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Preface

While it is true that excellent progress has been made in developing new and widely adopted wheat cultivars, diseases still pose a big challenge for sustainable production of this cereal. The first book on wheat diseases in Brazil, entitled, “Doenças do Trigo e seu Controle,” was published in Portuguese by Editora CERES, São Paulo, in 1978. Fifteen years later, the second updated edition of the book entitled, “Manejo Integrado de Enfermedades del Trigo,” was published in Spanish, under the patronage of World Bank, by Imprenta Landivar, Santa Cruz de la Sierra, Bolivia, in 1993. The first book was well received especially in Brazil, whereas the second book had a wide readership in a number of Latin-American countries since it was written in Spanish. In a few years both the books were out of print. Later, after almost 20 years, several people from the wheat community expressed the need for a book in English with updated information including re-occurrence of old diseases and emergence of new diseases as well as new races of pathogens, and their impact on global wheat production.

By and large, the severity of some diseases caused by necrotrophic pathogens is directly related to change in the tillage system. In the modern era of precision agriculture, the conservation tillage system is fast expanding and demands adequate changes which are also addressed in this book.

The objective of this book was to offer necessary information on biotic and abiotic stresses that adversely affect the wheat production, descriptions of the most important diseases including necessary illustrations to help the reader the correct diagnosis of diseases and comprehend their epidemiological aspects. The book also deals with pillars of integrated disease management which would be eco-friendly and reduce severity of diseases and yield losses. It encompasses different tools of disease management and their implications especially for the tropical and subtropical areas of the world with acquired Latin-American experiences of over 40 years.

The book neither deals with descriptions and recommendations of different fungicides nor with the various wheat cultivars because they are considered outside the scope of the present objective. Nonetheless, it offers a comprehensive list of references for each chapter to enable the reader to look for specific details on a given aspect including fungicides and wheat cultivars. It is hoped that this will serve as one of the reference books for students, young scientists, extension workers, and progressive farmers dealing with wheat and wheat production. Undoubtedly, it is a timely, and much needed publication considering the present world food crisis.

Londrina, Paraná, Brazil Y.R. Mehta

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Contents

Chapter 1
Wheat and Wheat Production Constraints

1.1 Wheat and Wheat Production Constraints

Wheat is staple food for the major part of the world's population. Approximately 630 million tons of wheat are produced annually, roughly half of it in developing countries (Peña 2007; Singh et al. 2011). It is especially important in India, in the USA, in Europe, and in the Latin and central-American countries including Argentina, Brazil, Bolivia, Chile, Mexico, Paraguay and Uruguay. Wheat production in the USA in 2011, was around 34.4 million tons harvested from 18.6 million hectares (Savary et al. 2012). Annual wheat production in the Latin American region, for example, used to be rather low compared to that in some technologically advanced countries and remained so, for some years (15 and 20 × 106 t). However, as in other countries, wheat productivity in this region has gradually increased during the past 20 years, reaching an average of over 2.0–3.5 t/ha, depending upon the country. This significant increase in wheat yield is mainly due to the introduction of high yielding cultivars and improvements in integrated disease management practices which are dealt with in the following chapters, followed by individual descriptions of some important wheat diseases that cause substantial yield losses in different wheat growing areas, of the world. Besides several diseases, the reoccurrence of scab, the emergence of an aggressive race of stem rust Ug99 and the spread of a relatively new disease—the Pyricularia blast, attacking cereals other than rice, are causing serious threats to wheat cultivation in much of the world (Vurro et al. 2010; Ralph et al. 2012).

1.1.1 Natural Limitations for Wheat Cultivation

Most wheat cultivation in Latin America is mechanized. In some cases soils are acidic with low pH and low fertility (<5.5), deficient in phosphorus and in some regions the level of exchangeable Al causes toxicity to the plant which is normally

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expressed by inhibition of root growth referred to as "Crestamento". In Al toxic soils lime application allied with the use of Al tolerant cultivars would be the best solution to overcome the problem (Hede et al. 2001). However, lime application in excess predisposes the plant to take-all disease caused by *Ophiobolus graminis*. The majority of Mexican wheats cultivated in the past were with high production potential but were sensitive to Al toxicity and to different fungal diseases as well. At present, most of the wheat cultivars are of local origin. In recent years, lot of progress has been achieved towards the development of Al resistant cultivars especially in Brazil. Matzenbacher (1988) reported that irrespective of the application of large quantities of lime the soil pH has not yet been corrected satisfactorily in the major wheat areas.

To solve the aluminum problem for example, the first efforts to incorporate aluminum tolerance of Brazilian wheats in Mexican wheats, with their wider adaptability, started in the early seventies with the collaboration of the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico. As a result of this collaboration a number of semi-dwarf cultivars with high production potential and with aluminum tolerance were released (Rajaram et al. 1988a, b). In recent years, the national wheat breeding programs of Brazil released several aluminum tolerant cultivars with high production potential (EMBRAPA 2011). Similarly, much progress has been made during the past 20 years to minimize other problems like soil compaction, low soil fertility and soil erosion.

Wheat cultivation is subjected to a number of other limitations like diversity of climatic and soil conditions, pests and diseases. Unfavorable conditions for wheat cultivation include hail storms, heavy and prolonged rainfall, germination on spike, drought and frost. Over 100 diseases caused by biotic and abiotic stresses affect wheat in the USA and in other countries (Bockus et al. 2011; Savary et al. 2012).

1.1.2 The Wheat Plant

Wheat is a self-pollinated plant however, in some cases the cross-pollination may reach up to 2–3 %. The wheat species can be classified in three categories; *Triticum aestivum* L., *T. compactum* Host (club wheat) and *T. durum* Dest. (hard wheat). The first two species are hexaploids containing three genomes AABBDD ($n=21$), whereas the third species is tetraploid [*Triticum turgidum* (L.) Thell.] containing 14 chromosomes AABB ($n=14$). The three species together represent about 90 % of the cultivated wheat in the world (Wiese 1987; Gill et al. 1991; Blanco et al. 1998; Bockus et al. 2011).

First of all it is necessary to get acquainted with the wheat plant to understand the plant-pathogen interaction and the recent advances that have been made in genetical, molecular and chemical aspects. Since the botany of the wheat plant is described in several publications, it is considered dispensable here in this book. However, a description of some aspects of the anatomy of wheat seed and the growth cycle of the wheat plant are considered worthwhile (Fig. 1.1, Tables 1.1 and 1.2).

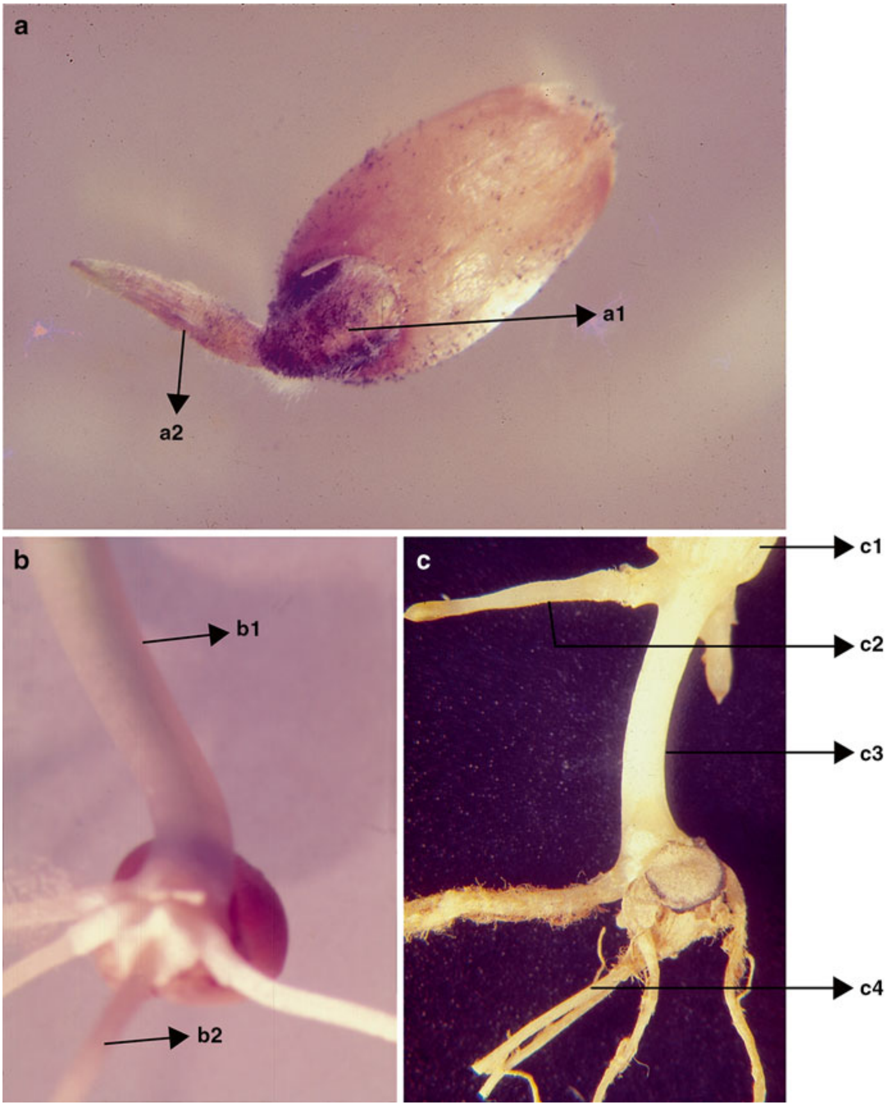

Fig. 1.1 Wheat seed germination. a1-plumule/coleoptile; a2-radicle; b1-coleoptile; b2-radicle; c1-stem; c2-crown roots; c3-coleoptile; c4-seminal roots

In order to make the reader familiar with a normal cereal plant, in the following pages the growth cycle as developed by Zadoks et al. (1974), is presented as; (a) Principal growth stages Table 1.1 and (b) Secondary growth stages Table 1.2.

Table 1.1 Decimal code for the growth stages of cereals (Zadoks et al. 1974)

1 Digit code	Description
0	Germination
1	Seedling growth
2	Tillering
3	Stem elongation
4	Booting
5	Inflorescence emergence
6	Anthesis
7	Milk development
8	Dough development
9	Ripening
T	Transplanting and recovery (rice only)

Principal growth stages

Table 1.2 A decimal code for the secondary growth stages (Zadoks et al. 1974)

2-Digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Germination		
00	Dry seed		
01	Start of imbibition		
02	–		
03	Imbibitions complete		
04	–		
05	Radical emerged from caryopsis		
06	–		
07	Coleoptiles emerged from caryopsis		
08	–		
09	Leaf just at coleoptiles tip		
	Seedling growth		
10	First leaf through coleoptile	1	
11	First leaf unfolded*		Second leaf visible (<1 cm)
12	Two leaves unfolded		
13	Three leaves unfolded		
14	Four leaves unfolded		
15	Five leaves unfolded		50 % of laminae unfolded
16	Six leaves unfolded		
17	Seven leaves unfolded		
18	Eight leaves unfolded		
19	Nine or more leaves unfolded		

(continued)

Table 1.2 (continued)

2-Digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
	Tillering		
20	Main shoot only		
21	Main shoot and 1 tiller	2	
22	Main shoot and 2 tillers		
23	Main shoot and 3 tillers	3	This section to be used to supplement record from other sections of the table: 'concurrent codes'
24	Main shoot and 4 tillers		
25	Main shoot and 5 tillers		
26	Main shoot and 6 tillers		
27	Main shoot and 7 tillers	3	This section to be used to supplement record from other sections of the table: 'concurrent codes'
28	Main shoot and 8 tillers		
29	Main shoot and 9 or more tillers		
	Stem elongation		
30	Pseudo stem erection	4–5	In rice: vegetative lag phase
31	First node detectable	6	
		7	Jointing stage
32	Second node detectable		
33	Third node detectable		
34	Fourth node detectable		Above-crown nodes
35	Fifth node detectable		
36	Sixth node detectable		
37	Flag leaf just visible	8	
38	–		
39	Flag leaf ligule/collar just visible	9	Pre-boot stage In rice: opposite auricle stage
40	–		
41	Flag leaf sheath extending		Little enlargement of the inflorescence, early boot stage
42	–		
43	Boots just visibly swollen		Mid-boot stage
44	–		
45	Boots swollen	10	Late-boot stage
46	–		
47	Flag leaf sheath opening		
48	–		
49	First awns visible		In awned forms only
	Inflorescence emergence		
50 51	First spikelet of inflorescence just visible	N 10-1 S	
			N = non-synchronous crops S = synchronous crops
52 53	1/4 of inflorescence emerged	N S 10-2	

(continued)

Table 1.2 (continued)

2-Digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
54 } 55 }	1/2 of inflorescence emerged	{ N { S 10-3	
56 } 57 }	3/4 of inflorescence emerged	{ N 10-4 { S	
58 } 59 }	Emergence of inflorescence completed	{ N { S 10-5	
	Anthesis		
60 } 61 }	Beginning of anthesis	{ N { S 10-51	Not easily detectable in Barley. In rice: usually immediately following heading
62	–		
63 } 64 } 65 }	–		
66	–		
67	–		
68 } 69 }	Anthesis complete	{ N { S	
	Milk development		
70	–		
71	Caryopsis water ripe	10–54	
72	–		
73	Early milk	} 11-1	
74	–	} 11-1	
75	Medium milk	} 11-1	
76	–	} 11-1	} Increase in solids of liquid endosperm notable when crushing the caryopsis between fingers
77	Late milk	} 11-1	}
78	–		
79	–		
	Dough development		
80	–		
81	–		
82	–		
83	Early dough	} 11-2	Finger nail impression not held
84	–	} 11-2	
85	Soft dough	} 11-2	
86	–	} 11-2	Finger nail impression held, inflorescence
87	Hard dough	} 11-2	

(continued)

Table 1.2 (continued)

2-Digit code	General description	Feekes' scale	Additional remarks on wheat, barley, rye, and oats
88	–		Losing chlorophyl
89	–		
	Ripening		
90	–		
91	Caryopsis hard (difficult to divide by thumb-nail)	11-3	In rice: terminal spikelets In rice: 50 per cent of spikelets ripened
92	Caryopsis hard (can no longer be dented by thumb-nail)	11-4	In rice: over 90 % of spikelets ripened
93	Caryopsis loosening in daytime		
94	Over-ripe, straw dead and collapsing		
95	Seed dormant		
96	Viable seed giving 50 % germination		
97	Seed not dormant		
98	Secondary dormancy induced		
99	Secondary dormancy lost		
	Transplanting and recoery (rice only)		
T1	Uprooting of seedlings		
T2	–		
T3	Rooting		
T4	–		
T5	–		
T6	–		
T7	Recovery of shoot		
T8	–		
T9	Resumption of vegetative growth		

The proposal of this codified system of secondary growth stages is of special interest in epidemiological studies, herbicide, gametocyte and fungicide applications and assessment of yield losses. Besides, it has an additional advantage over the Feekes and Large scale since it takes into account the post anthesis growth stages which are not well defined by the Feekes and Large scale (Tables 1.1 and 1.2). The new decimal codification system of the growth stages has been used by most research scientists worldwide.

1.1.3 Types of Diseases

Although the aluminum toxicity problem has been solved to a great extent, there are other threats to wheat cultivation such as diseases caused by fungus, bacteria and virus. These diseases can be divided into: (a) diseases caused by viruses; (b) diseases caused by mycoplasmas; (c) diseases caused by bacteria; (d) diseases caused by fungi; (e) diseases caused by nematodes; and (f) nonparasitic diseases.

Basic information about the causal agents of these diseases is herewith described.

Diseases Caused by Bacteria

Plant pathogenic bacteria are prokaryotic, unicellular, rod shaped, most of them gram negative, motile via flagella and aerobic or facultative anaerobic. They are introduced in the plant via heavy rain-splash and insects, but always through wounds. They are capable of producing toxins and enzymes which decay plant tissues. Their size and shape vary but in general they could be up to 2 μm long (Bockus et al. 2011). Most of the bacteria are also seed transmissible. They can be seen under a common microscope not requiring an electronic microscope as viruses do. Identification of bacteria is done through biochemical properties and pathogenicity tests in different hosts, contrary to the fungal pathogens whose identification is based mostly on morphological characters. In recent years several bacteria have been classified through serological tests using monoclonal antibodies and by using biotechnological methods like RAPD, RFLP, rDNA, ERIC-REP PCR, microarray, sequencing, etc. The multiplication of bacteria is by asexual means and their movement in plants can be localized or systemic.

There are five different bacteria causing diseases in wheat. They are *Clavibacter*, *Bacillus*, *Erwinia*, *Pseudomonas* and *Xanthomonas*. Among these bacteria Pseudomonads and Xanthomonads are of major importance since they cause heavy yield losses in a number of important plant species. In general, the phytopathogenic Pseudomonads produce green fluorescent pigment in culture medium deficient in phosphorus, whereas in common culture media colonies of these bacteria are whitish, shiny and somewhat raised. Xanthomonads, on the other hand, constitute a group of bacteria which produce yellow colonies in common culture media. Both *Pseudomonas syringae* and *Xanthomonas campestris* (*axonopodis*) include different forms which are distinguished by their pathogenicity on some host species and are referred to as "pathovar". *X. translucens* pv. *undulosa* for example, attacks wheat whereas *X. c.* pv. *hodei* attacks barley. Over eight bacterial diseases of wheat are reported: bacterial leaf stripe, also called black chaff (*X. t.* pv. *undulosa*), bacterial mosaic (*Clavibacter michiganensis* subsp. *michiganensis*, white blotch (*Bacillus megaterium* pv. *cerealis*), pink seed (*Erwinia rhapontici*), stem melanosis (*Pseudomonas cichorii*), bacterial sheath rot (*Pseudomonas fuscovaginae*), basal glume rot (*Pseudomonas syringae* pv. *atrofaciens* and bacterial leaf blight (*Pseudomonas syringae* pv. *syringae*), the first being the most important one worldwide (Mehta 1993; Mathur and Cunfer 1993; Maraite et al. 2007; Bockus et al. 2011).

Diseases Caused by Fungi

Fungal diseases are caused by biotrophic (obligate parasites which attack only the living plants) and necrotrophic fungi (facultative parasites which survive on dead tissues and do not necessarily need living plants). Numerous fungi are pathogenic to plants, animals and human beings. Fungal pathogens that attack plant species are grouped into four classes: phycomycetes, ascomycetes, basidiomycetes and imperfect fungi. In general, these fungi reproduce by spores which are resistant to ample temperature and humidity variation. Under adverse climatic conditions they can survive in the form of mycelia, sclerotia or clamydospores in the soil or in dead plant tissues. Most of the fungal pathogens are facultative parasites. Among different pathogens, the fungal pathogens represent the greatest threat worldwide. Depending upon the pathogen, the cultivar and the year, some of the fungal pathogens can cause 100 % yield losses.

Unlike viruses and bacteria, the fungi can be easily visualized through a simple microscope and in the majority of cases their presence can be verified by the naked eye. The causal organism of some of the common plant diseases can be identified based on symptoms whereas others need morphological and pathological characterization including their reaction on different host cultivars. A large majority of necrotrophic fungal pathogens can be easily cultivated on common artificial media.

The wheat fungal pathogens are widely distributed wherever the crop is grown and can attack different plant parts.

Diseases Caused by Mycoplasmas

Mycoplasma like organisms are prokaryotic and although they belong to one group of bacteria, they are smaller than the bacteria and lack a rigid cell wall. They are similar to pneumonia like organisms and can be cultivated in artificial culture media. As plant pathogens the mycoplasmas are responsible for diseases called "aster yellows". Mycoplasmas are transmitted by insects and their movement in the plant is systemic. So far there has only been one mycoplasma disease of wheat and it has not yet reported from Latin America. Aster yellows are reported to attack monocotyledonous plants like wheat, barley, rye and oats, but over 300 dicotyledonous plants are also known to be hosts of this disease (Bockus et al. 2011).

Diseases Caused by Nematodes

Nematodes are roundworms and are found in soil and water. They are eel-shaped and some females are sac-like and they can be observed with an ordinary microscope and multiply by eggs. The nematodes penetrate the host, especially the roots, through their stylet. Diseases caused by nematodes can be important especially those caused by a complex of fungal and nematode or fungal and bacterial pathogen (*Rhizoctonia solani* + *Pratylenchus* spp., *Anguina tritici* + *Corynebacterium tritici*). To date, several nematodal wheat diseases have been reported among them Cereal Cyst Nematodes, Root Gall Nematodes and Root Knot Nematodes may be of some economic importance in specific wheat areas (Mehta 1993; Bockus et al. 2011).

Diseases Caused by Virus

The morphological form of plant viruses differs greatly. Wheat viruses, for example, are filamentous, spherical or bacilliform. The main virus vectors are aphids, whitefly, mites, leafhopper, nematodes, etc. They are also transmitted by seed, sap, grafting, fungi and even by mechanical means. At least two viruses; Barley Stripe Mosaic (BSM) and Wheat Chlorotic Streak Virus are known to be transmitted by seed (Phatak 1974). Today over 30 different virus diseases are known to occur in wheat and among them two stand out as of special economic importance. Barley Yellow Dwarf (BYD) is the most widely distributed disease worldwide and Wheat Soil-Borne Mosaic transmitted by the fungus *Polymyxa graminis* is especially important in the southern region of Brazil, although its occurrence is reported in other countries like Argentina, the USA, Egypt and Italy. Some of the virus diseases are dealt with in one of the following chapters of this book. For other virus diseases of minor economic importance the reader may refer to other publications (Zaitlin and Palukaitis 2000; Bockus et al. 2011; Jones et al. 2010).

Diseases caused by viruses were discovered towards the end of the nineteenth century and thereafter several virus diseases of different plants were described. Diseases caused by viruses affect the biological and physiological process of plants and can be responsible for reduction in production potential of plants. Among the plant pathogens, viruses occupy a special position. They are sub-microscopic agents and constitute the central part of the nucleic acid (RNA or DNA) surrounded by a protective protein coat. They cannot be multiplied in artificial culture medium. They lack self metabolism process and hence depend totally on the synthesizing system of the host for their multiplication. Thus, the viruses differ drastically from other causal organisms like fungi, bacteria, nematodes, etc. A high resolution electron microscope is an essential equipment to visualize the extremely small virus particles measured in nanometer (millimicron). One nanometer is equal to 1/1,000 of a micrometer (micron) which in turn is equal to 1/1,000 of a millimeter. Plant viruses vary between 20 and 1,000 nm with some exceptions at either end of the scale. The potato spindle virus having lower molecular weight has no protective protein coat. Thus, a new term "virod" was proposed for this virus and for some other similar plant pathogens. For characterization of a virus, serological tests as well as some physio-chemical tests are deemed necessary along with electron microscopy to visualize the format of virus particles.

Nonparasitic Diseases

Nonparasitic diseases are not caused by any pathogen. They may be caused by several other factors like nutritional disorders, toxic effects of chemicals (like herbicides), very high or very low temperatures (like frost), insects, or nutritional imbalance (see Chap. 8).

1.1.4 Factors that Affect the Development of Diseases

Among the climatic conditions, the temperature and the atmospheric humidity play an important role. Almost all the plant pathogens are active under high humidity conditions provoked by continuous or intermittent rains for several days. Helminthosporium diseases can reach epidemic proportions under continuous rains and warm temperatures, whereas Septoria diseases require continuous rains but lower temperatures for several days. Wheat mildew caused by *Erysiphe graminis* (*Blumeria graminis*), on the other hand, can be severe under warm temperatures followed by humid and cloudy weather (Amuzescu 2009; Shaw and Osborne 2011; Pritchard 2011).

Predisposition of wheat plants to different diseases is another factor to be considered. In general, attack by one pathogen predisposes the plant to some other pathogen which may not necessarily be considered as a secondary pathogen. *Ophiobolus graminis* for example, predisposes the plant to *Septoria tritici* infection. In this case, *S. tritici* may be considered as a secondary pathogen since *O. graminis* causes almost 100 % damage to the plant. Nonetheless, epidemiologically speaking, *S. tritici* infection may become important since it adds to the amount of inoculum in the field. The same may be true when the plant is predisposed to *S. tritici* after it is infected by *Rhizoctonia solani*. While predisposition of a plant to another pathogen is known to occur, there is an antagonistic effect between *S. tritici* and leaf rusts. Some virus pathogens can also predispose the plants to infection by *S. tritici* (Sanderson 1964). Wheat powdery mildew as a predisposing factor was demonstrated several decades ago (Jonston 1934; Manners and Gandy 1954). Predisposition of wheat to *Septoria* after *Erysiphe graminis* infection was reported by Brokenshire (1974). Similarly, the susceptibility to *S. nodorum* was believed to be due to the infection of leaf rust (Van der Wal et al. 1970). Undoubtedly, this kind of predisposition drastically reduces the yield.

The principal factors that affect the development of wheat diseases are basically related to climatic conditions, wheat cultivars and virulence of the pathogen. All these factors are inter-related. If a cultivar is susceptible but a virulent pathogen is absent then the disease will not occur or else will occur in a very low severity. If the cultivar is susceptible and a virulent pathogen is present but the weather conditions are not favorable for the disease in question, the disease will not occur. In contrast, if all three factors are present, the disease will occur. This is referred to as "the disease triangle".

Wheat cultivars can be classified into four categories: highly resistant; moderately resistant; moderately susceptible; and highly susceptible. Cultivars that are highly resistant or highly susceptible to all the pathogens do not exist. This is because resistance is a genetic character of a plant and also because different pathogens demand specific climatic conditions for their development (Van der Plank 1963).

1.1.5 Economic Importance of Diseases

Importance of disease is estimated through the yield loss it causes. At times, the importance of a particular disease is ignored or else underestimated because of the lack of accurate research data on assessment of losses (Nutter 1993; Vurro et al. 2010; Savary et al. 2012).

Losses caused by wheat diseases vary a lot from country to country. An interesting review on crop losses due to diseases and their implications for global food production losses and food security is presented by Savary et al (2012). These authors stated that direct yield losses of global agricultural productivity could be between 20 and 40 %. The indirect yield losses refer to the quality of product and may affect the human and animal health. Losses caused by wheat diseases in the USA, France and Nordic countries are summarized by McMuller et al (1997) and Savary et al (2012). Most of the losses in these countries are due to the fungal diseases like leaf blotch and Septoria nodorum blotch (Jain 2011; Savary et al. 2012). Some examples on yield losses caused by wheat diseases are given in the following pages, however losses caused by individual diseases are cited under their respective chapters.

Experiments to obtain quantitative data on loss assessment are difficult to conduct since they depend on several factors such as:

(a) the experiments have to be conducted in "Hot spot" locations for different diseases to avoid disease escape. Cultivars exhibit differential responses, some are highly susceptible to a particular pathogen while others are moderately susceptible and the data are valid only for the cultivar tested;
(b) success in experimentation also depends on the climatic conditions favorable to the disease. In case of unfavorable climatic conditions, artificial inoculations and repeated irrigations become necessary;
(c) in general, experiments on assessment of yield losses depend on the availability of specific fungicides, or in other words, fungicides which control all the diseases but not the one against which yield losses are being estimated. Normally, wheat is attacked by several diseases during different stages of its development. Selective and highly efficient fungicides to control leaf rust

and/or powdery mildew have become outdated and are no longer being commercialized;

(d) relatively new diseases like bacterial leaf stripe and Pyricularia blast are not controlled by the use of fungicides and available fungicides against Fusarium head blight (scab) are not highly effective;

(e) in addition, soil-borne root rot diseases cause appreciable yield losses and are invariably overlooked. Yield losses caused by common root rots of wheat may vary between 18 and 30 % (Diehl et al. 1983; Reis 1985). Mehta and Gaudêncio (1991) studied the relation between the severity of common root rot caused by *Bipolaris sorokiniana* and the wheat yield during four years and reported that for each 1 % increase in the root rot severity there was corresponding yield loss of 49 kg/ha;

(f) size of the experimental plot also plays an important role in the success of assessment of yield losses. For wheat, usually the plot size is 10–12 m^2 and for this size of field plots invariably some inter-plot interference is observed hence the losses are somewhat underestimated (Forster and Schaad 1988; Mehta and Bassoi 1993). To minimize this problem, distance between the plots should be increased. Although there are no definite rules for this, it is expected that the higher the distance between the plots the lower will be the inter-plot interference. Forster and Schaad (1988) reported inter-plot interference for the bacterial stripe of wheat even when the distance between the plots was 4.6 m;

(g) the experiments on yield losses should be continuous using newly released cultivars, since data on old cultivars may lose its importance;

(h) finally, assessment of yield losses provoked by a particular pathogen at different growth stages of wheat would be of special interest, especially to establish an appropriate fungicidal spraying schedule. However, such experiments are difficult to conduct and would demand dedication from a team of research workers.

Some information about yield losses is available in Brazil. Most of the information refers to losses caused by a complex of diseases but some information on losses caused by a specific pathogen is also reported. Yield losses caused by *B. sorokiniana* in a susceptible cultivar were estimated to be over 86 %. Such susceptible cultivars do not exist anymore, but a loss of over 86 % only demonstrates the potential of the pathogen (Mehta 1993). Mehta and Bassoi (1993), estimated yield losses of about 20–40 % depending upon the cultivar and the level of seed infection by *X. t.* pv. *undulosa*. In the case of leaf rust, it was possible to demonstrate that the earlier the disease epidemic starts the higher the yield losses will be (Fig. 1.2). There are a number of other reports about yield losses (Reis et al. 2000).

In Bolivia, yield losses caused by helminthosporium and leaf rust diseases, were reported to be between 38 % and 60 % respectively (Languidey and Barea 1993). In Brazil, yield losses of up to 100 % may be caused by Pyricularia blast (Kohli et al. 2011).

Irrespective of all the aforesaid problems, research data on yield losses provoked by a particular pathogen on a particular cultivar are very much needed. Information generated on yield losses would permit producers to adopt the appropriate control measures and determine the cost-benefit ratio of the existing measures.

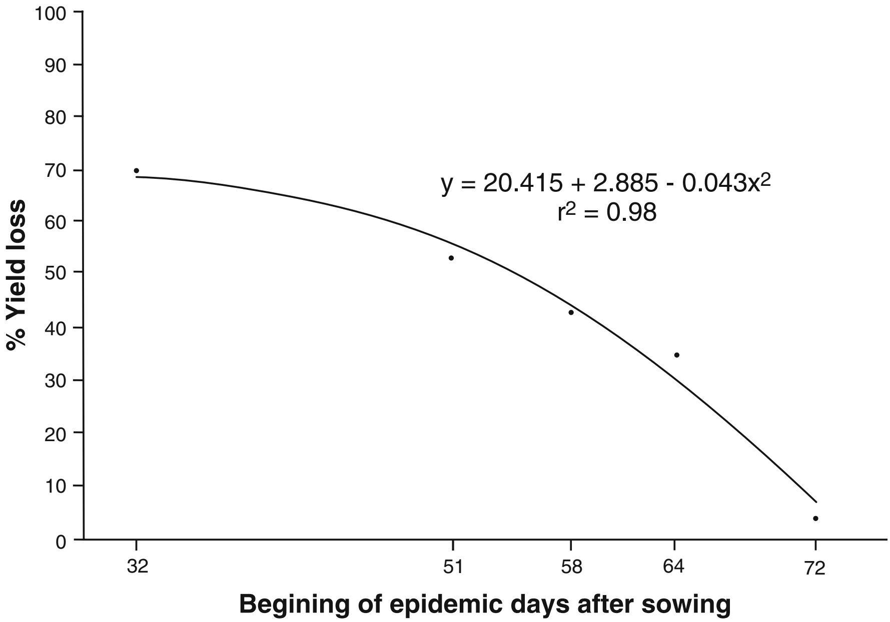

Fig. 1.2 Loss in yield in relation to the beginning of leaf rust epidemic in cv. Jupateco. Source: Mehta and Igarashi (1985)

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