenial ground for resumption of activity, after an intervening winter period, in which the fungi hibernate in the form of teliospores Heteroecism, thus, is a clever device for perpetuation of species and is very commonly employed by many rust fungi

A diagrammatic representation of this mode of life-cycle in *P graminis tritici*, as it occurs in the temperate regions is depicted below -

LIFE CYCLE OF BLACK STEM RUST OF WHEAT



The barberry, thus, provides a congenial ground for the maintenance of the infection chain before the resumption of the active and destructive uredial phase on the wheat crop, in summer The eradication of the alternate host (in this case, *Berberis vulgaris*) would naturally interrupt the chain of events that lead to a destructive outbreak of rust and is the basis of the countrywide Barberry Eradication Campaign in the U S A Some of the common heteroecious rusts and their alternate hosts are listed graphically in Figs 17 and 18

Heteroecism of an unusually ingenious type but quite distinct from the one described above has been developed by plant viruses, for maintenance of their infection chains Many plant viruses are able to persist in their insect " vectors " for varying periods, before the latter actually transmit them to their respective hosts, where the viruses resume their active parasitic role The position is, however, not homologous

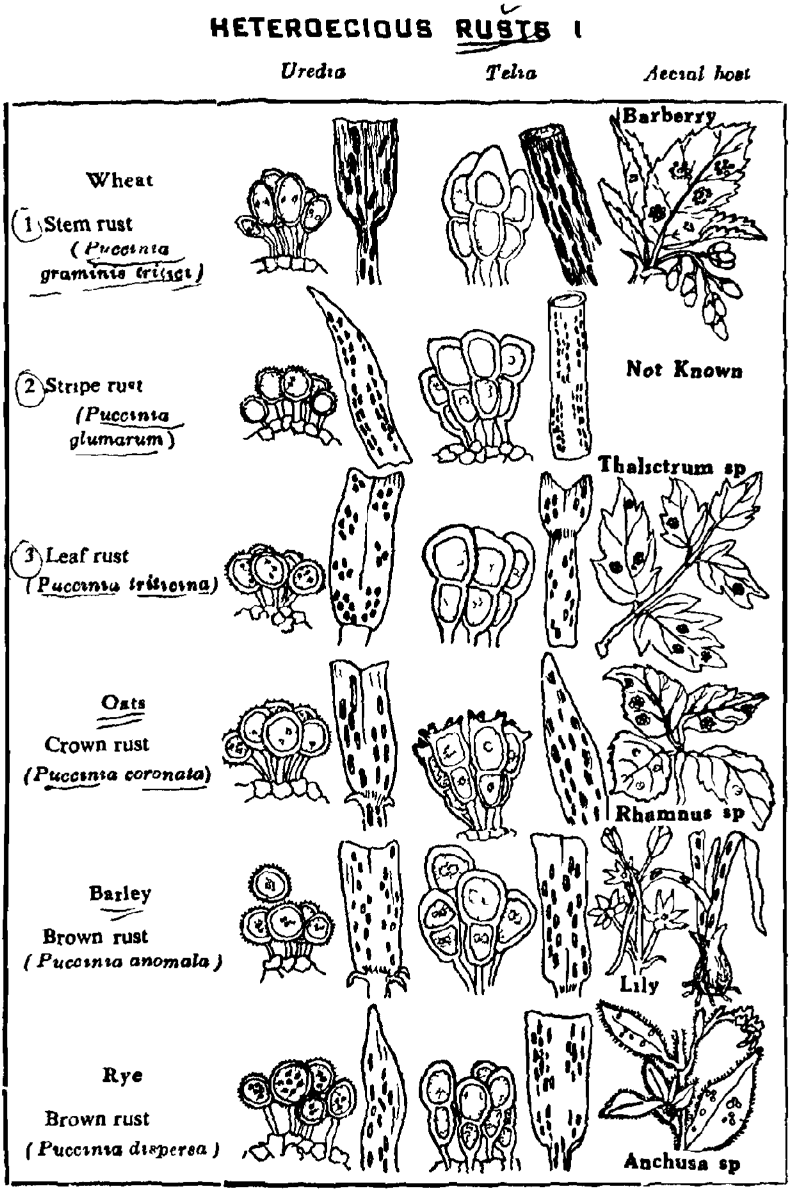


FIG 17 Heteroecious rusts [Kamat, 1953

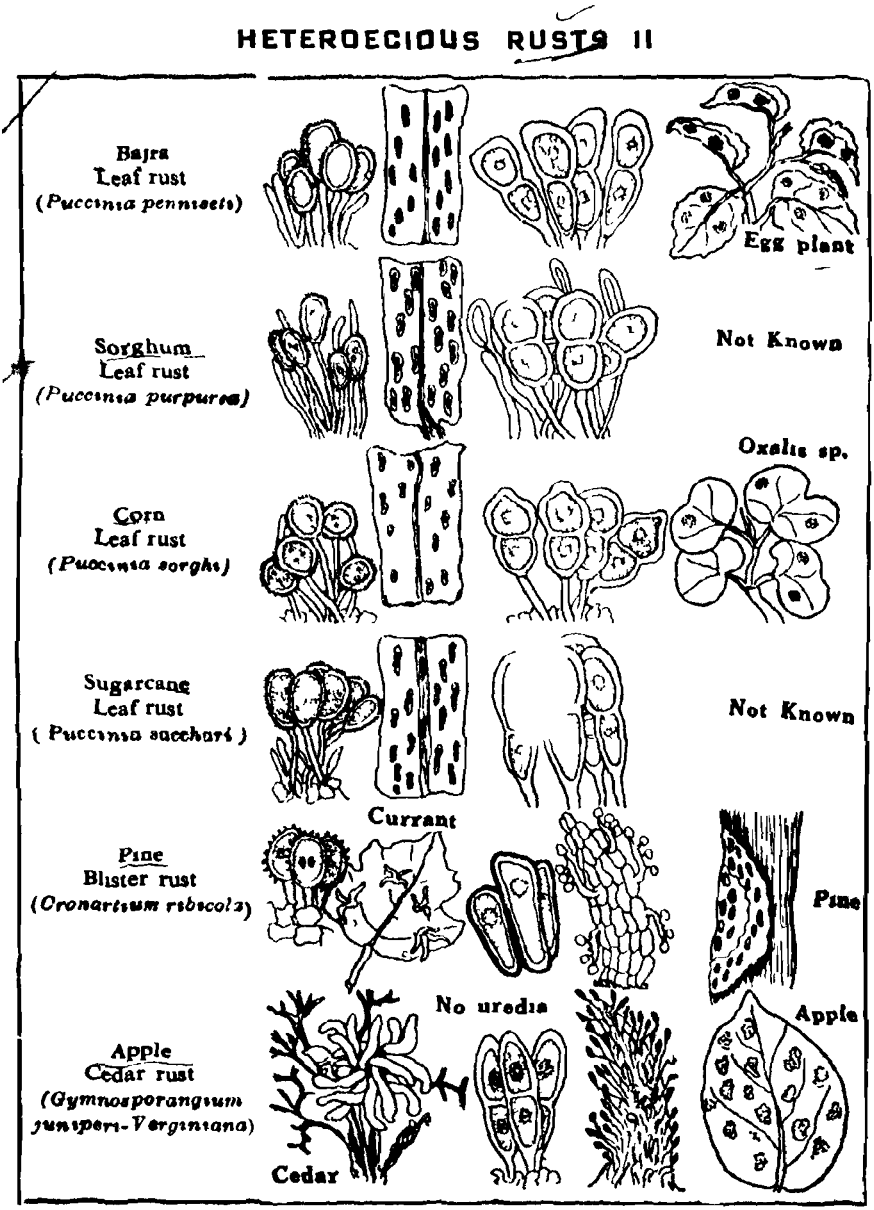


FIG 18 Heteroecious rusts [Kamat, 1953

to the one found among rust fungi, since in plant viruses, the insect besides supporting a part of the infection chain and allowing its multiplication, also acts as an agency of transmission (Vector) even as the *Anopheles* mosquito in human malaria The varying lengths of times the viruses spend in their insect vectors, commonly known as incubation period before resumption of activity in the plant hosts are given in table 2

Table 2

Incubation period of plant viruses in insect vectors

Name of virus	Plant Host	Insect vector	Period spent in insect vector	Authority
Leaf roll	Potato	*Myzus persicae* (aphis)	12 to 48 hours	Smith, 1934
Curly top	Sugar -beet	*Eutettix tenellus* (leaf hopper)	7 hours	Severin, 1924
Yellows	Aster	*Cicadula sexnotata* (leaf hopper)	10–17 days	Kunkel et al 1926, Black 1941
Yellows	Peach	*Macropsis trimaculata* (leaf hopper)	8–26 days	Black, 1941
Yellow vein	*Bhendi*	*Bemesia tabaci* (White fly)	7 hours	Verma, 1951
Leaf curl	Cotton	*Bemesia gossypi* (White fly)	6 hours	Kirkpatrick 1931
Leaf roll	Peach	*Colladonus geminatus* (leaf hopper)	45 days	Jensen D D 1953
Curly top	Tomato	*Agallaina encigera* (leaf hopper)	16–24 hours	Costa, 1952
Mosaic	Tobacco	*Myzus persicae* (aphis)	None	—

It has been recently shown (Maramorasch, 1953) that the incubation period in the insect vector is profoundly influenced by air temperatures

An excellent discussion on this topic is given by Holmes (1951), *Bawden (1951), Stanley (1949) and Leach (1940)*

3 **Polymorphism** —This phenomenon, so common in the rust and sooty-mould fungi, is of special significance in maintaining the infection chain and the persistence of the inoculum through periods of drought, desiccation and freezing The production of many types of

spores in the-life cycle which it denotes, has enabled these fungi to withstand rigorous conditions of life and is a clever adaptation to a comparatively more successful life, free from uncertainties and risks involved in **monomorphic** organisms This phenomenon, not only denotes rapid multiplication and phenomenal increase in the number of spores (inoculum) but also ensures a more stable life-cycle and a more efficient and successful " struggle for existence "

4 **Complimentary hosts** — Food requirements of pathogens differ widely, depending upon their ability to produce various types of enzymes, while some have a very wide range and are cosmopolitan in habit, others have a narrow host range, still others are highly specialised and obligate and restrict themselves not only to a single host but even to species and varieties thereof The problem of maintenance of the infection chain is, therefore, urgent in the case of the third category, as the first two have a continuous type of life-cycle and, therefore, not interrupted The other two, on the other hand, have a discontinuous life-cycle, which is interrupted by either (a) absence of a suitable host for a part of the year, (b) non-availability of the specific stage of the host or (c) absence of favourable conditions of growth or environment In the first category may be included such pathogens as species of *Pythium*, *Phytophthora*, *Sclerotium* and *Rhizoctonia* and many others To the second, with restricted host range, belong such parasites as *Phytophthora infestans*, *Xanthomonas malvacearum*, yellow vein mosaic virus of *Hibiscus*, mosaic of sugarcane, *Synchytrium endobioticum*, *Claviceps purpurea* while *Phytophthora arecae*, downy mildews, powdery mildews, the rust and the smut fungi can be classed under the third category of specific parasites

The question naturally arises what specific mechanisms and methods do these latter types of parasites employ, in nature, to maintain their infection chains? How do they persist from year to year ?

Phytophthora infestans, *P arecae*, *Plasmopara viticola*, *Xanthomonas malvacearum*, and many similar pathogens maintain themselves in nature by the formation of persistent mycelium located in plant tissues such as refuge, leaves, stems, tree-tops, seed and underground tubers in the absence of resistant or sexual spores

The stem rust of wheat normally hibernates through the formation of resistant spores, the teliospores, but in tropics, where the teliospores have lost function, oversummers on volunteer wheat plants in the uredial stage in the hills

In the case of the viruses cited above, the infection chain is maintained, in the absence of other hosts, through the medium of insect vectors, which also act as agents of transmission

Some of the very common methods employed by micro-organisms and viruses to maintain their infection chains in the absence of either the host or suitable environmental conditions are listed below

(1) **Facultatism** —*Pythium de Baryanum* (damping-off) *Pythium myriotylum* (foot-rot of ginger), *Phytophthora parasitica* (wilt in *Piper betel*), *P palmivora* (gummosis of citrus), *Urocystis cepulae* (onion smut), *Colletotrichum falcatum* (red-rot of sugarcane), *Colletotrichum circinans* (onion smudge), *Fusarium* wilts of cotton, banana and cabbage, *Rhizoctonia* and *Sclerotium* (root rot fungi), *Corynebacterium sepedonicum* (bacterial ring of potatoes), *Xanthomonas campestris* (black rot of cabbage) and several others

(2) **Persistent mycelium in vegetative parts** —*Synchytrium endobioticum* (Wart of potato), *Phy arecae* (Koleroga of arecanut) *Pythium myriotylum* (foot rot of ginger), *P infestans* (late blight of potato), *P parasitica var piperina* (wilt in piper betel), *Plasmopara viticola* (downy mildew of grape in tropics), *Taphrina deformans* (Peach leaf curl), *Uncinula necator* (powdery mildew of grape in tropics), powdery mildew fungi in tropics, *Cronartium ribicola* (white pine blister rust), *Colletotrichum falcatum* (red-rot of sugarcane), *Ustilago scitaminea* (whip smut of sugarcane), *Gloeosporuium ampelophagum* (anthracnose of grape), *Fusarium* wilt in banana, *Piricularia oryzae* (rice blast), *Helminthosporium* sp causing foot-rots and blights of cereals, *X malvacearum* (black-arm of cotton), *Corynebacterium sepedonicum* (ring of potato), Bunchy top virus in banana "*Katte*" virus in cardamom, potato viruses, neema diseases in potato

(3) **Internal mycelium in seed** —*Erysiphe polygoni* (powdery mildew of peas), *Ustilago tritici* (loose smut of wheat), *Colletotrichum lindemuthianum* (Bean anthracnose), viruses causing ring spot of tobacco, mosaic of lettuce, bean and cucumber

(4) **Resistant spores** —Downy mildews in the temperate zone *Albugo* causing white rusts, *Sclerosporas* (downy mildew of cereals), powdery mildew fungi in temperate zones, smut, bunt and rust-fungi

(5) **Resistant vegetative structures** —*Claviceps purpurea* (ergot of rye), *Sclerotinia fructicola* (brown rot of fruits) fungi causing root rots such as *Rhizoctonia*, *Sclerotium*, *Ozonium* and mushroom fungi This is achieved through the formation of such structures as the sclerotia and rhizomorphs

PHYSIOLOGIC SPECIALISATION

The concept of physiologic specialisation, sometimes also known as host specialisation, or specialisation of parasitism, has a vital bearing on the life-cycles of micro-organisms The first reference to this phenomenon dates back to the days of Schroeter (1879), who noted varying degrees of parasitism in the well-known cereal rust fungus, *Puccinia graminis* on wheat, rye, oats and timothy Such a phenomenon exhibits itself in three distinct aspects viz, **Pathogenic Physiologic** and **Cultural** The first aspect is mainly confined to obligate parasites, like the downy mildews, powdery mildews, rusts and viruses, where a single morphologic species shows widely differential capabilities of parasitism or infection not only within a single species of host, but even varieties thereof A very convincing experimental demonstration of this phenomenon was given by the Swedish Mycologist, Eriksson in 1894 in the well-known fungus causing stem rust in cereals, *Puccinia graminis*, based on cross-inoculation experiments, using the various cereal hosts and the uredial inoculum obtained from these hosts The following is a tabular representation of the results obtained by Eriksson and others with *Puccinia graminis*

Table 3

Host specialisation in Puccinia graminis

Name of host inoculated	Uredial inoculum obtained from				
	Triticum vulgare	*Hordeum vulgare*	*Avena sativa*	*Agrostidis* sp	*Secalis* sp
Triticum vulgare	+	+	—	—	—
Hordeum vulgare	+	+	—	—	—
Avena sativa	—	—	+	—	—
Agrostidis sp	—	—	—	+	—
Secalis cereale	—	—	—	—	+

+ = infection — = no infection

On the basis of such experiments, several physiologic races of *Puccinia graminis* are recognized

1	*P graminis tritici*	Wheat and barley
2	*P graminis avenae*	Oats
3	*P graminis poae*	Poae sp
4	*P graminis agrostidis*	*Agrostidis* sp
5	*P graminis secalis*	*Secalis* (Rye)

Eriksson termed these races as '*formae speciales*' Since then, extensive work has been done on this phase in the case of a large number of micro-organisms Specialisation of parasitism of an extreme type (now recognized as physiologic forms or biotypes) has been demonstrated by Stakman and his co-workers from 1911 onwards at the

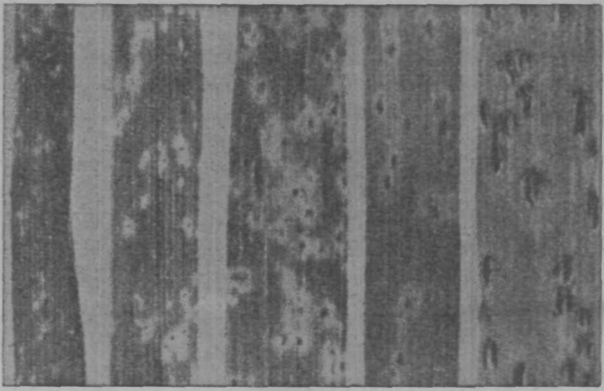
University of Minnesota, U S A in the stem rust of wheat, *Puccinia graminis tritici* and by many others among other fungi, bacteria, nematodes, viruses and even flowering parasites The following is a list of some of the important organisms with the number of physiologic forms recognised therein —

Table 4

Physiologic specialisation in pathogenic organisms

Name of organism	No of physiologic forms	Authority
Puccinia graminis tritici	240 and more	Stakman et al
„ „ „ (India)	10	Mehta et al
„ „ *secalis*	15	Cotter et al
„ „ *avenae*	8	Stakman et al
„ *coronata tritici*	30	Peterson et al
„ *glumarum tritici*	5	Allison et al
„ *sorghi*	6	Stakman et al
„ *hordei*	52	Levine et al
Melampsora lini (In India)	4	Lele
Hemileia vastatrix	2	Mayne
Colletotrichum lindemuthianum	34 (3 groups)	Barrus
Uromyces fabae	20	Wingard
Fusarium vasinfectum	3	Uppal and Kulkarni
Fusarium oxysporum	Several	Hansen et al
Sclerospora graminicola	2	Uppal and Desai
Erysiphe polygoni (marti)	7	Blumer
Erysiphe graminis	7 varieties	Marchal
Peronospora parasitica	Many	Gaumann, E
Albugo candida	5	Togashi et al
Heterodera marioni (nema)	5	Chitwood
Viscum album (Mistletoe)	3	Gaumann E
Helminthosporium gramineum	Over 125	Christensen et al
Ustilago zeae	Many	Christensen J J
Rhizoctonia solani	Many	Kerncamp
Sphacelotheca sorghi	6	Melchers et al
Ustilago tritici	8 plus 11	Grevel, Bever
Potato mosaic Virus X	3	Kohler
Ditylenchus dipsaci (nema)	2	Van Slogteren

These physiologic forms are identified either by their reaction on hosts (Pathogenecity), physico-chemical reactions or cultural characters The former is exclusively employed in the case of obligate parasites. Stakman and his co-workers have developed a key for the identification of forms in *Puccinia graminis tritici*, based on the "infection types" (Fig. 19) using twelve differential *Triticum* varieties. Similar charts and keys are available for other pathogens as well.



0 1 2 3 4

FIG. 19. Infection types in stem rust of wheat
0. Immune; 1 & 2. highly resistant; 3 & 4. highly susceptible.
[After Stakman et al.

Specialisation based on physico-chemical reactions is largely encountered in the Schizomycetes, while the third one differentiated on the cultural characters has been extensively studied in facultative and imperfect fungi viz. *Phytophthora*, *Helminthosporium*, *Fusarium*, *Colletotrichum* and many others.

ORIGIN OF PHYSIOLOGIC FORMS

Variation is wide-spread among micro-organisms. Such variability may manifest itself, as has been already explained in the sphere of virulence on hosts (parasitism) (Fig. 20), chemical or

FIG. 20. Strains of Helminthosporium gramineum showing varying degrees of pathogenecity. L to R : Decreasing degree of virulence.
[After J. J. Christensen.

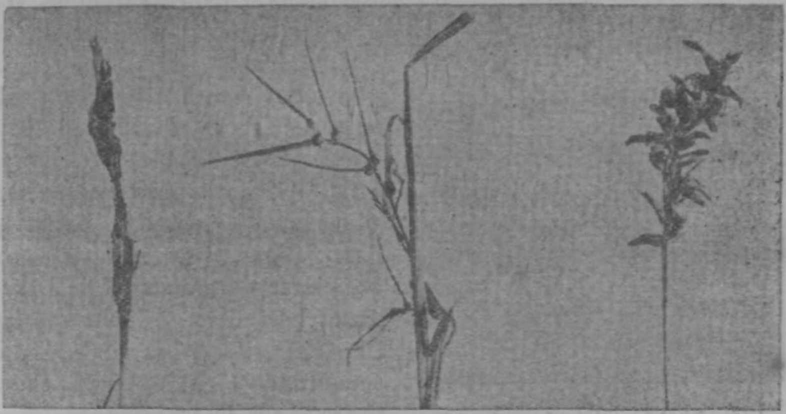


FIG. 21. Origin of physiologic forms by hybridization between headsmut & loose smut of sorghum. L: Headsmut, R: Loose smut, Centre: Hybrid with long sori. [After S. Vaheeduddin.

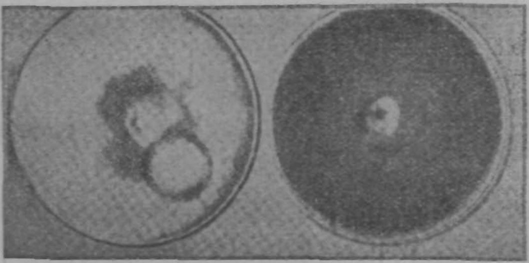


FIG. 22. Two isolates of *Helminthosporium sativum* from a single lesion of barley. L : White, R : Red.

[After J. J. Christensen & Graham.

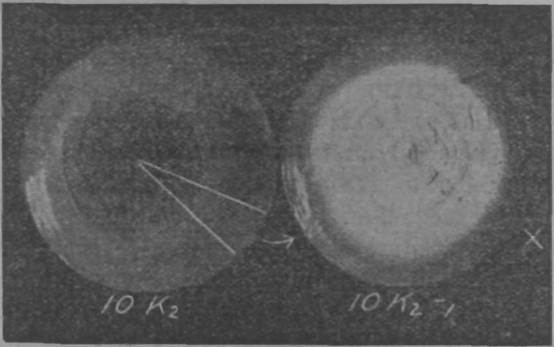


FIG. 23. Origin of new forms by mutation in *Ustilago zeae*. L : Brown parent culture. R : White mutant.

[After J. J. Christensen.

physiologic reactions or cultural characteristics. These variations may arise in nature, either by (1) *Hybridization*, (2) *Mutation* or (3) *Adaptation*. The first method is almost exclusively employed by organisms with sexual stages, such as rusts, smuts, powdery mildews and many other perfect forms (Fig. 21), while the latter methods which involve "sectoring" or nuclear dissociations, (segregations) have been largely encountered in imperfect forms like *Helminthosporium* (Fig. 22), *Fusarium*, and even in smut-fungi (Fig. 23). Fig. 24 shows the manner in which sectoring occurs in monosporidial culture of a smut-fungus. Origin of new forms by hybridization has been experimentally demonstrated in *Puccinia graminis tritici* on the aecial host, *Berberis vulgaris*, which, thus, not only provides an asylum to this rust, but also a breeding ground for new races. While the basis for physiologic specialisation in perfect forms, like rusts and mildews is "host specificity", it is in the nature of "degree of virulence" and "**heterokaryosis**" in imperfect forms like *Fusaria*, *Helminthosporium* etc.

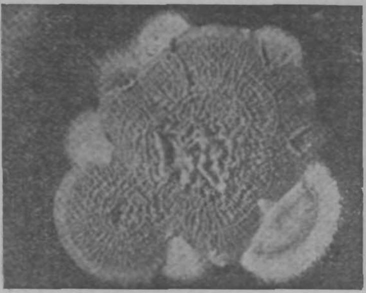


FIG. 24. Mutation (Sectoring) in mono-sporidial culture of Tolyposporium ehrenbergi.

[After M. N. Kamat.

The third method, viz., adaptation is not well understood and probably has a very limited application in nature. It is recognized that weak strains of *Phytophthora infestans*, increase in virulence with successive passage through resistant varieties of potato. Similar situations are met with in *Helminthosporium graminearum* in respect of its tolerance to toxic substances.

SIGNIFICANCE AND PRACTICAL APPLICATION

The demonstration of physiologic specialisation and presence of biotypes and parasitic strains within a morphological entity of 'Linnean' species have had a profound effect on the modern concept of plant pathology and even mycology in several directions. In the first instance, it has led to the abandonment of the original "species concept" of "Linnaean" origin, giving rise to a trinomial and even quadrinomial nomenclature of micro-organisms in place of the orthodox binomial system, splitting the morphologic entity into smaller units such as races, varieties and forms. A morphologic species, thus, has been proved to consist of a large number of individuals differing in parasitic ability, cultural characters and chemical reaction. In the realm of plant pathology, this concept has greatly helped in the proper understanding of the ever-changing disease situations arising from time to time, varying degrees of virulence and severity shown by the same pathogen (?) in different years and regions and in the analysis of the various factors leading to an epiphytotic Above all, it has provided useful information in the practical application of this concept in developing a rational and scientific technique for the control of plant diseases through a breeding programme for disease-resistance to be discussed in chapter 19 This is not all This concept and continual origin of new virulent strains in nature are likely to have a profound effect on the effectiveness of various fungicidal and antibiotic preparations, plant quarantine regulations and may even jeopardise the useful work done in the past in these directions The need for new breeding methods, diverse types of genetical materials and above all a continuous breeding programme aiming at selection of resistant types every few years, under these circumstances, cannot be over-emphasised A thorough knowledge and extent of variability in a pathogen is, thus, of prime importance for success in a breeding programme for disease-resistance

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CHAPTER 8

The Phenomenon of Spore discharge in Fungi

Fungi produce their spores either exogenously on conidiophores, or endogenously in spore-fruits of various types such as zoosporangia, sporangia, ascocarps, and basidiocarps, pycnidia, etc The former types are typical of conidial stages of downy mildews, powdery mildews sooty moulds and many leaf-spotting fungi, like *Cercospora*, *Alternaria*, *Septoria*, *Piricularia*, *Helminthosporium* and so on The problem of liberation of spores relates to the actual breaking away of such spores from the parent hyphae (as in exogenous spores) or from the parent receptacles (as in endogenous spores) and discharging them into air currents or bring them in direct contact with the various agencies of dissemination, such as wind, raindrops, insects and s o on Many fungi have special mechanism of active discharge, while others are passive in action The various mechanisms, employed by fungi in active as well as passive discharge (liberation) of spores will be discussed in this chapter

Passive discharge of spores, resulting in direct contact with air currents is characteristic of the conidia of downy and powdery mildews (Fig 25, B, C) and many leaf spotting fungi, which produce their spores on the surface of the host (ectophytic) or which push conidia and the conidiophores to the outside of the host through stomata or lenticells The smut fungi, specially those which produce their chlamydospores in evanascent sheaths like the loose smut of wheat, the head smut of sorghum, the smut of corn and the whip smut of sugarcane have no special mechanism of discharge and liberate their spores in air currents directly, by the shaking of the main axis or through the action of suction (Fig 25, A)

Active discharge of spores, on the other hand, is brought about by various types of special devices and mechanisms so admirably described by Buller (1909–1934) in his '*Researches of fungi*' Some of the common mechanisms employed by fungi, for this purpose, are described below

1 Abstriction —This phenomenon is of common occurrence in the discharge of conidia of Entomophthorales, basidiospores of mushroom fungi (Fig | 25, F) and the sporidia of the bunt and rust fungi (Fig 25, D, E) A liquid droplet appears at the point of attachment of the conidium or sporidium to its sterigma, the connection between the two is loosened and the droplet carries the conidium or sporidium along with it actively discharging it to a distance of a millimetre This

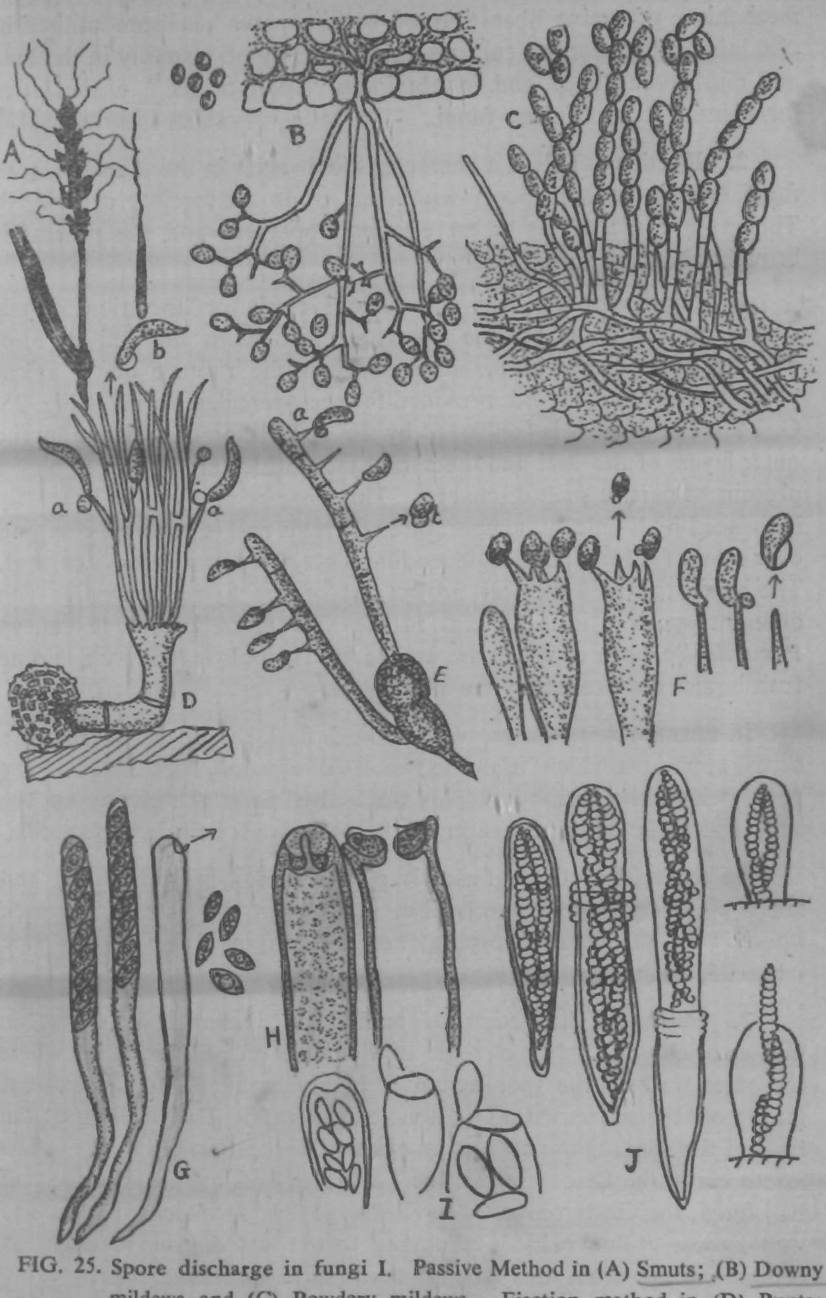

FIG. 25. Spore discharge in fungi I. Passive Method in (A) Smuts; (B) Downy mildews and (C) Powdery mildews. Ejection method in (D) Bunts; (E) Rusts; & (F) Mushrooms; (G) Streaming of ascospores; (H) Lid formation; (I) Formation of hinges; (J) Shooting action (After D, F & G Buller; H. Chadefaud; I. Englar & Prantl; J. Hodgetts).

[Drawing : Miss Kumud Lad.

mechanism of active liberation of basidiospores has been utilised in obtaining monosporous cultures for the study of sexuality in the rust and mushroom fungi and in obtaining " spore prints " of the latter for identification of these fungi

2 **Ejection** —This is a characteristic process in the Ascomycetous fungi, where the ascospores within an ascus are forcibly discharged The mother sac serves as an ejection apparatus and the process is brought about by varied mechanisms

During the process, the mature asci ready for liberation of their spores, protrude one by one above the hymenium and actively eject out the ascospores within, either through the rupture of the apical pore, the slit and the lid provided for the operculate forms (Fig 25, G, I) The process is facilitated by the absorption of moisture by the outer layers of the asci and the paraphyses, which are known to play a prominent part in such discharge This process of ejection is greatly influenced by humidity, temperature and light and is repeated over and over again for long periods depending upon favourable environment The height to which the asci project out of the hymenium varies with different species, it is 15 cm in *Pleurage fimiseda* and 45 cm in *P curvicolla*, both of which are apothecial saprophytes and have minute fruit bodies not exceeding one millimetre

In several Ascomycetes, with typical flask shaped perithecia, the actual apparatus which helps the process of ejection, is situated at the neck, where the periphyses play an active part the drying of the neck and ultimate compression of the ascus walls help in this process

" **Shooting** " action of asci is also common in some fungi and takes place through a mechanism situated at the base of the asci, whereby all the eight ascospores are shot off in a line one by one (Fig 25, J)

3 **Puffing** —The action of puffing or discharge of spores in masses or clouds is characteristic of *Pilobolus* of the Mucorales where the outer wall of the sporangium is highly cutinized and gives way, letting out the spores within, in a violent manner The swelling at the base of the sporangium acts as an ejection apparatus (Fig 29) The apothecia of the Discomycetes, the Tuberales and members of the puff ball fungi, the Gasteromycetes have also got similar mechanisms The well known " Puff balls belonging to the latter group derive their common name from this type of their spore-discharge There is no special mechanism in this case for liberation of spores, which are produced inside chambers and is effected by the physical wear and tear of the fruit-bodies brought about by environmental conditions such as temperature, moisture and light In underground fruit-bodies of the Tuberales, the truffles, fruits break open through pressure created by

animals and dogs, who dig them up from the ground and the spores within discharged in a " hissing " or violent manner.

4. Disjunctors :— This is a well-known mechanism employed by fungi in the liberation of their spores; small rectangular, conical, wedge-shaped or spindle shaped structures a r e produced at points of attachment of the spore in between it and the sterigma or conidiophore or in certain cases between spores in a conidial chain. The wedge-shaped disjunctors, sometimes designated " *hilum* " are of common occurrence in *Alternaria*, *Helminthosporium* and *Piricularia*, (Fig. 26) with the help of which the spore gets itself easily detached from the parent hypha. In *Albugo*, causing the well-known white rusts and in *Sclerotinia fructicola*, the brown rot fungus, the disjunctors or "pluggs" are placed in between spores in a conidial chain (Fig. 26, 1 and 2) and help in easy breaking off of the spores from the chain; the same mechanism occurs in the aecial chains in rust fungi. In *Syncephalis* belonging to the Mucorales, the spore is enveloped in a thin " ring ", which helps it to break away from the spore chain (Fig. 26, 3); these disjunctors are gelatinous and on account of their brittle nature, are admirably adapted to effect the liberation of spores, before they are carried away by various agencies of dissemination.

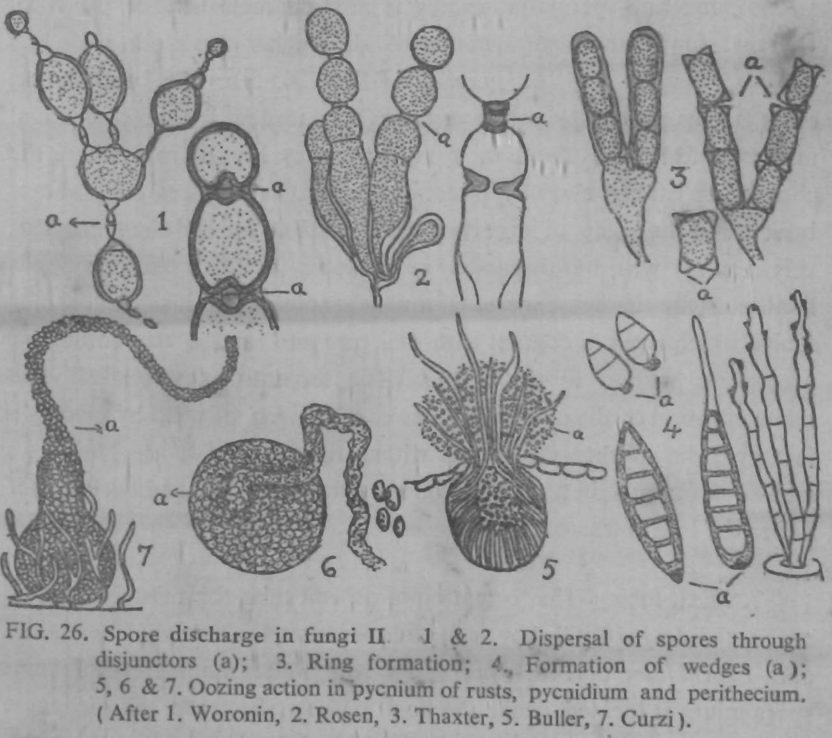

FIG. 26. Spore discharge in fungi II 1 & 2. Dispersal of spores through disjunctors (a); 3. Ring formation; 4. Formation of wedges (a); 5, 6 & 7. Oozing action in pycnium of rusts, pycnidium and perithecium. (After 1. Woronin, 2. Rosen, 3. Thaxter, 5. Buller, 7. Curzi).

[Drawing : Miss Kumud Lad.

5 **Lid formation.**—This is indeed a novel and ingenious mechanism and has been employed by a few fungi belonging to the Chytridiales and the Discomycetes (Pezizales) This method of liberation of spores, is common in *Synchytrium endobioticum*, *Physoderma zea-mays* of the lower Phycomycetes and the genera *Morchella*, *Ascobolus* and *Saccobolus* of the Ascomycetes With the maturity of spores within a sporangium or the ascus, as the case may be, the " Lid " opens out like a typical hinge and lets out the spores Such forms are known as " **operculates** " and the formation of these lids serves as an important taxonomic character to distinguish groups A few of the typical operculums are illustrated in Figs 25, I and 28, D, E

6 **Oozing** —This phenomenon is of common occurrence in the liberation of zoospores from the mouth of a sporangium in the Phycomycetous fungi, the serpentine fashion of spore-chains released by some Ascomycetes (Fig 26, 7), (*Microascus*) and pycnidia of the Sphaeropsidales of Fungi-Imperfecti (Fig 26, 6), oozing of pycnospores and spermatial spores is also characteristic of pycnia of the rust fungi and spermagonia of the higher Ascomycetes (*Mycosphaerella* and *Guignardia*) (Fig 26, 5) The well-known ergot fungus, *Claviceps purpurea* forms "honeydew' stage of conidial masses, and releases them in a mucilagenous liquid from where the conidia are carried away by insects In fact, in all cases cited above, insects and flies play an important role in their further dissemination, this aspect will be discussed in Chapter 9 The oozing action is facilitated by the presence of a mucilagenous liquid inside the spore-fruits, which swell in contact with moisture and release the conidia or ascospores within, in the characteristic serpentine fashion A vivid demonstration of the oozing process can be given, at will, by placing a few pycnidia of the well-known wither-tip fungi (*Phoma*, *Phomopsis* and *Phyllosticta*) in a drop of water on a micro-slide and observing it under the low power of the microscope

7 **Exit tube** —The formation of an exit tube for releasing spores is a special device utilised by such endoparasites as *Olpidium*, *Olpidiopsis* and *Lagenidium* of the lower fungi, the water moulds, the resting sporangium is located inside the host tissue and releases the zoospores through an exit tube (Fig 28, B, C)

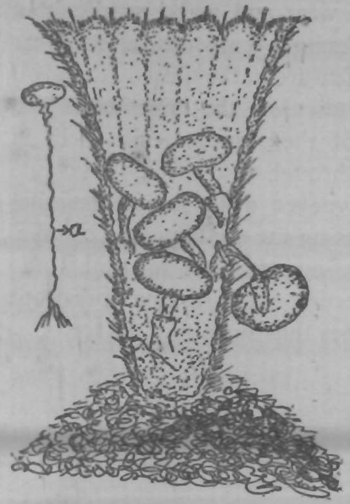

FIG. 27. Spore discharge in fungi. *Cyathus* fruit body with peridiole within and mechanism of dispersal through funicular cord (a)

[Drawing : Miss Kumud Lad.

8. Splashing :— Dispersal of spores of a very ingenious and highly specialised type occurs through the mechanism of elastic funicular cords in fungi belonging to the Gasteromycetes in the genera *Crucibulum* and *Cyathus* the wellknown birds–nest fungi, where the " peridiole " or miniature fruits produced in the fruit body are thrown out of the main body, to a distance of 3 to 4 feet through the help of funicular cords (Brodie, 1951 and Dodge, 1941), Fig. 27.

9. Phototropism :—Light acts as an important stimulus in enabling fruit-bodies of several fungi to discharge their spores into the air currents in the form of clouds. The fruit–bodies of such fungi like the *Pilobolus*, the apothecia of the Ascomycetous fungi, the mushrooms and the birds–nest fungi are well adapted to such responses, which place these bodies and their spore-bearing surface in the most favourable position for liberating the largest possible number of spores into the air currents (Fig. 29)

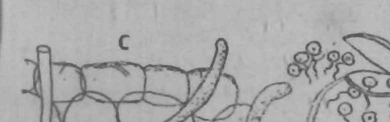

FIG. 28. Spore discharge in fungi III.

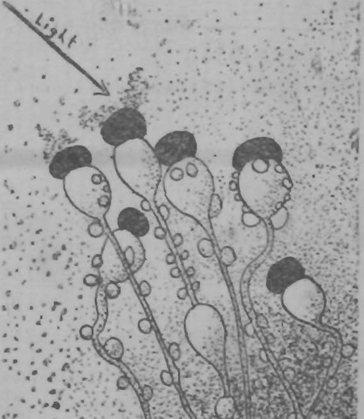

FIG. 29. Phototropism and spore-discharge in *Pilobolus*.

[Drawing : Miss Kumud Lad.

Dispersal of spores through physical wear and tear brought about by sudden changes in environment, particularly temperature, moisture and light intensities has been a common feature in the closed ascocarps, the cleistothecia belonging to the Plectascales, the appendages and other o u t g r o w t h s on the body of these spore-fruits, help in this phenomenon, the mechanism works through absorption of moisture by these outgrowths bringing about an uneven distension of the outer wall, resulting in irregular cleavage, releasing the contents, the conidia, the oidia, the asci and ascospores Spore-dispersal in a few smuts and bunts takes place at the time of the harvesting and threshing operations by the physical breakage of the membranes that surround the sori

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CHAPTER 9

Dissemination of plant pathogens

The next phase, in the life cycle of plant pathogens after the dispersal and liberation of their spores, is the transmission of these spores and inoculum, from host to host at various distances, short or long, continuous or discontinuous In other words, the question of manner of spread of pathogens and their transmission to new hosts, new fields, new localities and new countries, is upper-most in the mind of the plant doctor, as it naturally helps him in his endeavour to control, prevent and avoid plant diseases The simple question, therefore, is as to how infection travels

All parasitic diseases are transmissible, since otherwise, they will disappear with the disappearance or death of the hosts, they are, thus infectious with an ability to spread According to Butler (1917), such transmission or spread may be *continuous* or *discontinuous*, the former relates to the spread in a geographical unit and therefore may be termed " short distance transmission ", the latter involves " long jump transmission " and ordinarily takes place between two geographical units, separated by physical barriers such as oceans, mountains and deserts Dissemination may be effected through the help of various agencies as shown below

DISSEMINATION

Continuous	Discontinuous
1 Autonomous	1 Man
2 Wind	
3 Water	
4 Animals	
5 Birds	
6 Insects	

CONTINUOUS DISSEMINATION

This type of transmission may be termed also " short distance transmission " and is mainly responsible for spread of infection from host to host, field to field or locality to locality, closely connected by geography, in nature, such spread occurs by stages through rythmic cycles The well-known example of such spread which ultimately covers long distances, is the Black Stem Rust of wheat, which in the

U. S. A. spreads continuously, by intermittant stages, from the south to the main wheat belt area in the North (Fig. 30) or in India from the summer wheat in the Nilgiris to the *kharif* crops in the southern states, ultimately reaching the main *rabi* area in the Deccan plains.

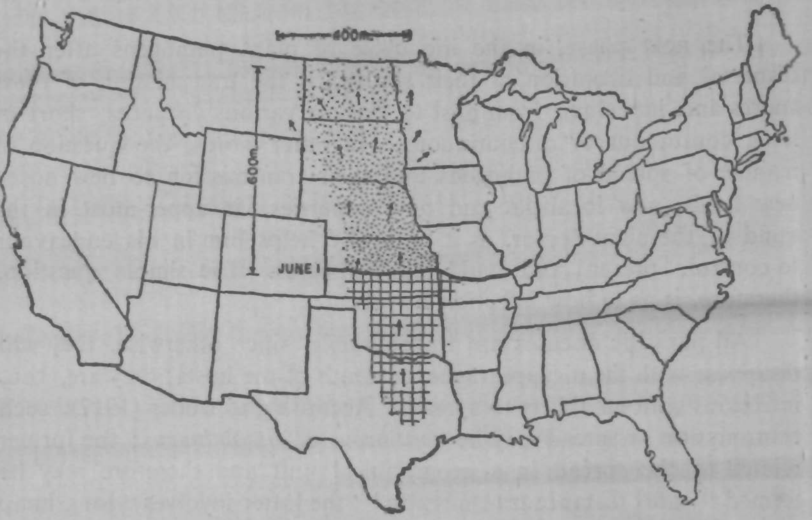

FIG. 30. Long distance aerial dissemination of urediospores of stem rust of wheat in U. S. A. Squared region : Oversummering urediospores. Dotted region : rust infection. [After E. C. Stakman.

We will now consider the various types of agencies that take active part in the transmission of pathogens by the continuous methods.

1. Autonomous transmission :— This manner of spread of plant pathogens, is restricted to short distances, unlike human pathogens, which spread over wide areas in a short space of time. Such rapid long distance spread also occurs with insect pests. This is largely due to the lack of " locomotion " in plant pathogens.

The autonomous transmission mentioned above is characteristic of the wood-rotting fungi, such as *Armillaria*, *Fomes*, *Ganoderma*, *Polyporus* belonging to the Hymenomycetes, which " migrate " independently by the active growth of their hyphal strands, through soil from plant to plant and even field to field (Fig. 31). This is a typical method of spread in forest areas and is effected through the formation of long radial hyphae or fungus cords known as rhizomorphs, (Fig. 31) so common with these fungi. The root-rot fungi such as *Sclerotium rolfsii*, *Rhizoctonia destruens*, *Corticium vegum*, *Phymatotrichum omnivorum*, *Rhizoctonia bataticola* and species of *Ozonium* also belong to the same category and spread themselves by the formation of underground hyphal strands or felts and sclerotia (Fig. 32). The rate of such spread in *Phymatotrichum omnivorum* through cotton crop is estimated at 5 to 30 ft. per season and 2 to 8 ft. per month in a Alfalfa crop (Streets, 1937).

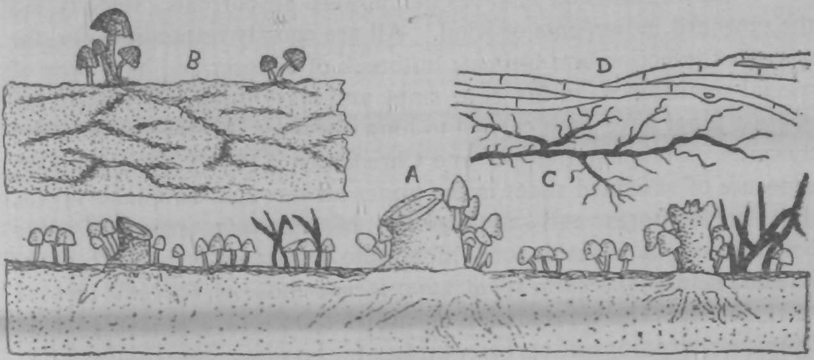

FIG. 31. **Autonomous spread of a mushroom fungus. A. Soil profile showing growth of rhizomorphs within and fruit bodies without, B. Surface view of (A), C. A single rhizoidal strand. D. Hyphae making C.**

[Drawing : Miss Kumud Lad.

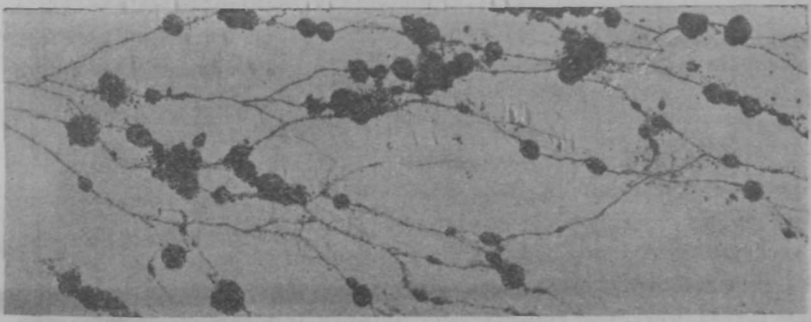

FIG. 32. Autonomous spread of the Texas root rot fungus through soil showing mycelial strands and sclerotia. [After Streets R. B.

2. Wind transmission :—This type of spread designated by Gaumann (1950) as " *Anemochory* ", is of special significance in wind-borne diseases. It is the most dangerous and potent mode of travel for most plant pathogens, specially fungi. Of the various types of plant pathogens encountered in nature, the fungi are effectively transmitted through air. Such of the fungi that produce their spores outside the surface of the host, like downy mildews, powdery mildews, leaf spots, sooty moulds and even several smuts with evanascent sheathes for their spore-powders such as loose smut of wheat, loose smut and head smut of sorghum and common smut of corn, are efficiently disseminated by wind Uredial stages of the rust-fungi travel long distances through air currents and are thus responsible for destructive epidemics over wide areas

Wind transmission involves the upward air currents, velocity and the downard movements of wind All are equally responsible for the spread of infection and ultimate outbreak of diseases and have been of special significance, in the rust, smut and blast fungi. Uredio-spores of rust fungi have been carried to long distances, both cross-wise and upwards Stakman (1946) and Christensen (1942) determined, by exposure of vaselined slides in the upper air through aeroplane flights, that urediospores and aeciospores of *Puccinia graminis* could be gathered in a viable condition upto a distance of 14000 ft above infected fields, *Alternaria* sp at 8,000 ft and those of *Puccinia triticina* at 12,500 ft The transmission of aecial spores of *Puccinia graminis* from several groups of barberry bushes to the wheat crop, showed that these spores travelled successfully over a radius of 3 Kms round about these bushes The blister rust fungus, *Cronartium ribicola*, is known to travel to a distance of 500 metres or 12,500 ft inside a plantation and the range is probably more in the open Similar observations have been made in respect of dissemination of chlamydospores of the smut fungi and the phenomenon is designated as " *Spore showers* "

It may, however, be remembered that in such long distance dissemination with intervening stages of infection, the retention of viability of spores is an important consideration that determines the extent and severity of epidemics, over wide areas The outbreaks of cereal rusts and blast of rice are examples of such dissemination Spores differ widely in their ability to survive long distance travel through air The conidia of downy mildews, powdery mildews and the aeciospores and basidiospores of the rust fungi are unable to withstand such long distance dissemination when they are exposed to desiccation and direct sunshine and thus are only capable of producing local epiphytotics of limited magnitude On the other hand, urediospores of rusts, chlamydospores of smut fungi and conidia of *Alternaria*, *Helminthosporium*, *Piricularia* and others are well adapted for long distance travel in a viable condition and are known to play a vital role in epidemiology (Fig 30)

Excellent reports are available on the aerial dissemination of plant pathogens by Stakman et al (1946), Christensen J J (1942) and Craigie (1940)

3 **Water transmission** — This type of transmission termed by Gaumann (1950) as " *Hydrochory* " is of minor importance The surface running water as a result of heavy showers of rain, the irrigation water from wells and canals serve as agencies for

transmission of such soil-inhabiting organisms as *Pythium*, *Synchytrium*, *Phytophthora*, *Fusarium*, *Sclerotium* and *Colletotrichum* Many pathogenic soil-bacteria are also disseminated in this manner The eelworm disease of potato and *Piper longum* have been known to be carried from field to field through surface water The spread of infection in the red-rot of sugarcane caused by *Colletotrichum falcatum* and the dissemination of the sclerotial bodies of *Sclerotium rolfsii* through soil, are chiefly brought about by irrigation water Water is an important agency of dissemination for the seeds of flowering parasites such as *Orobanche*, dodder (*Cuscuta*) and *Striga* through soils

Short distance transmission of pathogens from leaf to leaf of adjacent plants occurs through splashing rain accompanied by wind in the case of semi-aquatic pathogens like *Phytophthora arecae*, *Phytophthora parasitica P infestans* and other downy mildew fungi These fungi are well adapted to wind as well as water dissemination due to the formation of deciduous conidia capable of germination either by zoospores or germ tube and have thus developed into dangerous pathogens capable of wide-spread damage within a short period

4 **Animals** — The farm animals are a minor factor in the transmission of pathogens, this happens in nature by the inoculum adhering to the hoofs and legs or internally through the passage in the alimentary tract Soil-inhabiting fungi, and specially the sclerotia and rhizomorphs may be carried in this manner The smut fungi have been known to be carried from field to field through the alimentary canals of farm animals Grain or Kernal smut, loose smut and head smut of sorghum are well-known examples of such transmission, although of no great consequence

5 **Birds** — This mode of transmission, although of minor importance in general, is of great significance in a few specific cases The best known examples are the dissemination of the well-known flowering parasite (*Loranthus* sp) and the chest-nut blight fungus, *Endothea parasitica*, many migratory birds, such as mistle-thrush (*Turdus viscivorus*) in the temperate region and the crows (*Corvos brachyrhynchos*) in the tropics, take active part in transmission of the mistletoe (*Loranthus* sp) either through external contamination of their beaks and feathers or internally through the alimentary canals Internal transmission of spores of *Endothea parasitica* is carried on by many birds, which visit such diseased plants and get contaminated by the spores No less than 18 species of birds were found to be so contaminated (Heald and Studhalter, 1914)

Birds are also known to carry on their bodies, ascigerous stages of the powdery mildew fungi

6. **Insects :—** Insects play a dual role; they are capable of causing enormous damage to plant life independently and also as carriers of pathogens. The former aspect is dealt with by the entomologist. Insects transmit pathogens either *mechanically* or *biologically;* in the former case, they behave as casual *carriers;* in the latter as specific *vectors.* An excellent discussion on the role of insects in the transmission of plant pathogens is embodied in the book entitled "*Insect Transmission of Plant diseases*" by Leach (1940).

INSECT TRANSMISSION OF PLANT PATHOGENS

Insects play a specific role in the transmission of virus diseases of plants, where they act as specific vectors for the virus. This aspect has been discussed in Chapter 7. The role of insects and mites as mechanical carriers will only be dealt with in this chapter.

Like the birds, insects carry pathogens either externally or internally. Gaumann (1950) uses the terms *Epizoic* and *Endozoic* respectively for the two types of transmissions. Fig. 33 illustrates the endozoic mechanical transmission of fungus spores through several species of ants.

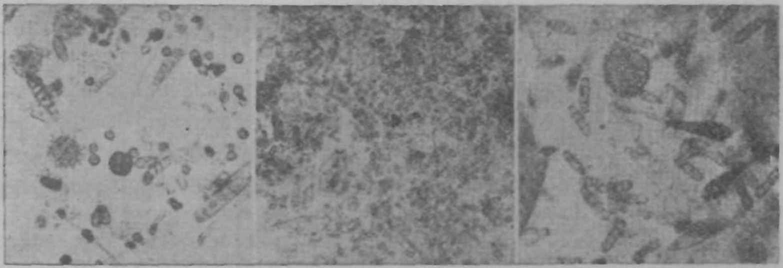

FIG. 33. Endozoic transmission of fungus spores through pellets of ants. (Photomicrograph) [After Bailey.

The external transmission of plant pathogens is of special interest in those fungi, which produce their conidia, oidia and spermatia in sweet or honey secretions having attractive odours. Some of the well-known diseases of this type are the ergot, the *Sclerotinia* brown rot of pears and apples, the honey-dew stage in the "sugary disease" of *Sorghum* in parts of India and the pycnial nectar in the cluster cup stage of rusts. The spermatial oozings at the mouth of spermagonia in the Ascomycetes attract various types of insects, flies, pollinating bees and wasps which play a dual role: pollination and transmission of pathogens. The fire blight organism (*Bacillus amylovorus*) and *Xanthomonas citri* causing the well-known citrus canker, are also carried in this manner, the former by flies and ants (Fig. 34) and the latter by the leaf miner.

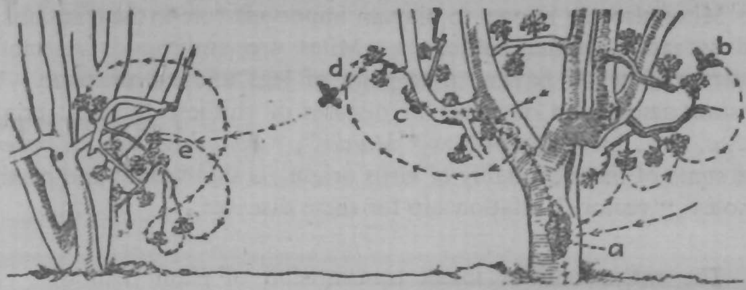

FIG. 34. Diagrammatic sketch showing the role of flies and ants in the spread of fire blight of apples. [After Thomas & Ark.

Interesting and ingenious transmission of pathogens, of an internal nature (endozoic) is provided by the Dutch Elm disease (*Ceratostomella ulmi*) and the olive canker (*Bacillus savastanoi*). The former is transmitted by the elm bark beetles (Fig. 35) and the latter by the olive fly (*Olea europaea*) (Fig. 36). These insects, unlike the epizoic group, appear to have a close biologic relationship with the pathogens, as they have not been reared without the contaminating pathogens; the relationship can be likened to " symbiosis "

FIG. 35. Insect transmission in Dutch Elm disease : Section through pine bark beetle showing masses of ascospores of *Ceratostomella ips* within (b). [After Leach et al.

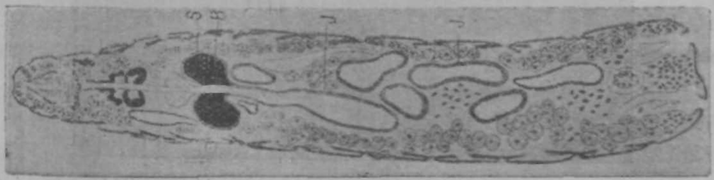

FIG. 36. Insect transmission in olive canker (Knot). Section of Olive fly showing colonies of *Bacillus savastanoi* within (B) [After Petri.

Mites also are known to play an important role in the transmission and spread of some pathogens. Mites are anthropods resembling spiders and ticks, having four pairs of legs and no antennae. The constant association of mites in diseases of chillies, tomato, brinjal, potato, etc., locally known as " *Murda* ", " *Bokadya* " and "*Tambera*" and some of them probably of virus origin, is significant, and possibly denotes " vector " relationship for these diseases.

The entire field of insect transmission of plant pathogens is of vital importance from more than one aspect and has, therefore, been receiving close attention of not only the plant pathologist but also the plant physiologist, since this relationship has an important physiologic bearing and may throw a flood of light on the real nature of plant pathogens, specially of the virus type.

7. **Biologic transmission** :—As has been already explained, this type of transmission commonly found in human malaria, is of special significance in virus diseases of plants, where various types of sucking insects play an important role. The persistence in and transmission of some plant viruses through dodder (*Cuscuta subinchusa*) from plant to plant was demonstrated by Bennet (1944). The phanerogamic parasite picks up the virus from the affected plants, without itself showing any signs of infection and transmits it through its haustoria. The dodder thus functions as an asylum for the virus as well as a transmitting agent, even as the insect vector does (Fig. 37).

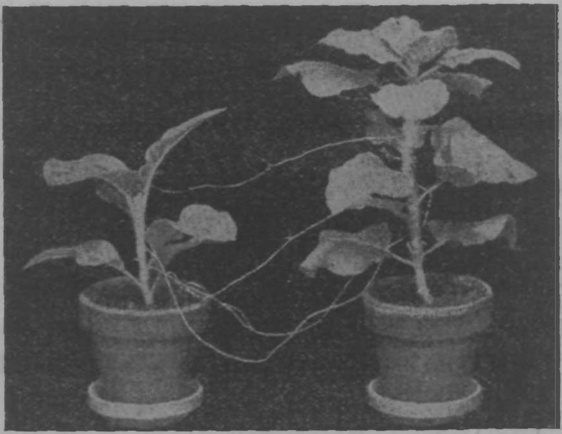

FIG. 37. Transmission of virus through dodder.
L : Healthy & R : Diseased plant. [After F. Johnson.

The following table summarises the mode of transmission of important plant pathogens through animal (*zoochorus*) agencies

Table 5

Plant pathogens and their carriers

Disease	Pathogen	Carrier	Nature of transmission
Root-rots	Soil fungi	Farm animals	External
Red-rot of sugarcane	*Colletotrichum falcatum*	Moth-borer & weevils	-do-
Smuts of sorghum	Ustilaginaceae	Farm animals	Internal
Stem galls of trees (Mistletoe)	*Loranthus* sp	Mistle-thrush, crows	External and internal
Dutch Elm disease	*Ceratostomella* [illegible]	Elm bark beetle	Internal
Chestnut Blight	*Endothea parasitica*	Various spp of birds	Internal
Ergot of rye (honey dew stage)	*Claviceps purpurea*	Wasps and flies	External
Sugary disease of sorghum	*Sphacelia sorghi*	Wasps and bees	External
Bacterial ring of potatoes	*C solanacearum*	Colarado potato beetle	External
Fire blight of apples	*Bacillus amylovorus*	Flies & ants	-do-
Anther smut of pinks	*Ustilago violaceae*	Moths	-do-
Citrus Canker	*X Citri*	Leaf miner	-do-
Bacterial wilt of cucumber	*Erwinia tracheiphila*	Cucumber beetle	-do- and Internal
Brown rot of pears (conidial stage)	*Sclerotinia fructicola*	Wasps and bees	External
Plant rusts	*Pycnial nectar*	Bees, flies and wasps	-do-
Pine Blister rust	*Cronartium ribicola*	Gypsy moth	External and Internal
Blossom blight of red clover	*Botrytis anthophila*	Bees	External

DISCONTINUOUS DISSEMINATION

Man plays the most efficient but dangerous role in this type of transmission, which takes place between geographical units, separated by physical barriers His part in the transmission of human diseases is indeed, unique Many infectious diseases of man like the tuberculosis, diptheria, pneumonia, catarrhs, small pox and others are mainly disseminated through his agency, the mode is different from that in plant pathology in the former, the host (in this case the diseased individual) takes an active part and itself carries the pathogens in the latter, the host is passive and has no direct part to play in transmission, this difference is due to the ability of locomotion in the former and lack of it in the latter

Man's role in this phenomenon is more indirect than direct In his zeal for new plants, ornamental or otherwise and with increasing *international contacts and trade, human agencies of various types,* individual, official as well as unofficial have transported new plants and plant products, the seed, the tubers, the propagating stock and fruits, which carried the plant pathogens, many times in a latent condition and which ultimately lead to the outbreaks of new diseases in places, hitherto free from them The diseases which are amenable to such transmission are mainly those that are carried in or on the propagative parts and seed, such as the white pine blister rust, the late blight of potato, the downy mildew of grape, the citrus canker, the chestnut blight, the Dutch Elm disease, the *Fusarium* wilt of bananas, the *Katte* disease of cardamoms, the bunchy top of bananas, the cankers and anthracnoses and several others The history of introduction of these and other diseases in different countries through the agency of man, makes very interesting but tragic reading and has been very graphically narrated by Large (1940) in his book *Advance of fungi* A few such diseases together with their places of origin and years of introduction are given below —

Table 6

Introduction of plant diseases in new areas

Disease	Original home	Introduced country	Year of introduction
Citrus canker	Asia	U S A	1907
Fire Blight of apples	U S A	New Zealand	1919
P mildew of grapes	U S A	Europe	1845
D mildew of grape	U S A	France	1878

Disease	Original home	Introduced country	Year of introduction
Blister rust of pine	Russia	U S A	1909
Scab of apples	Sweden	U S A	1834
Late blight of potato	South America	U S A	1830
-do-	U S A	Europe	1845
-do-	Europe	India	1870
Wart of potato	Europe	U S A	1918
Bunchy top of banana (virus)	Ceylon	South India	—
Dutch Elm disease	Holland	U S A	1928–30
Gooseberry mildew	U S A	Europe	1890
Chestnut Blight	Mediterranean region	U S A	1904
Paddy blast	South-east Asia	Madras	1918
Panama disease of banana	Panama canals	Bombay	1920

Many of these diseases, not very destructive in their homelands, have brought in ruin and devastation of an unprecedented magnitude, jeopardised the respective industries and even exterminated them in their entirety when introduced into new regions

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CHAPTER 10

SPORE GERMINATION IN FUNGI

Spores of fungi must germinate and produce infection tubes prior to the phenomenon of penetration into and infection of the host, the position is, however, different in bacteria, parasitic myxomycetes and viruses, which employ different types of mechanisms for this purpose, to be described in the next chapter Like seed, germination of spores is profoundly influenced by various factors, it is in the nature of growth process and involves a change from a passive resting stage to an active condition These factors can be grouped under two heads according to their nature, *Internal* or *Hereditory* and *External* or *Environmental* The internal factors include those which are inherent in the spore itself such as the nature and thickness of cell wall, viability, longevity, age, period of dormancy and conditions in which spores are actually formed in nature

The external factors are temperature, moisture, nutrients, oxygen, light, reaction of the medium and stimulatory products

TYPES OF GERMINATION

Spores, in fungi, germinate either directly or indirectly Three types can be recognised on the basis of its nature The direct germination consists of the formation of a germ tube, which subsequently gives rise to a mycelium the germ tube is indeterminate in character and directly takes part in the mechanism of penetration Th pe is characteristic of conidia and is well adapted for terrestrial hab t (Fig 38, 5) The indirect method of germination may consist of formation of zoospores (*zoosporal*) or formation of a limited germ tube, the basidium (*basidial*), the former is typical of aquatic and semi-aquatic fungi like the *Pythiums* and *Phytophthoras* (Fig 38, 1), and the latter of the smuts, the bunt and the rust fungi (Fig 38, 2-4) The zoospores are motile and stream through a pore in the mother sporangium, the basidium is determinate and therefore limited in growth and may be either septate or nonseptate and does not, as a rule, take direct part in the phenomenon of penetration Several modifications and variations in this phenomenon of germination occur *in nature, depending upon the environmental conditions obtained*

TECHNIQUE FOR SPORE GERMINATION

While it is possible to obtain germination of spores by sowing such spores in a drop of water on a glass slide, the best and efficient results are obtained by the use of the well-known ' *hanging drop*

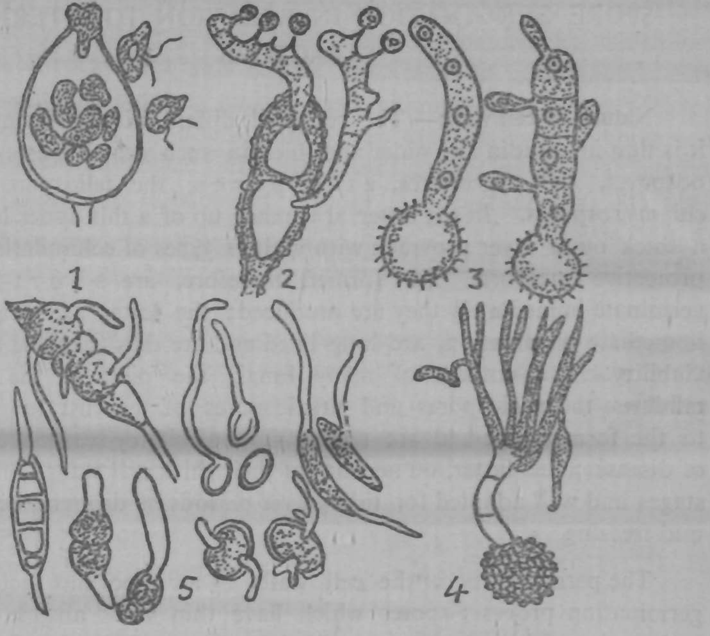

FIG. 38. Types of germination in fungus spores. 1. Zoosporal in aquatic fungi; 2, 3 & 4. Basidial in rusts, smuts and bunts; 5. Direct by germ tube. [Drawing: Miss Kumud Lad.

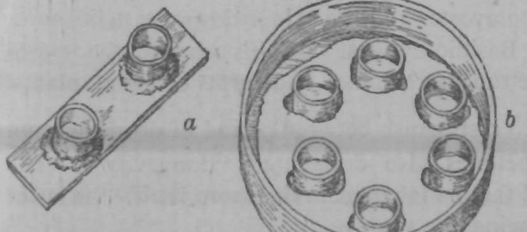

FIG. 39. Van Teighem cells used in spore germination studies; a. cemented to slide; b. fixed in filter paper. [After Duggar, B. M.

cultures "; these cultures are obtained by using the *Van Teighem Cells,* first employed by Hoffman in 1860 (Fig. 39). This method not only provides the best conditions for germination, but also admits of direct observation even through a high-power microscopic lens; besides, the chances of accidental contaminations are greatly minimised. Various modifications of this general technique have been advocated to suit special requirements of each case.

SPORE GERMINATION IN RELATION TO INTERNAL FACTORS

Nature of cell wall — The cell wall differs with different spores it is thin in conidia and oidia and thick in such sexual spores as the oospores, the zygospores, ascospores, the teliospores and in chlamydospores In the latter, it is made up of a thin inner layer and a thick outer layer provided with various types of echinulations as a protective measure The former, therefore, are short lived and germinate immediately they are produced, the latter are incapable of immediate germination, are long-lived and are thus capable of longer viability The conidia of many fungi, the oidia of the powdery mildews, the aeciospores and urediospores of the rust fungi belong to the former type and are mainly responsible for seasonal outbreaks of diseases, the latter, on account of their thick cell walls are resting stages and well adapted for tiding over periods of drought, desiccation and freezing

The permeability of the cell walls is an important factor in the germination process, spores which have thin walls absorb moisture and nutrient solutions more readily than those with thick impervious cell walls The latter type are, however, known to yield to special treatments, physical as well as chemical, to be described later

Period of dormancy — This varies with different types of spores The conidia do not have any dormancy period. It is a special feature of the sexual spores, the oospores and zygospores of the Phycomycetes, the ascospores of the Ascomycetes and the chlamydospores, teliospores and basidiospores of the Basidiomycetes In this respect, the spores behave like the vegetative tubers, rhizomes and corms of higher plants

It is important here to distinguish between period of dormancy and period of viability, sometimes also designated "longevity" The former relates to internal factors inherent in the spore itself, the latter to external factors influencing the spores

As a general rule, the resting spores pass through a varying period of dormancy before they are able to germinate This period, however, is amenable to termination by the application of special stimuli, such as alternate freezing and thawing, floating spores in films of water, exposure to volatile substances, treatment with organic acids, etc Heating of the spores and then placing them at normal temperatures has given good germination in spores not usually amenable to germination under normal conditions

Age or maturity of the spores —It is an important factor to be reckoned with, specially in comparative experiments Numerous conflicting results reported in literature on germination tests, are largely due to this factor As a rule, young vigorous spores germinate more readily, uniformly and rapidly than the older ones, which lose their viability quickly and behave erratically in germination tests Conidia of the hop downy mildew gave optimum germination within 5 hours when fresh and young while they took an erratic course and needed 10–20 hours when old, losing their viability rapidly with ageing Similar results were obtained for conidia of *Pestalotia psidii* Its fresh conidia gave 99% germination, which was 85% after 6 days, 65% at end of 14 days, 15% after 20 days and practically in traces at end of 25 days

Period of viability — This period varies with the type of the spore and is determined by external conditions like temperature and humidity In general, spores remain viable for longer periods at lower than at higher temperatures Spores in culture have shorter viability than those produced in host tissues The normal periods of viability of a few types of spores are given below —

Types of Spores	Period of viability
Smut Spores (*Tollyposporium*)	4 years
Sphacelotheca sorghi	2 years
Tilletia tritici	8½ years
Sclerospora (Oospores)	3 years in host tissue
Urocystis cepulae	5 years in soil
Slime moulds	5–32 years in herbarium
Aspergillus oryzea	22 years in test tube
Pestalotia psidii (in culture)	7 months
,, ,, (in host tissue)	1 year
Teliospores of rust fungi	5 months
Urediospores of rust fungi	30–60 days at low temperature
Aeciospores of rust fungi	45–90 days
Sporidia of rust fungi	1–6 hours

The actual conditions under which spores are produced have a profound effect on their viability Under green house experiments, teliospores of *Puccinia graminis* when formed at low temperatures retained their viability longer than those produced at higher temperatures Similar situations are found in nature In India, teliospores of *P graminis* and *Melampsora lini* lose their viability almost immediately they are produced, because of the high temperatures under which they are formed, these are " summer " spores in the tropics and " winter " spores in the temperate zones and hence their differential viability performance

Patel, Kamat and Pande (1952)* have also noted that in *Colletotrichum crossandriae* the conidia produced in open sporodochia

* Ind Phytopath pp 130–137 1952

in culture gave very scanty germination, while those obtained from acervuli in host tissue germinated vigorously and readily, giving as high as 76% germination

EXTERNAL FACTORS INFLUENCING SPORE GERMINATION

Temperature — It influences germination in three directions percentage germination, rapidity of germination and rate of growth of the germ tubes All these phases of germination directly or indirectly have a profound effect on the subsequent clinical picture of disease and its development, as will be discussed under "Epidemiology" in Chapter 15

The influence of air temperature on the percentage germination of spores varies widely with the species Many spores have a wide range and germinate readily between 5°C to 30°C, the tropical fungi, however, have, in general, a higher minimum and a higher optimum In Phycomycetous fungi of the type of *Pythium*, *Phytophthora*, *Plasmopara*, *Pseudoperonospora* and others, the two types of germination, zoosporal and direct, are profoundly influenced by this factor The zoosporal type is of common occurrence at lower limits and the direct germ tube at higher levels The cardinal temperatures for the germination of spores of some important fungi are given in the following table —

Table 7

Cardinal temperatures °C for germination of some fungus spores

Organism	Cardinal temperatures			Remarks
	MIN	OPT	MAX	
Pythiums	3	15	25	Zoosporal
Phytophthora palmivora	1 5	20	30	-do-
,, ,,	4 5	30	37	Germ tube
Phytophthora infestans	2	12	25	Zoosporal
,, ,,	12	24	30	Germ tube
Sclerospora graminicola sporangia	5	18	33	Zoosporal
,, ,, oospores	12	23	35	By tube
Erysiphe polygoni	10	24	30	Pea powdery mildew
Cereal rusts	0	20	33	Urediospores
Urocystis cepulae	10	18	33	Temperate
Tilletia tritici	5	16	27	Temperate
Fusarium vasinfectum	15	27	35	Cotton wilt (tropical)
,, *conglutinans*	5	15	30	Temperate
Alternaria burnsi	4 5	27	40	Tropical
Pestalotia psidii	10	30	35	Tropical

Moisture — Most spores will not germinate except in direct contact with water, while others require varying degrees of humidity, usually 95% and above The powdery mildew oidia, on the other hand, are capable of germination at relatively low humidity, due probably to high osmotic pressure of the cell sap of these spores (Clayton, 1942) In nature, rain, mist, dews and guttation water play a great part in this phenomenon The process of alternate wetting and drying has been able to break the dormancy period of some spores and facilitate their germination, by apparently making the thick resistant cell walls permeable to water

Nutrients — The nature of the substrate profoundly influences germination of spores While many spores germinate well in distilled or sterilized water, some need certain special nutrients, such as sugars, salts, nitrogen, magnesium and phosphorus Various plant decoctions, dung and soil infusions are known to favour germination, although the exact nature of this influence is difficult of estimation

Spores presoaked in various types of infusions like horse dung, soil, humus, etc , germinate readily and give higher percentage of germination than those not so treated

Oxygen — An adequate supply of free oxygen is an essential requisite for germination as a sequel to the higher rate of respiration during the process The influence of oxygen on the germination of spores has been noted by various workers in respect of not only percentage and vigour of germination but even the type thereof It is a well-known fact that spores situated at the margins of culture media show better germination than those located in the centre Similarly, spores floating on the surface, germinate more readily and vigorously than those submerged in the liquid In case of the latter the germ tubes remain small and abnormal

Uppal (1926) found that a supply of oxygen had a profound effect on the mode of germination Zoosporal germination was favoured by supply of oxygen in the case of *Albugo candida*, *Plasmopara viticola*, and *Sclerospora graminicola* but in the case of *Phytopthithora infestans*, *P colocassiae* *P Palmivora*, and *P parasitica*, the supply was not found essential However, oxygen was quite essential in the latter cases for the formation of germ tubes, the two methods of germination are different processes and naturally show differential behaviour in respect of this factor

Hydrogen-ion-concentration of a medium has a modifying effect on spore germination, although it is not a limiting factor In general, spores germinate within a wide range of pH Most fungi favour acid medium for germination

Stimulants — While most spores will germinate in plain sterilized water, addition of various types of stimuli in the form of organic acids, pretreatment, presoaking, natural plant products, infusions, decoctions, host tissues, chemicals, etc have stimulatory effect on the percentage and vigour of germination

Spores of many fungi show better germination when in contact with the respective host tissue than in sterilized water This is a general observation and holds good for most fungi studied This is probably due to the stimulatory influence of certain chemical substances diffusing out of the plant tissues (Brown, 1922), which is further corroborated by the general observation that the stimulatory effect is lost when boiled extracts and decoctions of the plant tissues are used Spores of *Colletotrichum lindemuthianum*, for instance, gave 83–95% germination with fresh bean tissue, 8% in bean decoction and only 3–6% in distilled water (Leach, 1923) Similar results were obtained by Patel, Kamat and Hingorani (1950)* for *Pestalotia psidii* these spores had very capricious germination in plain sterilized water but gave excellent results with the addition of fresh host tissue, they further noted that the stage of the host tissue had also a marked differential effect on germination, green host tissue stimulated germination (91 7%), while ripe host tissue was relatively non-stimulatory and gave only 40 0% germination The effect of host tissue, however, appears to be specific in nature, since addition of tissue other than that of the specific host, does not appear to have stimulatory effect

The presence of certain gases and volatile substances is known to influence germination profoundly Introduction of carbon dioxide favours germination very markedly Ethyl acetate, benzaldehyde, butyric acid, acetone and oxalic acid in various concentrations have similar stimulatory effect

The association of certain fungi and addition of mycelial extracts were also found to markedly stimulate germination The close association of an yeast, sp of *Torulopsis* was found to stimulate the spores of many mushroom fungi, while, in its absence no germination occurred (Fries, 1941, 1943) Spores of some fungi belonging to Mucorales, such as *Pilobolus* and *Basidiobolus* must pass through alimentary canals of certain animals, before they can germinate The exact nature of the stimulus exerted in such cases is obscure

Light does not appear to be of prime importance in germination Direct sunlight and Ultra violet light have, however, inhibitory effect and may even kill the spores Diffused light appears to favour germination in most spores

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* Ind Phytopath, pp 165–176 (1950)

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CHAPTER 11

HOST PENETRATION AND INFECTION

This phenomenon, which consists of the actual entry of the pathogen into the host, can be considered under two heads **The mechanism of infection** and **the Avenue of infection** The former relates to the various processes by means of which infection takes place and the latter with the actual manner of entry of the pathogen

MECHANISM OF INFECTION

The actual process differs according to the nature of the pathogen In fungi and flowering parasites of the type of *Loranthus*, the mechanism may be described as active or aggressive, while in bacteria and viruses it is of a passive type

The active mechanism employed by the former group of pathogens is illustrated in Fig 40, A-K and follows a line of action described below

In fungus pathogens, the process starts with the contact of spores with the host, the spore lodges in a drop of moisture and is stimulated to germinate by the growth secretions of the host, the germ tube grows in the direction of the host surface and attaches itself to the surface firmly by special structures, the appressoria (Fig 40, E), the pathogen, thus, makes an aggressive effort, curiously enough supported in the process by the host secretions and now starts the actual process of infection The appressorium gives rise to one or more thin finely pointed infection threads or hyphae, which directly pierce the cuticle and gain entry into the interior the actual process is *mechanical* and not chemical The infection hypha now meets with the epidermal wall, consisting mainly of cellulose and secretes enzymes, which dissolve the cell walls and gains further entry into epidermal cells and deeper into host tissues by its enzymic activities The entire process, thus is *mechanical* in its early stage and *chemical* in its later phase With direct contact of the infection hyphae and their enzymic activities, the contents undergo rapid degeneration, plasmolysis of the cytoplasm and nucleus sets in, causing ultimately injury to and disintegration of the invaded tissues, the infection process is completed by the establishment of closer relations between the parasite and the host often through the help of haustoria or the sucking organs Parasitism may be accomplished in two ways viz (1) by the destruction of cells and tissues (necrosis) as in many necrotic diseases caused by such parasites as *Fusarium*, *Phytophthora*, wood rotting fungi and others and (2) by establishing closer nutritional relationship

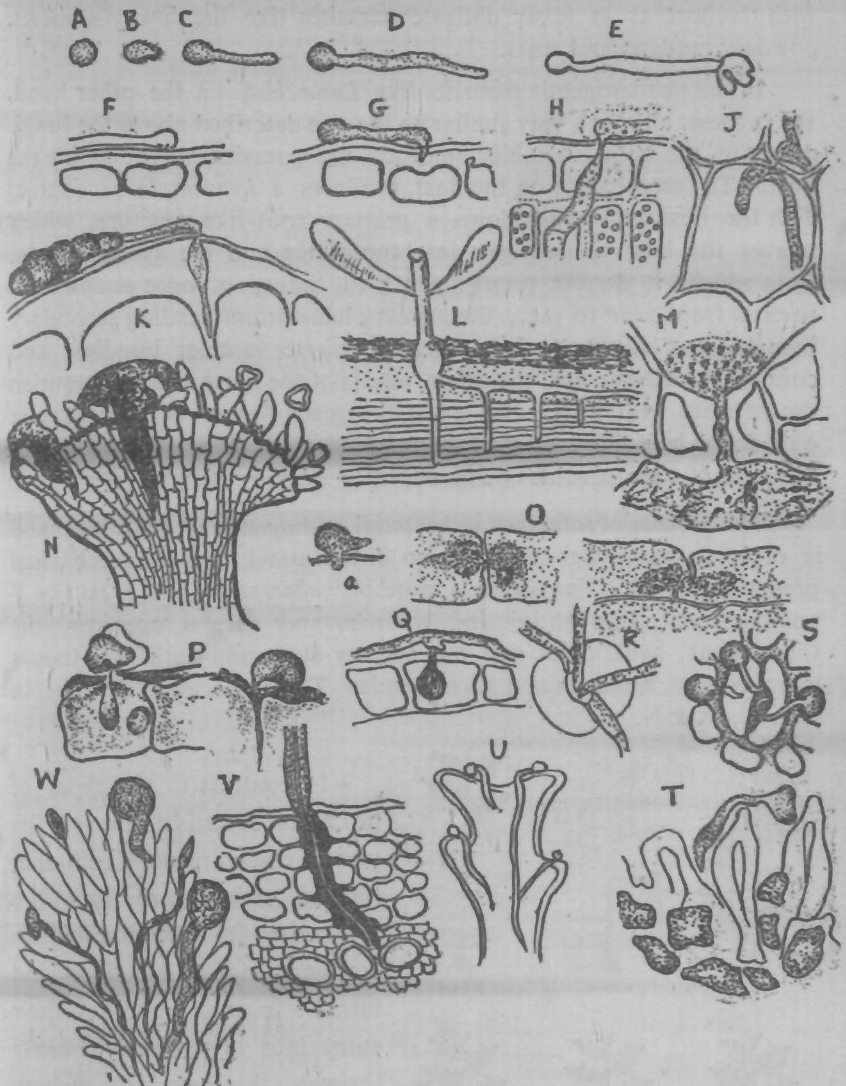

FIG. 40. Host penetration and infection. A–H. Stages of infection by *Botrytis cinerea*; JKPQ. direct penetration; L. same by Loranthus. Penetration through stomata in bacteria (M); Fungi (R.S.); N & U. Stigma; O. Root; T. Nectary; W. Anther; V. Insect styles; [After A.-H. Gaumann, J. Pearson, K. Samual, L. Neger, M & N. Hildebrand, O. Kunkel, P. Melhus, R. Mix, S. Colman, T. Curtis, U. Simmonds, V. Smith, K & W. Silow.

[Drawing : Miss Kumud Lad

with the host as in many obligate parasites like the downy mildews, powdery mildews and rusts

In the phanerogamic parasites like *Loranthus*, on the other hand, the process, although very similar to the one described above for fungi, differs in the actual establishment of the parasitic relation with the host The seed lodges on the host, produces a *hypocotyle* in contact with the host and sends down a primary root-like structure, which pierces the host tissues, gets into the cortex and the xylem vessels, from which, it derives nourishment, the infection, once established, persists from year to year, the primary haustorium sending secondary branches and haustoria, these haustoria pierce vascular bundles, and connect themselves with the xylem vessels of the host and thus nourish the parasite with water and salts, the green leaves of the parasite outside the host build up the food materials, this mode of nourishment is typical of semi-parasites (Fig 40, L)

The process of infection in bacterial pathogens on the other hand is of a passive type, there is no direct attack and no mechanical pressure exerted The action is more of "absorption" or "suction" and takes place through injuries, wounds, and natural openings like tne stomata, hydathodes and lenticels or such non-cutinized tissues as root-hairs, nectaries and stigma-ends This process is depicted in Fig 40, M & N

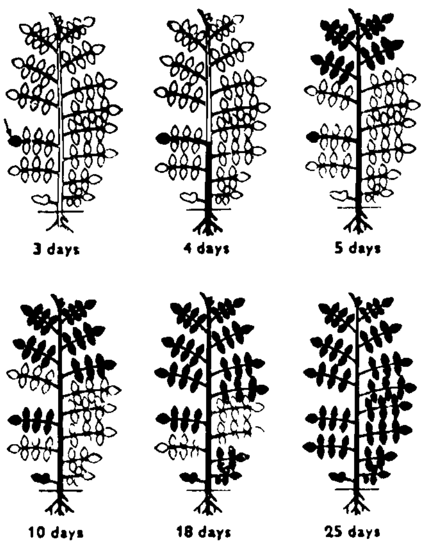

FIG 42 Systemic spread of virus through a tomato plant Arrow indicates initial infection [After Samuel

In contrast to the types of processes described above, the plant viruses are on a different footing with regard to the mechanism of infection They are very highly infectious and filtrable in nature, and find their entry into host tissues mainly through the help of sucking insects, which actually inject the virus into these tissues with the help of their finely-pointed "styles" (Fig 40, V), the virus then "multiplies" into the host cells and permeates the entire plant (Fig 42)

It will not be out of place here to compare and contrast the behaviour of plant and human pathogens with reference to the phenomenon and mechanism of entrance and infection and their effects on the respective therapy in the control of these diseases

PLANT AND HUMAN PATHOGENS COMPARED

	Plant pathogens	*Human pathogens*
1	Defence–Cuticle	Horny skin and sweat
2	Infection–Aggressive	Passive
3	Nature of infection–Pressure	Absorption
4	Reaction of secretions–Alkaline	Acidic
5	Role of secretion–Favours infection	Retards infection

The plant doctor, thus, has comparatively a more difficult task than the human doctor, the former depends primarily upon preventive measures and, therefore, deals with his plant patients *before* infection, while the latter deals with patients *after* infection, the first deals with the phenomenon of infection and the second with disease

This now brings us to the consideration of the next process **Avenue of infection** or the actual manner of entry of pathogens into their hosts This process may take place through several avenues depending upon the nature of the parasites, as shown in the following key

AVENUES OF INFECTION

- Direct
  - Cutinized surface
    - Epidermis
  - Non cutinized surface
    1. Root-hairs
    2. Seedlings
    3. Nectaries
    4. Needles
    5. Buds
    6. Stigma-ends
    7. Anthers
- Indirect
  - Natural openings
    1. Stomata
    2. Lenticels
    3. Hydathodes
  - Artificial openings
    1. Wounds
    2. Stalk-end
    3. Insect punctures

The process of direct entry of pathogens into plant tissues through a layer of uninjured cuticle has been already described in detail

There are, however, several plant tissues, which have no such cuticular defence line and make way for pathogens, which use these organs as passage for migration into deep-seated tissues Stigma-ends, buds, needle points, root hairs etc provide such avenues

Entrance through root-hairs — These structures are not cutinized, and therefore admit several soil-pathogens, which normally are unable to press through the cuticle This mode of entry is characteristic of *Fusarium* wilt, the club root organism (*Plasmodiophora brassiceae*), the Texas root rot fungus (*Phymatotrichum omnivorum*), the fungus causing " hollow stem " of sorghum (*Rhizoctonia bataticola*) It is of common occurrence in soil-borne bacterial pathogens and in many root rotting fungi A well-known example of an organism effecting its entry through the root hairs is the nodule-bacteria (Fig 40, O)

Seedlings as avenues of entrance — Seedling infection, sometimes also known as systemic infection, has been proved in several important diseases, the pathogen in such cases, is carried on seed-coat or comes in contact with the germinating seed in the soil infection of the young succulent tissues or through hypocotyle occurs at the time of emergence of the seedling In certain cases, such infections exhibit themselves in the form of characteristic symptoms in all above-ground parts of the host as in downy mildews of cereals (*Scleiospora* sp) In other types, the infection does not give rise to symptoms immediately but remains latent until formation of flower heads, when the typical symptoms appear such is the case in many smut and bunt fungi Seedling infection of the latter type is very commonly met with in the grain and loose smuts of Sorghum (*Sphacelotheca sorghi* and *S cruenta*), bunt of wheat (*Tilletia tritici*), flag smut of wheat (*Urocystis tritici*) and head smut of Sorghum (*Sorosporium reilianum*) The former type with immediate development of symptoms and disease is characteristic of the downy mildew of cereals (*Scl graminicola*), downy mildew of Sorghum (*Scl sorghi*), onion smut (*Urocystis cepulea*) and foot rots caused by fungi of the type of *Pythium*, *Fusarium* and *Rhizoctonia*

Flower infection — The stigma ends of the flowers provide highly receptive organs for entry of pathogens on account of their erect position, the sugary secretions given out by their heads and the succulent tissues making up the head A classical example of such infection is the loose smut of wheat (*Ustilago tritici*) It is of common occurrence in the long smut of Sorghum (*Tolyposporium ehrenbergii*), black smut of rice (*Neovossia horrida*), ergot of rye (*Claviceps purpurea*), smut of bajra (*Tolyposporium penicellariae*) and brown rot fungus (*Sclerotinia fructicola*), (Fig 40, U) Penetration through anthers has been demonstrated for blossom blight of red clover caused by *Botrytis anthophila*, (Fig 40, W)

The flower infection mentioned above can be grouped under two heads, one where stigma-ends serve only as channels for the entry of the organism, which immediately starts activity causing disease in the various parts making up the blossoms and the other where the germ tube enters the ovary through the stigma-end and style and takes asylum therein, remains passive and transmits the infection to its offspring in the succeeding season, as exemplified by the classical *Ustilago tritici* and *Botrytis anthophila*

Nectaries and **buds** also provide favourable avenues for infection in a few cases, on account of their non-cutinised tissues and sugary secretions (Fig 40, T) *Bacillus amylovorus*, causing the fire blight of apples, *Sclerotinia fructicola* responsible for brown rot of pears, the peach leaf-curl fungus, *Taphrina deformans* are examples of such mode of infection The fungus causing the scab of apples, *Venturia inequalis* makes its way into blossoms through the young buds

Infection through **needle points** is of special significance in the dreaded blister rust of pine, which uses these points as avenues of entry for the basidiospores of *Cronartium ribicola*

ENTRY THROUGH NATURAL OPENINGS

Stomatal infection — This is a very common type of entry for the plant parasites, the actual mechanism differing in different types of pathogens The penetration of bacterial pathogens, for instance, takes place through the action of absorption and is therefore passive in nature The action is in the nature of suction and is typical of *Xanthomonas campestris*, *Xanthomonas malvacearum*, *X phaseoli*, *sojens* and many other aerial bacterial parasites (Fig 40, M)

Many fungi utilise the stomatal openings for entry into their host plants The late blight fungus, *Phytophthora infestans*, the downy mildew fungus, *Plasmopara viticola*, the white rust organism, *Albugo candida* are examples The host penetration by urediospores in many rusts occurs primarily through stomata and is characteristic of the rusts of cereals, leaf rust of coffee, rust of linseed and others (Fig 40, R S) The basidiospores and the aeciospores of these rust fungi, on the other hand, have no use for such openings and directly bore into the host through the cuticle (Fig 40, P)

Lenticels as avenues of entrance — The entry of plant pathogens through the lenticels follows a course similar to the stomatal penetration and is of vital importance in diseases of vegetative parts such as tubers, stems, and root crops, these " breathing pores " in potato tubers, in stored fruits on citrus stems and on arecanuts admit the respective pathogens into their tissues, such is the case in powdery scab and common scab of potatoes, the black scurf of potato, the stem cankers of citrus trees, the canker of guava fruit, the ' Koleroga ' of arecanuts and ripe rots of stored fruits, the numerous lenticels present on the surface of these plant parts, provide suitable and easy avenues for the germ tubes of the respective organisms The organism causing the black rot of cabbage (*X campestris*) gains entry into host tissues primarily through hydathodes by the process of suction or absorption

ENTRY THROUGH ARTIFICIAL OPENINGS

Wounds as points of entry — This is a special mode of penetration and is mainly utilised by the wound and weak parasites These wounds or injuries may be caused by various agencies, such as physical bruises resulting from farm operations of harvesting, digging etc, by hail storms, animals, insects, borers, nematodes, sunburn and several others The organisms causing the well-known ripe rots and storage diseases, such as *Rhizopus*, *Aspergillus Penicillium*, *Diplodia*, *Gloeosporium*, *Colletotrichum*, *Vermicularia*, *Botrytis*, *Fusarium* and several species of bacteria have this mode of entry The notorious crown gall organism *B tumefaciens* and the fungus causing late blight of potato (in tuber infection) enter their hosts through this channel

Crevices into cuticle or bark tissues have been utilised by a few pathogens for their entry *Phytophthora palmivora* and *Ph citrophthora*, the cause of gummosis of citrus trees in India and California respectively, gain entry into the bark through crevices at bud joint

Hail-storm and **freezing injuries** have been known to aid entrance of some pathogens, which otherwise are innocent A recent outbreak of cold wave in Bombay (1937) brought about serious and wide-spread freezing injury in sugarcane which was followed by species of bacteria causing a severe type of bud rot Similar phenomenon is experienced in fruits directly exposed to sun scald when the weak parasites such as *Gloeosporium* and *Colletotrichum* gain ready entry through the weakened surface causing ripe rots

Entry through **stalk-ends** is a familiar sight in many fruit rots The common blue mould of lemons (*Penicillum italicum*), the ripe rots of mangoes and banana (*Gloeosporium raciborskii*) and the black rot of pineapple (*Thielaviopsis paradoxa*) are examples of pathogens, which are weak parasites and enter the plant parts through the stalk-ends

Entry through insect injuries — Injuries and wounds caused by insects are easily penetrated by various plant pathogens The well-known brown rot fungus (*Sclerotinia fructicola*) is not only carried by wasps and bees but these insects deposit the conidia in wounds caused by their beaks and this facilitates their entry into the fruits *Phomopsis versoniana* causing brown rot of pomegranates follows the path of the fruit borer In the notorious Dutch Elm disease (*Ceratostomella ulmi*), the elm bark beetle (*Scolytus* sp) facilitates entry of the pathogen through the injuries caused by it The secondary infection of sugarcane by the red rot organism, *Colletotrichum* *falcatum,* is greatly dependent upon borer and weevil injury of shoots and leaves.

The role of insects in facilitating entry of the viruses has been already discussed in Chapter 9, under " Dissemination of plant pathogens. " The role is specific and the relationship is of a biologic and not mechanical nature. The manner of penetration of these viruses through the agency of insects, is depicted in Fig. 41.

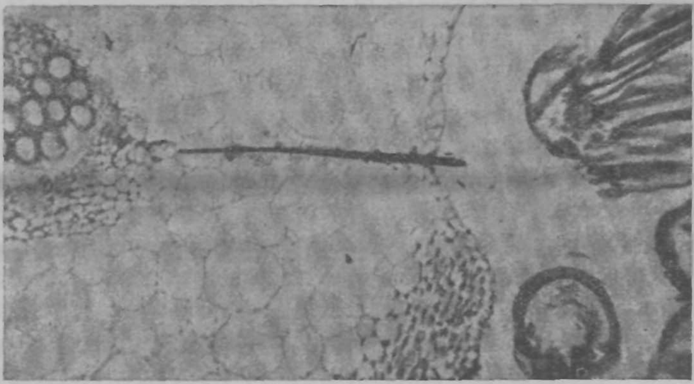

FIG. 41. Host penetration of virus through insect styles (Photomicrograph)
L : Host phloem. R : Insect mouth. Centre : style.

[After : Bennet, C. W.

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CHAPTER 12

SYMPTOMS OF DISEASE IN PLANTS

Symptoms are expressions of diseased condition and help in general in diagnosis although they do not, many times, provide a real basis for knowing the exact nature of the disease A rational control of a disease is possible only through a correct diagnosis Symptoms are many times confused with disease itself, fever, for instance, in human pathology is not a disease but is a symptom of disease, and may be expression of various diseases far removed from each other such as Typhoid, Tuberculosis, Cholera, Malaria and Small pox Even a simple wound or sprain may give rise to fever which is a rise in the body temperature Control measures in each of the above cases would be different Symptoms are also apt to be confused with "Signs", in specific cases, signs are more reliable than symptoms and help in accurate diagnosis Presence of sclerotia or felt-like mycelium on under-ground parts of wilting plants, pycnidia in leaf infections and perithecia in stem cankers are signs and very helpful in diagnosis Symptoms are often deceptive, chlorosis of plants may result from different groups of factors, it is present in downy mildews, virus diseases (Mosaics) and in defficiency diseases (Mottle leaf of citrus), the first is of fungus origin, the second of virus and the third category is due to deficiency of some minor element in the soil

Symptoms are expressed externally as well as internally Internal symptoms are more reliable than the external ones Blackening of vascular bundles, presence of mycelium in plant tissues, production of spore-fruits in diseased tissues, oozing of bacteria from infected parts (in bacterial diseases) are examples of the former types In human pathology, the physician depends upon X-ray screening, microscopic examination of blood, sputum, stools etc to help him in correct diagnosis

Symptoms are best grouped under three general heads, depending upon the "pathologic histology" or nature of tissue-changes involved Those which bring about reduction of tissues and result in under-development may be designated "**Hypoplasia**", those which stimulate tissues to overdevelopment as "**Hyperplasia**" and those causing destruction of tissues, "**Necrosis**"

HYPOPLASIA

(*Hypo*= under and *plasia*= formation)

The symptoms grouped under this head involve a reduction either in the chlorophyll content plant tissues, plant parts or the entire plant

Mosaics, scaly leaves and dwarfing may be cited as common examples As already explained, such symptoms may result from diverse causes, such as parasitic infections, virus infection and non-parasitic agencies such as deficiencies, excesses of minor elements in soil, shady situations, excess or want of water at roots of growing plants etc Some of the general types of symptoms, classed under this head, are listed below

1 **Yellowing** — This is generally known as etiolation, albinism and chlorosis and may be caused, besides parasitic causes, by deficiencies of zinc, boron, iron and manganese in soils, stagnation of water at the roots and even genetical factors High water table and hard pan of subsoil are common causes of such symptoms in orchards and are generally met with in citrus gardens

2 **Pallor** — This is synonymous with anaemic condition or bloodlessness, common in human pathology and is due to a general reduction of the chlorophyll apparatus induced by various agencies, mentioned above Deficiency of iron and excessive irrigation coupled with defective drainage and shady situations are common causes In legume crops, such a condition may result from deficiency or absence of nitrogen-fixing bacteria in soils

3 **Mosaic** — This is a typical symptom caused by virus infection, although similar symptoms may be induced by chemical deficiencies (mottle leaf of citrus) The virus mosaics however are highly infectious unlike similar symptoms caused by non-parasitic agencies Leaf mottles, however, are not always symptoms of diseases, those produced in the ornamental plants like coleus, crotons and caladiums, for instance, are highly prized for their exquisite patterns and are signs of health and *not* disease

Littleleaf, yellow mosaic, yellow-vein mosaic are some of the other types of hypoplastic symptoms and have been so named in accord with the patterns produced in each case The first denotes reduction in the leaf lamina, typical of the virus infection in brinjals tomatoes and cotton, the second of bean virus and the third, characteristic of *Hibiscus*, is expressed by yellowing of veins and typical mosaic pattern in the main lamina "**Yellows**" of aster also can be grouped under this head

4 **Dwarfing** — This denotes a general under-development of the entire plant, brought about by reduction of the internodes and attainment of a fan-shaped stunted appearance and is usually accompanied by "Hyperplastic" tissue changes, as in many virus diseases of plants Stunting with proliferation of buds, is of common occurrence in the early stages of the downy mildew infection in cereals (Fig 43, 1-8)

II HYPERPLASIA

(*Hyper* = over + *plasia* = formation)

This group of symptoms denotes over-development or enlargement of affected tissues, due to stimulation, the tissue-changes involved are of two types enlargement of individual cells and excessive multiplication of cells, the former tissue-change is known as *hypertrophy* and the latter as *hyperplasia* The well-known stem galls produced by *Loranthus* and club root of cabbage are common examples Some of the common types of symptoms met with in this class are listed below

1 **Root galls** —These are typical of nema-infections in solanaceous plants and are produced as little raised pimples in roots and tubers The roots in club root of cruciferous plants are converted into swollen structures of the type of "finger-and toes", by means of which the disease is easily recognised The **Stemgalls,** the **Ceder-galls,** the abnormal swellings produced in white rust disease of crucifers, the **blisters** accompanied by **leaf curls** characteristic of virus diseases of tobacco and *datura,* the **crown-gall** of various trees due to bacterial infection are all well-known examples of such symptoms

Abnormal and excessive stimulation of buds is of common occurrence in certain infections and brings about the notorious **witches brooms,** sometimes designated as **bunchy top** and sometimes as **green ear,** in accord with the actual tissues and parts involved

Hairy root and **spindle tubers** are typical virus infections, common in sugarbeet and potato respectively (Fig 43, 9-16)

III NECROSIS

Disorganization and destruction of tissues are the main types of tissue changes induced by this group of symptoms The infections may involve the epidermis, the collenchyma, the cambium layer, the vascular tissue, the laminar tissue of the leaf or the pith cells deeper down and may result in the complete death of the entire plants or parts and even tissues thereof (Fig 44)

1 **Damping off** is a special name given to denote wilting of young seedlings and is of common occurrence in seed beds It denotes sudden wilting and collapse of the infected seedlings and is characteristic of Cruciferous and Solanaceous seedlings Tobacco, cabbage and chillies often show such symptoms in the seed beds

2 **Wilts** are typical vascular infections and are generally found in adult plants, the internal infections characteristic of the wilts are the blackening of the vascular bundles, so commonly met with in cotton, banana, flax, tomato, water melon, *tur, lathyrus* and the bacterial

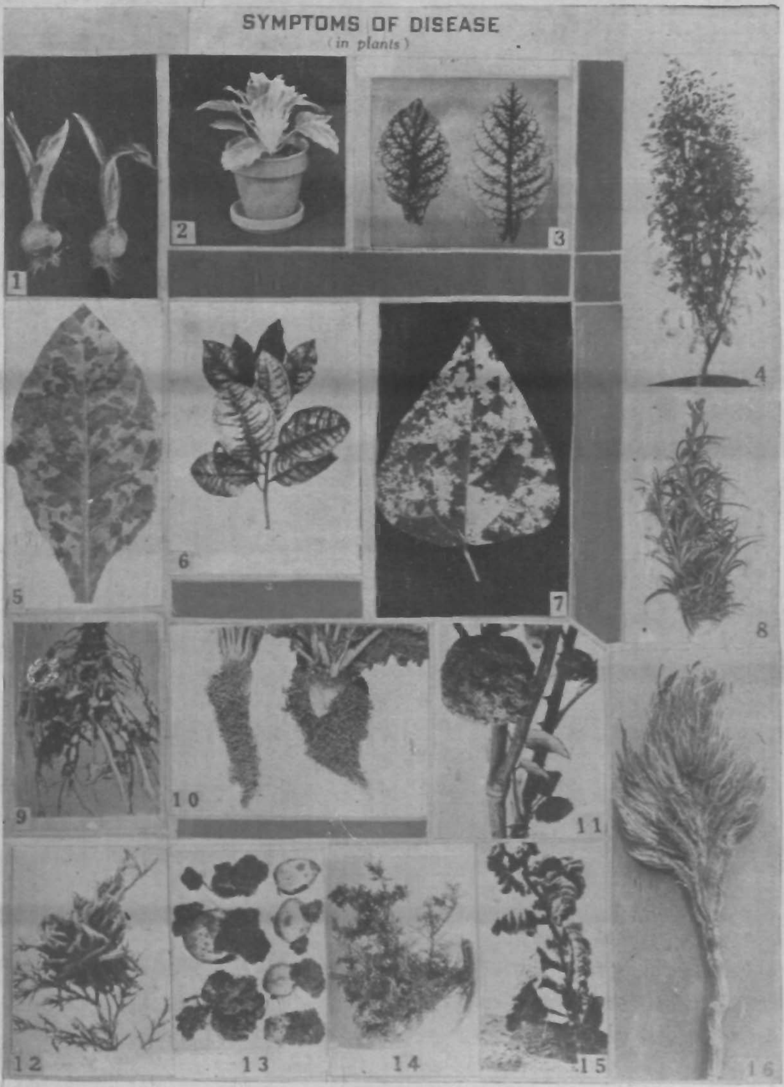

FIG. 43. Hypo- & Hyperplasia. 1. Chlorosis; 2. Yellowing; 3. Pallor; 4. Small leaf; 5. Mosaic; 6. Mottle leaf; 7. Yellow mosaic; 8. Dwarfing; 9. Root galls; 10. Hairy root; 11. Stem galls; 12. Cedar galls; 13. Tuber galls; 14. Witches broom; 15. Leaf curl blisters; 16. Green ear. [Kamat, 1953.

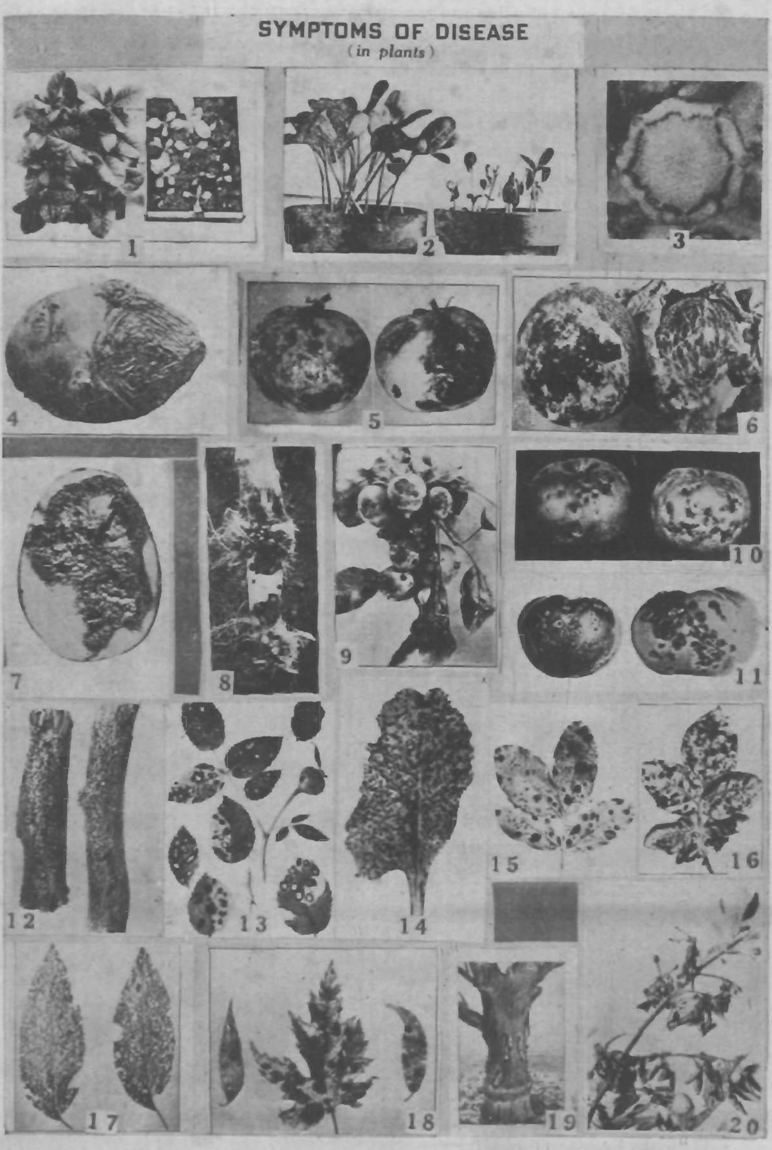

FIG. 44. Necrosis. 1. Damping off; 2. Wilt; 3. Vascular ring; 4. Dry rot; 5. Soft rot; 6. Rhizoctonia rot; 7. Black heart; 8. Root rot; 9. Scab; 10. Canker on fruit; 11. Bacterial canker; 12. Stem canker; 13. Anthracnose; 14, 15 & 16. Leaf spots; 17. Shot holes; 18. Tar-spots; 19. Exudations (Gumming); 20. Blight.

[Kamat, 1953.

oozings from the bacterial infections in black rot of cabbage and "ring" of potatoes

3 **Rots** are infections of parenchyma, collenchyma and pith tissues and may involve various parts of the plant The **root rots**, the **collar rots**, the **foot rots**, the **neck rots** and the **bud rots** are common examples These rots may impart different colour reactions, in which case they are designated as **black rots**, **red rots**, **white rots**, **brown rots** If the tissues retain firmness, they are known as **dry rots**, if soft, **soft rots** and if putrefaction sets in, **wet rots** These symptoms mainly occur in storage and may result from parasitic as well as non-parasitic agencies The well known **black-heart** of potatoes and other fruits is caused by high storage temperature and ill ventilation

4 **Scab** is epidermal infection and is not deep seated, the powdery scab of potatoes is a familiar example Prolonged exposure of delicate fruits like grapes, citrus and papaya to direct sun may also induce such infections

5 **Cankers** on the other hand are deep-seated and involve the cambium layer they involve destructions of woody tissues and are common infections on stems of citrus, mango and many fruit and forest trees

6 **Anthracnoses** destroy the collenchyma and cambium layers and are difficult to distinguish from the cankers described above, the lesions are sunken in the centre with raised margins, typical of grape, rose, beans and chillies

7 **Leafspots**, as the name indicates, are laminar infections, limited in extent and are imparted with various colour reactions The "birds-eye" and the "frog-eye" are distinctive names given to the spots on account of their similarity to such animal structures While in the majority of cases the affected leaf tissue is intact, in others, it withers away leaving holes behind, such a phenomenon is designated as "**Shot-hole**"

8 **Blights and blast** are other types of tissue-destructions met with and are so designated because of the overhaul effects produced in infected plants, they involve rapid and general destruction of growing, succulent tissues, like shoots, blossoms, and twigs etc and are designated shoot-blight, twig-blight, early blight, late blight and so on

9 **Exudations** are plant excretions and are brought about by diseased condition of the infected plant Plants excrete various types of exudates in their normal life which must therefore be distinguished

from those of pathological origin Rubber, gum, latex and *neera*, are normal excretions and are valued in industries The pathological exudations, on the other hand, are of a harmful nature and result in damage to and destruction of such infected plants The gum disease of citrus and bleeding disease of palm are of the latter type

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CHAPTER 13

THE DISEASE IN PLANTS

Disease is a biological phenomenon brought about by an interaction among the host and the parasite, aided by environment In this association, the parasite " acts " (offensive) and the host " reacts " (defensive), the sum total of this reaction manifests itself into the complex phenomenon of disease Disease mainly originates as a disturbance in the functional process, which ultimately may lead to an unthrifty development of the organism It is a conflict beween host and the parasite, the ultimate success or failure of which is determined by the " action " of the parasite (*virulence*) and the reaction of the host (*resistance*) The course of this biological conflict is largely governed by environment as stated in Chapter 14

Since disease is a dynamic phenomenon, the two parties to the phenomenon continually modify their respective positions and tactics to suit the situation arising from time to time, acting and reacting in the process and trying in their own subtle way to overcome each other It is a virtual race between the host and the parasite, the external or internal factors sometimes aiding the host and at other times, the parasite and which ultimately determine the course and severity of the disease The situation is more complex in infectious disease where both the host and the parasite are living entities and capable of continual adjustment and modifications of their innate characteristics

It would be well, at this stage to compare and contrast the phenomenon of disease, as it occurs in phytopathology and human pathology, since such a comparison will lead us to a clear understanding of the phenomenon and aid us in devising rational methods of controlling it, which, after all, is the main object of our study

PHYTOPATHOLOGY AND HUMAN PATHOLOGY COMPARED

	Human Pathology	*Phytopathology*
Defence	Skin and sweat	Cuticle
Nature of defence	Acid	Alkaline
Pathogens	Mainly bacterial	Fungus and bacterial
Mode of infection	Passive	Active
Mechanism of infection	Absorption	Invasion
Nature of dissemination	Autonomous	External agencies
Effect of environment	Slight	Profound
Doctor's part	After infection	Before infection
Nature of control	Curative (Therapeutic)	Protective (Prophylactic)

Disease, in plants, thus is a complex phenomenon and therefore more difficult to control, on account of its nature and mode of infection, dissemination and the profound effect of the environment on its ultimate clinical picture On account of the relatively minor part that environment plays on human diseases, the doctor deals with the host and its parasite while the plant doctor has to concern himself, in addition, to the third factor of environment, which governs not only the life processes of the host but also of the parasite The plant doctor is beset with another formidable difficulty, he is unable to critically study the behaviour of the parasite and clinical course of the disease except under natural conditions, which on account of their ever-changing nature, are difficult to imitate under any artificial experiments Such a study, however, is greatly facilitated in human pathology because of the comparatively slight influence of the external conditions on the human body and the pathogen

Disease manifests itself in the form of symptoms (**Symptomatology**) and effects or structural changes (**Pathologic Histology**), which have been discussed in Chapter 12 A clinical picture of the phenomenon of disease comprises of the following phases

1 Infection 2 Incubation 3 Disease expression
4 Recovery or healing 5 Return to health

In plant disease, the 4th and the 5th phases are absent, as once infected, a plant rarely recovers or regains health, and hence the plant doctor depends more upon preventive rather than curative measures of control An example of a plant cured of a disease is very rare in plant pathology, a possible exception being the powdery mildew

Various modifications of this life association between the host and the parasite exist in nature One of the commonest examples of such highly organised association is " **Symbiosis** " in the well-known lichens, where a fungus lives in close association with an alga for mutual benefit

Similar association between *Rhizobium leguminosarum* and the roots of legumes (the nodule bacteria) is of an ingenious type and not only derives mutual benefit but is of highest significance in Agriculture

" **Mycorrhizal** " associations, so common in forest trees, between certain plant roots and fungi, have important implications in silviculture

An association exhibiting partial parasitism exists between the green mistletoe (*Loranthus* sp), and the roadside trees, between the *Striga* and the *Sorghum* and several others These associations are stable in character and do not involve violent disturbances in the equilibrium of the two organisms and are, therefore, comparatively less harmful in nature

Diseases are often spoken of as " caused " by an agent, living or non-living This is not the correct manner of description, disease is really tiated or incited and may or may not exhibit itself at the point of ection In systemic diseases, the infection takes place at one point t the actual symptoms of disease appear much farther away, such example is the smuts and bunts of cereals, where the actual infection ɔt is the seedling but the symptoms of disease appear in the ɔssoms, removed both in time and space

Disease, thus, may manifest itself in the following spheres of the ıst

1. Anatomy (Structure) 2 Physiology 3 Function

Disease has an individual as well as an agricultural aspect While former is the concern of a mycologist, who continually looks for w records of fungi, bacteria and other micro-organisms and is refore more academic, the latter aspect is the domain of the plant thologist, who seeks a critical study of the disease, as it affects the riculturists and his agricultural economy, it is an intrinsic and realistic proach to the economic aspects of the problem, which ultimately termine the welfare of mankind Thus, diseases of economic portance, whether of parasitic, non-parasitic or virus origin, horough investigation into their nature, etiology and measures of ntrol form the main theme of the science of phytopathology Such all-pervading concept of disease includes those that not only reaten the life of plants but also those which lower the value of ricultural crops and their produce as economic producers and for ırket purposes Examples of the latter type are the scab-affected fruits, nker-affected lemons and eelworm-affected tubers, which on account their ugly appearance, become unfit for market

Having discussed the phenomenon of disease, its manifestations, , implications, the gross effects produced and nature of the associations, , modifications and its various aspects, it is now possible for us to ɔnsider the question of control, which comprises mainly of prophylactic easures This will be done in the next few chapters

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CHAPTER 14

Environment in relation to disease in plants

That environment played a great part in the development of disease in plants, was recognised since times immemorial Early writings, on the subject, are full of such observations on the profound influence of the various factors such as temperature, rain, cloudy days, dew fall and so on Environment plays a more determined part in phytopathology than in human pathology, as it vitally affects the growth and life processes in plants more than in man Plants are more subject to outside environment, readily react both internally and externally and continually modify their mode of life, their structure and their organization, to suit these ever changing conditions Disease is a complex phenomenon, resulting from an interaction among the host, the pathogen and the environment The susceptibility or resistance of the host, the relative aggressiveness and virulence of the parasite and the various factors of the environment, combine and react to produce this phenomenon The relative part each of the above factors play in this phenomenon therefore is difficult of accurate assessment and must be determined by cumulative effects The subject has been well discussed by Foister (1935) and Jones (1924), Humphrey (1941) and Chupp (1946)

Environment comprises of three groups of factors (1)*Meteorological* (2) *Soil* and (3) *Biological* These factors seldom act alone, they are *cumulative* in effect They sometimes act independently (direct) on the parasite and at other times indirectly through the host Some of the important factors, so influencing disease, are listed below

ENVIRONMENT

(1) *Meteorological*	(2) *Soil*	(3) *Biological*
Temperature	Soil temperature	Insect flora
Humidity	Soil moisture	Soil flora
Precipitation	Soil condition	
Dews	Soil reaction	
Topography	Soil deficiencies	
Light		
Hail-storms		
Industrial by-products		

METEOROLOGICAL FACTORS

Air temperature, in general, has a profound effect on the development of disease. Diseases can be grouped in a broad sense into tropical, temperate and sub-tropical on this basis as follows

Tropical	*Temperate*	*Sub-tropical*
Blast of rice	Late Blight of potato	Black stem rust of wheat
Long smut of sorghum	Rust of linseed	Downy mildew of grape
	'Yellows' of cabbage	
Root-rots	Stripe rust of wheat	Powdery mildews
Leaf rust of sorghum	Common smut of corn	Cereal rusts
Leaf rust of sugarcane	Bunt of wheat	Loose smut of wheat
Leaf rust of *bajra*	Brown rot of stone fruits	Fusarium wilts
Plant viruses	Ergot of rye	

A well-known and clear cut example of the role of air temperature in development of disease is provided by three rusts of wheat in the Indian sub-continent. The black stem rust (*P graminis tritici*) is generally prevalent in southern parts, the leaf rust (*P triticina*) in central India and the stripe rust (*R glumarum*) in extreme northern sections, with corresponding clear-cut temperature limitations during the growing period in these regions, as shown below

Table 8

Distribution of the three rusts of wheat in India

Regions	Range of air temperature during growing period	Prevailing rust	Remarks
1 North	55 – 65°F	Stripe rust (yellow)	Oversummers above 7000 ft
2 Central	60 – 70°F	Leaf rust (Brown)	Oversummers above 5000 ft
3 South	70 – 80°F	Stem rust (Black)	Oversummers above 4000 ft

Air temperature is also a controlling factor in the development of the late blight of potatoes, virus diseases of potatoes, powdery mildews and storage diseases. The cardinal air temperatures for the development of late blight of potatoes in the field are 3–4°, 19° and 25° C. In storage, the potatoes do not develop the storage rot below 10°C and the susceptibility of the tubers increases with increase in the storage temperatures, similar is the case in the field, where air temperatures are a limiting factor in the development of disease This is corroborated by the extensive incidence of the blight in the cooler regions and in hill stations and its absence from the plains, where air temperatures in the growing season, are above the optimum

Air temperatures also play a very important role in green house studies for determination of rust reactions in cereals Working with *Puccinia glumarum tritici*, Gassner and Straib (1929), found that the reactions of this rust on wheat varieties were greatly modified by change in air temperatures At 10°C the reaction was of susceptible type, while at 20°C it was of immune type On the other hand, results obtained with *Puccinia graminis* (Newton and Johnson, 1932) showed a reverse position viz that the reaction was of resistant type at 14°C and highly susceptible type at 24°C (Fig 45)

Similar results were obtained in stripe disease of barley caused by *Helminthosporium grameneum* which has cardinal temperatures of 0°, 25° and 33°C The severity of infection was found to increase with reduction in air temperature At 5–10°C the severity ranged between 80–83%, at 15–20°C it was 15–45% and it was only 5% at a temperature of 25°C These results, however, vary with varieties of the host and the strains of the parasite (Isenbeck, 1937) Many storage diseases, such as dry rot and black heart of potatoes, onion smudge, ripe rots, brown rot of peaches, etc are profoundly affected by storage temperature (Fig 46), In such cases however aeration of the storage also plays a prominent part The temperature relations for the development of the fruit rot of banana caused by *Botryodiplodia* sp in storage were determined by Chona (1933)* in Punjab and are given in the following table

Table 9

Development of fruit rot of banana at different temperatures in storage

Temperature °C	Percent infection
15	10
20	15
25	45
30	75
35	90
40	10

* **Ind Jour Agri Sci 3 673–687, 1933**

Some of the common diseases and the cardinal **air temperatures** at which they develop are shown below

Table 10

Cardinal temperatures °C for development of disease in plants

	Min	Opt	Max
Late blight of potatoes	12	22	27
Downy mildew of grape	12	22	30
Powdery mildews	10	24	35
Black stem rust of wheat	15	25	33
Early blight of potatoes	15	25	35
Downy mildew of hop	10	17–18	30
Leaf mould of tomato	5	22	33
Brown rot of stone fruits	0	20	30
Dry rot of potato (storage)	5	24	30

It will be seen from the above statement that the typically tropical diseases have a higher optimum (25–27°C), while the temperate diseases develop best at lower temperatures viz 18–22°C

Humidity plays a great part not only in the development of disease but also in influencing infections and determining incubation periods of a disease In diseases caused by aquatic and semi-aquatic pathogens, it is a limiting factor and determines the severity and course of the disease Many downy mildew fungi depend largely on this factor for their development, severity and destructiveness The downy mildew of grapes, the "*Koleroga*" of arecanut, the late blight of potatoes, the downy mildew of hop, the downy mildews of cereals and many others are highly influenced by relative humidity Similar is the case with such blight diseases as blast of rice, early blight of potato, bacterial blight of soyabean, angular leaf spot of cotton and scab of apples This factor mainly acts through the parasite, as high humidity favours it although its action on host in making the foliage more susceptible, cannot be ruled out altogether, the opening of the stomata and lenticels, the excessive water supply and a low rate of transpiration resulting from changes in air humidity, tend to favour infection and increase the incidence of the diseases, by increasing the "*predisposition*" of the hosts, concerned

Precipitation and dew fall play their own part in increasing atmospheric humidity and cannot be considered in isolation Heavy dewfall has been known to favour germination of spores and infections in such diseases as downy mildew and rusts and thus help in the actual course and severity of the diseases These factors in combination with temperature have brought about epiphytotics of black stem rust of wheat, late blight of potatoes, "*Koleroga*" of arecanut, downy mildews of grapes and corn and blast of rice The notorious country-wide epidemic of black stem rust of wheat in India during 1947–48, the destructive nature of the outbreak of downy mildew of grape in Bombay during 1928, the widespread damage caused by the downy mildew of corn in the Philippine islands during 1918–20 and above all the ruinous and wide-spread nature of the outbreak of blast of rice in Bombay during 1949–50 were mainly the results among others, of the *cumulative* influence of the above factors

Precipitation and the resultant high humidity have played an important role in the course and development of the "*Koleroga*" of arecanut in parts of Bombay and other southern states The plantations situated in valleys and heavy rainfall tracts, surrounded by dense forests in the interior, always suffer heavily, sometimes verging on total destruction, while those planted on high level areas with moderate rainfall are much less subject to the ravages of this disease Kernal bunt of wheat caused by *Neovossia indica* develops best in areas with showers of rain and low temperatures (15–20°C) at blossoming periods, while the infection is negligible in periods of dry weather The development of leaf rust of coffee caused by *Hemileia vastatrix* in Ceylon and South India is intimately influenced by the prevailing rains and humidity

The part played by **hail-storms, lightening** and **industrial fumes** is of restricted nature and occasional, the aspect is of special significance in areas situated near industrial cities and towns and in the vicinity of smelters Some of the common poison gases causing injuries and damage to growing plants, crops, kitchen gardens and delicate water and ornamental plants, are sulphur dioxide, hydrochloric acid, chlorine and flourine These fumes arise as a result of incomplete combustion and are highly toxic to delicate foliage and blossoms Plants trailed on iron posts like the grapes are liable to lightening injury The role of these factors in causing injury to crop plants, has not been adequately appreciated and studied on account of their occasional visitations

SOIL FACTORS

Soil temperature by far has a profound influence on the development of soil-borne diseases and greatly modifies their course, incidence and severity This factor generally acts through the host, which is highly susceptible to the ever-changing micro-climates of the soil A general retardation in the growth of the host at low temperatures brings in greater opportunities for the parasitic attack and higher incidence of disease which is the result and sum total of the conflict between the host and the pathogen and is therefore determined by the amount of success attained by either parties to the conflict Disease, thus, is in the nature of a race between two opposing forces, the one trying to overtake the other Soil temperatures, in short, have modifying effect on the course of this race Many soil-borne diseases and those of seedling infection types, are profoundly influenced by this factor A convincing proof of the great influence exerted by this factor in the field is provided by two soil-borne diseases viz Root rot of tobacco caused by *Thielavia basicola* and cabbage "yellows" (*Fusarium oxysporum f conglutinans*) in southern Wisconsin (U S A) The behaviour of these two soil-borne diseases in two contrasting seasons, is depicted in the following statement

Comparative development of two soil-borne diseases at different soil temperatures (After Jones L R et al)

Mean soil temperatures	Development of disease	
	Root Rot of tobacco	Cabbage Yellows
1915 season 20–24 °C	Total failure	Good stand
1916 season 26–30 °C	Good stand	Total failure

The above tells its own tale The behaviour of the two parasitic diseases was in contrast, one favoured by low temperatures (20-24°C) and the other by high temperatures (26-30°C) The seasonal variations in soil temperatures in the field are apt to be so wide and their effect on the incidence of soil-borne diseases so varied, that immediate necessity was felt of experimental methods, to assess as accurately as possible, the modifying influence of this factor, which profoundly affected the course and severity of such diseases Pioneer work in this direction was started by Jones and his associates (1926) at Wisconsin (U S A) with the development of the well-known "**Wisconsin soil temperature tanks**", which seeked to control the soil-temperatures by a thermostatic device (Fig 47) Considerable amount of data has now accumulated on this aspect as a result of this improved technique, which has given a convincing corroboration of the field observations of the type cited above Figs 48 and 49 illustrate the influence of soil-temperature on the development of smudge of onion and *Fusarium* wilt of tomato

The *following* table summarises the results obtained by various workers with some of the important soil-borne diseases with special reference to the relation of soil temperatures to their development

Table 11

Cardinal soil temperatures (°C) for development of plant diseases

Disease	Cardinal soil temperatures for development of disease MIN	OPT	MAX	Authority
1 Scab of potatoes (*Actinomyces scabies*)	12	22	30	L R Jones et al
2 Club root of cabbage (*Plasmodiophora brassicae*)	10	20	35	Monteith (1924)
3 Cabbage yellows (*Fusarium oxysporum f conglutinans*)	17	26	37	Tisdale (1923)
4 Wilt of tomato (*F oxysporum lycopersici*)	20	28	35	E E Clayton (1918–20)
5 Wilt of cotton (*F oxysporum f vasinfectum*)	20	27	35	Uppal et al
6 Root rot of tobacco (*Thielavia basicola*)	15	23	30	Johnson and Hartner (1919)
7 Root rot of brinjal (*Verticillium dahlia*)	10	22	25	Patel et al (1949)
8 Smut of onion (*Urocystis cepulea*)	10	20	30	Jones (1921)
9 Smudge of onions (*Colletotrichum circinans*)	15	28	35	J C Walker (1921)
10 Wilt of Lathyrus (*F orthacerus var lathyri*)	20	26	35	Uppal and Bhide (1948)
11 Bunt of wheat (*Tilletia tritici*)	5	12	20	Faris (1924)
12 Black scurf of potatoes (*Corticium vagum*)	9	18	30	Richards (1921-23)
13 Seedling blight of rice (*Helminthosporium oryzae*)	–	20	36	Ocfemia (1924)
14 Stripe of wheat (*Helminthosporium sativum*)	12	28	36	Mckinney (1923)
15 Hollow stem of sorghum (*Macrophomena phaseoli*)	30	36	40	Uppal and Kolhatkar (1936)
16 Flag smut of wheat (*Urocystis tritici*)	10	22	30	Sattar et al (1952)
17 Wilt of flax (*Fusarium lini*)	20	25–30	35	— do —

A careful perusal of the above table in respect of the optimum soil temperatures reveals that in the case of serial numbers 6, 8, 11, 12 and 13, the factor has worked indirectly through the host, which has been literally overtaken by the rapidly growing parasite, the crops involved are tropical requiring higher temperatures for their optimum growth and have, therefore, suffered most at low temperatures due to the attack of the rapidly growing pathogens

A very interesting and convincing example of the indirect influence of soil-temperature, working through host, is provided by the seedling blight of wheat and corn, incited by *Gibberella zea* and is diagrammatically represented in the following table

Table 12

Development of seedling blight of wheat and corn at different soil temperatures (After Dickson, 1923)

Host	Development of host & disease			
	12–16°C		24–28°C	
	Host vigour	Disease	Host vigour	Disease
Wheat	vigorous	slight	slow	severe
Corn	slow	severe	vigorous	slight

The cardinal soil temperatures for development of seedling blight in wheat and corn are as follows

1 *Wheat* 12–28–32° C

2 *Corn* Below 8–16–24°C

The soil temperature in these two cases has acted directly on the host and through it on the course and development of the disease In such cases, it is a virtual race between the host and the parasite and the success or failure of either party is determined by the nature of environmental conditions under which these two parties find themselves

Fig 50 gives a graphic representation of data presented in table 12

Soil moisture does not appear to have the same controlling effect on the development of disease as the soil temperature In fact in judging the effect of soil moisture, it is difficult to consider this factor in isolation from other soil factors, such as physical condition, water holding capacity, drainage, retentivity and so on All these factors tend to make up a micro climate, which influences the course of disease collectively and not individually In general, moderate soil moistures favour disease and high soil moistures are injurious to the pathogens, because of their impeding effect on their respiration The incidence of flag smut of wheat in the Punjab, for example, was found to be 7% at

22, 15% at 17, 72% at 11, 50% at 7 and 25% at 4 5 soil moistures (Sattar et al, 1952) Similarly 25% soil moisture was found to be the optimum for development of wilt in banana caused by *F oxysporum f cubens*, while the incidence of the wilt decreased with increase in the moisture content (Stover, Phytopath, 1953)

In a few specific cases, this factor may retard the growth of the host and eventually increase the chances of parasitic attack Such a phenomenon is known as "**Predisposition**" Such is the case in the well-known foot rot disease of ginger, *Zingiber officinale* and damping off of papaya (*Carica papaya*) Soil moisture also materially affects the course of disease in *Phytophthora* wilt of *Piper betle* and gummosis of citrus In *Fusarium* wilt diseases, conflicting results have been obtained by different workers high soil moisture favouring tomato wilt but retarding development of seedling blight of cereals and common scab of potato Many non-parasitic diseases like the blossom-end rot of tomatoes and corky spot of apples, mango and other fruits are variously influenced by soil conditions with special reference to the water relation The balance between intake of water through roots and transpiration process through leaves, has intimate relation with the development of such diseases the exact nature of that relationship being, however, obscure and not well understood

Soil reaction has a profound effect on the development of common scab of potatoes, cotton wilt and club root of cabbage An alkaline soil favours development of the scab, while an acid reaction is very congenial for the club root organism High soil acidity is inimical to the development of the tobacco root rot caused by *Thielavia basicola*, while such a condition is highly favourable to wilt of tomatoes The behaviour of *Fusarium oxysporum f vasinfectum* causing the cotton wilt in U S A and India was studied by Mundkur (1936), who found that the American strain favoured *acid* reaction, while the Indian strain developed best at *alkaline* reaction Root rot of cotton caused by *Rhizoctonia destruens* is favoured by light soils with acid reactions, while *Fusarium* wilt of cotton in India develops best in heavy alkaline soils The incidence of covered smut of oats (*Ustaligo levis*) varies with varying soil reactions The disease develops best at pH of 7-8 and falls sharply with either decrease or increase in the soil pH, it is moderate at 6 5 pH

Soil deficiencies in respect of such minor elements like zinc, iron, boron, manganese, favour the development of deficiency diseases, such as mottle-leaf of citrus, red leaf blight of cotton, "*band*' disease of arecanut and " potash hunger " in potatoes and cotton, these diseases are practically entirely influenced by the presence or absence of available chemical constituents in the soil, specially the trace elements and have been largely cured by the supply of these elements to the soil either through soil or by sprays This aspect of subject has been treated in detail by Bear and Coleman (1949) Zinc deficiency is the main cause of mottle leaf of citrus and deficiency of copper, that of "*band*" disease of areca palms in Bombay

On the other hand, heavy doses of nitrogenous fertilisers make wheat and other cereals greatly "predisposed" to rust and mildew infection, while phosphatic and potath fertilizers tend to make them resistant, this is due to the density and delayed maturity of the crops, brought about by such applications

BIOLOGICAL FACTORS

These factors include the insect flora of the locality and the flora that comprises the soils The insect flora are very important in virus diseases of crop plants and is known to determine the distribution and severity of these diseases A familiar example of a human disease, profoundly influenced by the "vector" is malaria, which entirely depends upon the "*anopheles*" mosquito for its dissemination and virulence, while its course remains unaffected by the "*Culex*" species Similar has been the behaviour of a few virus diseases of plants both as regards their distribution, dissemination and virulence This has been specially so because of the "specific" relationship that exists between the particular virus and the specific insect vector

The Dutch Elm disease caused by *Ceratostomella ulmi*, is not well adapted to wind dissemination and can only be transmitted through the help of insects The part played by the *Scolytus* bark beetle in such transmission is very significant and the disease would probably not assume virulence in the absence of the insect "vector"

This "vector influence" in distribution, severity and new introductions, is more pronounced in virus diseases The well-known curly top of sugar beet is almost exclusively confined to arid regions of the West in the U S A and is absent from the humid areas of the eastern States, as the vector, *Eutettix tenellus*, does not appear to thrive under high humidity On the other hand, the disease is transmitted in Argentina, through the agency of the leaf hopper, *Agallea stictocollis*, which, however, thrives at high humidity and therefore may tend to extend the range of the curly top virus in the U S A, if introduced in that country

The soil flora comprises of bacteria, fungi, eelworms (nematodes) and protozoa, they are either saprophytes or parasites, they act as friends as well as foes

The position regarding their interaction between themselves and their varying influence on the incidence of disease is more complex than is apparent at first sight It may be in the nature of "**biologic antagonism**", antibiotic activity or mere competition The inhibition and control of the Texas root rot organism (*Phymatotrichum omnivorum*) in cotton soils of the southern U S A, through application of green manures, is probably of the latter type between the pathogen and many saprophytic organisms attacking and growing in green humus The beneficial activity of various types of saprophytic fungi and nitrogen fixing bacteria of the type of *Rhyzobium*, *Azotobacter* and *Clostridium* is well known the moulds act on complex organic matter, reducing them into simple substances and help the green plants in ready assimilation In other respects they are scavangers and help to keep the earth in sanitary condition The part played by the nodule-bacteria is of vital importance to agriculture and materially helps in replenishing the fertility of soils and indirectly assist a good crop stand free from disease The presence of *Azotobacter* in rice soils, which remain unfertilised in parts of India, has been a boon and is mainly responsible for good crops, which otherwise would end in failure of stand These organisms, however, are profoundly influenced by soil temperatures, low soil temperatures impeding their growth, and indirectly of the legume crops (Fig 51), soils deficient in such beneficial bacteria, are known to become unfit for vegetation unless replenished by addition of these organism, which in advanced countries like the U S A, is carried out through top dressing of pure cultures of such organisms, specially in cool regions Similar situations are in existence in parts of Gujarat, where, due to deficiency of nodule bacteria, peas (*Pisum sativum*) have not been known to give a healthy crop, specially in sandy soils, which are very poor in this beneficial soil-flora Addition to such soils of pure cultures of *Rhizobium leguminosarum* as top dressing has materially helped in obtaining good stand and crops of peas and other legumes

Soils are known to harbour pathogenic organisms such as bacteria, fungi and nematodes and thus many times become unfit for cultivation, such a condition is known as "sick-soil" Some of the common harmful organisms that inhabit soils are *Fusariums*, *Rhizoctonias*, *Sclerotiums*, *Phythiums*, *Xanthomonas campestris*, *Phytobacterium solanacearum* and *Heterodera* examples of such sick-soils which become unfit for cultivation are provided by soils infected with *Fusarium oxysporum f cubens*, *Phyto-bacterium solanacearum* and *Xanthomonas campestris* in parts of India It became impossible to grow crops of banana, potato and cabbage respectively in such soils, until the position was redeemed by introduction of resistant varieties in some cases, and annual importation of snow-grown potatoes in

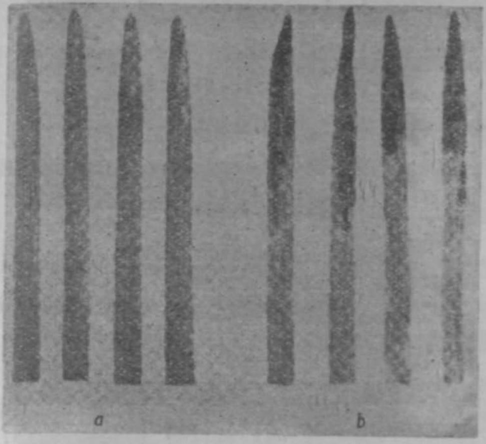

FIG. 45. Influence of air temperatures on the reaction of wheat plants to stem rust in green house.

a : Resistant (14°C).

b : Susceptible (24°C).

[After Newton and Johnson.

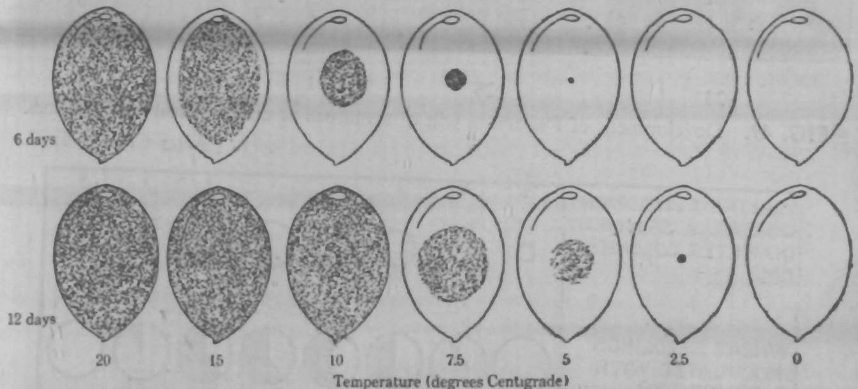

FIG. 46. Progressive development of brown rot of peaches at different temperatures in storage. [After Brooks and Colley.

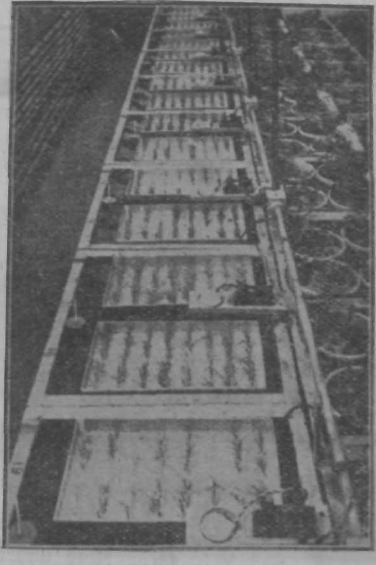

FIG. 47. A battery of " Wisconsin " soil temperature tanks.

[After Jones, L. R. et al.

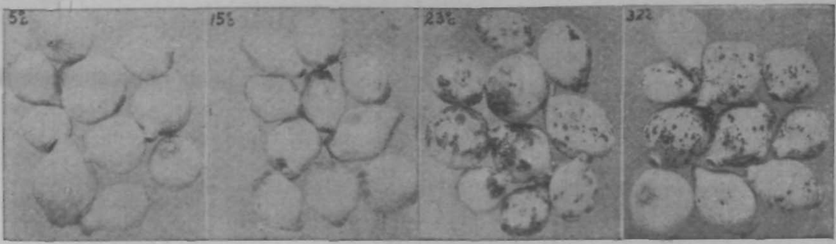

FIG. 48. Development of smudge of onions at different soil temperatures.

[After Walker J. C.

23 28 31 35

FIG. 49. Development of *Fusarium* wilt of tomatoes at different soil temperatures.

[After Clayton E. E.

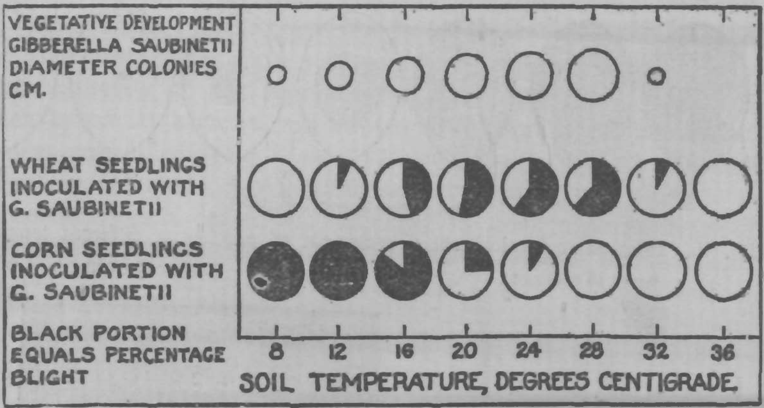

FIG. 50. Graphic representation of indirect influence of soil temperature on the development of seedling blight of corn and wheat, caused by *Gibberella zeae*.

[After Dickson

FIG. 51. Influence of soil temperature on the development of soyabean plants & nodule bacteria. Note under-development at lower limits.

[After Jones, F. R. et al.

others Similar situations were experienced in U S A and other countries, in connection with " Yellows " of cabbage in the State of Wisconsin, foot rot of wheat and wilt of flax in North Dakota and in parts of Bombay State, the onion smut in Northern section of U S A, *Fusarium* wilt of cotton all over the world and Texas root rot of cotton in southern parts of U S A

Soil infestations with *Heterodera* have become a limiting factor in parts of Bombay in the cultivation of *Piper betle* and *Piper longum* which consequently have been largely abandoned

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CHAPTER 15

EPIDEMIOLOGY

Epidemiology of disease is the study of the outbreak of disease, its course, its intensity, cause and effects and the various factors governing it Disease may affect isolated individuals within a crop and is termed **sporadic** On the other hand, if a disease assumes destructive nature over wide-spread areas, involving sudden outbreaks, concentrated in character, such appearance is known as **epidemic** or in American terminology, **epiphvtotic**, when the host and the pathogen reach a state of " biologic equilibrium " and the association assumes apparently harmless character, the disease is termed **endemic** The citrus canker is endemic in its home, Asia but becomes epidemic when introduced in a new locality, as was the case in Florida (U S A), the downy mildew of corn became epidemic in the Philippine Islands, although it is proverbially an endemic disease in India

When an epidemic disease spreads over continents or sub-continents and involves mass mortality, it is considered as **pandemic** The outbreak of plague in the earlies of this century and that of Influenza at the close of the 1st world war in India, are examples of pandemic diseases Similar was the case with the outbreak of black stem rust of wheat in India during 1947

An epidemic may cause wide-spread and mass destruction in a short space of time or may become " long drawn out " persisting for long periods depending upon the three factors, responsible for disease host, pathogen and environment

A course that an epidemic may follow in nature differs with the nature of the host, the pathogen and the environment In *Areca catachu*, the "Koleroga" fungus (*Phytophthora arecae*) assumes a destructive aspect during the monsoon period (July-Sept) and wanes away with rising temperatures and dry conditions, to return again in the succeeding rainy season Similar situations have been experienced with the outbreak of *Phytophthora* wilt of *Piper betle* in parts of India In temperate zone, the peach leaf curl and the apple scab follow similar course and the character of the epidemic may be described as "seasonal ' or annual

Epidemics caused as a result of introduction of new pathogens in localities hitherto free from them, appear in two phases-the first is a progressively destructive phase and the other a comparatively innocent phase, due to the ' biologic equilibrium ' reached between the " new comer " and the original inhabitant The well-known epidemics of late blight of potatoes in Europe and the blast of rice in Bombay constitute such categories Similar has been the experience of epidemics of downy and powdery mildew of grapes in Europe, the leaf rust of coffee in Ceylon, and the anthracnose of grape (*Gloeosporium ampelephagum*) in India, where the pathogens after taking heavy toll, have " settled down " and live in comparative peace

Cultivation and concentration of a single crop in large areas as for instance wheat in North America, Cotton in parts of India, and rice in south-east Asia, are frought with danger of an epidemic, on the other hand "mixed cropping", so generally practised in India, has much less chances of facing an epidemic

FACTORS GOVERNING EPIDEMICS

A disease is sometimes sporadic and assumes epidemic proportions under special circumstances A discussion of these circumstances will be useful in the proper understanding of these phenomena Since disease is the product of an interaction among the host, the pathogen and the environment, such factors can be grouped under the three heads, as follows

1 *Nature of the host,* its relative susceptibility, its predisposition and concentration

2 *Nature of the pathogen,* its virulence, its ability of propagation and dissemination, specialization of parasitism and tolerance to extreme conditions

3 *Environment,* its fluctuations and nature

An epidemic can only result from the *cumulative* effects of *all the three* factors mentioned above, acting *simultaneously* This is a remote possibility in nature and fortunately accounts for the comparative low frequency of epidemics Besides, only a few pathogens are capable of assuming epiphytotic proportions, while others are sporadic in nature The fungi inducing late blight of potato, the downy mildews, the rusts, the blast of rice and a few of the blight causing fungi, are among the former group

SUSCEPTIBILITY OF HOST

Plants possess innate ability to combat disease which manifests itself as susceptibility or resistance Plants also are capable of avoiding disease and sometimes become " predisposed " to the attack in accord with their nature, the environment and stage of growth Early maturing varieties of groundnuts, and wheat for instance are known to avoid infection by *Cercospora arachidicola* and *Ustilago tritici* respectively Late sown sugarcane avoids leaf rust infection in the

Deccan canals in Bombay Wheat becomes susceptible to black rust at the "*boot*" stage but is "resistant" when young Susceptibility of rice plants to blast increases with application of heavy doses of nitrogenous manures Similar experience is true of wheat crop in respect of rust infection Numerous examples of hosts becoming "predisposed" to infection are found among soil-pathogens Cotton is susceptible to *Fusarium* wilt at soil temperatures of 26-28°C, brinjal to *Verticellium* wilt at 29°C, *Sorghum* to root rot at 30°C, rice to seedling blight (*Helminthosporium*) at 20°C but "resistant" at lower or higher soil-temperatures

The **accumulations of susceptible plants** in wide-spread localities is an important factor favouring epidemics The destructive epidemic of "*Tikka*" (*Cercospora* sp) of groundnut in Bombay state during 1912-13 was mainly the result of cultivation of local varieties, which on account of their late maturing quality and large concentrations, fell a ready prey to the ravages of this disease The experience with Panama disease of banana during 1935-40 and the *Piricularia* blast of rice during 1948-49 in parts of Bombay, tells similar story The mass cultivation of a highly susceptible table variety of banana (*Son*) in an isolated but important centre was greatly responsible for the destructive epidemic in that area and resulted in a complete anihilation of this important industry, until the situation was revoked by introduction of a resistant variety (*Basrai*)

The situation with regard to the unprecedented outbreak of black rust of wheat in the U S A and Canada from time to time and of rice blast in South-East Asia, where these crops are grown in concentrations in large areas extending from Mexico in the south and Canada in the north in the case wheat, unprotected by any natural barriers, is indeed unique and intrigueing and mainly accounts for the frequent epiphytotics of stem rust and blast in the respective areas

The position with regard to outbreaks of red rot (*Colletotrichum falcatum*), the whip smut (*Ustilago scitaminae*) and leaf rust (*Puccinia sacchari*) in sugarcane in Bombay, is, indeed, very interesting The country-wide cultivation of the local varieties (*Pundia*, *Khajuria* and others) prior to the present introduction of exotic varieties, developed a situation where the red rot organism saturated itself in these varieties and practically made their cultivation impossible, on account of their high susceptibility This position was saved by the introduction of new varieties (Co & P O J) which were resistant to red rot The importation of these new varieties, however, developed into a menacing situation, which brought to the forefront, outbreak of new diseases viz whip smut and leaf rust, which hitherto were of no significance or absent in the crop and are now endangering the cultivation and even the existence of these varieties of sugarcane

Another example of an epidemic caused by **the introduction of a new host** is furnished by the recent outbreaks of the Angular leaf spot of cotton (*Xanthomonas malvacearum*) in Bombay Deccan This organism and the disease were of very minor importance in Bombay due to the resistance of the indigenous varieties, although they caused serious damage to Cambodia cotton (*G hirsutum*) in the neighbouring Madras State The introduction and cultivation of an exotic variety C4 (Cambodia) in large concentrations in the humid canal areas during 1948 onwards, developed an intrigueing situation and the pathogen, which was considered harmless, grew into a virulent parasite and caused wide-spread damage and misery under the new set-up Here, it was again a highly susceptible host that determined the character and the course of the epidemic

Recent observations (unpublished) have shown that the rust situation in Peninsular India with referenee to wheat, is steadily undergoing a perceptible change Stem rust (*Puccinia graminis tritici*) which held sway in this area, is slowly giving way to the leaf rust (*P triticina*) which was of very minor importance so far but is likely to develop into a major problem with the growing cultivation of the new stem-rust resistant hybrid wheats locally known as "*Kenphad*"

The introduction of a **new alternate host** is an important factor in determining the course and intensitv of an epidemic This is of special significance in heteroecious fungi like rusts The history of the outbreak of the heteroecious blister rust of pine (*Cronartium ribicola*) in Europe & North America makes interesting reading and proves beyond doubt, how man's activities appearently innocuous in making new introductions of plants, lead to a devastating epidemic of a disease

The blister rust was endemic in Eastern Europe, the variety of pine being *Pinus cembra*, which had apparently developed resistance by long association Man in his zeal for better varieties of timber, imported into Europe, the pine variety, *Pinus strobus* from the U S A which went into extensive cultivation and brought it in contact with the endemic area The new situation created by the introduction of the new host developed into a disaster and the rust, which was hitherto endemic and innocuous, developed into an epidemic, covering practically the whole of North European countries

The picture is not complete The pathogen was reintroduced into North America from Europe on pine stock in 1909 through the activities of man and brought in ruin of a wide-spread nature to pine forests in the East and the West, where this species of pine was found in large concentrations over wide areas

An endemic disease, thus, flared up into not only an epidemic but even into pandemic proportions as a result of a simple introduction of a new alternate host

NATURF OF PATHOGEN AS A FACTOR IN EPIDEMICS

In considering the influence of pathogen and its nature on the course and severity of an epidemic, some of the important factors determining such a course are the aggressiveness of the parasite, introduction of new virulent strains of the parasite, high fecundity and efficient mode of dissemination

AN AGGRESSIVE PATHOGEN

The history of the outbreak of blister rust of pine in the U S A has been already narrated above, this is an instance of how introduction of a new pathogen into that area lead to the development of an epidemic, which took a heavy toll of the pine industry

Some of the well-known instances of such epidemics caused as a result of introduction of new pathogens, are provided by the epidemics of downy and powdery mildews of grape vine, and the gooseberry mildew in Europe, the citrus canker and chestnut blight in the U S A The outbreak of a disastrous virus disease of banana (Bunchy-top) in Southern parts of India and a similar disease (chlorosis) in papaya (*Carica papaya*) in Bombay, narrates the same story The long drawn out and tragic history of the introduction of new pathogens and the consequent development of epidemics have b e e n graphically narrated by Large (1940)

A very interesting example of introduction of an aggressive insect parasite causing wide spread destruction is provided by the part played by cochinial insect (*Cactoblast* sp) This insect was introduced into India from Ceylon and spread like wild fire, destroying, in its wake, bag and baggage, the flourishing hedge plant, the spiny cactus, (*Opuntia diffenii*), the spineless variety remained absolutely unaffected the country was literally made free from this obnoxious hedge plant, within a very short time

Similar results were obtained in the elimination of the obnoxious weed in Australia through the introduction of the moth borer, *Cactoflastis cactorum* from Argentina during 1925–32

The great epiphytotic of late blight of potatoes in Europe (1843-45) resulting in wide spread potato famine and large scale migration was caused as a result of the introduction of the pathogen, *Phytophthora infestans*, on some solanaceous hosts from its native home, South America, which, although endemic in the native home, assumed an unprecedented aggressive character when brought in contact with highly susceptible potato varieties grown in large concentrations in Europe

VIRULENT PATHOGENIC STRAINS

The story of the outbreak of the country-wide epidemic of black stem rust of wheat on the Indian continent and specially Bombay during 1947, where it flared up like " wild fire " and developed into a total " wheat famine " is indeed most interesting, the dominant factor that brought in disaster was the presence of virulent strains or forms of the rust organism The number of physiologic forms of this rust found in India is comparatively small, of which forms 15, 21, 40, 42, 75, and biotypes of 42 are of common occurrence In Bombay, the varieties of wheat grown are " *Durums* " in dry areas and " *dicoccum* " (*Khapli*) in irrigated tracts, both varieties are highly susceptible to form 42 and its biotypes of the rust, although *Khapli* is well-known for its high resistance to other forms The year 1947 was specially marked out by abnormal weather conditions, accompanied by drizzling rains and heavy dew fall during the growing season of wheat (Jan -Feb) These explosive weather conditions were reinforced by the dominant presence of the virulent forms of rust (F 42, 42A & 42B) which brought in disaster and swept away both varieties of wheat, *durums and Khapli*, although such results were not expected in normal times with the highly " resistant " *Khapli* variety

Similar experiences have been recorded in the U S A and Europe with regard to the epidemics of black rust (Stakman, 1934), bunt, loose smut and stripe of wheat Highly rust-resistant varieties of wheat like *Kanred*, *Ceres* and *Thatcher*, *Hope & Lee* when introduced into northern sections of the U S A maintained their resistance for some time but suffered heavily from stem rust as a result of appearance of new but more virulent " races " or " forms " in these regions capable of attacking these new introductions The possibility of outbreak of epidemics increases with the number of physiologic forms or pathogenic strains of the parasite present in a locality Comparatively, therefore, the wheat belt area of North America & Canada would be more subject to the outbreak of epiphytotics of stem rust than the wheat belt area in India, because of the relatively large number of parasitic forms (over 200) present in the U S A The presence of pathogenic strains, therefore, in an area not only complicates the breeding programme for disease-resistance but also increases the chances of epiphytotics, just in the same manner as new pathogen would

HIGH FECUNDITY OF PATHOGENS

Pathogens with high reproductive capacity and capable of rapid dissemination over wide areas are more fitted to cause epidemics Endophytes with the formation of their reproductive parts inside plants and tissues, are less efficient in this respect, than those which produce them on the surface of host or readily break through The finger and toe disease of Crucifers, the wart of potato, the peach leaf curl are examples of diseases, which on account of their endobiotic habit of spore-formation, are not well adapted for producing epidemics On the other hand, pathogens of the type of *Phytophthora infestans* and *Ph arecae*, the downy mildew and the powdery mildew fungi, the rusts and the blast fungus, *Piricularia oryzea*, are eminently fitted for this purpose, on account of their high fecundity and efficient and long distance dispersal of their conidia, through the agency of wind and water, provided other conditions requisite are fully satisfied

The high degree of fecundity and the enormous amounts of inoculum produced by some common plant pathogens can be judged from the following table

Table 13

Reproductive capacity of fungi

Pathogen	Extent of fecundity	Authority
1 A single spore-horn of chestnut blight fungus	150,000,000 spores	Wallace, E
2 A single gall of cedar rust of apples	Two billion teliospores	Lloyd et al
3 A single barberry bush with aecial cups	64,000 million aeciospores	Levine, M
4 An acre of stem rust-infected wheat	Ten trillion uredio-spores	Stakman, E C
5 An acre of smut-infected corn	Fifty billion spores	Christensen, J J
6 A single fruit body of *Fomes applanatus*	5460 billion spores	Stevens, F L
7 A corn plant with downy mildew	225 million conidia in one night	Weston Jr
8 Downy mildew in a vine yard	32,000 conidia per sq cm	Millardet
9 An apothecium of (*Sclerotinia*)	31 million asco-spores	Stevens, F L
10 A single kernel of bunt of wheat	6-12 million spores	Heald et al

ENVIRONMENT AS A FACTOR IN EPIDEMICS

Environment, specially fluctuations in meteriological conditions play a predominent role and mainly determines, the course and severity of epidemics The downy mildew of grapes had been present in Bombay practically since 1910 but was not known to cause any appreciable damage, the main problem in vine cultivation was powdery mildew, which was kept under control through spraying of bordeaux mixture In 1926, attempts were made to introduce the simple sulphur dust treatment in place of the cumbersome and expensive spray programme, for controlling the powdery mildew, which used to attack vines during the dry cool period (Nov -Feb) In 1928, abnormal weather conditions prevailed, for the first time, in the vine areas during its fruitting season, accompanied by frequent drizzling rains and heavy dew fall with resulting wet conditions, the copper spray which was a specific for downy mildew, had disappeared from the scene and the pathogen, which was leading a passive and latent life, resumed activity and flared up virtually like wild fire inflicting unprecedented ruin and misery to the vine growers The situation was, indeed, intrigueing and arose out of an unusual conspiracy between abnormal weather and change in control measures, the plant pathologists were caught unawares and kept "at bay" and had to retrace their steps to evolve a combination programme consisting of copper spray and sulphur dust (Kamat, 1955)

The position with regard to the outbreak of paddy blast (*Piricularia oryzea*) in Bombay during 1948-49 was of a similar nature The pathogen has a very high fecundity and is capable of producing millions of conidia, which are capable of very easy dissemination over wide areas through air currents The disease which was of local importance in southern districts, spread with rapidity and high speed following ideal weather conditions and contact with highly susceptible varieties, throughout the rice-belt in the state within a short space of two years and developed into a destructive epiphytotic All the three conditions viz concentrations of susceptible hosts, high reproductive capacity of the pathogen and prolonged wet and warm weather, conspired to develop an epidemic of blast

It is a normal phenomenon that epiphytotics reach a "peak' and then tend to subside It is also a common place experience that epidemics become progressively harmless with age and their frequency wanes unless new factors enter the situation Such has been the case with the epidemics of downy mildew of grapes, the black stem rust of wheat, the blast of rice and many others This is largely due to the development of resistance through natural selection in hosts and the increased tolerance of the pathogen, aptly designated as "**biologic equilibrium**" It is difficult, however, to separate these factors as these exert a *cumulative* effect and do not act in isolation Nature brings into play several forces, which act sometimes on the host making them more resistant or tolerant and at other times on the pathogen, which gets "accustomed" to its host, resulting in reduced aggressiveness

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CHAPTER 16

PRINCIPLES OF PLANT PROTECTION

" Prevention is better than cure " forms a golden rule in the control of plant diseases, for, like the humans and animals, plants can not be cured of disease The problem, therefore, in plant pathology is really protection or prevention from disease-producing organisms This is largely due to the inherent differences in the constitution of the two groups of organisms and the nature and mechanism of infection, already discussed in chapter 13 under '*The Disease*" The vital role played by environment in plant pathology makes the position more complicated as control measures devised against a disease under one set of factors become useless or obsolete with a new set up The well known instance of this character is the outbreak of downy mildew of grapes in Bombay State and its control, already described under " Epidemiology " The methods of control or rather protection, therefore, are primarily designed as preventive measures Measures of control in plant pathology are, not directed against individuals as in human medicine but against groups or mass of crops and *seek to protect them against infection* and not disease Economic limitations are of the highest consideration in devising such methods They are mainly **prophylactic** in nature and correspond to public hygiene in medicine The four wholesome principles governing such measures are *1* Prevention of introduction of disease into a new locality (*Exclusion*), *2* Prevention of dissemination of infection and disease (*Eradication*), *3* Prevention of disease-producing organisms from infecting plants (*Protection*), *4* Develop resistance in plants against disease (*Immunology*) Nos 1, 2 & 4 aim at indirect approach, while item 3 represents direct method of the control problem

EXCLUSION

These methods aim at excluding new pathogens and diseases from reaching an area hitherto free from them This is achieved through quarantine laws and Disease and Pest Acts passed by legislatures of either State or Central Governments or local authorities Quarantines, thus, are man-made barriers and operate through various legislative measures All civilised and progressive countries of the world have resorted to such laws to safeguard their Agriculture from the attack of new pathogens The general impression, however, gained over long periods, has been that these laws have remained ineffectual in practice, since many new diseases and pathogens have ' filtered their way " into new localities inspite of such laws The quarantine laws were enacted in the U S A in 1912 and are known as Federal Plant Quarantine Act

In India the Destructive Insects and Pests Act was passed in 1914 and subsequently supplemented by other provisions Such quarantine laws were enacted in France in 1660, in Denmark in 1903 and specially aimed at destruction or eradication of the barberry bush, which has been known since early times to harbour black rust of wheat These laws are enforced by periodical inspections in the field, market and port of entry or embarkation, carried out by authorised state agents The introduction of air-travel between countries and its rapidity have made the question of enforcement of these laws more difficult

Reasons for instituting quarantines are two-fold, viz 1 to prevent a new disease from migrating to regions free from such disease and 2 to isolate and localise a disease after it has reached a locality so as to eradicate it

Quarantine laws, enacted indiscriminately, defeat their own purpose, they are ineffectual Some of the important considerations governing enactment of such laws and acts are **biologic** as well as **geographic** The etiology or exact life cycle, the manner of spread, the mode of transmission, the host range, the phenological relations of the pathogen and disease are important biological considerations Some of the inherent characteristics of the pathogen may, themselves, act as barriers and therefore, may not necessitate operation of quarantine laws The late blight and the powdery scab of potatoes, for instance, are typically temperate and have no chance of developing in the tropical climates A quarantine in such cases is uncalled for Similar is the case in typically air borne diseases like the cereal rusts, smuts, and blasts whose migratory habits are beyond the operation of any man-made laws

Geographic considerations include the nature of the country, contiguous and non-contiguous and the presence of such formidable natural barriers like the oceans, deserts and mountains Quarantines in such cases, may be effective only with non-contiguous countries, such as between continents or regions of the latter type In contiguous countries such laws can be and are enforced to localise and isolate a few specific diseases specially those carried on or in plant stock and other vegetative parts Panama disease of banana and "*Katte*" disease of cardamom in parts of Bombay and bunchy top of banana in southern states of India, Ceyon and Australia, are amenable to such local enforcement

Quarantine laws, thus, are effectivelly enforced in diseases, which are primarily carried and disseminated through plants, plant stock and other vegetative parts such as tubers, cuttings, rhizomes, corms, bulbs and other nursery stock These laws have been of special significance in preventing and regulating movement of diseases like wart of potatoes, citrus canker, grape anthracnose, angular leaf spot of cotton, bunchy top and Panama disease of banana, "*Katte*" disease of cardamom etc all of which are carried through vegetative propagative parts

According to these laws, the exportation of plants and plant stock must be accompanied by a health certificate regarding freedom of such stock from diseases and pests listed in the Act which otherwise are liable to be destroyed at port of entry While it is comparatively easy to detect infection of fungus or bacterial origin, diseases of virus origin are detected only in standing crops Special measures are, therefore, taken in such plant stock, the seed-merchants or societies dealing in such stock are prohibited from selling or exporting such stock without a health certificate from an accredited agent, who carries out periodical examination of *standing crops* and then issues certificates accordingly Special techniques such as "*Tuber-indexing*" (Fig 55) and "*Seed-certification*" are resorted to in such cases and are now a regular practice in Europe, U S A and other progressive countries

Although not much success has attended man's attempts to exclude new pathogens from reaching areas hitherto free from them, the part played by *local quarantine* measures in isolating new diseases and radication thereof, cannot be minimised Phenomenal success has been achieved in stamping out citrus canker from Florida and other Gulf states of the U S A and South Africa, wart of potatoes and Dutch elm disease from North America, bunchy top of banana from Ceylon and Australia and "*Katte*" disease of cardamom from outhern districts of the Bombay State This has been done through ystematic operation of local quarantine measures and application of he Insect Pest and Disease Acts It is true that this has been achieved at great costs, which, however, have "paid" in the long run Millions of dollars have been and are being spent in the U S A, Australia and other countries for uprooting these and other diseases, that have aken a foot-hold in those countries, with great benefit to the agriculturists and relief to agricultural economy

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CHAPTER 17

METHODS OF ERADICATION

These measures primarily aim at breaking the "infection chain" by removal of "foci of infection" and starvation of the pathogen. A critical study of and insight into the life cycle of pathogens with special reference to the methods of hibernation, host range and habit of growth are essential pre-requisites for devising appropriate sanctions against the diseases concerned. Such measures, in general, however, are "prophylactic" in character and mainly consist of maintenance of general sanitation and hygiene, clean-up campaign and the practice of improved cultivation; these measures necessarily differ and are as varied as diseases themselves. Some of the important measures so directed will be discussed in the following pages.

1. Maintenance of sanitation by destruction of diseased parts :— This is a simple prophylactic method and aims at maintaining general sanitary conditions in the field; destruction of diseased parts of plants in the field removes the main "foci" of infection and thus breaks the chain. Excellent example of control of this type is provided by the "Koleroga" of arecanut, where the pathogen, *Phytophthora arecae*, over-summers in tree-tops, during the off seasons, (Fig. 52) resuming activity during the monsoon. Destruction of such affected tree-tops and maintenance of general sanitation in the gardens by burning all diseased nuts and leaf-sheaths has led to an effective protection against the onslaught of the disease. Field trials made over several years in parts of Bombay, have demonstrated the effectiveness of such simple measures. The spread and dissemination of many virus diseases and of citrus canker can be materially checked and severity greatly minimised by such practices, which are the main lines of attack in these diseases. This method of "tree surgery" is of special significance in orchards and forest areas for controlling diseases.

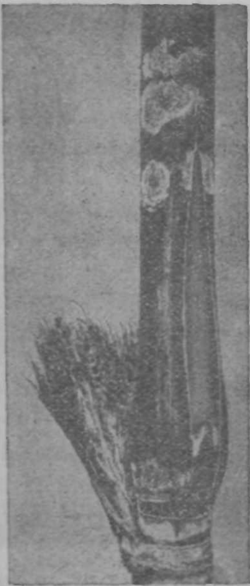

Fig. 52 A tree-top of Arecanut palm showing infection by *Phytophthora arecae*.

[Courtesy: Mysore Dept Agri.

The removal of mummified fruits in orchards affected with brown rot organism (*Sclerotinia fructicola*) and burning them, is a wholesome practice and materially aids in breaking the infection chain and minimises subsequent development of the disease The organism causing the late blight of potatoes chiefly persists through infected tubers and refuge which act as primary sources of infection Careful and systematic removal and destruction by fire of such refuge and tubers is, therefore, of utmost importance in preventing not only primary infection but even further dissemination of the disease Similar experience has been obtained in the control of Angular leaf spot of cotton, by removal of volunteer cotton plants, which harbour infection and help in perpetuating the infection chain

2 **Improved cultural practices** — These methods are mainly designed to modify environmental conditions and make them unsuitable for the growth and development of the pathogen The foot rot of ginger *(Pythium myriotylum)* in parts of India is a disease of the low bed areas, which are subject to flooding and are ill-drained and which consequently favour the aquatic pathogen and retard the growth of the host plants which, thus become "predisposed" to infection A radical change in this condition is effected through an improved cultural practice, consisting of planting the crop on raised beds instead of flat beds and has secured excellent control, the raised bed system has removed the environmental conditions that favoured the pathogen and indirectly invigorated the ginger plants to better growth and stand Similar results have been obtained in the control of onion smut (*Urocystis cepulae*) in the U S A An onion crop, raised by " seeding ' a field is highly susceptible to the smut, the incidence of this smut has been largely prevented by a change in the usual practice of culture, by the method of ' transplanting" giving way to "seeding", a simple contrivance of disease-escape

3 **Rotation and fallow** — This is a whole-some practice in the control of persistent soil-borne diseases The pathogens have varying periods of viability in soil and affect a single or group of hosts A knowledge of this aspect of their life cycle is thus, quite essential before devising scientific methods of rotation and fallow The method aims at preventing continuous cropping for varying periods depending upon the nature of the pathogen In chronic soil-infections, long term rotations or *fallows* are desirable and aim at starvation of the pathogen by eliminating the host and its means of subsistence for varying periods Diseases like the bacterial ring of potatoes, black rot of cabbage, powdery scab of potatoes, Neema diseases, black leg of cabbage, and the like are amenable to such methods which are, however, of a temporary nature Some of the common soil-pathogens with their periods of viability in the soils are given in the following table

Table 14

Period of viability of some important pathogens in soil

Pathogen	Period of persistence in soils
Urocystis cepulea	5 years
Fusarium lini	10–12 years
F oxysporum f conglutinans	11–14 years
Pythium sp	3–5 years
Sp of *Sclerotium* and *Rhizoctonia*	3–4 years
Phymatotrichum omnivorum	Indefinite
Corynebacterium solanacearum	6 years
Fusarium nivum	15–18 years
Spongospora subterraneae	3–5 years
Plasmodiophora brassiceae	6–10 years
Wheat mosaic virus	6 years

These soil pathogens can be broadly grouped as those attacking cereal crops and those infecting non-cereals It is, therefore, of advantage to rotate a cereal crop with a non-cereal one in a system of rotation for control of such persistent soil pathogens

4 **Rogueing** — This practice consists of destruction of affected plants from the fields at an early stage by removing " foci ' of infection and preventing wide dissemination of the pathogen, this method has been successfully employed in protecting plants against virus diseases The control of yellow mosaic of *Hibiscus* and "*Katte*" disease of cardamom in Bombay has been secured through such methods, carried out in a systematic manner, the whip smut of sugarcane (*Ustilago scitaminae*) in the canal areas of Bombay in Co 475 variety has been greatly checked by such methods carried out over wide areas and long periods In Jamaica, a country-wide campaign of destroying infected plants has succeeded in the control of Panama disease of banana Bodily removal of such parasitic growth as *Loranthus* growing on trees and the rust galls from the Cedars has provided good control, though of limited value, in preventing spread of these diseases

5 **Destruction of alternate host** — While this practice has not succeeded in completely stamping out diseases like the heteroecious rusts of cereals, the rust of apple and pine, experience gained over long periods have definitely established the wisdom of such methods in greatly minimising the severity of attacks and frequency of epiphytotics

FIG. 53 Eradication of barberry bush by sulphur treatment for control of stem rust of wheat.

[After Cotter R. U.

The Barberry eradication campaign in the control of black rust of wheat (Fig. 53), of the buck–thorn (*Rhamnus* sp.) in the control of crown rust of oats, of *Thalictrum* sp. in controlling the leaf rust of wheat (*Puccinia triticina*), of currents and Cedars in the protection of pine forests and apple orchards from the ravages of blister rust and cedar rust respectively in the U. S. A , Europe and Australia, tell a hopeful tale and have completely changed the entire picture and brought hope in place of despair (Fulling, 1943). Figures and facts collected in the U. S. A. have clearly shown the remarkable success of the Barberry Eradication Campaign since its inception in 1918 (Fig. 54). The success of such measures would naturally be determined by the extent and manner of operation of the campaign which if carried out on a mass and country wide scale, are bound to yield excellent results. State sanctions and agencies are thus, the only appropriate medium for operating such campaigns, since experience has shown the futility of leaving them in the hands of indifferent individual farmers.

6. Destruction of complimentary host : — This measure has its limitations and can only succeed in special circumstances, where pathogen persists on wild hosts and weeds. In diseases of a

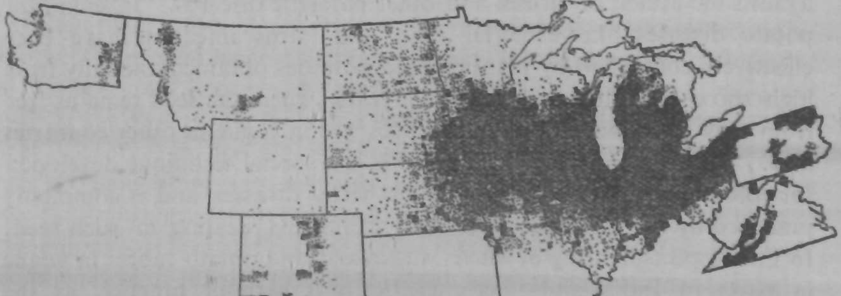

FIG. 54. Extent of barberry eradication campaign in U. S. A. (1918–1949)
Dots represent barberry bushes. [After Stakman E. C.

cosmopolitan nature where pathogens, like the *Sclerotium* or *Rhizoctonia* are able to infect a large number of hosts and perpetuate themselves on perennial hosts like the fruit trees, such measures have less chances of success The yellow vein-mosaic of *Hibiscus* persists on a wild host (*Hibiscus tetraphylus*) in nature and the systematic removal of this wild plant has succeeded in stamping out the disease in the experimental areas in Bombay On the contrary the virus causing mosaic of *Carica papaya*, which is a perennial plant perpetuates itself on many cultivated hosts like the cucumbers and bottle guard and is, therefore, not amenable to such measures Successful control of Fire blight of apples and pears (*Bacillus amylovorus*) has been obtained in New Zealand by a State Act passed in 1922, requiring compulsory removal, from the vicinity of the orchards, of hauthorn bushes (*Crataegus* sp) which serve as collateral hosts for the pathogen Similarly, effective control has been obtained in sugarcane against mosaic, in Barbodos, by the eradication and systematic removal of maize from the neighbourhood, as the latter acts as a collateral host for the perpetuation of the virus infection chain

7 **Seed selection** —This is a purely preventive method and althougn not of general application, has remarkably succeeded in certain specific instances, in keeping down the infection and spread of disease The seed-borne diseases carrying infection internally into either seed or propagative vegetative parts, are specially amenable to such treatment The red rot and whip smut of sugarcane, the bacterial ring of potatoes, the foot rot of ginger (*Zingiber officinale*), wilt of *Piper betle*, loose smut of wheat, bunchy-top and Panama disease of banana, can be kept under proper control and damage greatly minimised by rigid selective methods of seed, carried out *before* planting Such disease-free seed can be obtained either from areas known to be free from such diseases or by maintaining special seed-plots in isolated areas Such practices such as frequent change of seed and " Tuber indexing " have been resorted to for obtaining disease-free seed and protecting crops against the attack of viruses and other parasitic diseases In India, the potato diseases like bacterial ring and virus infection have been effectively controlled by planting seed potatoes obtained annually from high snow-clad altitudes, the Simla Hills, where the seed remains free from such infection Similar practices are in vogue in other countries also " Tuber indexing " (Fig 55) is a special technique developed for protecting potato crops against virus diseases and is commonly practised by the nurseries and seed merchants dealing in such seed In this respect planting of *whole* sugarcane and potato tubers in vogue in parts of India and other countries is a harmful practice, as the presence of infection in such propagative parts, is not easily detected at planting time The practice of taking "*ratoon*" crops of sugarcane

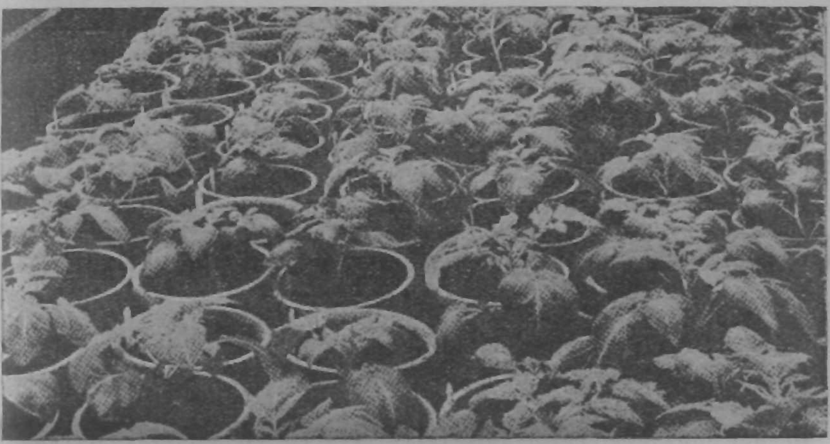

FIG. 55. Method of Tuber–indexing for virus control in root-crops.

[After Stevens and Stevens.

should also be avoided, specially in crops infected by whip smut (*Ustilago scitaminea*), and red rot (*Colletotrichum falcatum*) as the underground parts left over, harbour the parasitic mycelium and the diseases consequently intensified in the succeeding crops.

8. Closed season :— This method also known as " crop–free period " which aims at avoiding continuity of crop and break its chain, is only successful with annuals but not with perennials. A part of the season is " closed " for cultivation and helps in breaking and interrupting the " infection chain " ; this method is primarily based on the same consideration and principles as those governing removal of alternate and complimentary hosts. Prohibitory orders are issued by the state authorities under the Disease Acts to prevent cultivation of crops in certain season in such cases. The control of the black stem rust of wheat in India and the yellow vein mosaic of *Hibiscus* are examples illustrating the effectiveness of such methods. In the absence of its alternate host, the *Barberry*, the rust fungus oversummers in India in the uredial stage on summer wheat in the hills, from where the " inoculum " is carried by air currents to the next " *kharif* " crop grown at the foot of the hills and ultimately reaches the main " *rabi* " wheat belt area in the plains; there is thus continuity of wheat crop which is dangerous and helps in perpetuation of the rust fungus. Since the crops grown in hills and in " *Kharif* " season are of little economic importance and yet dangerous and provide " infection foci ", a good control of the rust can be obtained by " closing " the summer and *Kharif* seasons for the wheat crops (Gokhale et al, 1952). The growing of *Kharif* crops has, thus, been banned in Bombay State by enactment for this purpose. Good results have been obtained in the control of the yellow vein mosaic of *Hibiscus* with this method, which consists of banning of cultivation of this vegetable in one season, so as to break the continuity of the crop chain and eventually also of the infection chain

The enforcement of a " crop-free " period for celery in California has been effective in greatly reducing the incidence of mosaic, a virus disease The yields of celery which fell from 1000 crates to 300 crates per acre between 1930–1935 due to the ravages of this virus, were restored back with three continuous and systematic " Celery-free " seasons (Stevens, 1947)

9 **High budding** —This is purely a mechanical way of avoiding infection and is practised in the control of gummosis of citrus trees, the "low budded" plants, where the "bud" point is in close proximity to the infection centre (the soil), become readily diseased High budding, therefore, is a simple device for lengthening this distance between the bud-point and the infected soil, so that the soil-borne pathogen (*Phytophthora palmivora* and *P citrophthora*) has no chance of reaching the bud-point, through which it enters the bark In the brown rot infection of citrus fruits by the same organisms, **staking** of lower-most branches arising close to the soil, increases the distance between the fruits and the soil inoculum and removes the chances of brown rot infection

10 **Change in planting season** has been practised with remarkable success in the control of leaf rust of sugarcane (*Puccinia sacchari*) and blast of *ragi* (*Piricularia oryzae*) in parts of Bombay and Madras respectively This is a typical case of "disease escape" The crops are planted during September-October instead of in June–July and thus escape the onslaught of the pathogens

11 **Obtaining seed from disease-free localities** has been very successfully resorted to in the elimination of many seed-borne diseases In the U S A , seed-potatoes are invariably grown in northern snow-clad sections, where viruses are practically absent and then exported to various other sectors in the south Similar practice has been in vogue in India, where seed-potatoes are annually imported in southern states from Simla hills for control of viruses and bacterial ring In the U S A , the seed growing areas have been shifted to arid pacific regions for such crops as cabbage, turnip, beans and peas for obtaining disease-free seed and indirectly controlling such diseases like black leg and black rot of cabbage and turnip and anthracnose of beans and peas etc

Similar practice is obtained in parts of Bombay, where the foot rot of ginger (*Zingiber officinale*) caused by *Pythium myriotylum* prevalent in the southern parts, is controlled through the importation of seed-rhizomes from disease-free arid regions of the north, where the disease is practically non-existent on account of the dry climate, lighter soils and moderate rainfall.

12. Trenching between rows of trees in orchards has been effectively utilised in arresting the growth of the Texas root rot organism (*Phymatotrichum omnivorum*) through soils in the U. S. A. This method has worked successfully in the recovery of citrus trees from dieback in parts of India by improving soil aeration and drainage. The growing of an *intercrop* of cereals such as corn or

FIG. 56. Control of "potash hunger" in cotton by soil application of potassium sulphate. L : Non-treated, diseased. R : treated, healthy.

[After Young, V. H.

FIG. 57. Inter-cropping (centre) as a method of control for Texas Root rot of peaches. L : diseased, R : healthy. [After Young, V. H.

Sorghum between rows of peach trees has similarly given good results in combating the Texas-root rot infection in the U S A (Fig 57) The cereals remain unaffected by the soil-parasite and thus work as an effective barrier

12 **Mixed cropping** — This method of cultivation is of special significance in Asian countries and has been discussed in Chapter 14 under Epidemiology This practice has materially helped in effectively checking the spread of infectious diseases The root rot of cotton caused by *Rhizoctonia bataticola* and the blight of pulse crops caused by *Phyllosticta phaseolina* in parts of Punjab, have been successfully overcome by such practices The growth of an intercrop of *math*, a legume, in between rows of cotton tends to keep down the high soil temperatures, which are so essential for the development of root rot and thus indirectly reduces the incidence of the disease Similar results have been obtained in respect of the blight disease by growing the pulses as a mixed crop with cereals like *Sorghum* and *bajra* Experiments made in Uttar Pradesh (India) with the root rot and wilt of cluster bean *(Cyamopsis psoraloides)* have also demonstrated the efficacy of this method of culture in combating these soil-borne diseases Intercropping of *Sorghum* and *Phaseolus* in a crop of cluster bean reduced the incidence of the two diseases from 50-60 percent in single crop to 8-15 per cent in the mixed crop (Sing, 1954)

14 **Modifying soil reaction** — This method, which consists of application of either lime or sulphur to soil, has been employed with good success in the control of club root of cabbage and powdery scab of potatoes The former is controlled by the application of lime (1200 pounds per acre) and the latter by sulphur (900 lbs per acre) In the Punjab, root rot of tobacco caused by *Macrophomena phaseoli* has been overcome by the application, to the soil, of 1-2 tons of lime per acre The method works through modifying the pH of the soil, making it unsuitable for the growth of the pathogen

Growing of " **trap-crops** " and **pruning** are some of the other methods employed in the eradication of infectious diseases Improved methods of **irrigation and drainage** have given good results in the control of both parasitic as well as non-parasitic diseases, mainly arising through soil conditions The die-back of citrus has yielded to such methods

Other unusual but simple methods of eradication employed in various countries, besides the above, consist of **shallow planting** immediately followed by flooding in the control of smuts of sorghum, bunt of wheat in Egypt and flag smut of wheat in northern parts of India, use of resistant "*jamburi*" stocks for budding sweet lime for the control of gummosis in India, the use of *vinifera* stocks for grafting

American grapes for the control of chlorosis in the U S A, syringing water under pressure for the control of powdery mildews of rose, beans, cucumbers and cereals, and flooding for 6 to 8 weeks employed for killing sclerotia of the brown rot fungus in Florida (Stevens, 1947) A recent discovery of a wild sp of *Vitis* resistant to diseases in nature found in India provides excellent stock for obtaining disease-resistant grapes (Syamal, 1953)

Application of chemicals specially certain essential elements like copper, potash, zinc, manganese, iron and boron has indirectly helped to control deficiency diseases such as "mottle leaf" of citrus, potash hunger in potatoes and cotton (Fig 56) and "*band*" disease in arecanuts, bitter pit of apples, frenching of tobacco, browning of cabbage and cauliflower, sand-drawn in tobacco etc

The addition of organic manures such as green compost, humus or hay (in the proportion of 25-30 tons to an acre) to the soils, has successfully overcome the root-rot infection in cotton, in southern parts of the U S A by encouraging profuse growth of saprophytic organisms, which in turn bring about inhibition of the pathogen—an ingenious method of *biologic control*

The measures discussed above are specially useful in preventing dissemination of the pathogens into new areas and arresting the spread of infection The value and effectiveness of these methods are determined by the systematic manner of operations carried out and the co-operative efforts put in by the farmers in a given locality Although these measures are not spectacular in nature and effect, like the protective measures discussed in the next chapter, they constitute effective but inexpensive means of combating infection specially in such crops, where other expensive measures are not either a practical proposition or do not "pay" It would, therefore, be advisable to lay greater stress and emphasis on such measures where man power is freely available at comparatively low cost

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CHAPTER 18

METHODS OF PROTECTION

The main purpose of these measures is to prevent germination of pores that lodge on the surface of the hosts and their subsequent enetration and infection This is accomplished by applications of arious types of agents, chemical or otherwise, dusts or liquids, to the urface of plants, plant parts, seed and their environment This nethod is mainly protective and has its own limitations, it involves igh costs, technical knowledge and skill and is cumbersome to operate nd can, therefore, be employed with economy and success in only noney crops, orchards and plantations, which leave large margins of rofits Application of these methods is not a profitable proposition n *the case of general crops like the cereals, vegetables, pulses, fodder* nd legumes In the latter cases, "remedy is liable to be worse than he disease itself'

The agents or substances employed in the applications are known as **ungicides** A fungicide is any agent that is used to protect plants and lant parts against disease-producing organisms be they fungi bacteria, nematodes or flowering parasites, in the latter two cases, such agents re known as **nematacides** and **weedicides** respectively It may be hemical in nature or may be in the form of heat and steam, it is ungicidal but *not phytocidal* A good fungicide should have the ollowing important characteristics

1	Fool-proof	5	Easy spreading nature
2	Non-toxic to host	6	Easy of application
3	Easily available	7	Economical
4	Long residual effect	8	Simplicity in preparation

A fungicide, therefore, will defeat its own purpose, unless it satisfies the above requirements in large measure Selection of a fungicide, manner and mode of application are important considerations and determine the success of the operation A fungicide, for instance, in a liquid form though effective, has less chances of being accepted by a farmer than one in dust form, because of the cumbersome nature of the former The copper sulphate steeping method in the control of grain and loose smuts of *Sorghum* in India, although an effective protection, has not found favour with the farmers, who have preferred to have the alternative method of sulphur dust Similar has been the experience with the application of sprays as against dusts Soil applications, as a general rule, can only be practised with efficiency and profit, in small-scale areas like those in seed beds, green and hot houses, but are rarely practised on a field scale Instances of application of the latter type are rare and are available in the control of *Phytophthora* wilt of *Piper betle* in India and of onion smut in the U S A Economic considerations and the easy manner of applications are thus, " *sin qua non* ' to the selection of a fungicide in a control programme

For the purpose of these protective measures, diseases can be grouped under four heads **1 Soil-borne, 2 Seed borne, 3 Air-borne** and **4 Insect-borne**

The time of applications of fungicides, thus, must conform to the nature of the disease, against which they are aimed, in order to obtain the best results, in other words, such applications, in order to be effective must be made at certain definite stages of the plant growth

SOIL APPLICATIONS

This is a method of soil disinfection, sometimes also known as soil-sterilization and is largely curative in nature as it primarily aims at killing the soil-pathogens and making the soil "safe" for the growth of plants In some respects, however, the method is also protective and seeks to protect the germinating seed, in its early stages and young seedlings from the onslaught of soil-pathogens The method, thus, can be curative in some cases (Damping-off in seed beds wilt and root **rot-organisms** in green houses and experimental plots, root-knot organisms etc) and protective in others (seedling blights of cereals, onion smut and wilt in *Piper betle*) In the latter case, it creates a "*safe fungicidal island* which prevents the pathogens from their onward march

Heat, steam, formaldehyde, Bordeaux mixture and its various substitutes, like *Perenox*, *Dithane* and chestnut compound, various soil fumigants like *Fernoxone*, Benzol, *Methyl* bromide and *Ethylene* compounds have been used in different countries, for the purpose

Soil disinfection by the use of heat and steam is a common practice in hot houses, green houses and glass houses in the cultivation of mushrooms and experimental plants, it is used on limited scale in nurseries and seed-beds for the control of damping-off diseases and other soil organisms like *Fusarium and Rhizoctonia* Application is made through underground pipes at depths varying from 9" to 18" depending upon the nature of the pathogen, the steam is allowed to act at a temperature of 200 F for 15 to 20 minutes

Chemical disinfection of soil is carried out by the use of formaldehyde, Bordeaux mixture and its substitutes and corrosive sublimate this, however, is of a restricted application, as it involves

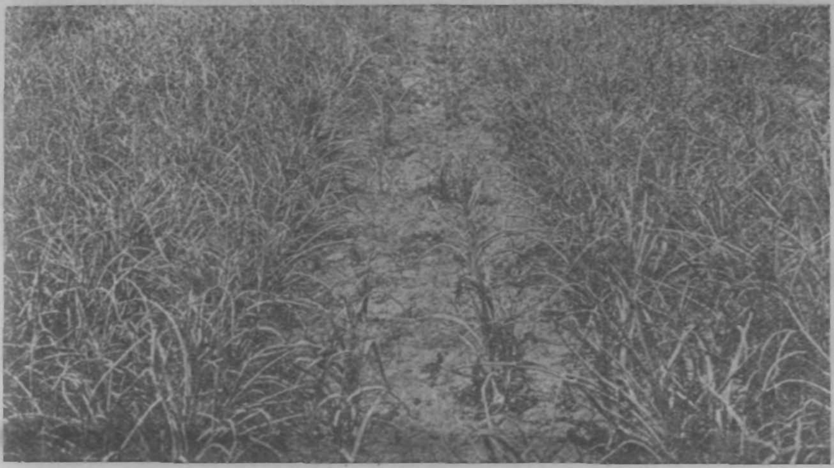


FIG. 58. Control of onion smut by soil application to formaldehyde.
Centre rows, non-treated. (After Anderson

high costs, many times prohibitive and is carried out only in forest culture, valuable nurseries and in experimental plots. Formaldehyde is probably the best for the purpose, being readily filterable through the soil and in gaceous state permeates through the air pores; it is also a powerful fungicide and has been used against root rot of trees caused by sp. of *Fomes*, *Ganoderma*, *Polyporus* and *Armillaria*, in the proportion of 1:50 at the rate of half a gallon to a square foot; the spot is drenched with the solution and then covered over by a wet cloth for 48 hours. Excellent control has been obtained in onion smut by the applications to the soil of a solution consisting of one part of the commercial product and 128 parts of water (Fig. 58), applied at seeding time, at a rate of 200 gallons per acre with the help of machines specially devised for the purpose (Fig. 59). *Fermate*, applied to the

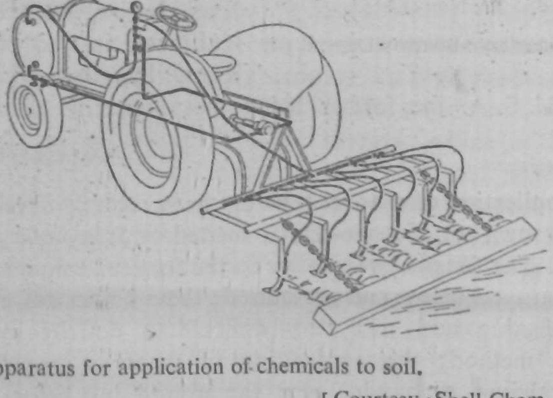


FIG. 59 Apparatus for application of chemicals to soil.
[Courtesy : Shell Chem. Corporation

soil 2 days before seeding has also given good control of this smut. This is probably the first case of soil-disinfection carried out in the U. S. A. on a field scale in the treatment of a soil-borne disease. Another example of control of serious soil-borne disease by soil-applications is provided by the notorious *Phytophthora* wilt of *Piper betle* in India. This consists of the application of Bordeaux mixture of 2-2-50 strength to the field before and after planting, around the growing vines at regular intervals beginning with planting and then monthly intervals between June and September, which is the critical period for infection to start and spread. The applications are made with a can at the rate of two gallons of the mixture to a 10 ft. row (Fig. 60).

FIG. 60. Control of betelvine wilt by soil application of Bordeaux mixture (Diagrammatic),
L : treated, R : Non-treated.
[Courtesy : Bombay Dept. Agri.

Effective control of "damping-off" of tobacco seedlings in Northern districts of Bombay and South India has been secured by application, to the seed bed areas, of *Perenox*, a commercial substitute of Bordeaux mixture, in the proportion of 1½ pounds of the ingredient to 50 gallons of water; the mixture is sprayed by a powerful pressure-sprayer, onces before (pre-emergence) and the others after (post-emergence) seeding and at weekly intervals. Similar control has been obtained by the use of formaldehyde dust *semesan phygon* and other chemicals. Good control of damping-off in tomato has been secured by seed-treatment, instead of soil-treatment, by *cuprocide* and 50% *arasan* in U. S. A. the former being more effective than the latter (Fig. 61).

Soil application of a novel type has been recently developed in the control of brown rot of stone-fruits, incited by *Sclerotinia fructicola* in the U. S. A. The fungus overwinters in the form of "mummies" which fall to the ground below and are buried; these bodies act as important foci of infection and are very difficult to destroy by the usual mechanical method; the application of "*ground spray*" of *Krenite* (0.5%) or calcium cyanamide over the ground just before the spring has given excellent results and helped to nip the disease in the bud by destroying the initial foci of infection.

Excellent control of "damping-off" of seedlings in tomato due to sp. of *Pythium* and *Fusarium* and of black root rot of tobacco *(Thielavia basicola)* has been obtained by the application, to infested soil, of chloropicrin vapour; this, however, has limited scope. Soil disinfection with such chemicals as Methyl bromide, *Killoptera*, *Iscobrome*, ethylyne compound, D-D, has been effectively practised in the control of root-knot diseases caused by nematodes. The chemicals are applied to the soil by means of injectors (Fig. 70). Application of sulphur dust (2–5 pounds) per tree round about the stem has secured good control of *Ganoderma* stem rot of Cocoanuts in Madras and root rot of grapes caused by *Rosselinia necatrix* in parts of Bombay.

FIG. 61. Control of " damping-off " of seedlings by soil application of chemicals. L : Semesan R : Formaldehyde.

SEED APPLICATIONS

This is probably, the best, effective and economic method of disease control and has been advocated as a regular and routine practice in crop protection work in recent times, against soil-borne and seed-borne pathogens; it is essentially a protective measure. Apparently simple and inexpensive in its application, it has achieved phenomenal results in controlling diseases, which otherwise are known to cause wide-spread damage and losses and indirectly stepping up food production, which, in India, has been estimated at 5–12%. The grain smut of *Sorghum* in India, is a typical example. The disease, which with individual farmers, is of minor importance, causes an estimated aggregate loss of Rs. 10,0000000 to the Indian exchequer. And yet this disease with such high potentialities has been effectively controlled by a remarkably simple and inexpensive method of seed-treatment with sulphur at a ridiculously low cost of half an anna per acre. The seed is treated and " dressed " with fine sulphur powder, *before* seeding, with 4 ounces of dust to 60 pounds of seed in a revolving drum.

A wide range of chemicals has been developed in recent years as seed dressers and are now available, as proprietory compounds, mercurial and non-mercurial in nature *Ceresan*, *Semesan*, *Uspulun*, *Germisan*, *Fernasone*, *Agrosan*, *Spergon*, *Phygon*, *Arasan* and a host of others are placed on the market, besides the usual copper sulphate, copper carbonate, *cuprocide*, *perenox*, formalin, and mercuric chloride These chemicals can be used either in solution or in dust form As a rule, the proprietory seed-dressers are used in dust form and being largely mercurial have not only given effective control of diseases but also a good stand by stimulating better germination and growth Mercurial compounds are, however, dangerous to handle, specially with uneducated farmers and must, therefore, be used and recommended with care In general, the dusts are used in the proportion of 2 to 3 ounces of the powder to 60 pounds (a bushel) of seed, a thorough coating or dressing is effected through the help of a revolving drum (Fig 62) In advanced countries, seed-dressing is carried out by state agencies co-operative seed farms and even by seed merchants for the control of seed-borne diseases like the smuts and bunts of cereals, the stripe of barley and wheat, the blackarm of cotton, the black rot of cabbage, the anthracnose of cotton and seedling blights of wheat and corn

Formalin in 1 to 40 gallons of water has given good control of black scurf and scab of potatoes, the treatment consists of steeping the infected tubers in the solution for three hours The chemical has also given good control of covered smut of oats and barley

Mercuric chloride has been effectively used to disinfect cabbage seed against the black rot organism, this is done by steeping the seed in the 1 1000 solution for 30 minutes, it is no doubt a powerful fungicide but must be used with care on account of its high toxic effects It is used in the laboratory for general disinfection work against table tops, glassware, culture chambers etc

Copper sulphate has been a universal chemical used since a long time in the treatment of seed against cereal smuts, it is a standard method employed in disinfection of seed, seed-stock and other vegetatively propagated parts like tubers and cuttings It is mainly used in solution Steeping of *Sorghum* grain in 2% solution for 15 minutes gives excellent control of the two seed-borne smuts The solution is also used for disinfection of utensils, pots, bins, sickles, knives etc used for experimental purpose or in cutting operations in diseased parts, it is liable to injure the seed and affect the stand, if not handled properly

Sulphur is mainly used as a dust and has become exceedingly popular in India as a seed-dresser for controlling seed-borne (external) smuts of *Sorghum*, replacing the cumbersome steeping method, on account of its low cost and safe handling, several brands are available in the market The efficiency of this chemical as a fungicide is determined by the fineness of its particles 200 to 300 mesh fine sulphur dust gives excellent control, is economical to use and has better adhesive properties In grain smut control, a proportion of 4 ounces to 60 pounds of seed has given excellent results (Uppal and Desai, 1931)

Copper carbonate has been a very popular fungicidal dust for seed treatment against bunts of wheat in the U S A and Australia Flag smut of wheat (*Urocystis tritici*) is also effectively controlled by seed dressing with this chemical, the proportion used is 2 ounces to a bushel of seed (60 lbs), the ingradient must be in very fine form to give good results, it is an expensive seed-dresser but does not affect the stand as in the case of copper sulphate

Proprietory compounds with various trade names are now available in the market and there is almost a bewildering range, they may be either mercurial or non-mercurial, the former are highly toxic and must be used with caution Some of these compounds not only act on the pathogen found on the surface of the seed, but are also known to improve germination and ultimate stand *Germisan*, *Ceresan*, *Uspulan*, *Agrosan Gn* are mercurial, while *Spergon*, *Vancide*, *Nomersan* (TMTD), *Phygon*, *Arasan* & *Fermate* are non-mercurials, the latter are safe to handle and could be recommended for general use even in under-developed countries The usual proportion is 2 to 3 ounces to 60 pounds of seed

The use of these compounds has become a routine practice in plant protection work both for disease control as well as improvement of stand Excellent control and stand have been obtained in cereals and vegetable against " damping off " and foot rots caused by sp of *Pythium*, *Fusarium*, *Rhizoctonia* and *Helminthosporium* These seed dressers are also effective in warding off the initial infection and inoculum in the control of black arm and anthracnose of cotton and blast of rice Treatment of flax seed with tetramethyl thiurum disulphide (TMTD) commercially known as " *Nomersan* " gives good control of the anthracnose disease Delinting of cotton seed and subsequent dressing with either *ceresan*, *perenox* or *agrosan Gr* is a wholesome practice in vogue in India, Sudan and the U S A in the control of cotton diseases, mainly black arm and anthracnose *Arasan* used in the proporiion of 1/10 lb to 1 pound of seed has given food control of the notorious Onion Smut, *Urocystis cepuleae*, in parts of U S A Recently, control of black rot of swede caused by *Xanthomonas campestris* has been secured in Canada by immersion of seed in the antibiotic *Aureomycin* (1 1000) for 30 minutes

Table 15

Common methods of seed treatment for some important seed-borne and seedling diseases

Disease	Fungicide	Nature of treatment	Dosage
Grain Smut of Sorghum Loose Smut of Sorghum	Sulpur 200 mesh fine	Dust	4 ozs 60 lbs of seed
Bunt of wheat Flag smut of wheat	*Ceresan* improved	Dust	¼ oz 60 lbs of seed
— Do —	Copper Carbonate	Dust	2 ozs 60 lbs of seed
Loose smut of wheat	Hot water or Solar heat	Soak or *expose to Sun*	See text
Seedling blight of wheat	*Nomersan*	Dust	3 ozs 60 lbs of seed
" Damping off " of vegetables	*Ceresan, Arasan, Phygon, Nomersan*	Dust	0 5 to 1 00 %
Onion Smut	*Arasan*	Dust	1/10 lb to 1 pound of seed
Angular leaf spot of Cotton	*Nomersan*	Delint & Dust	3 ozs 60 lbs of seed
Anthracnose of flax	*Nomersan*	Dust	" " "
Loose & Covered Smuts of Oats	*Ceresan* improved	Dust	½ oz. 60 lbs of seed
Covered smut of barley	" "	"	" " "
Black scurf of potatoes	Formaline	Soak	40 % for 3 hours
Black rot of Cabbage	Mercuric chloride	Soak	1–1000 for 30 minutes
Streak of Sugarcane	Hot water	Soak	52°C for 20 minutes
Loose & Covered Smut of Oats	Formaldehyde	Spray	1 1 spray on 300 lbs of seed
' Stunt ' disease of Sugar Cane	Hot water	Soak	50°C for 2 hours.
" " " "	*Hot air*	Exposure	*54°C for 8 hours*
Anthracnose of Cotton	Agrosan Gn	Dust	3 ozs 60 pounds of seed

In addition to the above chemical seed-dressers, **hot water** and **solar heat** have been used in certain seed-borne (internal) diseases, which are not amenable to chemical control, on account of the difficulty involved in reaching the internal mycelium Hot water treatment of seed was first devised by Jensen in 1887 for the control of loose smut of wheat and has been since improved upon to avoid injury to seed The seed to be treated, is initially soaked in cold water for 4 to 6 hours to activate the internal mycelium and subsequently immersed in hot water at 129°F (54°C) in a water bath for 10 minutes, the temperature is maintained throughout the period to avoid injury to seed, the treated seed-grain is then immersed in cold water and immediately dried to avoid mouldiness The process involves technical skill of a high order and is, therefore, undertaken by co-operative seed societies and state agencies, who distribute such treated seed to individual farmers The exact manner of this treatment is graphically depicted in Fig 63

In India, a simple substitute treatment has been devised (Luthra, 1934 & 1953) where the summer heat is utilised for disinfection, instead of the hot water The seed is presoaked in cold water for 4 to 6 hours and then spread over in thin layers on a sheet of plain galvanised iron during hot summer days from 1 to 3 p m when the usual out door temperatures are in the neighbourhood of 130°F (Fig 64) The seed is well dried in shade and stored with usual precautions for subsequent planting

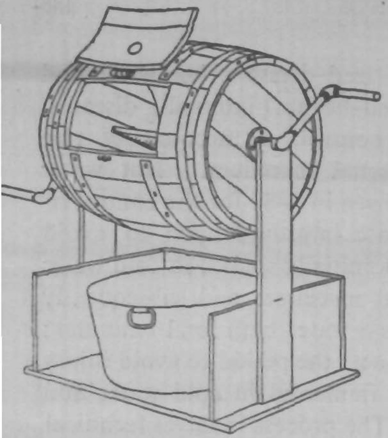
The hot water treatment has given good control in black rot of cabbage and streak of sugarcane The seed-pieces of sugarcane are immersed in hot water at 52°C for 20 minutes In the Bombay Deccan, a hot water treatment for 2 hours at 50°C has given good control of "stunt" disease of sugarcane of virus origin*, the remedy, however, is liable to become "worse than the disease" unless proper precautions are taken to maintain uniformity in temperature and time of treatment

Some of the common methods of seed treatment used in protecting crops from seed-borne and seedling diseases are given in Table 15

PLANT APPLICATIONS

In these measures, the applications are made at different stages of plant growth creating a thin uniform film of a fungicide on the surface so as to prevent the germination of spores and their infection – a purely protective method These methods are mainly useful in the control of air-borne diseases like the mildews, blights, anthracnoses, leafspots and rusts The applications are made by specially designed appliances such as sprayers and dusters to be described later Uniformity of

* Gumaste et al Proc Deccan Sugar Tech Asso India (1955)



IG. 62. A revolving drum used in seed treatment.

[After Durrell.

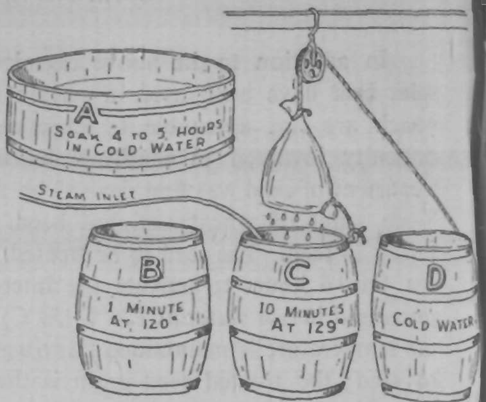
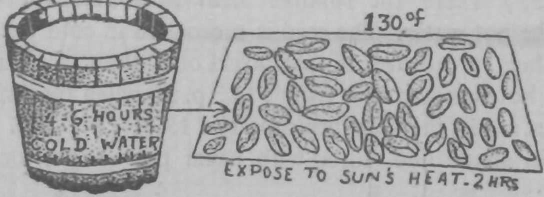


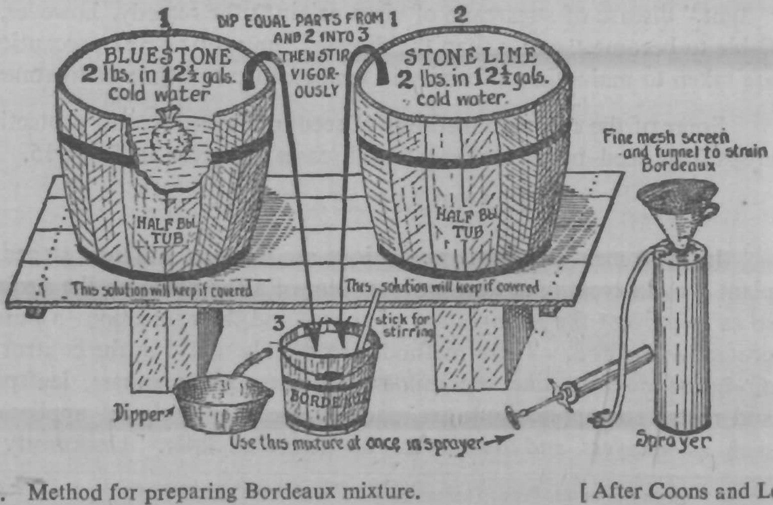
FIG. 63. A simple method of hot water treatment for control of loose smut of wheat.

[After Brentzel.



IG. 64. A simple method of solar heat treatment for control of loose smut of wheat.

[Drawing: Miss Kumud Lad.



IG. 65. Method for preparing Bordeaux mixture. [After Coons and Levine.

application, economical consumption of the fungicide and easy mode of operation are essential requisites for the success of the treatment effected through such appliances The general considerations governing such applications have been already discussed in the opening para of this chapter

Fungicides comprising copper, sulphur and lime have been used for many years in the control of plant diseases and have occupied a prominent place in the plant protection work The earliest use of copper was made by Prevost in 1807 and of sulphur by Robertson in 1821 These non-specific protective chemicals are now being substituted by organic compounds of high specificity, which, however, are not likely to find favour in under developed countries for reasons already discussed Some of the important and outstanding fungicides, their preparation and use will be briefly discussed

COPPER-CONTAINING FUNGICIDES

Bordeaux mixture —This is the best known fungicide in general use and has remained a standard preparation inspite of many substitutes The history of the discovery of this mixture by Millardet in 1882 is well-known and needs no repetition

Bordeaux mixture is prepared by mixing copper sulphate solution with solution of either stonelime or hydrated lime in definite proportions The two solutions are prepared separately in wooden or earthern utensils (to avoid corroding) and the dilute copper sulphate solution is *slowly* poured into a concentrated lime mixture in a third tub provided with constant agitation, the resulting mixture is neutral or slightly alkaline and has no injurious phytocidal properties This mixture is used almost immediately it is prepared and deteriorates on standing In such a case, stock solutions of the two ingradients can be prepared and mixed together in the requisite proportions whenever required (Fig 65)

Bordeaux mixture is used in various concentrations, depending upon the nature of the pathogen, the nature of plants and plant parts and stages of the host, while higher concentrations are useful in woody, tough and mature tissues, lower concentrations give good results with succulent, growing tissues, at blossoming stages and on young berries and fruits, as they avoid spray-injury 5-5-50 is the standard formula, consisting of

Copper sulphate (blue stone)	5 lbs
Stone or hydrated lime	5 lbs
Water	50 Gallons

This is a 1% mixture and can be modified to suit each case While ordinarily, this mixture is quite effective and has good adhesive properties in dry seasons, addition of certain adhesives or spreaders is quite desirable in wet seasons and during monsoons, to avoid washing of the spray Casein, Rosin and fatty oils are used for the purpose Recently a tendency to increase the proportion of lime has developed for spraying fruits aginst scab and brown rot attack with the main purpose of avoiding spray injury

While this mixture has remained unrivalled as a fungicide, it suffers from a few draw-backs It is cumbersome to prepare, deteriorates on standing and stains the fruit making them ugly and unmarketable, the latter defect makes it unserviceable for use in ornamental plants

Bordeaux mixture is a specific against Downy mildews, Late blight of potatoes, *Koleroga* of arecanuts, Coffee rust, leaf spots, blights and anthracnoses It has remained as a standard fungicide against downy mildew of grapes and hop, since its inception in 1882 This mixture, in addition to its fungicidal properties, has stimulating effect on the foliage and growth of the sprayed plants and prevents defoliation The fungicidal action of this mixture is due to the liberation of free copper, which, in the presence of dew and water, is toxic to the spores that lodge on the host surface.

The details about the actual spray-programme followed in each specific case may be obtained from standard books dealing with such diseases While one application is enough to control the *Koleroga* (*Phytophthora arecea*) of areca palm in southern parts of India, three are required for controlling the downy mildew of grapes, four for downy mildew of hop and two each for late blight of potatoes and coffee rust In Bihar (India) 1–2 applications of this fungicide or its substitutes like *perenox* or *dithane* give good control of leaf spot of potato caused by sp of *Cercospora* *Time is the essence of the treatment*, which if not strictly observed may end in disaster Since environment plays an important role and determines infection and progress of a parasitic disease, the spray programme has to be adjusted to suit the changing weather and seasonal conditions

Burgundy mixture, sometimes known as Soda-Bordeaux mixture, has been a popular fungicide as a substitute for the standard Bordeaux mixture and is widely used in spraying fruits and ornamentals to avoid staining Its use against anthracnose of fruits of banana and papaya (Sp of *Collectotrichum* and *Gloeosporium*) has given good control in Bombay The formula is

Copper sulphate	4 lbs
Sodium carbonate	5 lbs
Water	50 gallons

The mixture is a little expensive but is easy of preparation and specially suitable in tracts where fresh stone lime is difficult of procurement and storage

Ammoniacal solution of **copper carbonate, copperlime dust, cuprous oxide** *Agricop*, *Fungicopper*, Copper acetate and colloidal copper known as "*Bouisol*" and *Dithane* are other preparations used as substitutes for Bordeaux mixture and have given good control in specific cases but are not of general application

SULPHUR-CONTAINING FUNGICIDES

Sulphur was used for the first time as a fungicide by Robertson in 1821 and in England for the control of powdery mildew of vine as early as 1846 It has now become a universally accepted fungicide alone or in combination for the control of powdery mildew, scab of apples and brown rot of fruits in the form of dust as well as solution The effectiveness of sulphur as a fungicide is determined by the fineness of its particles, 200-300 mesh fine brand being excellent for the purpose

Several brands of sulphur are available in the market-ground sulphur, sublimed sulphur, precipitated sulphur and commercial brands of various combinations *Kolodust* is a proprietory compound and has high fungicidal properties Sulphur dust is sometimes mixed with a "filler" consisting of gypsum, talc and even lime to reduce its injurious effect on foliage and berries Dusting sulphurs of 300 mesh fineness are now available in the market and have powerful fungicidal effects, besides being ecomomical to use

Sulphur dust is applied to the plants by means of specially designed dusting machines, of which there are many in the market, a very thin and uniform covering is made, which acts as a chemical barrier against the surface pathogens Sulphur has a tendency to "cake" and this is prevented by the provision of a "stirrer" in the hopper of the machine Sulphur "acts at a distance" and being volatile, readily acts as a fungicide by the formation of either sulphur dioxide (SO_2) or hydrogen sulphide (H_2S) in the presence of atmospheric oxygen This action is slow and accounts for the long residual effect shown by the fungicide

Sulphur is effective against powdery mildews, it is extensively used all over the world for powdery mildew of rubber in the East Indies and Ceylon, of grapes, mango, cumin, peas, *beetle leaf*, rose, *hibiscus*, gooseberry and many other vegetables in the U S A , Europe, Australia, America, India and other countries

The actual dusting programme varies with the crop and the seasonal conditions The number of applications is 3 to 5 in grapes, 2 to 3 in mango and 1 each in peas, cumin and *beetle leaf*. The quantity required for effective control is 75 lbs. in grapes, 25 pounds for peas, cumin and beetle leaf per acre, two pounds per tree in the case of mango and 20 pounds per 100 bushes in the case of gooseberry. A method known as "ground-dusting" has been developed in South India for the control of powdery mildew of tobacco, when sulphur dust is applied at the base of the plant at the rate of 40 lbs. per acre; this is done to avoid damage to the aroma of the leaves and "acting at a distance" is effective in preventing mildew (Mathrani et al, 1955).

Sulphur dusting is a more economical operation than spraying bordeaux mixture; it has however its own limitations; the dusting is ineffective in humid weather and in rainy season.

Sulphur dust has been recently used to control stem rust of wheat in the U. S. A. and Canada through the help of helicopters (aeroplane-dusting) (Fig. 66); one application of 30 pounds per acre is given at blossoming time, which is critical for the rust infection. It is a good

FIG. 66. Aeroplane dusting by helicopters.

[Courtesy : New England Craberry Sales Co.

remedy in experimental areas and nursery plots for protecting valuable cultures from the rust attack; excellent results have been obtained by this method in highly susceptible varieties at the rust experimental plots at Mahableshwar in Bombay; the method, however, is not a practical proposition on a field scale owing to the narrow margins of profits left behind.

Lime-sulphur solution:-This is a concentrated solution and is made by combining lime with sulphur in the following proportions:

Sulphur (flowers)	2 pounds
Stone lime	1 pound
Water	1 gallon

The stone lime is slowly slaked and kept boiling in water, the sulphur is made up into a thin paste and then added slowly to the boiling lime solution, the boiling process is continued for 45 minutes until a deep amber coloured product is attained, the specific gravity of the mixture should be about 27–30 Baume, the concentrated mixture is stored in stoppered bottles for future use and should be diluted with from 40 to 90 parts of water before application

This fungicide is finding more favour in spraying programmes in orchards, fruit trees and ornamentals It is also a good remedy in combined infections of fungi and insects It is being widely used in the control of mite infections in potatoes, chillies and citrus in India and in scab and brown rot of apples and pears in Europe and U S A The apple mildew (*Podosphaera leucotricha*) is effectively controlled in America by 5-8 applications of this fungicide, the pure sulphur treatment is found to injure the foliage

Lime–sulphur dust – This is a dry preparation and used in the dust form and is convenient in dry seasons The proportion used is equal parts of the ingredients, it is, however, not as effective as the solution, the rate per acre is 25–30 pounds

Many substitutes are available in the market, under various trade names " Wettable " sulphur, floatation sulphur, *sulsol*, *sulfinette*, *ultra-Sulphur* are a few examples and have been claimed to give good results as substitutes in place of commercial lime-sulphur and Bordeaux mixture Some of these compounds, however, must be used with care, as some plants are "Sulphur-sensitive" Plants like apple, cotton, fig, tobacco and cucurbits are known to be damaged by sulphur and its combinations

Sulphur–DDT–Dust – This is a combination fungicide and has been found to give excellent control of the combined infection of *oidium* and hoppers (*Ideocerus* sp) in mango in peninsular India It is prepared by mixing 20 parts of 50% D D T with 80 parts of finely ground sulphur A ready made compound commercially known as *Guesarol* combining sulphur and D D T has been effectively used in place of the above dust

WOUND APPLICATIONS

Prunning is a common practice in orchards and tea and rubber culture, and in forest areas where such wounded surfaces are required to be protected with a disinfectant to prevent infection by wound-parasites The protection of wooden posts and rafters used in railway tracts, agricultural estates and road sides, from the attack of fleshy fungi and white ants has become an urgent and pressing problem

Excellent protection is afforded by the application of **coaltar** and its bye-products, **creosote** oil and **carbolic acid** to the wounded surface as these are highly impregnable and constitute good barriers against microbial activities. In India and the U. S. A. these products are being extensively used for disinfection of gum-wounds caused by infection of *Phytophthora palmivora* and *P. citrophthora.*

Zinc chloride, Zinc sulphate, Cynide of mercury, Bordeaux paste and many other disinfectants and "wound dressers" have been recently developed for use in such instances. Soft **grafting wax** and **lead paint** are used in fruit plantations to cover the wounds caused by prunning.

The manufacture of various types of "wood preservations" for protecting timber, logs of wood, railway posts and rafters, fencing posts and the like from invasion by micro-organisms has developed into an important and flourishing industry in the U. S. A. and millions of dollars are being spent annually in such work.

CONTROL OF STORAGE DISEASES

Fruits, tubers, bulbs and other vegetative parts are subject to various types of infections by pathogenic as well as saprophytic micro-organisms in storage and in transit. *Rhizopus, Aspergillus, Fusarium, Rhizoctonia,* bacteria, *Colletotrichum, Botrytis, Gloeosporium* and *Cladosporium* are a few such organisms that attack such stock. The ripe rots, dry and wet rots, the blue mould, black-heart, neck-rots are some of the storage diseases, so caused.

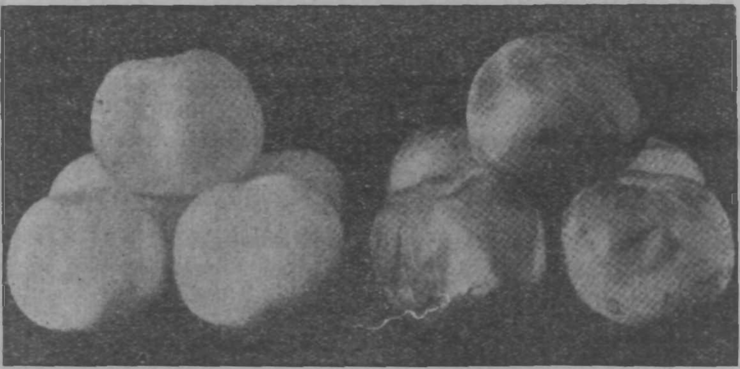


FIG. 67. Control of apple scald in storage by oil wrappers.
L : Wrapped. R : Exposed.

[Courtesy : Bureau Pl. Ind. U. S. Dept Agri.

While prophylactic methods consisting of general sanitary measures, disinfection of storage places, cold storage, thorough drying of grain and bulbs, rigorours selection of sound fruits etc. are essential, special methods for disinfecting plant stock and fruits have been devised for tackling the growing problem of transit losses **Bleaching powder, Sodium bicarbonate, Calcium hypochloride, Borax, Nitrogen trichloride, Potassium metasulphide** are variously used as fruit washes, gas-disinfectants or dressers The use of wrappers previously impregnated with diphenyl has been also recommended for the purpose [Fig 67] Treatment of fruit with 8–10% solution of borax as a fruit wash has given excellent protection to citrus fruits against blue moulds Potassium metasulphide is mixed with the packing dust used in transit of grapes against *Penicillium* and *Botrytis* mould (Brooks, 1939) Painting of stalk-ends with copper sulphate paste or benzoic acid has been effective in reducing stem-end rots of water-melons and black rot of pine apples respectively in transit

CONTROL OF INSECT-BORNE DISEASES

Virus diseases of plants are mainly insect-borne, in the sense that many, infact, most of them, are transmitted in nature through the help of sucking insects In such cases, therefore, fungicides have no place in a control programme Instead, insecticides are likely to afford protection to plants against such insect "Vectors' In practice, however, insecticides have failed to afford the desired relief, as the "vectors" persist on weed and other collateral hosts, besides the main crop, and are thus difficult to reach, besides such a method, though effective, involves high costs and therefore is prohibitive This method, however, can be practised with success, in green house studies, in experimental areas and for disinfection of virus and glass houses and, therefore, has limited application

BIOLOGICAL CONTROL

This mode of attack is becoming more common in the control of insect pests and is being extensively experimented upon Many entomogenous fungi have been used in such trials with some success (Dresner 1949) It is known that in nature fungi causing powdery mildews, rusts and ergot are parasitized by other fungi (hyperparasites) like Sp of *Darluca* and *Cerebella*, the practical applications of such methods, on a field scale, however, are problematical The control of root rot of tea caused by *Armillaria melea* has been attempted by the use of Sp of *Lasidiplodia* in Nysiland Remarkable control of *Rhizoctonia* damping-off of sugar beets has been recently obtained through the addition of live cultures of *Bacillus subtilis* to the infected soil, in the U S A (Dunleavy, 1952) In Hawaii, control of root-knot nematode of pineapple has been secured by the application to the infested soil of pineapple refuge at the rate of 100 to 150 tons per acre The application of the organic matter favours the growth and development of the nematode trapping fungus, *Dactylella bembicoides*, which kills the soil-nematodes and thus makes the infested land safe for further cropping (Fig 10) A very recent example of insect control by biological method is provided in the canal areas of Bombay in sugarcane The leaf-hopper *(Pyrilla* Sp) which causes great damage to this crop, has been controlled both in experimental areas as well as field scale by spraying a spore suspension of the *muscardine* fungus, Sp of *Materrhizium* (Kamat et al, 1952), this method has been also successfully employed in the control of frog hoppers in sugarcane in the West Indies Insect control by the use of fungi has been attempted in many cases (Fawcett 1944 Dressner, 1949)

SPRAYING AND DUSTING APPLIANCES

These appliances are designed and modelled in different mechanisms and are very useful in the application of fungicides, insecticides, and weedicides to the growing plants the soil and storage place for protection against diseases, pests and obnoxious weeds A great variety of these appliances are now available in the market These appliances enable the operator to make these applications economic, thorough, rapid and effective through the mistlike sprays or clouds given out by these machines

Sprayers are used for application of liquids and dusters for dry powders The hand machines of the type of knapsack, holder, pressure and bucket pumps are mainly useful on small scale basis and are being extensively used in areas where labour is cheap and easily available (Fig 68) In big orchards and large scale estates, such machines have no place Instead, power driven machines are used and have been found to be economical and give satisfactory results The latter type are now in common use in the U S A, Russia and other countries, where large scale applications are required , they are used both for applications to low as well as high crops and have been employed in orchards and forest areas The spray nozzle is an important part of the equipment and enables the operator to deliver the liquid in fine mist-like form with uniform coverage and economy Aeroplane dusting has been resorted to in the U S A and Canada for dusting wheat belt and forest areas with sulphur and other insecticides for control of stem rust insect pest and in desert areas of India and Pakistan for control of locusts (Fig 66)

The dusting machines are of three types, bellows, crank (Centrifugal) and power Crank type hand machines have been very popular all over the world where small scale operations are needed (Fig 69, 2 & 3) Bellow types (Fig 69, 4) have become obsolete, are not efficient and do not give good " coverage "

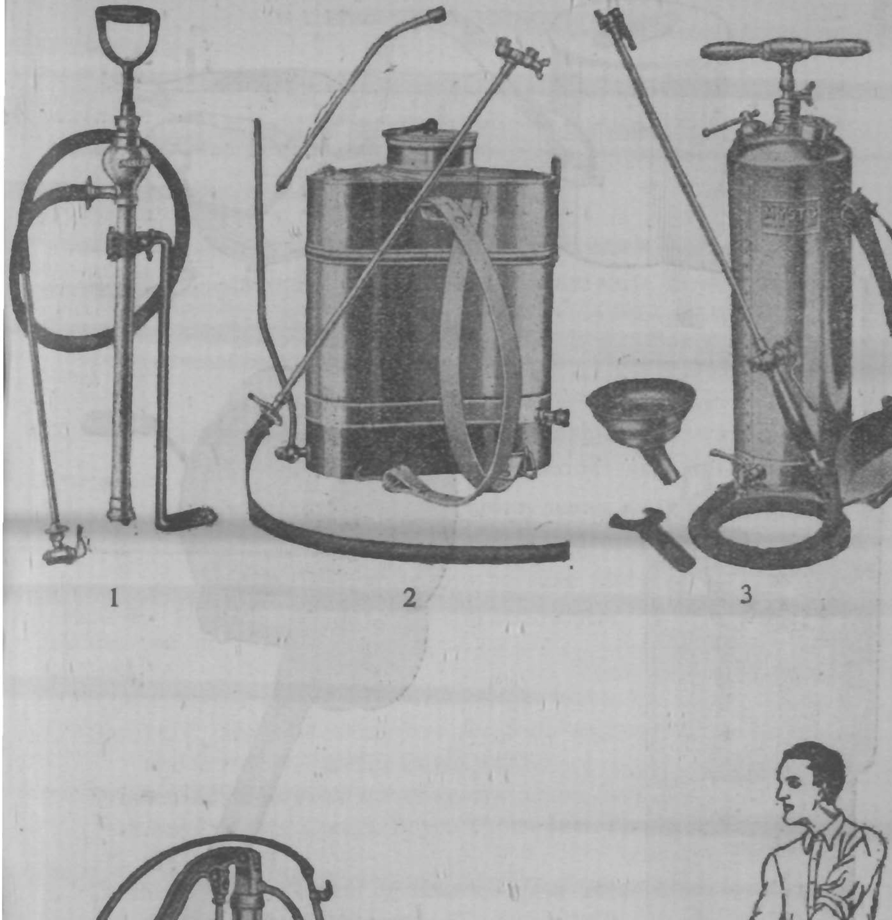


FIG. 68. Sprayers, various types.

1. Bucket. 2. Knapsack. 3. Pressure. 4. Barrel. 5. Hyject.

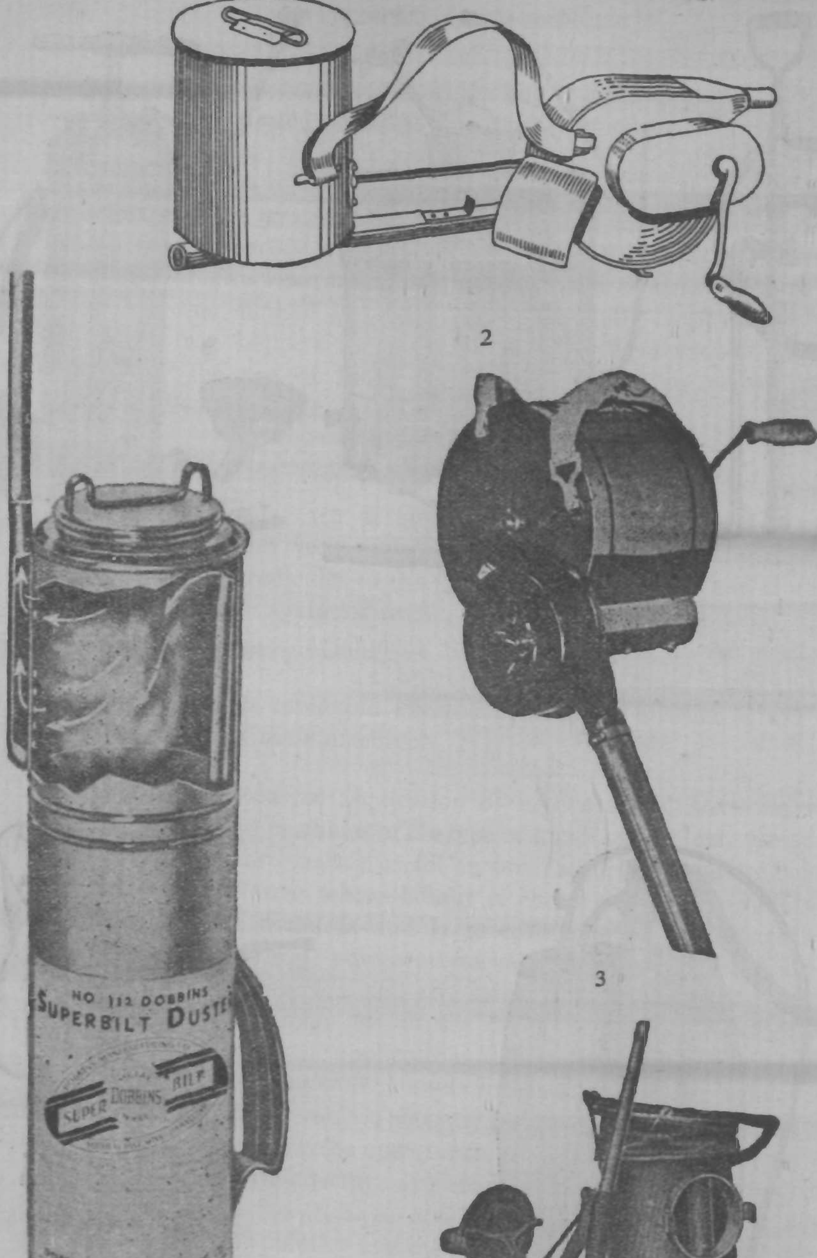


FIG. 69. Dusters, various types.
1. Hand. 2. Dust-gun. 3. Roots. 4. Bellows.

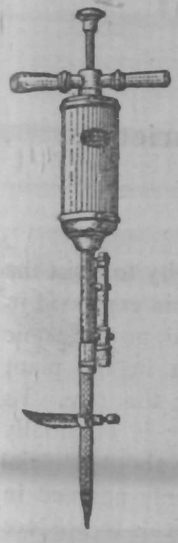


FIG. 70. Soil Injector used in soil fumigation.

Special types of pumps known as "Soil-injectors" have been devised for fumigating soils in the control of root-knot organism (Fig. 70).

Spraying is an effective operation against most endophytic diseases like blights, rusts, downy mildews and late blight of potatoes, as the liquids have a long residual effect as compared to dusting dry powders. The operation, however, is cumbersome and labour-consuming. In certain ectophytic diseases like powdery mildews, mite infections and pests, dusting has given effective control being more rapid, easy of operation and economic. Dusting, however, has a limited scope being possible and effective only in dry seasons and in still atmosphere.

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CHAPTER 19

Development of disease-resistant varieties of crop plants.

Plants show a wide variation in their natural ability to resist the onslaught of disease; such an ability is inherent and is expressed in the form of morphological, structural, functional and protoplasmic peculiarities. Disease-resistance commonly met with in the plant kingdom is relative in nature, total immunity being too rare. Its hereditary transmission from parent to off-spring is essentially "Mendelian", but often polygenic. Attempts to bring about artificial immunity to diseases in plants by the therapy commonly adopted in animals with serum, vaccination, inoculation and chemicals to produce antibodies, have been of limited avail (Stoddard, 1949). This appears to be largely due to the differences in their anatomical structures and the absence of a definite and body-wide circulatory system. Temporary resistance is, no doubt, offered by plants to penetration and infection by micro-organisms, more specially viruses, but definite proof of antibodies having been involved in such a phenomenon is not forthcoming. The well-known example of such acquired immunity is provided by tobacco plants infected with ring spot virus which "recover" but still harbour the virus within and act as foci of infection even as the notorious "Typhoid Mary" did for the typhoid fever. As in animals and man, the immunity is specific and directed against the particular infection and none else (Fig. 71).

FIG. 71. Recovery of tobacco plant from the ring spot virus.

Lower: Diseased, Upper: healthy.

[After Price W. C.

Another interesting example of aquired immunity by "pre-inoculation" is furnished by plants of *Nicotiana sylvestris* inoculated by tobacco mosaic virus, which consequently, developed immunity to subsequent infection of aucuba mosaic virus (Fig. 72). At best, such a therapy can be practised in individual plants but is not practicable as a measure of crop protection on a field scale.

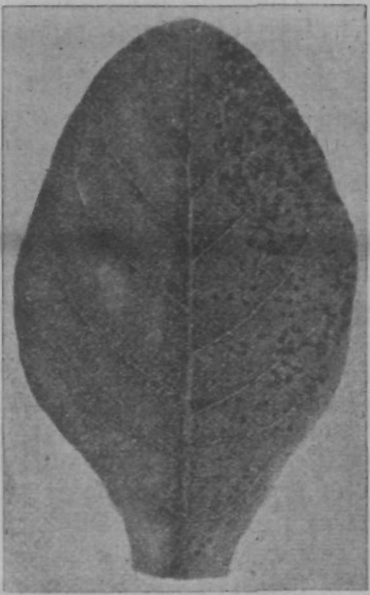

FIG. 72 Premunization of tobacco leaf against Aucuba mosaic virus.
L : treated, R : Non-treated
[After Kunkel, L. O.

Apparent resistance in plants could either be environmental e. g. (*Disease - escape*) and (*Disease-endurance*) or hereditary e. g. morphological, structural, functional or protoplasmic (*True resistance*); while the first two types are of a casual nature and variable, true resistance is inheritable and has therefore been taken advantage of in the development of disease-resistant varieties of crop plants. This line of work has achieved phenomenal success as a major item in the control programme in recent years.

Biffen (1905) in England was the first to recognise the importance of such measures in his breeding work for rust-resistance in cereals. Orton (1909) followed in the U. S. A. on similar lines and succeeded in developing wilt-resistant varieties of cotton, cowpea, watermelon and other farm crops. Voluminous literature has since been developed in this subject, which has made rapid strides and has been recognised as one of the best and effective methods of tackling the disease problem in plants. The programme of development of disease-resistant plants has, by its nature, to be a long term one and involves high technical skill and an intimate knowledge of the sciences of plant pathology, plant breeding and genetics. The programme has its own limitations and is operated through State agencies, co-operative societies and scientific organizations, who can command highly technical staff and a big finance; it is generally beyond the scope of individual farmers.

Control of plant diseases through resistance need to be adopted only in certain specific categories of diseases, which cannot usually be controlled by other easier means discussed in the preceding chapters or where ordinary control measures are prohibitive in cost. The well-known diseases, which deserve to be tackled by such methods are wilts and root rots, rusts of cereals, red rot of sugarcane and blast of rice, stripe diseases, blights etc. It would be inadvisible, for instance, to operate such a programme in the control of smuts of *Sorghum*, mildews of orchards and fruit crops, which are amenable to protective measures like seed-treatment, spraying and dusting. Besides, the cost, labour and difficulties involved in such a long term programme would not "pay".

NATURE OF DISEASE-RESISTANCE IN PLANTS

Disease-escape, disease-endurance and true resistance are the three categories encountered in plants. These categories are, however, not rigid and are capable of being modified to some extent by both internal and external factors. Environment plays a prominent role in this respect.

Disease escape:— Plants may "escape" disease due to factors other than resistance which are inherent in the plants themselves or to various environmental or seasonal variations. Early maturing varieties of groundnut escape "*Tikka*" infection (*Cercospora arachidicola*); early varieties of wheat are also known to escape rust and loose smut infection. A change in planting season has also been successfully employed as a measure of securing escape; the leaf rust of sugarcane (*Puccinia sacchari*) in the canal areas of Bombay severely affects cane when planted in June, but is of minor importance or absent in crops, sown in October; similar is the case with *Piricularia oryzea*, affecting the ragi crop (*Eleusine coracana*) in parts of Madras, where an effective control of the blast has been obtained by sowing the crops in October instead of in June. In soil-borne diseases like root rots and wilts where soil-temperature at growing periods determines the severity of infection, variation of a few weeks in sowing time may make a great

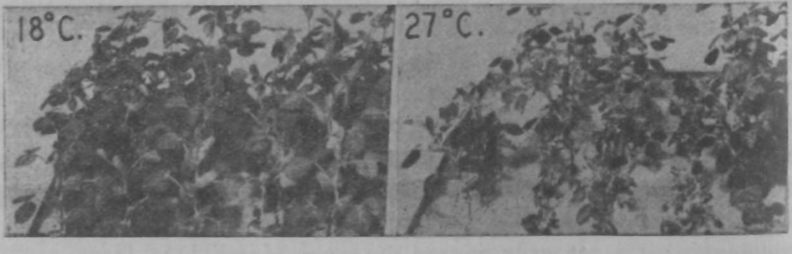

FIG. 72 a. Influence of soil-temperatures on wilt-resistance in highly susceptible variety of peas under artificial infection.
L: Disease escape at low temperature (18°c); R: High infection at 27°C

[After Wells, D. G. et al.

difference in the ultimate clinical picture of the diseases, as in *Fusarium* wilts of cotton in Bombay, flax in Punjab and peas in U S A, where soil-temperatures at sowing time play an important role in determining severity of disease At low soil temperatures (18-20°C), even highly susceptible varieties show high degree of resistance, a typical example of disease-escape (Fig 72 a) A change in the actual method of cultivation also enables plants to "escape" disease Transplanted onion seedlings, for instance, escape the smut infection (*Urocystis cepulae*) but not the seeded fields in the U S A High-budded lemons and *mosambies* are known to escape infection by the gummosis fungi and so do the lemon fruits higher up on the tree, escape brown rot infection more successfully than those on the lower branches A very interesting case of "disease escape" has been recently recorded in the Bombay State in respect of yellow mosaic of *Dolichos lablab*[1] A selection of this legume was found to be consistently "resistant" to the virus under field tests, but succumbed miserably under artificial infection carried out through the ' vector" in the green house This apparent "resistance" was ultimately traced to the deterrent action exerted by the legume on the vector brought about as a result of the highly glabrous and hairy nature of the host The "resistance" was phenotypic, not determined by any gene complex and thus not inheritable

In all these cases, the resistance exhibited is of the nature of "disease escape" and therefore unreal, since these plants, if exposed to artificial infection under controlled conditions, might show high degree of susceptibility to these diseases All the same, disease-control based on such methods, should not be lost sight of, since it is one of the simplest and the most economic methods of control

Disease endurance—This is brought about by influence of external factors It is a well-known phenomenon that plants fertilized with phosphatic and potash manures are more tolerant to disease, this is the case in wheat against rust infection Rice crops fertilized by silicates are "resistant' to blast (*Piricularia oryzae*) in Japan Wheat crops fertilized by potash and phosphatic manures are highly tolerant to mildew and rust infection The fertilizers, in such cases, act indirectly to arrest vegetative growth and promote early maturity, better straw and strengthening tissues which form a bulwark against pathogenic invasion The Niphad 4 variety of wheat is highly tolerant of black stem rust on account of its being early to mature in addition to its possessing the low resistance of one of its ancestors "*Khapli*' Several varieties of rice when tested for blast (*Piricularia oryzae*) have been found to tolerate infection remarkably (Fig 73) Such phenomenon thus offers a good field of investigation and a comparatively easier method of control of diseases

1 Curr Sci, **19**, p 248 1950

FIG. 73. Relative resistance of rice varieties to blast, under artificial infection. 1-3 : Highly tolerant; 4 : Highly susceptible; 5-7 : Highly resistant.

[Courtesy : Bombay Dept. Agri.

THE BASIS OF RESISTANCE

True resistance is inheritable and much less subject to environmental influence. It is *specific* in character. The basis of resistance may be either **morphological, functional, structural** or **protoplasmic.**

Morphological characters determining such resistance include nature and thickness of cuticle, skin, cell membranes, bloom, hairs and waxes (Fig. 74).

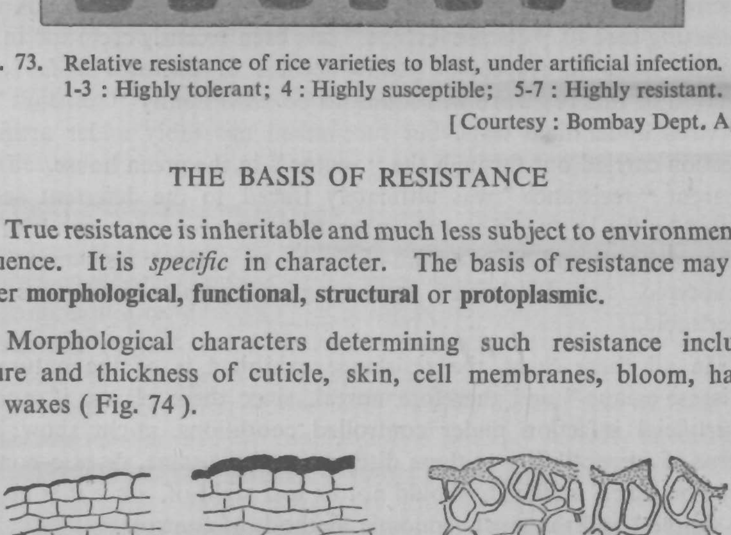

FIG. 74. Morphological resistance to disease in plants due to thickness of cuticle (1) and nature of stomata; (2) S : Susceptible, R: Resistant.

[After 1 Ainsworth, 2 Mclean.

Functional nature of resistance is determined by opening of the stomata, time of opening of flowers and time of maturity, rate of cork formation and cambial activity.

Structural characters include the proportion of strengthening tissues, fibre content, nature of middle lamella, corky layers, number and structure of stomata and lenticels and their sizes (Fig. 75).

Protoplasmic factors controlling resistance are related to cell contents, and include acids, tanins, anthocyanins, chemical constituents and their proportion, antibiotic activity and hypersensitivity present in the plant cells and in addition, biological antagonism of the protoplasm of the host and the pathogen (Fig. 76).

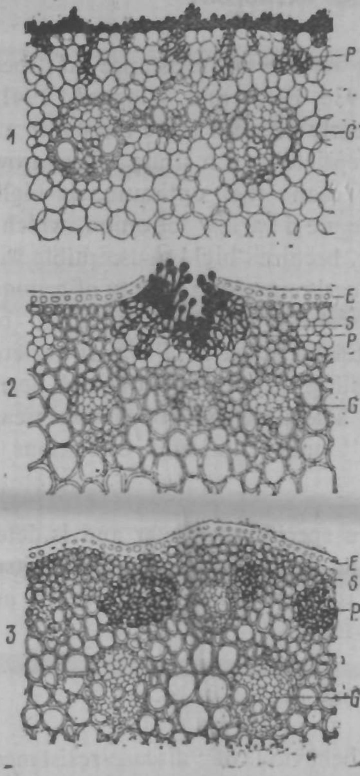

FIG. 75. Structural resistance to stem rust in wheat due to sclerenchyma tissue. 1. Highly susceptible, 2. Moderately resistant, 3. Highly resistant, E. Epidermis P. Parenchyma, S. Sclerenchyma, G. Vascular bundles. [After Hurch.

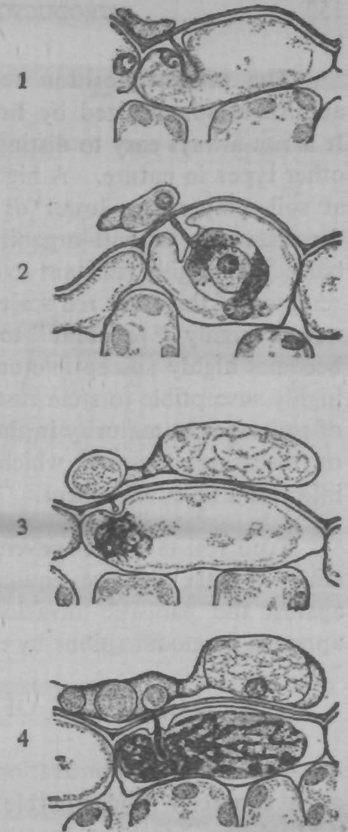

FIG. 76. Protoplasmic resistance to powdery mildew in red clover. 1 & 2 Upper, Susceptible, 3 & 4 Lower, Resistant. Note abortive haustoria in latter. [After Smith, O. F.

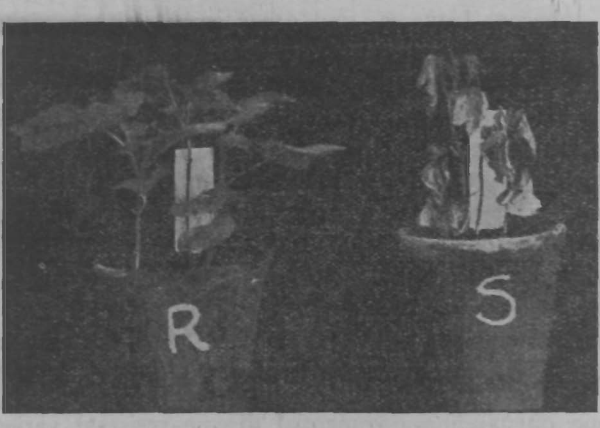

FIG. 77. Resistant (R) and Susceptible (S) varieties of cotton growing in wilt-sick soil in pot tests. [Courtesy : Kulkarni Y. S.

The present position regarding nature of resistance has been admirably summarized by Brown (1936, 1948) and Wingard (1941) It is not always easy to distinguish clearly between true resistance and other types in nature A highly susceptible cotton strain when grown at soil-temperature lower or higher than the optimum, is highly "resistant" to wilt-organism, the red variety of onion, which is considered highly resistant to smudge, becomes highly susceptible with removal of the outer red scale The early maturing variety of groundnut is highly "resistant' to *Cercospora arachidicola* in nature but becomes highly susceptible under artificial infection Wheat varieties highly susceptible to stem rust in seedling stage may show high degree of resistance at maturity in the field These are cases of disease-escape or disease-endurance, which "fail" under optimum conditions of infection and environment

True resistance, however, is of a specific character and is determined by the defence equipment and activities of the plant itself against the parasitic invasion and is therefore not subject to any appreciable modifications by external factors

GENETICS OF DISEASE-RESISTANCE

The earliest demonstration of the behaviour of "disease resistance" as a character transmissible from parent to off-spring in the "**Mendelian**" fashion, was given by Biffen (1905) in his work on yellow rust of wheat Since then, intensive work has been done on this aspect which has proved the value of applying genetical principles in developing disease-resistant varieties of plants for effective control of diseases

Much useful work has been done in cereals, vegetable crops, cotton, tobacco, legumes, and other crops, with a view to obtain resistant varieties against such parasitic diseases as *Fusarium* wilts, root rots, blast, mildews, late blight, rusts, chaff, smuts, bunts, stripes, and even viruses Outstanding attainments in this direction include wilt-resistant varieties of cotton, cowpea, water-melon, *lathyrus*, tobacco, tomato, brinjals, peas and flax, anthracnose-resistant beans, club-root-resistant crucifers, and late blight-resistant potato, "yellows"-resistant cabbage, virus-resistant beans, mosaic-resistant sugarcanes, wart-resistant potatoes, rust-resistant asparagus, blast-resistant rice red rot-resistant sugarcanes, mold-resistant tomatoes, blight-resistant *gram*, curly top-resistant beets, rust-resistant cereals and many others, too numerous to mention

Some outstanding commercial disease-resistant varieties of crop plants together with the locality of their origin are given below —

Table 16

Some important commercial disease-resistant varieties of crop plants *

Sr No	Crop	Disease	Resistant varieties	Locality of origin
1	Watermelon	Wilt (*Fusarium oxysporum f nivum*)	"Conqueror", Eden	South U S A
	—do—	Anthracnose (*Colletotrichum lagenarium*)	Congo	—do—
2	Cotton	Wilt (*F oxysporum f vasinfectum*)	Dilon, Dixie, River	South U S A
3	Cotton	— do —	*Jayawant*, *Jayadhar*,	Bombay Karnatak
4	Cotton	— do —	*Virnar*	Bombay Khandesh
5	Cotton	— do —	*Digvijay*, *Vijay*	Bombay Gujarat
6	Lathyrus	Wilt (*F orthacerus* var *lathyri*)	Indore–T–12	Bombay Gujarat
7	Rice	Blast (*Piricularia oryzae*)	Co varieties	Madras, India
8	Sugarcane	Red Rot (*Colletotrichum falcatum*)	P O J and Co 475, Co 419	Bombay & U S A
9	Sugarcane	Mosaic (virus)	P O J	South U S A
10	Wheat	Stem rust (*Puccinia tritici*)	*Kenphad* Khapli	Bombay, India
11	Wheat	— do —	Ceres, Thatcher, Hope, Lee	North U S A
12	Wheat	— do —	Marquis, Regent, Gaza	Canada
13	Wheat	— do —	Kenya, Hofed	Australia
14	Oats	Crow rust (*P coronata*)	Victoria, Bond, Clintafe	(Iowa) U S A
15	Cow pea	Wilt and Nematodes	Iron	U S A
16	Flax (Linseed)	{ Wilt (*Fusarium lini*) { Rust (*M lini*)	Bison, Newland	U S A
17	—do—	— do —	P 174, 186, 189	Punjab, India
18	Gram	Blight (*Ascochyta rabiei*)	C–12–34	Punjab, India
19	Cabbage	Yellows (*F oxysporum f conglutinans*)	Hollander, All seasons	Wisconsin, U S A
20	Beans	Mosaic–Virus	Robust, Refugee	E U S A

Table 16 *(Contd)*

Sr No	Crop	Disease	Resistant varieties	Locality of origin
21	Beans	Rust (*Uromyces appendiculatus*)	Bonita, Criolla	U S A
22	Beans	Anthracnose (*Colletotrichum lindemuthianum*)	White marrow, Clipper	E U S A, Canada
23	Potatoes	Late Blight (*Phytophthora infestans*)	Katahdin, Chippawa, Empire	E U S A
24	Pea	Wilt (*Fusarium pisi*) and mosaic	New era	Wisconsin, U S A
25	Sugarbeet	Curly top – virus and downy mildew	U S 1, U S 15	U S A
	—do—	Leaf spot – (*Cercospora beticola*)	U S 216	U S A
26	Tomato	Wilt (*Fusarium oxysporum f lycopersici*)	Pan America, Tippecanoe	E U S A
27	Tomato	Mold (*Cladosporium fulvum*)	Vetomold, Globe	E U S A
28	Oats	Stem rust (*P graminis avenae*)	Hajira	E U S A
29	Asparagus	Rust (*Puccinia asparagi*)	Mary Washington, Martha Washington	E U S A
30	Banana	Wilt (*F oxysporum f cubense*)	*Basrai*	Bombay, India
31	Sorghum	Smut (*Sphacelotheca sorghi*)	Milo, Feterita, Reed, Red	U S A
32	Sorghum	Smut (*Sphacelotheca cruenta*)	Milo, Feterita, Reed, Red	Unsuitable as commercial varieties
33	Sorghum	*Striga lutea*	Bonganhilo	E Africa
34	Sann hemp	Wilt (*F vasinfectum*)	D IX	Bombay, India
35	Cucumber	Mosaic–virus	Pickling, Niagara	U S A
36	Chillies	Mosaic–virus	Puerto Rico, Perfection	U S A
37	Egg plant	Wilt–?	Puerto Rican Beauty, Rosita	U S A

• Partly compiled from U S D A Plant Disease Year Book, 1953

The results obtained in respect of the inheritance of this character of resistance and its factorial basis, are, however, not uniform and show varying behaviour While resistance is a dominant character in some crosses, it is recessive in others The factorial basis also differs Resistance is sometimes governed by a few genes and at other times by polygenes Many instances, however, of a straight simple inheritance governed by a mono-hybrid ratio have been on record and provide hope and stimulus for more extensive work on this aspect of disease control

Resistance to one disease is seldom synonymous with resistance to another disease of the same crop plant Such a state of behaviour is seldom encountered in nature Sugarcane resistance to red rot is highly susceptible to leaf rust and whip smut Wilt-resistant American and Egyptian cottons are highly susceptible to black arm and rust in India Rust-resistant varieties of wheat are highly susceptible to black chaff disease in the U S A *Marquis* wheat which was resistant to stem rust and bunt, was found to be highly susceptible to scab infection Several oat varieties, which were resistant to crown rust and smut, were highly susceptible to *Helminthosporium* stripe, due to their "Victoria' blood The highly rust-resistant *Khapli* wheat was found to be highly susceptible to *Helminthosporium* stripe in Bombay, the late blight resistant potatoes were equally susceptible to powdery mildew in Holland "*Thatcher*" wheat highly resistant to stem rust was found to be susceptible to leaf rust in north U S A Instances of this type can be multiplied times out of numbers

Another perplexing phenomenon, which has materially added to the difficulties of the Plant Breeder and the Plant Pathologist, is the close association, of either physiologic or genetic (linkage) nature, between inferior agronomic characters and disease-resistance The phenomenon is widespread among plants, even as in animals Highly wilt-immune "Million Dollar" cotton of Chinese descent has very inferior agronomic characters which show a close linkage The superior "*Son*" variety of banana is highly susceptible to *Fusarium* wilt, while the inferior "*Kali*" is highly resistant The "*baxi*" wheats of India, highly prized for their quality and yield are highly susceptible to stem rust, while the inferior "*Khapali*' is highly resistant The sweet varieties of citrus are highly susceptible, while the sour varieties show high degree of resistance to gummosis infection Superior types of rice like the "*Bhangar Kaddi*' and "*Kolamba* readily succumb to blast infection (*Piricularea oryzae*), while the inferior and wild types show high degrees of resistance Instances of this kind have been recorded in a wide variety of crop plants and are a real obstacle in the development of disease-resistant varieties of desirable commercial qualities It is the latter aspect which is more difficult of attainment and entails long delays and high technical skill and knowledge of plant breeding and genetics

MEANS OF SECURING RESISTANT VARIETIES

Disease-resistant crop plants may be obtained in the three following ways -(i) Introduction, (ii) Direct selection and (iii) Selection in hybridized material

1 Introduction

As previously stated, resistance to disease is an inherent characteristic of some plants and occurs in varying degrees throughout the plant kingdom A very simple and inexpensive way would be to make direct introduction of varieties exhibiting high resistance, into regions affected by a specific disease, in order to combat it While theoretically this method appears a very simple proposition, unfortunately in practice, it is beset with great difficulties and even risks As already explained, the real problem in this respect is not so much of obtaining resistant varieties as of securing varieties combining disease-resistance with commercial or desirable agronomic characters It is the latter aspect that confronts the plant pathologist and the plant breeder Seldom do these two characters go hand in hand in nature and hence a simple introduction does not have high chances of success in a new locality with different sets of environmental conditions It is sometimes possible that strains of the same pathogen prevailing in the new locality may be different The risks involved in such a procedure cannot also be overlooked Again a newly introduced variety may prove resistant to one disease but may be extremely susceptible to another disease Experience of introductions shows many instances of this kind as already explained under the chapter on "Epidemiology" Besides, environment and seasonal conditions play a prominent role in the development of the disease The acclamatization of these new introductions to new environment is in most cases a difficult problem

The introduction of Co 475 variety of sugarcane in Bombay has conquerred red rot but brought in leaf rust and whip smut to the fore The *marquis* wheat in the U S A conquerred stem rust but brought in the problem of scab, wilt-resistant American cotton varieties introduced in India, became highly susceptible to red blight, rust and black arm *Kenya* varieties of wheat which are highly resistant to stem rust became highly susceptible to loose smut in experimental areas in Bombay The introduction of Hope and H44 varieties of wheat in the U S A brought stem rust and bunt under control, but introduced a new problem of black chaff to which these varieties were highly susceptible In other words, introductions while solving the problem of a prevalent disease may bring in new diseases, probably more virulent and devastating and therefore cannot be depended upon for controlling diseases (Stakman et al 1938) However, cases of success attending such direct introductions are on record The introduction into India of early maturing varieties of groundnut from the U S A has successfully conquerred the problem of *Tikka* (*Cercospora arachidicola*), Indore variety of *Lathyrus sativus* resistant to *Fusarium* wilt introduced into northern sections of Bombay, have solved the wilt problem in that locality So was the case with " *Basrai* " variety of banana in the control of Panama disease, in parts of Poona district These instances are, however, so few and far between that such a method cannot be considered as of general application in a control programme

2 Direct selection

This is a better method than the previous one and has more chances of success in obtaining disease-resistant plants The work of selection is carried out either in the naturally infected fields under field conditions from out of the mass of heterogenous material or in individual cultures to be tested under conditions of artificial epidemic either in the nurseries or special glass houses with controlled environment (*Plant selection*) The former is an ineffective method and many times ends in failure, since the selections made may be only in the nature of " disease escapers " and not truly resistant individuals In years of heavy epiphytotics, field selections are likely to yield better results, as such selections will have been effected from amongst plants which have survived the epidemic (Fig 78, 6) Besides, the close association often found in plants between disease-resistance and inferior agronomic characters, presents obstacles which can hardly be surmounted by selection in naturally varying material

3. Hybridization

This method of developing disease-resistant crop plants combining commercial qualities, though effective and the best, is a long-drawn-out process involving high technical skill It is, however, the only effective way to break up the unwholesome association of characters and overcome the difficult situations referred to above and obtain eventually combinations and recombinations of characters, with the ultimate view of selecting out of this material, desirable individuals combining resistance to disease The degree of success and rapidity with which it is achieved are naturally determined by the nature of the original material, the environmental conditions under which the work is carried out and the pattern of the breeding programme Due regard must be paid to the three factors that make up " disease " in plants viz the host plant, the pathogen and the environment The presence of more than one parasitic strains or physiologic forms in a given pathogen and the complications arising out of such phenomenon have intimate bearing on the breeding programme, so is the case with environmental factors, which must be controlled in order to obtain reliable results The programme of breeding, which normally consists of initial hybridization (for obtaining combination and recombination of characters) followed by systematic selection and selfing (for fixing such characters) must be carried out under conditions of environment which are standard and optimal for the development of disease and standard infection using all the prevailing parasitic strains of the pathogen Such a programme reduces to a minimum the risks involved in isolation of "disease-escapers" The modern conception of disease-resistance is broad-based and takes into account the various parasitic strains within the pathogen and the varying environmental conditions influencing the ultimate clinical picture and severity of disease Any rational and scientific programme for developing disease-resistant crop plants must, therefore, be based on such conception, in order to achieve real success

The pioneer work of obtaining disease-resistant varieties of crop plants carried out at Wisconsin by L R Jones and his associates in soil-borne diseases, the breeding programme for obtaining rust-resistant varieties of wheat carried out in the U S A by E C Stakman and his associates and by other workers in Canada, Australia and India, the success that attended the development of wilt-resistant varieties of cotton and *lathyrus* in Bombay by Uppal and his associates and blight-resistant varieties of gram (*Cicer arietinum*) in Punjab by Luthra and his co workers, to mention only a few, were mainly based on and due to such comprehensive considerations having formed the basis of the breeding programme

In general, such a programme for breeding and development of disease-resistant crop plants assumes the following pattern :-

1 Make field selections from heavily infected areas from variable material, either available from natural populations or from segregating generations of crosses
2 Self such plants and obtain progenies
3 Test the progenies in pot cultures *individually* for disease-resistance, under artificial infection (Fig 78, 79 & 80)
4 Use *all prevailing strains* of the pathogen for infection
5 Maintain optimal conditions of environment either of soil (in soil-borne diseases) or meteorological (in airborne diseases) throughout the trials
6 Eliminate all susceptible individuals
7 Transplant pot and glass-house selections in disease nursery, specially maintained for the purpose

FIG. 78. Methods of study with soil borne diseases. 1. Preparation of wilt-sick soil; 2. Pot tests in glass house. Field tests for wilt-resistance in 3. Cotton; 4. Tobacco; 5. Cabbage; and 6. Mass selection for wilt resistance in cabbage

[After 3. U. S. D. A. 4. Johnson, J. 5 and 6. Walker, J. C.

FIG. 79. Glass house tests for varietal resistance in rice to blast under artificial infection.

[Courtesy : N. B. Kulkarni.

METHODS OF INVESTIGATION

(In plant rusts)

FIG. 80. Methods of Study in Plant rusts. 1. Seedling inoculation; 2. Incubation chamber for seedlings; 3. For adult plants; 4. Interior of a rust glass-house; 5. Hypodermic needle inoculation; 6. Special chambers for maintaining rust cultures; 7. Heavily rust-infected plants; 8. Creating artificial rust epidemic in field by the muslin canopy method. [Kamat, 1953.

8 Self desirable cultures and repeat the process in subsequent generations until homozygocity is attained
9 Make selections for both agronomic characters and disease-resistance, every time discarding the undesirables
10 Carry out tests of the selections so made under varying field conditions on state farms, for commercial and disease-resistance characters
11 Multiply seed of the best selections for general distribution

Modifications of the general procedure outlined above are made in accordance with the nature of disease, pathogen, environmental conditions for the development of the disease, nature and genetical constitution and behaviour of the host and the facilities and equipment available In soil-borne diseases, like wilts and root rots, special artificially infected plots are maintained for testing individual performance of each plant culture, besides the uniformly infected pot cultures (Figs 78 & 83) and the selections so made are finally tested under uniform soil temperatures in *soil temperature tanks* (Fig 47) to check up the real nature of resistance and eliminate the " disease escapers ' if any, before the selections are multiplied for general distribution In air-borne diseases, like rusts, blights, blasts, black chaff etc , the tests of F_2 and subsequent generations are carried out under heavy *artificial epidemic conditions* (Figs 79 and 80, 8) with a fixed layout, using various techniques described in Chapter 20 (Patel and Kamat, 1950) The main purpose of such a procedure is the elimination of " disease escapers ", which are apt to creep in, if these conditions of infection and environment are not maintained to a standard for optimal development of the disease

A standard system has been developed for proper evaluation of the differential reactions of plant cultures to the disease, through " infection types " which vary with different diseases Two such charts depicting the " infection types " utilized in breeding work in stem rust of wheat used by Stakman et al and cotton wilt (developed by Uppal et al) are illustrated in Figs 81 and 82 On this basis, three groups of " reactions " are recognised viz Immune, highly resistant and highly susceptible and these are designated for convenience by the numerals 0, 1 and 2, 3 and 4 respectively

Hybridization or crossing, thus, has become an established and effective method for obtaining disease resistant varieties of plants This is accomplished by effecting crosses between varieties as well as species In addition to the usual technique of straight crosses, two other effective techniques have come into prominence in recent years viz **Backcrossing** and **Polyploidization**, the former enables the breeder to recombine and fix desirable parental characters in the hybrid

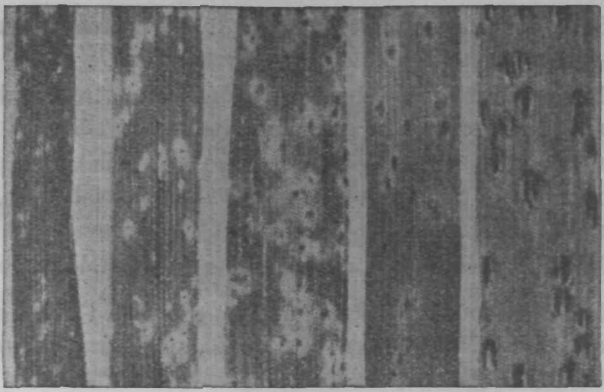

FIG. 81. Infection types in stem rust of wheat. 0 : Immune, 1 & 2. Highly resistant, 3 & 4. Highly susceptible. [After Stakman, E. C.

FIG. 82. Infection types in *Fusarium* wilt of cotton. L to R. Decreasing resistance determined by extent of leaf mottle.

[After Uppal, B. N. et al

FIG. 83. Resistant (Left) and Susceptible (Right) varieties of tobacco growing in root-rot infested soil. [After Johnson J.

generation and the latter has been utilized in securing fertile plants out of an otherwise infertile hybrid of interspecific and intergeneric cross by the well-known "*colchicine* treatment' Inter-specific hybridization has been of great value in introducing desirable resistance from wild types into commercial varieties

The foregoing discussion about the methods employed in the development of disease-resistant varieties of crop plants will not be complete without a brief reference to the difficulties encountered in this type of work Some of these difficulties have been already discussed but will bear a repetition The most important of these are as follows --

1 Association of resistance and inferior commercial characters

2 Absence of resistance to major diseases in commercial varieties

3 Existence of parasitic strains of varying capabilities in a pathogen

4 Self-sterility in the host plant

5 Strictly regional aspects and requirements

The position with regard to items 1, 2 and 3 has been already discussed Self sterility in plants is a great impediment at fixation of characters and attainment of homozygocity in the off-spring The position is identical with cross-fertilized plants like corn cabbage, *crotolaria* etc and is overcome through special techniques like "sib-crossing' or controlled pollination between different lines carried out through the medium of pollinating bees (Uppal and Kulkarni, unpublished data)

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CHAPTER 20

Methods of Study with Plant Diseases

Methods involved in the study of and investigation into plant diseases vary with the nature of diseases concerned A knowledge of the general laboratory technique consisting of the use of camera lucida, micrometry, preparation of media, methods of sterilization and pure culture is prerequisite The student would be able to obtain sufficient information on this score from the laboratory guides (3, 4, 7,) cited at the end of the chapter The following discussion will therefore relate to the general procedure followed in the investigation into infectious plant diseases in the laboratory and the field

The first step, in this direction, is to examine the diseased plant carefully, either in the fields or in the laboratory A thorough macroscopic as well as microscopic examination is necessary This is done, generally, in three ways **direct observation, sections and isolations** The first one is done by a hand lens or with a binocular for the presence of any fungus parts, felt of mycelium, sclerotia, perithecia, pycnidia or bacterial ooze, characteristic with wilt and root rot organisms, powdery mildew or bacterial diseases Sections will help to locate the mycelium and its nature, the type of spore-fruits and their actual relationships with the host tissues and are, therefore, likely to give the worker a true idea of the nature of disease In case the two methods fail to throw light on the actual nature of the disease, the third method of isolation is employed, this method aims at obtaining the possible pathogen from the diseased tissues in pure culture, and is sometimes also known as single-spore or tissue cultures This is accomplished by either *spore isolations* or *tissue isolations* through such techniques as "dilution" or "plating" method (Fig 84), loop and cylinder method, the micromanupilator and many others (Hildebrand, 1950)

In diseases caused by obligate parasites like the downy and powdery mildews and the rusts, the pathogens are cultured in living plants and are known as plant cultures which are used in subsequent investigation work (Manners, J G 1951) The methods of culturing pathogens of facultative nature differ from the above This is done in artificial media, of which there are many, the commonest ones employed for this purpose, being potato dextrose agar, oats meal agar and nutrient agar Such organisms like smuts, *Phytophthora, Pythium, Alternaria, Fusarium* and bacteria could be so cultured and maintained in the laboratory for further study (Fig 85)

The next step in this direction after the organism is brought in culture, is to test it for its pathogenecity, for, the mere presence or

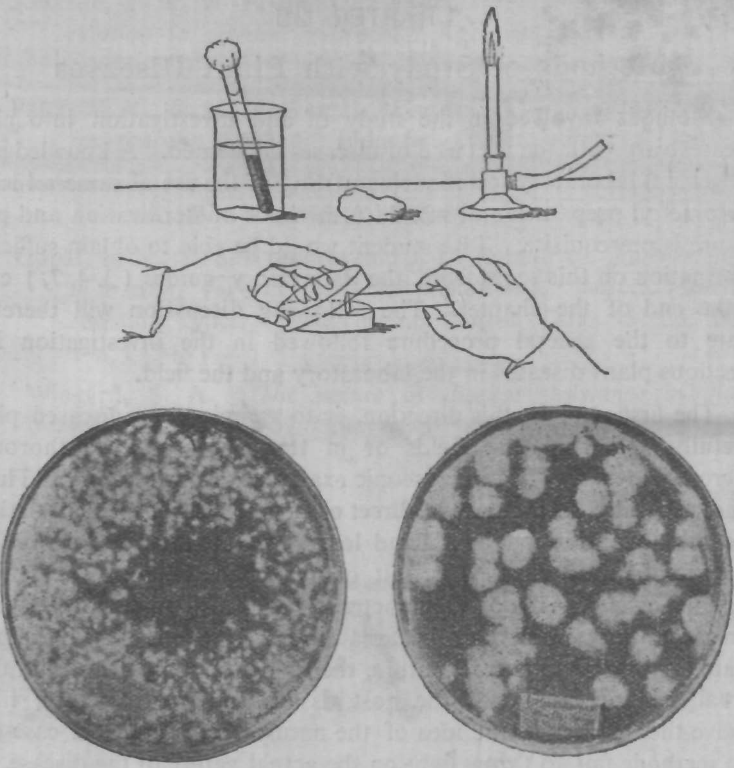

FIG. 84. Dilution method of isolation (Upper) and Colonies (Lower).

[After L. Lohnis, R. Dugger.

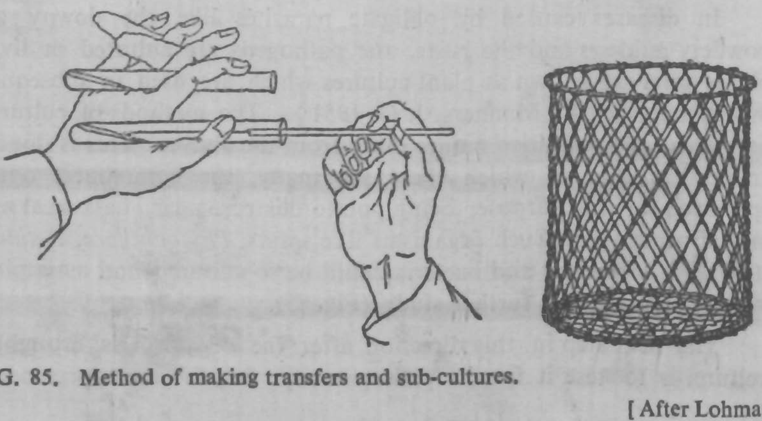

FIG. 85. Method of making transfers and sub-cultures.

[After Lohman.

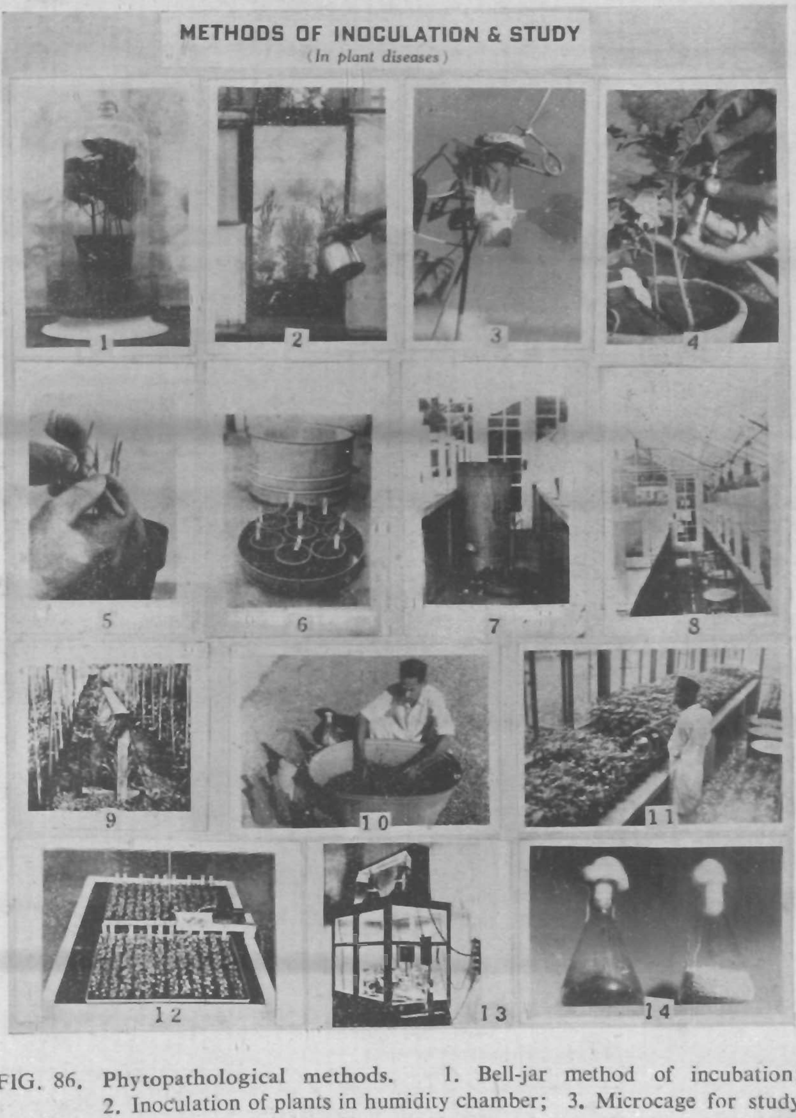

FIG. 86. Phytopathological methods. 1. Bell-jar method of incubation; 2. Inoculation of plants in humidity chamber; 3. Microcage for study of virus-vector relationship; 4. Hypodermic inoculation; 5 Spatula method of inoculation; 6. Incubation chamber for seedlings; 7. Incubation chamber for adult plants; 8. A glass-house for culturing rust fungi; 9. Glass canopy method of creating artificial disease epidemic in nurseries; 10. Preparing wilt-sick soil (*note* giant cultures of the fungus in flasks on left) 11. Study of varietal reactions of cotton to Fusarium wilt in pot tests; 12. Soil temperature tank for study of soil-diseases at controlled soil-temperature; 13. Incubation chamber with controlled temperature, humidity and light; 14. Sorghum seed inoculated with smut spores.

[Kamat, 1953.

IG. 87. Method of preparing wilt-sick soil for pot tests. L : Mass cultures of *Fusarium*, R : Mixing inoculum with soil.

G. 88. Canopy method of creating artificial epidemic in air-borne diseases.
[Courtesy : Plant Pathologist, Bombay.

association of the organism on, in or with plant tissues is not the true index of its parasitism This is done by **inoculation methods** of which there are many and vary with the nature of the organism and disease (Fig 86) Inoculation may be defined as introduction of live inoculum (pathogen) into or upon a host Such methods are only possible and desirable with parasitic diseases including viruses but not with nonparasitic ones The technique employed in the former two types only will be discussed in this chapter

An inoculation experiment may be designed with the following purpose

1 To prove parasitism of the organism isolated
2 To study life cycle of the organism
3 To study host range of the organism
4 To study specialization of parasitism
5 To study relation of environment to disease
6 To study varietal resistance of host

The essential requirements of a successful inoculation experiment were long innunciated by Robert Koch (1876) and are well known as **Koch s postulates** which may be summarised as follows —

(i) Isolation of organism in pure culture from diseased individual,
(ii) Inoculation of the organism in healthy individual,
(iii) Reproduction of typical symptoms and disease,
(iv) Reisolation of original organism from diseased individual

Since disease is the product of an interaction between the host, the pathogen and environment, an inoculation experiment also must satisfy these three conditions, which should be brought together in such an experiment For this purpose, the hosts after inoculation are grown under bell-jars, muslin cages, glass houses, specially designed for the purpose, (Fig 86), and where *environmental conditions* such as temperature, light and humidity are controlled In soil-borne diseases, the inoculum (pathogen) is inoculated into soil and plants to be tested grown in such " sick " soil (Fig 87) In air-borne diseases, the inoculum is sprayed on the plants in the form of spore-suspension, which are then incubated under moist chambers In seed-borne or seedling diseases, the inoculum is smeared over seed or placed round about seed at sowing time Various modifications of these methods are resorted to, to suit each special case (Fig 86)

In field experiments, where the plants and the pathogen are tested and studied on a mass scale, the inoculum is either sprayed on growing plants (in air-borne diseases like the rusts, blast and blights) or is added to the soil in measured doses (in soil-borne diseases) specially maintained for the purpose and plants to be tested grown in such sick soil (Fig 87) In air-borne diseases special muslin cages or canopies are used to cover the inoculated plants for maintaining high humidity (Fig 88) to aid in successful infection

METHODS WITH VIRUS DISEASES

The methods of research and investigation into virus diseases of plants are necessarily different from those described above, because of the obligate nature of the virus, its mode of transmission and its ultra-microscopic character The "virus" particles are permeated through the cell sap, which, in turn, are transmitted to new plants through the punctures of sucking insects in the majority of cases The pathogen (?) thus cannot be cultured in artificial media nor will it admit of inoculation with the usual technique employed for parasitic diseases Instead, the cell sap is expressed from diseased individuals and inoculated into healthy plants by needle punctures or other suitable mechanism

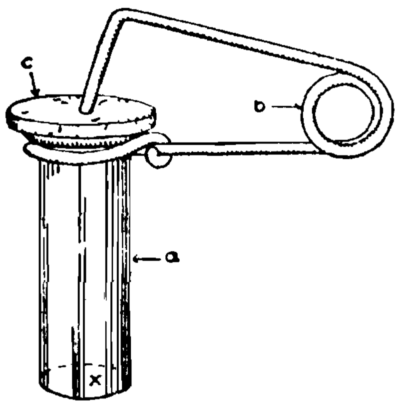

FIG 89 A micro-cage used in insect transmission of viruses
[Courtesy Verma P M

In cases, where this method is not successful, sucking insects such as aphids, leaf-hoppers, white flies and the like, usually found feeding on the diseased crop, are reared artificially in specially designed cages (insectaries) on healthy plants, allowed to feed on diseased plants for varying length of time under controlled insect-proof cages and these "viruliferous" insects then transferred to healthy plants in "micro-cages" (Fig 89) This mode of inoculation is known as insect-transmission These methods and modifications thereof, can be employed in the investigation of virus diseases to determine (1) parasitism of virus (2) mode of transmission (3) insect vector involved (4) host range (5) incubation period in the insect vector (6) relative resistance of host (7) isolation of viruses from mixed infection etc etc (Smith, 1937)

Studies in the **life cycle of pathogenic organisms** have vital bearing on control measures, the study of the organism itself in its various aspects such as habit of growth, formation of spores and sporefruits, spore germination and viability, provide important information, on the nature of the organism The method of oversummering, mode of transmission, host range and environmental factors affecting the development of disease, yield weak spots, which ultimately help the plant pathologist in his onerous task of developing rational measures of protection

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CHAPTER 21

TAXONOMY AND NOMENCLATURE

Taxonomy in fungi is beset with great difficulties on account of their diversified nature, fragmentary knowledge of their structure, developmental process, cytology, sexuality and other aspects of their life cycles The student is naturally bewildered with the conflicting interpretations found in the various classifications presented in standard books of mycology, but will do well to remember that mycology is undergoing a "transitional" stage and will take some time before it crystalises and takes a definite shape Taxonomy, to be successful, must be based on a natural system and aid the student in readily identifying the various micro-organisms

All organisms are either plants or animals, excluding those of intermediate nature, such as the slime-moulds also known as **mycetozoa** meaning animal-fungi Fungi have more affinities with plants and as such are grouped under the plant kingdom Of the three well known groups of Cryptogams (Sporophytes), fungi belong to the **phylum, Thallophyta,** which comprises, in addition, the bacteria, the slime-moulds and the algae A simple key to the various classes of the Thallophyta is given below —

THALLOPHYTA

(A simple key to the classes)

A	Chlorophyll, present, aquatic			**Chlorophyta** (Algae)
B	Chlorophyll, lacking			
	BB	Unicellular, dividing by fission	Class	**Schizomycophyta** *Schizomycetes* (Bacteria)
	CC	Vegetative body, naked, a plamodium	Class	**Myxomycophyta** *Myxomycetes* (Slime moulds)
	DD	Typically filamentous with cell wall, dividing by buds		**Eumycophyta** (True-fungi)
	1	Mycelium non-septate, asexual spores motile or non-motile, spore-fruits absent	**Class I**	*Phycomycetes* (Algal-fungi)

Sporefruits present, mycelium septate, propagation by non-motile conidia		**Carpomycophyta**
2 Sexual spore, an ascospore	Class II	*Ascomycetes* (Sac-fungi)
3 Sexual spore, a basidiospore	Class III	*Basidiomycetes* (Basidial-fungi)
4 Sexual spore, absent	Class IV	*Fungi-Imperfecti*

The **Chlorophyta** constitute the green algae, the **Schizomycophyta** the bacteria, which are typically unicellular and probably the smallest known micro-organisms, exclusive of the viruses, which have a problematical position, the **Myxomycophyta** are the slime moulds, consisting of naked multi-nucleate vegetative body, the **Plasmodium** The **Eumycophyta** constitute the true fungi with typically filamentous form, a true sexuality, a definite cell wall and dividing by budding

These **phyla** are further subdivided into orders, families, genera, species, sub-species, races and forms The names assigned to these divisions and all descriptions are in Latin, which provides a common medium of nomenclature and therefore admit of easy comparison between the various scientific workers, working in different parts of the globe

NOMENCLATURE

The well known, "Binomial system' introduced by *Carl Linnaeus* in 1753 published in his book, *Species Plantarum*, forms the basis of modern system of nomenclature A plant bears, thus, two names, the first, a noun, the *genus*, and the second, an adjective, the *species* These names are often designated after well-known mycologists (*de Baryanum*, *Butleri*, *Ajrekari*, *Kulkarniella*, *Kunhii*, *Dasturiella* and so on) or after distinctive hosts (*brassiaceae*, *arecae*, *palmivora*, *graminicola*, *solani*, *fici*, *gossypi*, *tritici*, *helianthi*, *chrysanthemi*, *sorghi* and so on) or again after countries or regions in which they were discovered (*indica*, *bengalensis*, *himalayansis*, *philippinensis*, *poonaensis*, *cubensis* etc) or after part of the host affected (*vasinfectum*, *fructicola*) and so on

The names of the orders end in -*ales*, those of families in -*ceae* and higher rank -*ete* The name of the author who first named the organism immediately follows the binomial viz *Phytophthora arecae* Coleman In case of shifting of names and more than one name appearing after the binomial viz *Sclerospora sorghi* (Kulk) Weston and Uppal, *Neovossia indica* (*Mitra*) Mundkur, *Neovossia horrida* (Tak) Padwick & Azam, the name in the parenthisis is the original author and the one outside, who subsequently modified the binomial

Rules of nomenclature have been framed by the International Botanical Conferences held from time to time, on a standard and universally accepted system, which is now being followed by all biologists the world over The authors and dates which have been accepted for the purpose of naming organisms are as follows

Myxomycetes	1753	Linnaeus	*Species Platarum*
Fungi, Basidiomycetes	1801	Persoon	*Synopsis Methodica Fungorum*
Fungi, other groups	1821	Fries	*Systema Mycologicum*

New names are permissible only for such organisms that are discovered *after* the above dates

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CHAPTER 22

THE PHYCOMYCETES

This class of Eumycophyta, sometimes known as algal-fungi or lower fungi, includes aquatic, amphibious and terrestrial forms The lowest forms possess a simple undifferentiated thallus and are thus called **holocarpic**, while the higher forms produce richly branched filamentous mycelium and reproductive bodies and are called **eucarpic.** The vegetative mycelium is typically **coenocytic** (unicellular and ultinucleate)

Asexual reproduction takes place by zoo-sporangia or conidia, hich, in lower forms, give rise to **zoospores** or **swarmspores** and to irect germ tube in the higher forms The zoospores are motile and ossess one or two **flagella** on their body and are adapted for aquatic abit and water-dissemination In higher forms, the conidia are roduced endogenously in sporangia and are known as **aplanospores**, iese are typically terrestrial and are wind-disseminated *No spore-uits are produced in these fungi*

Sexual reproduction is diverse and ranges from copulation between iotile gametes in lowest forms, heterogamy or oogamous types in itermediate and isogamous in highest forms The three types are esignated as **planogametic copulation, oogamous fertilization** and **ygogamous conjugation** and result in the formation of **zygotes, oospores** nd **zygospores** respectively

Parasitism and habitat are of a varied type The lowest are 'ater-moulds and saprophytic, the intermediate forms are semi-quatic or amphibious in habit and are either **facultative** or exhibit **bligate parasitism** Such fungi as *Pythium* and *Phytophthora* are of the ormer type, while members belonging to *Peronosporaceae*, sometimes lso known as downy mildew fungi, are of latter type The members of he highest group constitute the moulds, which mainly grow on ecaying organic matter and are therefore, in the nature of scavangers he *Mucors* and the bread mould belong to this category

Many members of this class cause serious and wide-spread diseases of crop plants The classical lite blight of potatoes, the wart of otatoes, the downy mildew of grapes, hop and cereals, the white rust of cruciferous crops, the *koleroga* of arecanut, the wilt in betel vine, he gummosis of citrus all belong here Some members parasitize nsects and have been utilized in biological control of insect pests

The classification of this class is mainly based on the nature of the plant body (thallus), the type of sexuality and sexual spores and the number and type of flagella of the zoospores The older classification

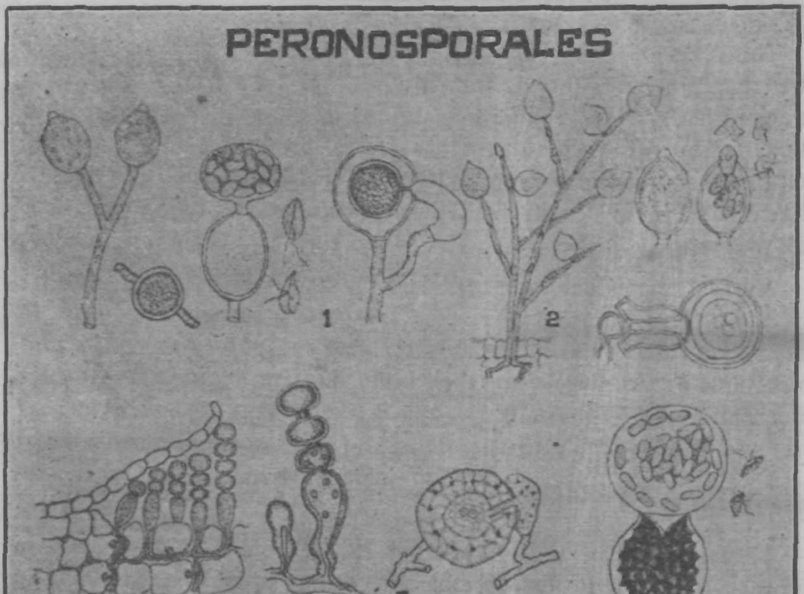

FIG. 90 Generic characters. 1. Pythium; 2. Phytophthora; 3. Albugo: 4. Basidiophora; 5. Peronospora; 6. Plasmopara; 7. Bremia; 8. Sclerospora.

[Kamat, 1953.

has been based primarily on the former two characters, while the modern system (Sparrow, 1943) has been framed in accordance with the number and type of flagella present on the body of the zoospores

Accordingly, the Phycomycetes have been subdivided into three sub-classes or series as follows

A KEY TO SUB-CLASSES OF THE PHYCOMYCETES

A *Zoospores present*

1 Holocarpic, aquatic sexuality, planogametic copulation — 1 **Archimycetes**

2 Eucarpic, semi-aquatic, sexuality oogamous, an oospore — 2 **Oomycetes**

AA *Zoospores absent*

3 Eucarpic, terrestrial, sexuality isogamous, a zygospore — 3 **Zygomycetes**

The Archimycetes, the Oomycetes and the Zygomycetes are in general homologous to the modern series, the Uniflagallates, the Biflagellates, and the Aplanates respectively

The order Peronsporales constitute fungi of very great economic importance and comprise practically all the destructive diseases caused by members of this class The type of the conidiophore is a distinctive character in taxonomic classification of this order (Fig 90)

A detailed classification of the three sub-classes will be found in any standard book of mycology

A statement giving the important diseases caused by these fungi, their nature, causal organisms, host range, hibernation and distribution is given in the accompanying Statement I

REFERENCES

1 Alexopoulos, C J *Introductory mycology* John Wiley and Sons (1952)

2 Fitzpatrick, H M *The lower fungi* McGraw Hill Book Co N Y , (1930)

3 Sparrow, F K Jr *Acquatic Phycomycetes exclusive of the Saprolegniacea and Pythium* Uni Michi Press, Ann Arbor (1943)

CHAPTER 23

THE ASCOMYCETES

The Ascomycetes, well-known as sac-fungi, comprise a large number of species which are characterised by the formation, in their perfect stages, of the **ascus**, this structure is a distinctive feature of the class and is homologous in its morphology to the sporangium of the Zygomycetes Many members of this class were originally grouped under Fungi-Imperfecti on account of the absence of asci in their life cycles but were transferred back to their proper position under this class, with the discovery of the ascigerous stage

Unlike the Phycomycetes, the mycelium is profusely septate and commonly forms stromata, sclerotia and chlamydospores Conidia are abundant in certain groups and scarce or absent in others The ascus, which takes such diverse forms as clavate, globose, cylindric, palisade-like, filiform etc , contains usually eight **ascospores** This number may vary in certain species but is, in general, a multiple of two and a definite number The asci, in turn, are produced in typical spore-fruits known as ASCOCARPS which are mainly of three types (1) **Cleistothecium,** a closed spherical body opening by breakage of its outer wall and discharging the asci within (2) **Perithecium,** a globular or flask-shaped fruit with a narrow ostiole through which the asci and ascospores are released (3) **Apothecium,** a cup or saucer-shaped body, generally fleshy in character, and lined on its inner sides, with asci, in parallel or palisade layer, which discharge the ascospores directly into the atmosphere In a few primitive species, however, none of the fruit-bodies described above are present and the asci in these fungi are naked, some-time single or formed in groups or layers (Fig 91) The ascus, thus, constitutes the perfect stage of the fungi grouped under the class It is a sexual structure and the ascospores, sexual spores

These fungi greatly vary in their parasitism, ranging from obligate saprophytism to true parasitism and are well adapted to terrestrial dissemination They carry out their active phase with the help of diverse types of conidia or asexual spores followed by the ascigerous phase which is a hibernating stage **Pleomorphism** occurs in many species, a phenomenon lacking in Phycomycetes Physiologic specialization of a high order is met with in several forms

Sexual phenomenon is of isogamous type in the primitive groups and highly developed heterogamous in higher forms In the latter, a specialised female cell known as **ascogonium** is fertilised by a male cell, the **antheredium**, often with help of a **trichogyne**, which forms a receptive structure of the female cell, unlike the fertilization tube in the

Oomycetes; the ascogonium, on fertilization, gives rise to one or more **ascogenous hyphae** which ultimately grow into asci and surround themselves in higher forms with an outer supporting structure, the peridium; between the asci, are many times intermingled the sterile hair-like hyphae, the **paraphyses.**

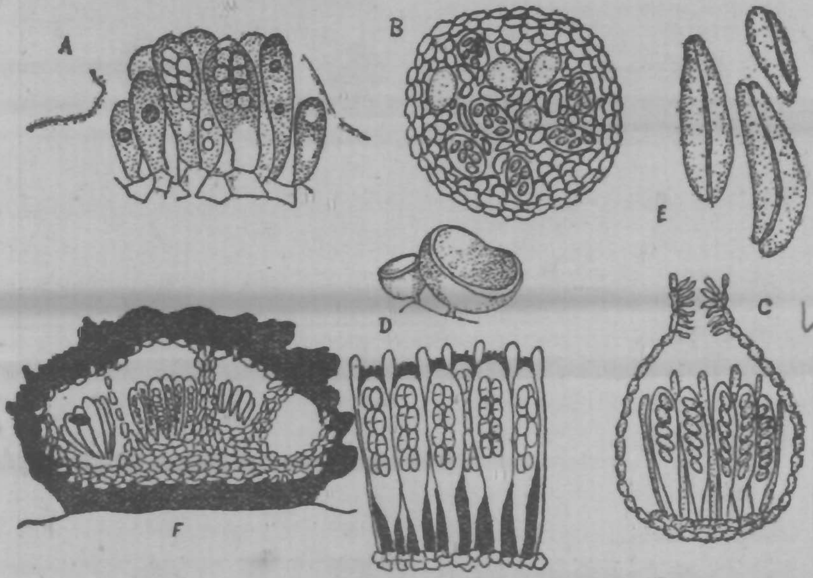

FIG. 91. Spore-fruits in the Ascomycetes. A. Naked asci; B. Cleistothecium (Section); C. Perithecium (Section); D. Apothecium; E. Hysterothecium; F. Asci in locules.

[Drawing : Miss Kumud Lad.

The classification of the class is mainly determined by the manner in which the asci are produced and the type of the ascocarp. Accordingly four well-defined groups can be recognised on the basis of this characteristic. In the well-known powdery mildew group, the Erysiphaceae, the number of asci formed in the fruit-body together with the type of appendages form distinctive generic features (Fig. 92).

Some of the important diseases caused by members of the Ascomycetes are the powdery mildews, the sooty moulds, brown rot of stone fruits, the "ergot" of rye, the Dutch elm disease, the blight of *gram*, the scab of apples and the chestnut blight. Yeasts, the well known black and green moulds belong here and have been utilised in industries and medicine. The famous antibiotic, *Penicillin*, has been obtained as a result of the activities of the green mould, *Penicillium*. Yeasts are of great importance in bakeries and breweries in making bread and wine.

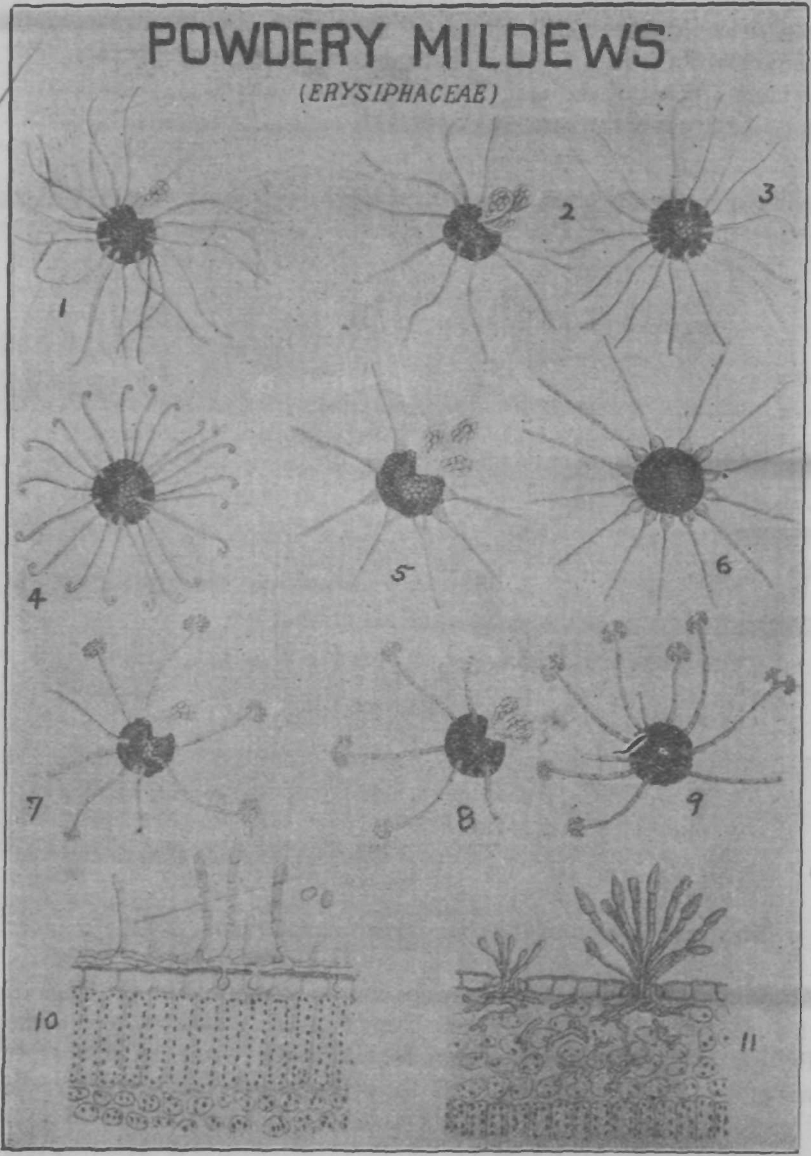

FIG. 92. Generic characters of the Erysiphaceae: 1. Sphaerotheca; 2 & 3. Erysiphe; 4. Uncinula: 5 & 6. Phyllactinia; 7. Podosphaera; 8 & 9. Microsphaera; 10. Oidium; 11. Oidiopsis.

[Kamat, 1953.

The class has been subdivided into two sub-classes according to the presence or absence of the spore-fruits, and is further classified into series on the basis of the type of spore-fruit, as follows:

A SIMPLE KEY TO SUB-CLASSES AND SERIES OF ASCOMYCETES

(A) Ascocarp lacking, asci naked →	Sub-class	**Hemi-ascomycetes**
(B) Ascocarp present →	Sub-class →	**Euascomycetes**
1 Ascocarp, a *cleistothecium* with no ostiole	Series I	*Plectomycetes*
2 Ascocarp, a *perithecium* with narrow ostiole	Series II	*Pyrenomycetes*
3 Ascocarp, an *apothecium* with a broad ostiole	Series III	*Discomycetes*

These divisions are further subdivided into orders and families The details of the classification will be found in any standard book of mycology

A statement giving important diseases caused by members of this class, their causal organisms, nature, mode of dissemination and hibernation, host range and distribution is given in the accompanying Statement II

REFERENCES

1 Alexopoulos, C J *Introductory mycology* John Wiley and Sons N Y, (1952)

2 Stevens, F L *The fungi that cause plant diseases* McMillan and Co, N Y, (1913)

3 Wolf F A and T E Wolf - *The fungi* I - John Wiley and Sons N Y, (1947)

CHAPTER 24

THE BASIDIOMYCETES

The Basidiomycetes comprise of fungi characterised by the formation, in their life cycle, of **basidium** and **basidio-spores** The basidiospores are borne exogenously on the basidium which may take various forms, septate or non-septate, the basidiospores may be definite or indefinite in number, in higher forms, they are usually four, but always a multiple of two, a characteristic feature found in the ascus of the Ascomycetes, the basidiospores are haploid in many species and mate in pairs before infecting the host and produce in them a **dikaryotic** mycelium, in this respect they are in the nature of gametes

The mycelium is typically septate Chlamydospores and resting spores are produced in several species, while rhizoidal or cord-like sclerotial bodies are a feature in certain wood-rotting fungi The spore-fruits, vary in their structure from closed or open sori, flask-shaped pycnia, cupshaped aecia to such highly developed **basidiocarps**, like mushrooms, toadstools, bracket-fungi and puff-balls In addition to the typical basidiospores, conidia and oidia of various types are produced which help the fungi in secondary dissemination Pleomorphism is of common occurrence and is highly developed in rust-fungi

Parasitism varies from obligate saprophytism to obligate parasitism with intermediate *facultatism* The fleshy fungi are mainly saprophytes, the rusts obligate parasites and the smuts and bunts, facultative saprophytes The basidiospores in smuts and bunts are *functional gametes* and therefore, admit of culture in artificial media and accurate morphological, cytological and even genetical study Host-parasitism is of a highly organised type and the rust fungi specially exhibit a specialization of an extreme type, the like of which has been rare in other groups

The smuts, bunts and rusts are important groups of diseases occurring in this class

Sexual development has been of varied type and may, in general, be described as highly developed isogamous copulation The nucleus in the basidium or promycelium is diploid which undergoes reduction division forming four haploid nuclei which ultimately migrate into the basidiospores or sporidia, the haploid basidiospores copulate in pairs and develop dikaryotic mycelium when the nuclei of opposite sex come together, but do not fuse, they are **conjuate** and divide as such until

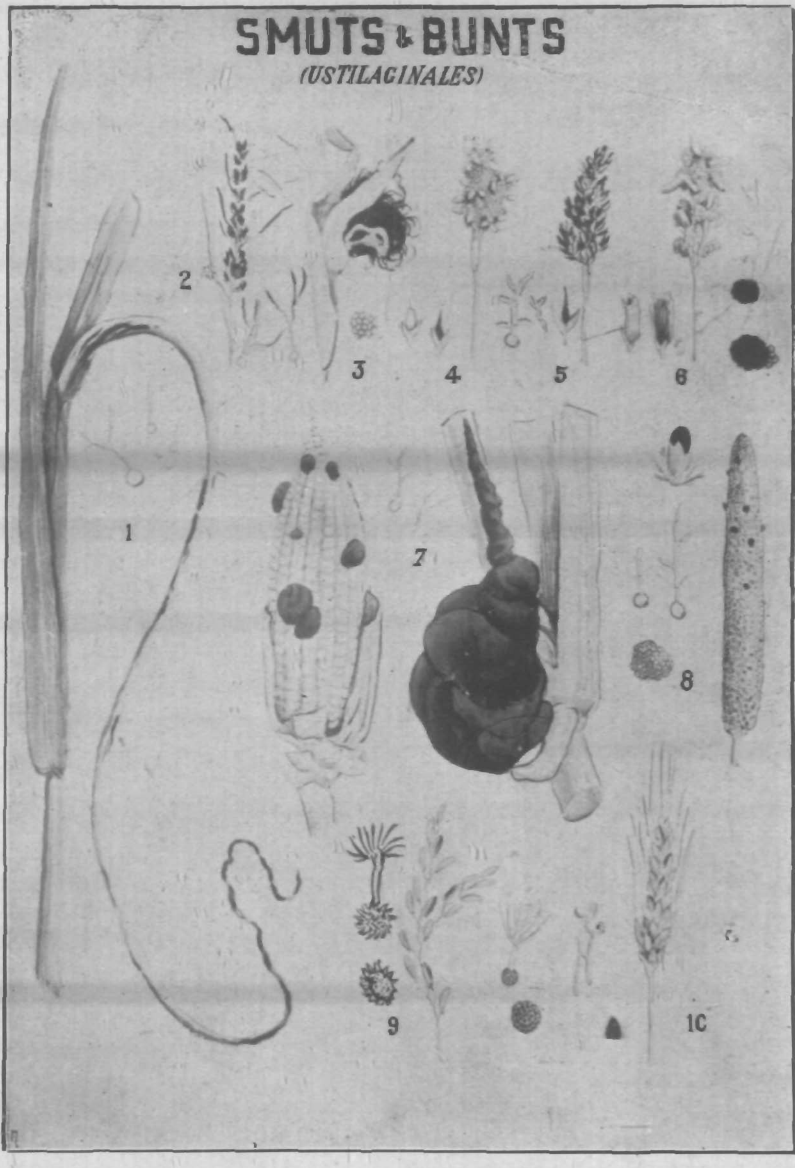

FIG. 93. Generic characters and effects on host. 1. Whip smut of sugarcane, spores and their germination; 2 Loose smut of wheat (*Ustilago*); 3. Head smut of sorghum (*Sorosporium*); 4. Kernel smut of sorghum; 5. Loose smut of sorghum (*Sphacelotheca*); 6. Long smut of sorghum (*Tolyposporium*); 7. Common smut of corn (*Ustilago maydis*); 8. Common smut of bajra (*Tolyposporium*); 9. Bunt of rice, spores and germination (*Neovossia*); 10. Bunt of wheat and germinating spores (*Tilletia*). [Kamat, 1953.

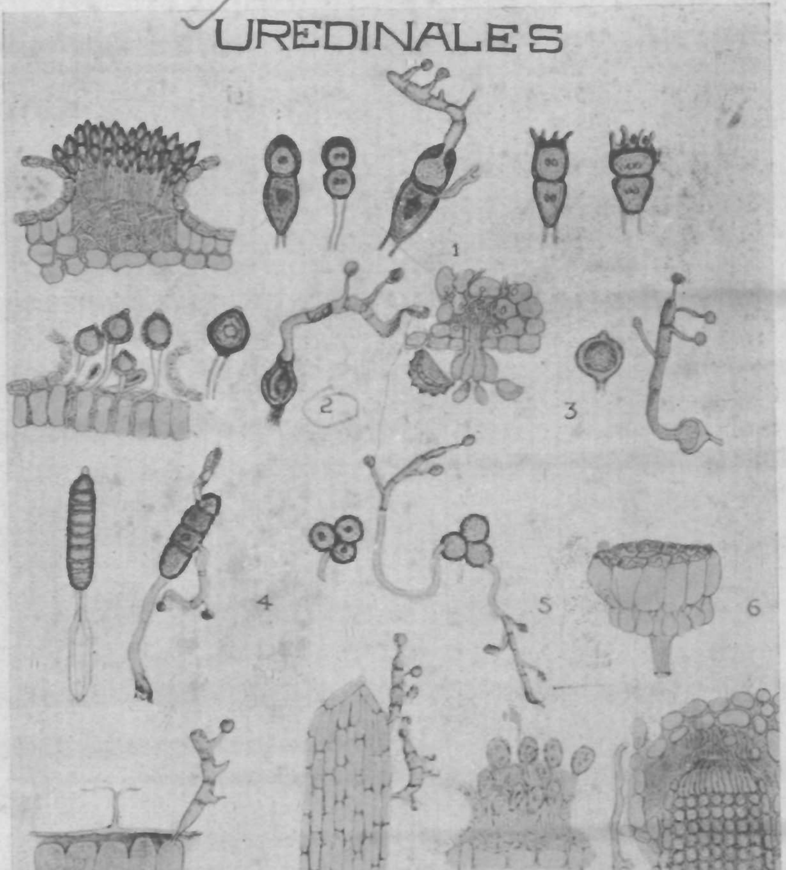

FIG. 94. Generic characters. 1. Puccinia; 2. Uromyces; 3. Hemileia; 4. Phragmidium; 5. Triphragmidium; 6. Ravenalia; 7. Melampsora; 8. Cronartium; 9. Uredo; 10. Aecidium (after Stevens).

[Kamat, 1953.

the chlamydospore is produced, where they fuse prior to its germination In certain fungi, specially the mushrooms, the haploid nuclei come together by a characteristic process, known as **diplodization**, with the help of **anastomosis** and **clamp connections**, which are found in abundance in such fungi Homothallism and heterothallism are common phenomena in this class The sexuality may be bipolar or tetrapolar

The classification is mainly based on the morphology and structure of the basidium and the number of basidiospores formed by it

Some of the common diseases of economic importance caused by members of this class are the cereal rusts, the white pine blister rust, the cedar rust of apples, the coffee rust, the flax rust, the leaf rust of sugarcane, the rust of jasmin, rust of *bajra*, the smuts of sorghum, wheat, oats barley and corn, the bunts of wheat and rice, the flag smut of wheat and rye, the whip smut of sugarcane and the wood-rots of forest trees

Mushrooms, and puff balls which belong here, are greatly prized for their food value and are cultivated extensively in special hot houses in the U S A and Europe, for canning purposes, some of these are however highly poisonous and fatal to animals and man

The class is subdivided into three sub-classes in accordance with the nature and septation of the basidium and the number of basidiospores produced by each basidium as follows

Basidiocarp absent

A	Basidium septate, basidiospores indefinite, perfect spore, a chlamydospore	Sub-class I order	**Hemi-basidiomycetes** *Ustilaginales* (Smuts & bunts)
B	Basidium, septate, basidiospores definite, perfect spore, a teliospore	Sub-class II order	**Protobasidiomycetes** *Uredinales* (Rusts)

Basidiocarp present

C	Basidium, nonseptate, basidiospores, definite	Sub-class III	**Eubasidiomycetes**
	Basidiocarp, open	Series I	*Hymenomycetes* (Mushrooms)
	Basidiocarp, closed,	Series II	*Gasteromycetes* (Puff-balls)

The generic characters of the Ustilaginales (smuts and bunts) and Uredinales (rusts) which constitute fungi of great economic importance are depicted in Figs 93 and 94

A statement showing important diseases, their causal agents, host range, mode of dissemination and [redacted], their nature and distribution is given in the accompanying Statement III

REFERENCES

1 Alexopoulos, C J *Introductory Mycology* John Wiley & Sons N Y, (1952)

2 Stevens, F L *The fungi that cause plant disease* McMillan & Co N Y, (1913)

3 Wolf F A & T F Wolf *The fungi* I John Wiley & Sons N Y, (1947)

CHAPTER 25

THE FUNGI-IMPERFECTI

The Deuteromycetes, an old name for this group of fungi, is a more or less artificial and heterogenous group of thousands of species unrelated to each other phylogenetically. None of them have perfect stages and may, therefore, be considered as "**form-genera**"; in many cases they have been discovered to be conidial stages of Ascomycetes and in a few cases of Basidiomycetes, in which classes they have been ultimately placed. They reproduce mainly by conidia of diverse types and in a few cases, conidia are absent and the fungi are found in vegetative stages, in which case *sclerotial* bodies of various types are produced.

These fungi, however, are of great importance as many are known to cause serious diseases of economic crops.

The mycelium is richly branched and profusely septate, hyaline to coloured; it forms chlamydospores, sclerotia and rhizomorphs. Conidia which are of diverse forms are produced on conidiophores which in turn are either free and naked, or organised in groups, masses, clusters, **sori, pycnidia, acervuli, sporodochia, pinnotes, coremia** etc. (Fig. 95).

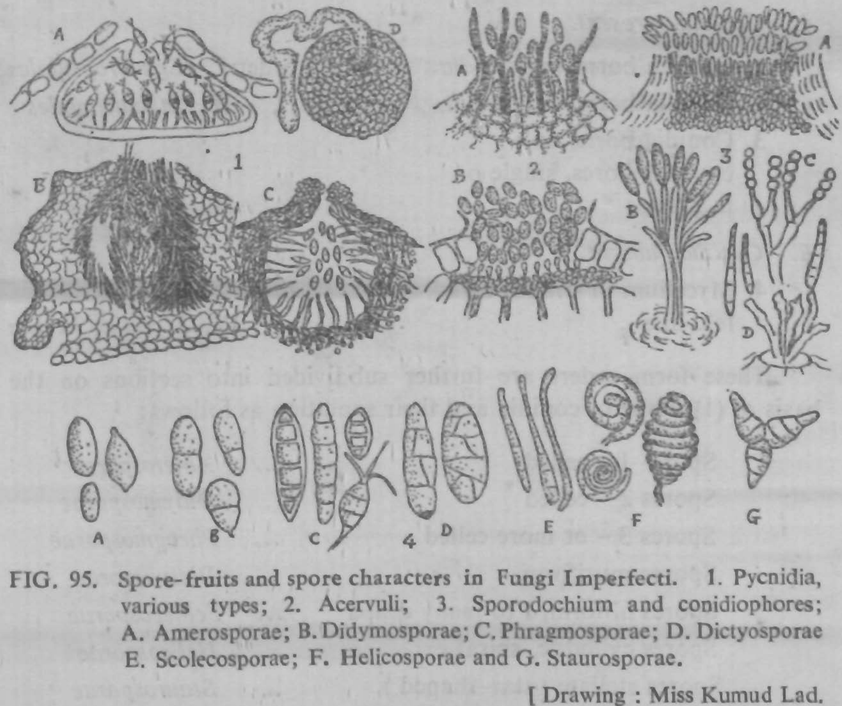

FIG. 95. Spore-fruits and spore characters in Fungi Imperfecti. 1. Pycnidia, various types; 2. Acervuli; 3. Sporodochium and conidiophores; A. Amerosporae; B. Didymosporae; C. Phragmosporae; D. Dictyosporae E. Scolecosporae; F. Helicosporae and G. Staurosporae.

[Drawing : Miss Kumud Lad.

Parasitism is mainly of a facultative type which enables the fungi to oversummer under adverse conditions There are many obligate saprophytes in this class Pleomorphism and physiologic specialization are present, though not of such extreme types as in the rust fungi

Some of the most important groups of diseases of economic importance caused by members of this class are the leafspots, anthracnoses, fruit-rots, wilts and root rots The "*tikka*" of groundnut, the anthracnose of grapes, the wilt of cotton, the "yellows" of cabbage, the Panama disease of banana, the blast of rice, the red rot of sugarcane and the bean anthracnose and a host of others are all caused by these fungi

The taxonomic arrangement is based on (1) type of spore-fruit (2) shape of conidia, (3) septation of conidia and (4) colour of conidia and is, therefore, purely artificial, without any definite mutual affinities (Fig 98) The group is divided into four form-orders in accordance with the character of the spore-fruit and is further sub-divided into form-families and sections on the basis of spore-characters as follows

A KEY TO THE FORM-ORDERS OF THE FUNGI IMPERFECTI

A *Conidia, present*		
1 Conidia borne in *pycnidia*	Form order I	*Sphaeropsidales*
2 Conidia borne in *acervuli*	,, ,, II	*Melanconiales*
3 Conidia borne on conidiophores, single or in groups	,, ,, III	*Moniliales*
B *Conidia, absent*		
4 Mycelium in strands or felt-like	,, ,, IV	*Mycelia-Sterilia*

These form-orders are further subdivided into sections on the basis of (1) shape of conidia and their septation as follows

Spore 1 - celled	*Amerosporae*
Spores 2 - celled	*Didymosporae*
Spores 3 - or more celled	*Phragmosporae*
Spores muriform	*Dictyosporae*
Spores filiform, 1 to many celled	*Scolecosporae*
Spores cylindric, spiral	*Helicosporae*
Spores stellate (star-shaped)	*Staurosporae*

These sections are further subdivided into sub-sections on the basis of spore-colour viz hyaline, bright or dark

Important deseases caused by members of this form-class are given in the accompanying statement IV

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1 Alexopoulos, C J *Introductory Mycology* John Wiley & Sons, New York, (1952)

2 Stevens, F L *The fungi that cause plant diseases* McMillan & Co, N Y, (1913)

3 Wolf, F A & T F Wolf *The fungi* I John Wiley & Sons, N Y (1947)

CHAPTER 26

THE SCHIZOMYCETES

The Schizomycetes constitute the bacteria, which may be considered as the smallest organisms known, excepting, perhaps, the viruses, which have a doubtful position These organisms were first discovered by Locwenhoek, a Dutch lens maker in 1676 The epoch-making discoveries and researches of Pasteur (1860-64) on their fermentative activities, of Robert Koch (1876) in respect of bacterial origin of anthrax, those of Burrill (1878-83) on their phytopathogenic nature were the true beginnings of a new era in the advancement of this science Pasteur, thus, may aptly be considered as the father of the science of Bacteriology

Bacteria are unicellular micro-organisms devoid of chlorophyll and dividing by fission Although thev have close similarities to animals, specially in their motility and mode of nutrition, they are traditionally grouped under plant kingdom in the division Thallophyta the spore-plants Being devoid of chlorophyll, they have no independent metabolism and are either saprophytes or parasites, deriving their nourishment from non-living and living organic matter respectively The former are scavengers and also play an important role in Industries, Agriculture and Medicine and are thus beneficial to man, the latter cause diseases of man, animals and plants The former are largely used in many of our industries, such as brewery, bakery, vinegar making, silage, soil fertility and the like Many of the modern antibiotics like *streptomycin*, *chloromycetin* and *aureomycin*, which have powerful bacteriocidal properties and used in the treatment of tuberculosis, typhoid and other dreaded diseases of man, are the products of *chemical* activity of bacteria and related organisms like the Actinomycetes

MORPHOLOGY OF A BACTERIAL CELL

Bacterial cells vary greatly in size, the majority being 1 u in length These cells may be spherical (**cocci**), rod-shaped (**bacilli**) or spirals (**spirili**) These cells may, occur in groups and are designated **strepto-bacillus** in rod shaped bacilli, **micrococcus** when in a single layer, **diplococcus**, when arranged in pairs, **pediococcus** when in squares, **staphylococcus**, when in irregular groups, **streptococcus** when in chains and **sarcina** when in cubes or pattern of eight or more, these various groupings are due to the ability of the various species to divide in various planes

The cell wall is composed of chitin, cellulose and other proteinous material, the exact nature of which has not yet been definitely determined Many bacterial cells have the capacity to secrete a slimy or mucilagenous **sheath** or **capsule**, which may afford protection against injurious chemicals

Although the presence of a true nucleus has not been definitely demonstrated, recent researches (Knyasi, 1951) claim satisfactory demonstration of a true nucleus, with resultant mitosis The existence of a true bacterial nucleus can, thus, be taken for granted

Locomotion Many of the true bacteria are provided with organs of locomotion, called **flagella** over their bodies, these are flexible and whip-like fine threads and are much longer than the main cell The number and position of these organs vary with *genera* The cells without flagella are called **atrichous**, those with a single flagellum at one end, **monotrichous**, those with tufts of flagella at one end, **lophotrichous**, **peritrichous** when flagella surround the entire body and **amphitrichous** in the case of bipolar flagella Flagella are very delicate and difficult to observe, except through special staining techniques or through the electron microscope Some bacteria, specially spore-formers, lose their flagella with age

Spores This constitutes the resting stage and is a feature of animal pathogens They are surrounded by a thick resistant, impervious wall and remain dormant for a period and resume activity with the return of favourable conditions Such spores are formed within vegetative cells and are known as **endospores**, they are in the nature of hybernating stages The majority of the spore-formers are found in the rod-shaped bacteria, the family *Bacillaceae*, which are human and animal pathogens (Fig 96)

Sexuality The presence of sexuality in bacteria is a moot question, not yet satisfactorily settled, the opinions and evidences presented are contradictory, the demonstration of a true nucleus, doubtless, means that bacteria are capable of transmitting hereditory characters in the same fashion as other organisms Sexual fusions have not been directly observed but the evidence for the occurrence of such a phenomenon is forthcoming and with better cytological technique, may be definitely settled in course of time Asexual reproduction by transverse fission, in the meanwhile, appears to be the only method of cell division in bacteria

Cultural characters Bacteria are capable of growth in culture media, both liquid and solid On the latter, they produce colonies, which are distinctive for species and which have been used for

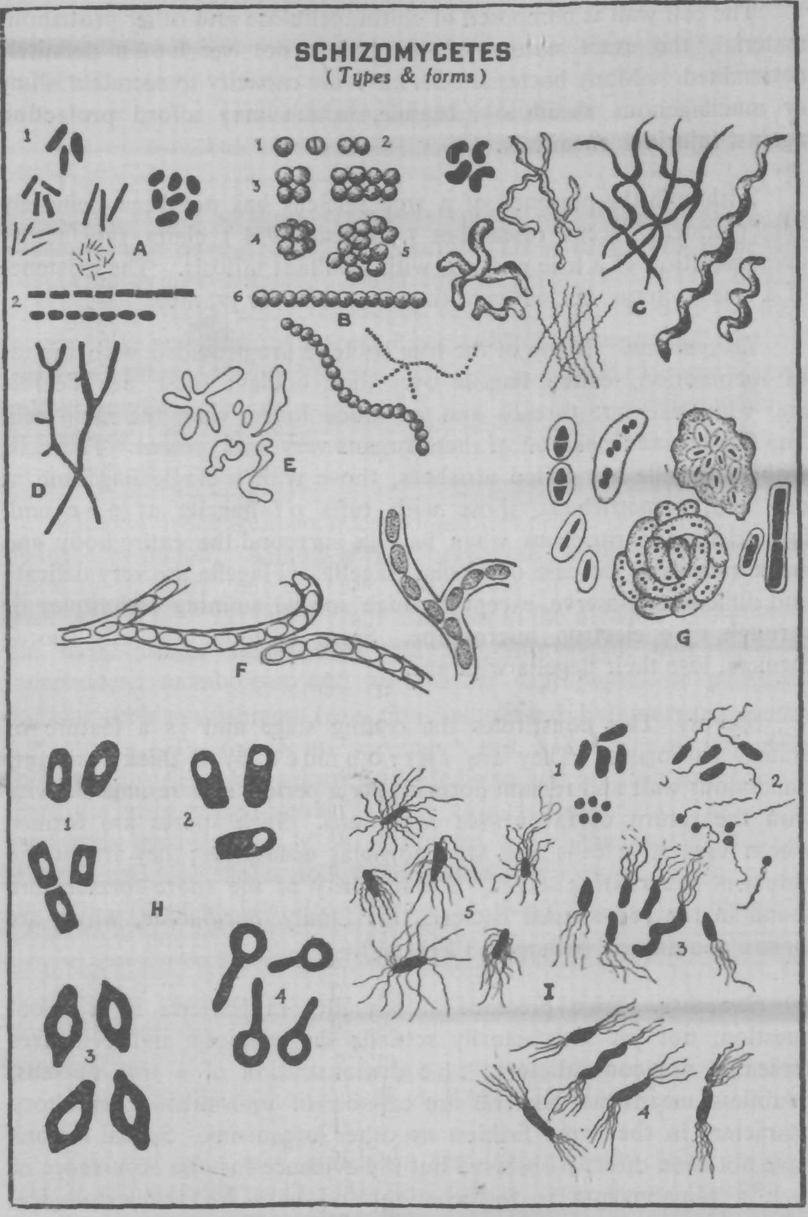

FIG. 96. Structure and types. A. *Bacilli*, different types, streptobacillus; B. *Cocii*, various types, micro-, diplo-., strepto-, staphylo, sarcina; C. *Spirilla*, various types; D. Trichobacteria; E. Involution forms; G. Capsules, various types; H. Spores, 1 equatorial, 2 polar, 3 clostridium type, 4 plectridium (drum sticks): I. Flagella. various types, 1 atrichous, 2 mono-trichous, 3 lophotrichous, 4 amphitrichous, 5 peritrichous.

[Kamat, 1953.

separation of groups. Colonies differ in colour, transparency, topography, marginal variations and may be designated and described in various ways as shown in Fig. 97. Common media used for culturing bacteria are nutrient broth and nutrient agar. Special media either of vegetable, non-synthetic or synthetic type, are used for special purposes.

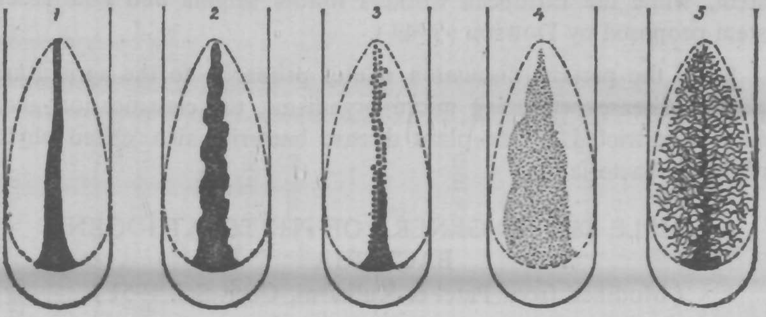

FIG. 97 Types of streak cultures. 1. Filiform; 2. Echinulate; 3. Beaded; 4. Effuse; 5. Arborescent [After Frost.

Life cycle. The life cycle of a bacterial cell is probably the simplest among plants. In non-spore formers, the cycle is repeated by successive asexual cell divisions and formation of daughter cells, which separate as independent unicellular plants, leading an active life all through and only interrupted by unfavourable environment.

In spore-formers, on the other hand, a resistant spore (endospore) stage intervenes, enabling these organisms to with-stand conditions of desiccation and freezing; these resistant thick-walled cells resume activity with the return of favourable environment.

Classification. Being the smallest organisms known, bacteria are mainly classified on the basis of physiological and cultural characters and staining reactions and less on morphology and structure; the latter aspect helps in separation of broad groups and the former is mainly used for identification of genera and species.

The class *Schizomycetes* is subdivided into six orders as follows :

A KEY TO ORDERS OF SCHIZOMYCETES

A. Structure, simple, various shapes.	Order	*Eubacteriales*
B. Structure, fungus-like, filamentous.	,,	*Actinomycetales*
C. Structure, alga-like, sheathed	,,	*Chlamydobacteriales*
D. Structure, slime-like, resembles slime moulds.	,,	*Myxobacteriales*
E. Structure, flexuous, screw-like, amoeboid.	,,	*Spirochaetales*
F. Structure, minute, human parasites	,,	*Rickettsiales*

Much confusion exists regarding the nomenclature of these organisms, the same generic name being used by different workers to designate different types Some of the important classifications are those of Migula, Erwin F Smith, Dowson, S A B Committee and the recent one proposed by Patel and Kulkarni (1951) for phytopathogenic bacteria American bacteriologists follow S A B system, while the European workers follow Migula and the recent system proposed by Dowson (1949)

Since the present discussion relates primarily to the agricultural aspect of disease-producing micro-organisms, the classification given below is restricted to the plant disease bacteria, also called phytopathogenic bacteria

A SIMPLE KEY TO GENERA OF PHYTOPATHOGENIC BACTERIA

(Modified from Patel & Kulkarni, Curr Sci 1951)

Family *Phytobacteriaceae*

General characteristics Short or long rods, generally motile and gram negative, **non-spore formers**, not acid fast, aerobic, hydrolise starch, gelatin and casein, ferment dextrose, capsulated, do not attack cellulose, Vogues-Proskauer and indol negative, various colour reactions

Optimum growth temperature, 20-30°C, plant pathogens, causing leafspots, cankers, soft rot, galls, wilts and blights

A *Motile, polar*

1 Colony, greenish, water soluble, incites leafspots & cankers — Genus *Chlorobacter* (Syn Pseudomonas)

2 Colony, white, incites leafspots or blights — Genus *Phytobacterium* (Syn Pseudomonas)

3 Colony, yellow, water insoluble, incites leafspots and blights — Genus *Xanthomonas*

4 Colony, white, pectin not-attacked, incites hypertrophy and galls — Genus *Agrobacterium*

B *Motile, peritrichous*

5 Colony, white, pectin not-attacked, incites blights — Genus *Erwinia*

6 Colony, white, pectin attacked, incites soft rots — Genus *Pectobacterium*

C *Non-motile*

7 Colony, white, or other shades, incites wilts — Genus *Aplanobacter* (Syn Corynebacterium)

Some of the important distinguishing characteristics of the seven genera of phytopathogenic bacteria are given in the following table

Table 17 *Important systems of nomenclature compared*

(Adopted from Patel and Kulkarni Ind Phytopath 1951)

Motile (Polar)	Motile polar and Non-motile	Non-motile	Non motile, motile (Peritrichous)	Motile (Peritrichous)	Authority
Pseudomonas		Baterium		Bacillus	Migula (1900)
Bacterium		Aplanobacter		Bacillus	Smith (1905)
	Phytomonas			Erwinia	S A B (1923)
Pseudomonas (Xanthomonas)		Corynebaterium	Bacter um		Dowson (1939-42)
Phytobacterium, Pseudomonas, Xanthomonas, Agrobacterium		Aplanobacter		Erwinia	Magrou and Prevot (1948)
Pseudomonas, Xanthomonas, Agrobacterium		Corynebacterium		Pectobacterium, Erwinia	S A B (1948)
Chlorobacter, Phytobacterium, Xanthomonas, Agrobacterium		Aplanobacter		Pectobacterium, Erwinia	Patel and Kulkarni (1951)

Table 18 *Important characteristics of genera of Phytobacteriaceae*

(Adopted from Patel and Kulkarni, Ind Phytopath 1951)

Character	Xanthomonas	Phytobacterium	Chlorobacter	Agrobacterium	Aplanobacter	Pectobacterium	Erwinia
Symptoms on plants	Leaf spot	Leaf-spot	Leaf-spot	Hypertrophy	Wilt	Rot	Blight
Colony colour	Yellow	White	Greenish	White	Shades of grey	White	White
Gram reaction					+	∓	
Motility	Polar	Polar	Polar	Polar	Non-motile	Peritrichous	Peritrichous
Shape	Rod	Rod	Rod	Rod	Rod	Rod	Rod
Gas						∓	
Lactose	Acid	No-acid	Acid	Acid	Acid	Acid	No-acid

The important features characterising the bacterial plant pathogens distinguishing them from the animal pathogens, are their inability to produce spores, their rod shape and their motility, the first characteristic has great influence on the life cycles and is of practical importance in the control of these pathogens

Some of the important diseases caused by bacteria in crop plants together with their causal organisms, hosts, their nature, and distribution are listed in the accompanying statement V

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CHAPTER 27

PLANT VIRUSES

Virus diseases, also known as *degeneration diseases*, constitute a distinct group of plant maladies which may be described as a connecting link between the non-parasitic and parasitic group They attack a variety of plants of economic importance and cause serious damage and losses The highly infectious nature of viruses was first demonstrated by Iwanowski in 1892 and subsequently confirmed by Beijerinck in 1898

The well-known virus infections in man are small-pox, infantile paralysis, yellow fever, measles, mumps and scarlet fever

SYMPTOMS AND EFFECTS

Some of the important types of symptoms may be mentioned as follows

1 Yellows, 2 Mosaic, 3 Yellow Vein, 4 Rosette, 5 Curly Top, 6 Bunchy Top, 7 Streak, 8 Ring-spot, 9 Small leaf, 10 Leaf Curl, 11 Phyllodae

While some viruses can be recognised on the basis of symptoms, they do not provide reliable criteria for classifying them Viruses rarely cause death of affected plants they are in the nature of degeneration diseases and seriously affect growth, yield and performance Mosaic and Yellowing are common symptoms (Fig 98)

MODES OF TRANSMISSION

1 *Grafting* This is the only method employed in certain special types of virus diseases Peach yellows, "Spike" disease of sandal and "small leaf" of cotton in India are well known examples

2 *Sap transmission* This is done by rubbing or injecting the diseased sap into healthy individuals and is a very common method in "Mosaic" types of viruses Many virus diseases can be transmitted experimentally by this means

3 *Through seed* This type of transmission through true seed is rare and has been observed in ring spot of tobacco, mosaic of lettuce, beans and cucumber

4 *Vegetative parts* This is a very common method of transmission in vegetatively propagated plants, such as potato,

VIRUS DISEASE SYMPTOMS

(in plants)

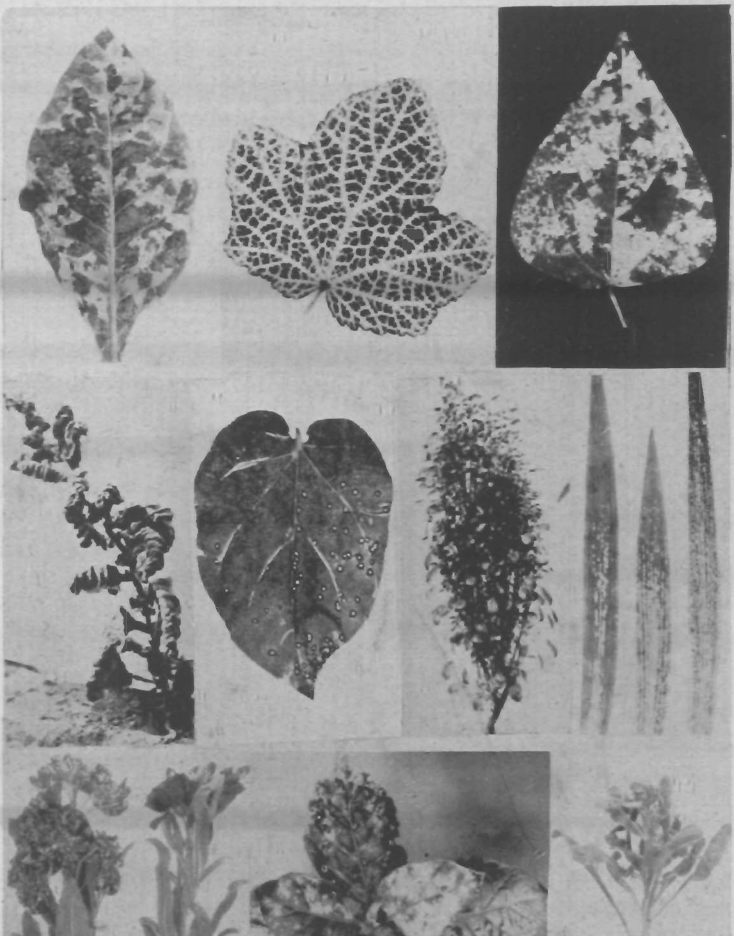

FIG. 98. Virus symptoms. 1. Mosaic; 2. Yellow Vein; 3. Yellow Mosaic; 4. Leaf Curl; 5. Local lesions; 6. Little leaf; 7. Streak; 8. Breaking of flowers; 9. White mosaic; 10. Bunchy top.

[Kamat, 1953.

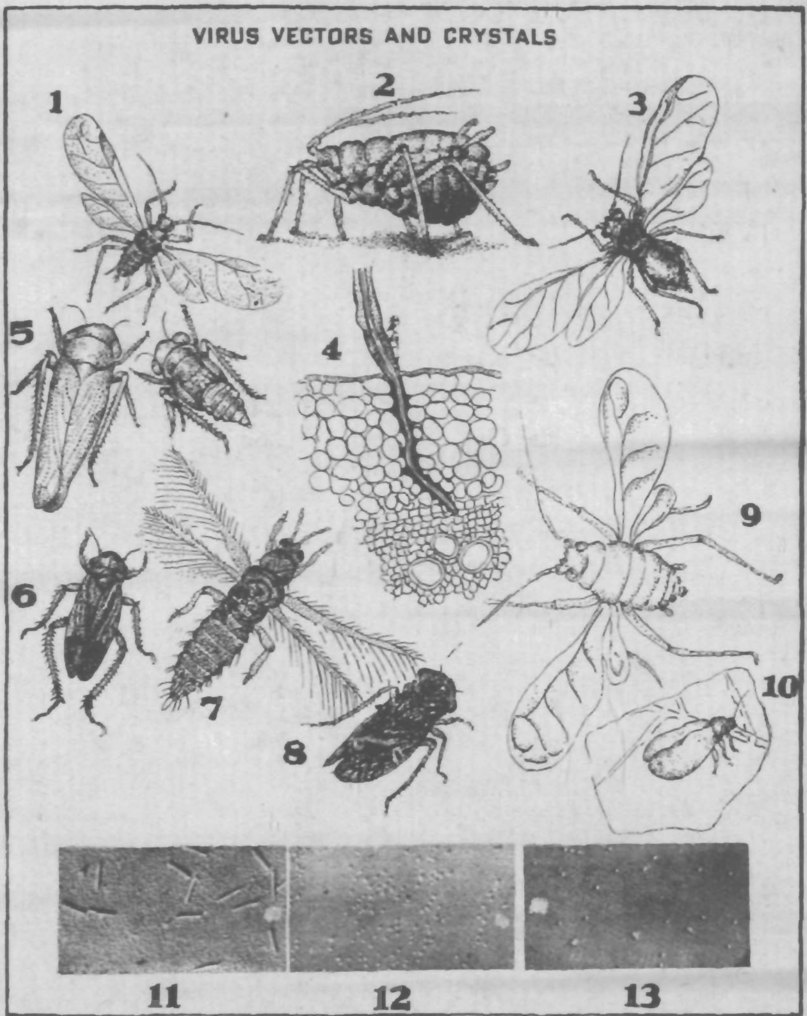

FIG. 99. Virus vectors and crystals. 1. Aphis (*Myzus persicae*), adult, vector of mosaic of papaya, bean, peas and cucumber; 2. Nymph of same in act of feeding; 3. *Aphis maydis*, adult, vector of mosaic of sugarcane; 4. Intracellular path followed by stylet to reach phloem tissue; 5. Leaf-hopper (*Eutattix tenellus*) vector of curly top of beets; adult & nymph; 6. Leaf hopper (*Nephotettix apicalis*) vector of "Dwarf" of rice; 7. *Thrips tabaci*, vector of tomato spotted wilt; 8. Leaf hopper (*Mycropsis trimaculata*) vector of peach yellow; 9. Aphis (*Pentalonia nigronervosa*) vector of bunchy top of banana; 10. White fly (*Bemisia tabaci*) vector of leaf curl of tobacco and yellow vein of *hibiscus;* 11, 12 & 13. Crystals of tobacco mosaic, southern bean mosaic and tomato bush mosaic respectively (as seen through electron microscope).

[Kamat, 1953.

gladiolus, cardamom, sugarcane and banana Bunchy top of banana and " Katte " disease of cardamom are well-known examples

5 *Contact* Some viruses are more infectious than others, and are capable of being transmitted, in nature, by the hands of workers in the fields, the implements used for various agricultural operations and knife blade used for cutting tubers and other vegetative parts of propagation Mosaic of tobacco and cucumber and the spindle tuber of potato are examples of this category

6 *Through soil* This is a very rare method and has been demonstrated for winter wheat mosaic and "big vein" virus of lettuce, where the virus persists in soil for varying length of time and infects the plants through the root system

7 *Transmission by dodder* This is affected through the phanerogamic parasite, the *Cuscuta* popularly known as dodder, which picks up the virus from the diseased plants through its haustoria and transmits it to healthy plants through newly formed haustoria (Bennet 1940) The dodder, thus functions both as an alternate host and an agent of transmission This method though not reported in nature has been used successfully in transmitting viruses, which are not amenable to mechanical transmission (Fig 37)

8 *Insects* No other group of diseases is so dependent upon insect life for their dissemination under natural conditions as viruses Such insects which carry the virus are known as " *Vectors* "

Most vectors belong to " sucking " type of insects comprising the class of leaf hoppers (Cicadellidae), the aphids (Aphididae), and the Aleyrodidae, popularly known as white-flies Thrips and beetles also transmit a few viruses Aphids play a more important role in virus transmission than other groups The aphis, *Myzus persicae*, is able to transmit over 50 viruses (Fig 99)

INSECT TRANSMISSION OF VIRUSES

Specific relationship exists not only between certain insects and viruses but also between definite groups of insects and viruses "Yellows" group of viruses are generally transmitted by leaf hoppers, while the ' mosaic ' group are usually carried by aphids

Vectors exhibit differential capabilities in the actual manner of transmission While some insects carry the infective agent as if mechanically, a very large number possess *specific* relationship with the virus Each virus, thus, is transmitted by a specific insect or insects and no other This may be termed as biological method and is very similar to the relationship of the *anopheles* type of mosquito to the transmission of the malarial parasite Many viruses spend varying periods of time in their insect vector before they are capable of being transmitted to their respective hosts This latent period is known as "*Incubation period*" and is specific to the vector In this respect, viruses exhibit an ingenious type of heteroecism The insect vector thus is not only a transmitting agent but also allows multiplication of the virus within its body The perpetuation of the virus through colonies of insect vector and its multiplication therein, have been recently demonstrated (Carl Maramorosch, 1951) for aster yellows

NATURE OF CAUSAL AGENTS

Viruses were variously described as ultra-microscopic bacteria protozoa, enzymes, toxins or abnormal products of mal-nutrition Highly invisible and filterable nature of these viruses was, however, recognised since a long time That they passed through the bacteria-proof filters definitely pointed out to their distinctive nature from the normal bacterial cells Beijerinck (1898) described it as "*Contagium vivum fluidum*" Duggar (1921) described it as "Chemical entity produced from host cells and capable of inducing disturbances in living tissues." He subsequently advanced the ingenious theory that viruses were "wandering genes" and incited disturbances in plant cells. Stanley (1935) isolated a crystalline protein from tobacco mosaic, which when inoculated into healthy plants, multiplied and induced typical symptoms Tobacco mosaic virus, thus occupies a classical position in virus investigations It was the first to be investigated regarding its infectious nature (Meyer, Holland, 1886), its filterable character (Ivonowski, Russia, 1892) and its chrystalline properties (Stanley, U S A 1935) The nucleo-protein nature of several viruses has since been confirmed by other investigators (Fig 99, 11–13)

Viruses, thus, may be described as **Nucleoproteins,** comprising nucleilic acid and proteins, with the following important characteristics

1 Highly infectious
2 Ultra-microscopic
3 Capable of multiplication in living host tissue
4 Incapable of being cultured in artificial media, and
5 Capacity to mutate under changing environment

The question as to whether viruses are living or non-living will be determined by what constitutes "life" Viruses have many attributes usually associated with "life" and may be considered as a stepping stone between the inanimate and the animate world, although direct proof of their living nature is not yet definitely forthcoming

SIZE AND SHAPE OF VIRUS BODIES

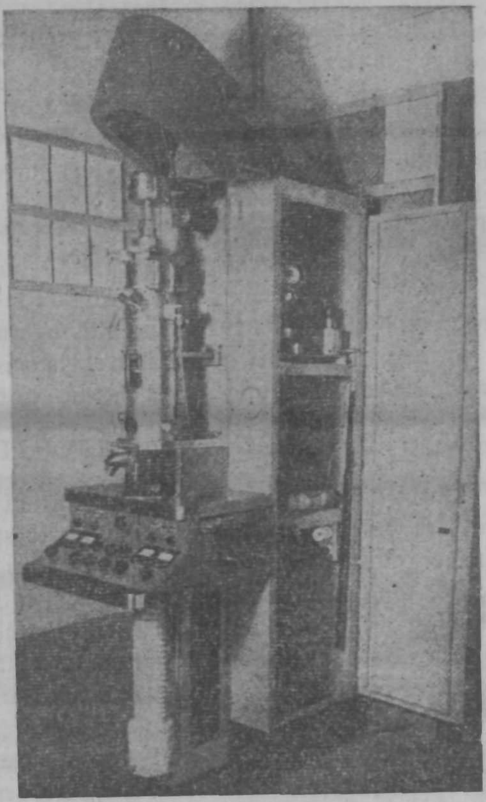

FIG. 100. Electron microscope.
[R. C. Model.

The unit of measurement in viruses is 1/1000th of a micron (1 milimicron or 1 m. µ.). It will be seen from the table given below that viruses vary from 10 to 250 m. µ. in size; the smallest bacterial cell measures 0.5 to 1.00 µ; this means that the viruses are 1/10th to 1/250th times *smaller* than the normal bacterial cell.

Viruses can also be measured by forcing them through porcelain filters of known pore-size. This method, however, has not the merit of accuracy.

The shape of virus particles has been determined through the help of the electron microscope (Fig. 100) at a magnification of 10,000 to 20,000 and has been found to be either spherical, small and big rods and groups thereof, very similar to the bacterial groupings.

Comparative sizes of viruses and other micro-organisms and bodies.

Normal fungus spores.	1 µ and above.
Normal bacterial cell.	0.5 to 1 µ.
Red blood corpuscle.	7500 m. µ.
Parrot fever virus.	250 m. µ.
Small Pox virus.	150 m. µ.
Chicken cancer virus.	100 m. µ.
Tobacco mosaic virus.	75 m. µ.
Foot and mouth disease virus.	10 m. µ.
Haemoglobin molecule.	6 m. µ.
Egg albumin molecule.	4 m. µ.

(Modified from Stanley)

Viruses, thus, cover a range in size between chemical molecules and bacteria

NOMENCLATURE OF VIRUSES

Until 1927, viruses were designated by the host name and nature of symptoms produced viz peach yellows virus, potato spindle tuber virus, tobacco mosaic virus, sugar beet curly top virus and so on The viruses were, subsequently, named by Smith (1937) with latin names of host and numbers such as *Hibiscus* virus 1, *Nicotiana* virus 1, *Prunus* virus 2, *Solanum* virus, 1, 2, 3, and so on A binomial system of the type used for nomenclature in higher plants has been proposed by Holmes (1939) and although no finality has been reached as to the practicability of the above systems, the latter may, perhaps, provide a basis for future virus classification

VIRUS DISEASES OF PLANTS

Virus diseases constitute an important phase of plant pathology and are responsible for great and widespread damage to a large number of economic plants They thus provide a really serious menace to Agriculture and have consequently attracted great and close attention of the Plant Pathologist and Physiologist in recent years, owing to their mysterious behaviour and nature Spike disease of sandal, mosaic of papaya (*Carica papaya*), small leaf of cotton (*Gossypium* sp) "*Katte*' or marble disease of cardamom (*Elettaria cardamomum*) in India, "yellows ' of aster, curly top of sugar beets, mosaics of tomato and beans, potato and tobacco, and the destructive and widespread " Bunchy Top " and chlorosis of banana (*Musa sapientum*) are a few of the well-known virus diseases of economic importance causing extensive damage

Some of the most common and destructive diseases of virus origin, their nature, mode of transmission, vector relationship, host range and distribution are given in the accompanying Statement VI

GENERAL METHODS OF CONTROL

Being highly infectious and insect transmitted, direct measures are of little avail in the control of these diseases Methods of eradication consisting of rogueing, seed-certification, isolation carried out on a systematic country-wide scale, offer the best, effective and practical solution to the problem Plant Pests and Disease Control Acts, local, national as well as international, can be and have been successfully enforced in stamping out such diseases like the Bunchy top of banana and mosaic of sugarcane, "*Katte*' disease of cardamom and others Annual importation of seed from hill stations has yielded excellent results in combating the virus diseases of potatoes in penninsular India Development of virus-resistant varieties of crop plants, althoguh a new and recent line of development, offers a good field, though difficult of achievement and has remarkably succeeded in a few cases, such as bean mosaic, leaf curl of cotton, mosaic of sugarcane and curly top of sugar beets A novel method of "crop-free" period or "closed season" has worked very effectively in controlling the "yellow vein mosaic" of *Hibiscus* in parts of Bombay and in mosaic of lettuce in California Tuber-indexing has been developed as a special method (Fig 55) in controlling virus diseases of potatoes and other root-crops in U S A

The enforcement of strict quarantine regulations in the movement of seed-stock, isolation, and seed-certification have yielded good results and constitute general methods of controlling these diseases

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CHAPTER 28

PLANT-PARASITIC NEMATODES

Nematodes are round worms belonging to the invertebrates and live mostly in moist soil either as parasites on plants and animals or are free-living The parasitic nature of nematodes in plants was first discovered by Berkeley in 1855 Hook-worm disease and Guinea worm in man and root knot in plants are well known examples of diseases caused by these animal-parasites Some species are beneficial and feed on eggs and larvae of insects

NATURE AND STRUCTURE

These organisms belong to the round worm family and are minute, mostly 1 m m in length and sometimes even microscopic (80–100 u with a breadth of 50–100 u) The structure of the main body is round, tubular, with the digestive system within, overlaid by an outer pad of muscle, which, in turn, is enclosed in a layer of tough "*chitin*" They are provided with well-developed nervous and excretory systems The mouth and head are provided with sharp teethlike structures Many species of nematodes are bisexual and are known to be very prolific, laying eggs at the rate of 300–500 per female The two important genera, causing plant diseases, are *Tylenchus* and *Heterodera* which can be distinguished from each other by the shape of their females, the female is elongated in the former and swollen in the latter (Fig 101)

HOST PLANTS

The parasitic nematodes are very cosmopolitan in their host relationships, the root knot nematode is known to infect over 1200 species of plants, both wild and cultivated, while the *Anguillulina* type has a restricted range, infecting many cereals Some of the most important host plants so affected by the former are potato, tomato, brinjal, tobacco, Cruciferae and Brassiacas, *Piper longum*, *Piper beetle*, onions, gladiolus, cannas, dahlias, chrysanthemum, cotton and many others, while the latter is restricted to cereals, such as wheat, rye, and oats Cereals, peanuts and velvet beans are unaffected by the root-knot types.

SYMPTOMS AND EFFECTS

The well-known symptoms of nematode infestation are the formation of little raised pimples or galls on the under-ground parts in the case of root-knots and distortion, malformation and blistering of the

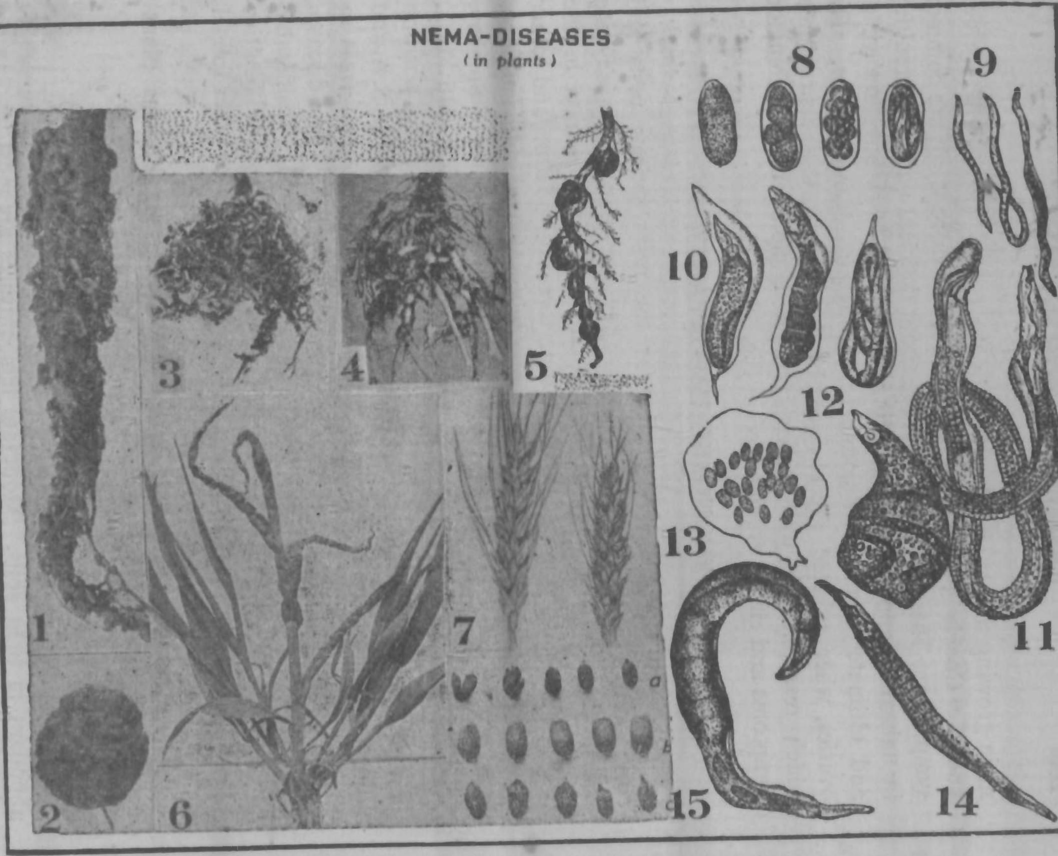

FIG. 101. Effects and causal organisms. 1. Root galls on beet; 2. Potato; 3. Tomato; 4. Grape; 5. Chrysanthemum; 6. Nema-infected wheat plant showing dwarfing & twisted shoots; 7. Healthy and infected ear. a & c. Infected, b. healthy wheat grains; 8. *Heterodera merioni*, stages in egg development; 9. Stages in development of young worms; 10. Stages in development of male; 11. Fully developed male; 12. A female worm; 13. Mass of eggs; 14 & 15. Male and female of *Anguillulina tritici*. (1 after Bessey, 2–5 Bessey and Byars, 6 & 7 Fromme, 8–13 Stone and Smith, 14 & 15 Byars.)

[Kamat, 1953.

main growing shoots and dwarfing in the case of the cereals Root-knots, "Cockle", hard smut, false ergot, brown root rot are common symptoms These infestations bring about deficient nutrition, resulting in unhealthy appearance, yellowing, bad stand, dwarfing, low yields and ultimately partial or complete wilting in advanced cases The ovaries, when affected, are replaced by dark hard gall like structures, which resemble the well-known "ergots" Some of the common symptoms and effects are depicted in Fig 101, 1-7

ECONOMIC IMPORTANCE

Root-knot nematodes are by far the most serious pests and cosmopolitan in their host relations They are known to cause wide spread damage to many crops and are a limiting factor in the cultivation of such crops like cotton, tobacco, potato, and other solanaceous crops in all parts of the globe, with sub-tropical conditions *Piper longum* and *Piper betle* are seriously affected in parts of Bombay, where these diseases have become a limiting factor in their cultivation Cockle disease of cereals, specially wheat, has assumed serious position in northern parts of India and Pakistan, Southern sections of U S A and Europe The golden nematode in potato is confined to small areas in the eastern parts of U S A and in hill stations in India These diseases have a world-wide distribution and have assumed considerable importance on account of their persistent nature, difficulties experienced in their control and for being fore-runners for other fungal and bacterial pathogens

The "meadow nematode" is one of the most serious plant nematodes and affects a large range of host plants

LIFE CYCLE

Nematodes are mostly soil-dwellers, and live in moist soil being abundant in light soils Moderate temperatures are most favourable for their growth and activity, they are practically non-existent at or lower than 13°C Root-knot nematodes thrive best at 25°-27°C They are known to persist in soil for varying periods, sometimes even 30 & 40 years The wheat and the rye nematodes are known to persist for 28 & 39 years respectively in soil cultures A female is capable of laying 300-500 eggs, which escape into the soil through disintegration of the affected roots and are carried mainly by irrigation water to different parts of the fields They are capable of completing 10-12 generations in a year under favourable environment Many species of nematodes are bisexual, laying eggs following fertilization Females greatly predominate the males in several free-living forms Recent studies have established the presence of host specialization in these organisms with varying degrees of infection capacity and host range Fig 101, 8-13 depict the life cycle of the root knot nematode

FIG. 102. Soil fumigation by soil injector for nematode control.

[Courtesy : Stevens & Stevens.

GENERAL METHODS OF CONTROL

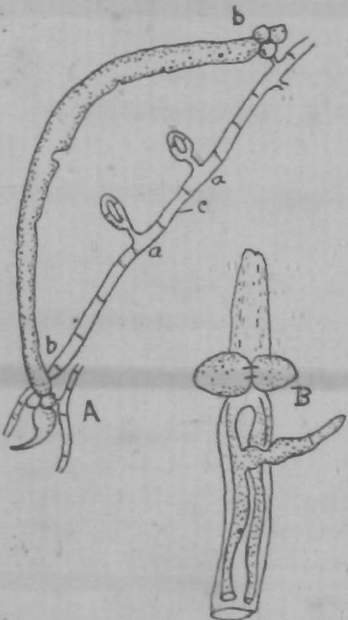

FIG. 103. Nematode-trapping fungus, *Dactylella bembicoides*, A. A nema trapped at both ends, a. open trap; b. closed trap; c. the fungus; B. Fungus feeding within nematode. [After, Couch.

Nematode infestation is very difficult to control by direct methods, specially in perennial crops like *Piper longum* and *P. betle*, where fumigation is neither a practical nor an effective proposition. Since root-knot nematodes are not known to infect cereals, some control can be secured by the practice of long rotations. Growing of trap crops and soil-fumigation are other methods advocated for reducing the nema population. Some of the fumigants which have given promising results are *Chloropicrin*, D-D, *Iscobrome*, Methyl bromide and ethylene dibromide. *Chloropicrin* is applied to the soil at 200 lbs. per acre and allowed to act for 10–15 days before planting. The treated soil is covered with a thin film of water to prevent evaporation. The fumigation is carried out with the help of a soil-fumigator (Fig. 102). In Hawaii, nematode infestation in pineapple crop has been effectively controlled by a method of "biological control," using the nematode-trapping fungus, *Dactylella bembicoides* (Fig 103)

The "cockle" disease of wheat and other cereals, on the other hand, is relatively easy of control, being largly seed-borne Rigid seed selection and soaking seed in salt water for removal of infected grain, prior to seeding, are sufficiently effective in combating the disease

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GLOSSARY OF MYCOLOGICAL TERMS

Albinism The white appearance of plant parts resulting from the failure of chlorophyll production

Antheridium The male gamete-producing organ

Antherozoid A motile male gamete

Apothecium A saucer-shaped ascus-containing fruiting body

Aplano spores Non-motile spores produced in a sporangium

Ascogonium Female gametangium of Ascomycetes

Ascus A sack producing endospores, typical of Ascomycetes

Atrophy The reduction in size of an organ by disturbed metabolism

Autoecious The need of only one host for completing a life cycle

Bacterium A rod-shaped bacterial cell

Basidiospore A spore formed exogenously on a basidium

Basidium A club-shaped structure producing exogenous spores, typical of Basidiomycetes

Blight The rapid discoloration and death of the tissues over certain portions of plants

Canker A dead area on a stem surrounded by living cortical tissues

Carrier A plant that carries a virus or other infective agent without showing symptoms

Chlamydospore A thick-walled spore formed by the modification of a hyphal cell

Chlorosis Destruction of chlorophyll

Cilium A hair-like vibratory filament attached to a cell

Clamp connection A bridge-like hyphal connection typical of higher Basidiomycetes

Cleistothecium A closed, thick-walled ascus-containing fruit

Conidium An exogenously produced asexual spore

Conidiophore The hyphal branch that bears the conidium

Contagious Spreading from one to another

Curl The distortion of a leaf resulting from the unequal development of its two sides

Degeneration A gradual disappearance or catabolic modification of normal structures of the cells

Dikaryon A pair of closely associated nuclei of opposite sex

Diploid The 2n number of chromosomes

Disinfectant Any agent for destroying the causal agent of disease

Disease Result of interaction between host, parasite & environment

Dwarfing The underdevelopment of any organ of a plant

Ectotrophic Mycorrhizal association in which the fungus has its hyphae outside or between the cells

Endogenous Produced inside

Endobiotic Living within another organism

Endophytic Living within another plant

Endospores Spores produced within the mother cell

Epibiotic Living upon or outside another organism

Epidemic The widespread and destructive development of a disease on many plants in a community

Epiphyte A plant which lives upon another plant deriving little or no nourishment from it

Epiphytotic See Epidemic

Etiolated Yellowed as a result of insufficient light

Etiology The description of the cause of disease

Exogenous Produced outside

Exudations Liquids discharged from the protoplasts

Facultative parasite An organism that is ordinarily saprophytic but under proper conditions may be parasitic

Facultative saprophyte An organism that is ordinarily parasitic but under proper conditions may be saprophytic

Flagellum A long, delicate, contractile filament protruding from certain cells

Fungicide An agent that inhibits or kills fungi

Fungus A filamentous, chlorophyll-less thallophyte dividing by budding

Gall An overgrowth induced by an infectious entity

Gametangium A gamete-producing cell

Gamete Sex cell with 1n condition of chromosomes

Gram-negative A negative reaction to the standard Gram's stain

Gram-positive A positive reaction to the standard Gram's stain

Hairy root The development of large numbers of small roots on a limited area

Haploid The chromsome number n of the gametophytic generation or phase

Haustorium A fungus structure used in absorbing food

Heteroecious Requiring two or more unrelated hosts for completing the life cycle

Heteroecism The development of different spore stages of the life cycle of a parasite on two unrelated hosts

Heterothallic Producing gametes on separate and distinct mycelia

Homothallic Producing fusing gametes on the same mycelium

Host The plant on or in which the parasite lives and obtains its food

Holocarpic Condition where entire thallus is converted into reproductive structure

Hymenium A fertile layer giving rise to reproductive bodies

Hyperplasia The abnormal increase in the number of cells without their enlargement

Hypertrophy The abnormal enlargement of cells

Hypha A single filament of a fungous mycelium

Hypoplasia The underdevelopment of cells, tissues or organs

Immunity A zero relationship between a plant and a causal agent

Infection The invasion and multiplication of a causal agent

Intercellular Between the cells

Intracellular Crossing the cells

Karyogamy Fusion of nuclei

Knot Overgrowth on roots

Lesion A local injury or morbid structural change

Malady A multiplicity of diseased individuals

Meiosis Reduction division of the necleus forming haploid nuclei

Micron A thousandth of a millimeter

Monotrichous Having only one flagellum

Mosaic Variegated pattern in green parts due to chlorotic patches

Mummification The drying down and shrivelling of fruits and other plant parts

Necrosis The death or disintegration of cells and tissues

Oospore A fertilized egg that develops into a resting spore

Oogonium Female gametangium of Oomycetes

Oogamous A sexual process characteristic of Oomycetes

Ostiole An opening of the fruit body

Parasite An organism that lives within or upon another living organism from which it derives nourishment and in which it may cause various degrees of injury

Parasitism The phenomenon of the growth of one organism, the parasite, at the expense of another, the host

Pathogen An entity capable of producing disease

Pathogenicity The capacity of an entity for producing a disease

Perithecium A round to flask-shaped, ostiolate spore fruit producing asci

Peritrichous Having flagella all over the periphery of the cell

Plasmodium A naked multinucleate, vegetative body capable of amoeboid motion

Plasmogamy Fusion of protoplasm

Polymorphism The possession of several asexual spore stages in the life cycle of an organism

Pustule A local elevation of the epidermis that may rupture to expose the causal agent

Pycnidium A variously shaped cavity containing conidia

Race A strain of a pathogen characterized by the limitation of its host range to certain species and varieties

Resistance The sum of the qualities of the host that retard the activities of the causal agent

Rhizoid Intracellular thallus branch that absorbs food and provides anchorage

Rhizomorph An aggregation of hyphae into a cord-like cable

Rot State of decomposition

Saprophyte An organism that derives its nourishment from dead organic matter

Scab The abnormal thickening of the outer layer or layers of tissues resulting from local irritation

Sclerotium A small, compact, hardened mass of hyphae that may bear fruiting bodies, a fungus tuber

Sign The manifestation of disease by the presence of structures of the causal agent

Sorus A compact aggregation of spores and sporophores

Sporangiophore A sporangium-bearing hypha

Sporangium A sac that forms the asexual spores endogenously

Spore A one-to several-celled body set apart for reproduction

Sporogenous Capable of forming spores

Stroma A compacted mass of hyphae that may produce fruiting bodies

Symptoms Expressions of disease

Susceptibility The sum of the qualities of a plant that allows the development of the causal agent

Thallus The undifferentiated vegetative body of the lower plants

Tolerance Ability of the plant to endure the development of the parasite without showing marked symptoms of disease

Variety One or more races of a pathogen that are characterized by the limitation of their host range to a certain genus or genera

Vector An agent that may transmit a pathogen

Vascular necrosis Destruction of vascular bundles, typical of wilt diseases

Wilt The loss of turgescence of plant tissues, usually as a result of inadequate water supply

Witches-broom A broom-like overgrowth produced by the dense clustering of branches

Yellowing Etiolation caused by destruction of green pigment

Zoospore Naked motile spore

Zygospore A resting spore produced by the fusion of isogametes

Zygote A resting spore with 2n condition of chromosomes

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