Diseases of maize in South and South-East Asia: problems and progress

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In Asia, maize ranks third after rice and wheat both in area and production. In recent years, maize production has shown a steady increase without much increase in area, but productivity has been low (2.8 t ha^{-1}). The major maize-producing countries in Asia are China, India, Indonesia, Philippines, Thailand and Vietnam. Information embodied in this review pertains to the countries of South and South-East Asia. The ubiquitous incidence of diseases at the preharvest stage has been an important bottleneck in increasing production. The major diseases in the region are five downy mildews, four foliar, two pre-flowering and four post-flowering stalk rots, and leaf and sheath blight. Information on virus diseases, nematodes and postharvest microbial problems is also given. Information on distribution of diseases is provided. Concerted efforts involving regional and national programmes sponsored by the Rockefeller Foundation and the Centro Internacional de Mejoramiento de Maiz y Trigo have yielded good dividends, particularly in the case of downy mildew diseases. The development and release of cultivars resistant to downy mildew has been an important outcome of this cooperative research. The use of disease management methods other than host resistance has also been highlighted.

Keywords: Maize; *Zea mays*; disease control/management

In Asia, represented by as many as 34 countries, maize (*Zea mays*) as in the rest of the world, ranks third after rice and wheat, both in area and production. However, in the 1985 crop year, maize occupied the second rank after rice, because of the significant increase in maize production in China. Long-range trends in production have been analysed recently by the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT, 1992). In recent years, maize production in Asia has steadily increased. However, the average productivity was 2.8 t ha^{-1}, exceptions being China and North Korea with average yields of 3.7 and 6.7 t ha^{-1}, respectively (*Table 1*). It is acknowledged that increases in area are no longer possible and only increased productivity will be able to meet the increasing demand for maize, not only as a food commodity but also as a feed and industrial crop. The major maize-producing countries in Asia are China, India, Indonesia, the Philippines, Thailand and Vietnam. In this review, emphasis is mainly on countries of South and South-East Asia, including Afghanistan, Bhutan, Burma, India, Nepal and Pakistan in the former region and Indonesia, Philippines, Thailand and Vietnam in the latter.

An important bottleneck in increasing productivity is the ubiquitous incidence of diseases at the preharvest stage. The production trends during the last 3 years in India itself show how, by ensuring the availability of adequate seed of improved cultivars, it is possible to increase production without increasing the crop area. However, with suitable disease management practices, this production could be increased to an even greater extent. As was pointed out by Payak (1985), if agronomic practices and cultivars remain unaltered, the same level of productivity in India itself could be raised by 67 kg ha^{-1} by adopting the simple measure of seed treatment alone (see below).

Since the introduction of this crop in Asia, it has proved quite vulnerable to downy mildews. In fact, one of the earliest epidemics on this crop was Java downy mildew or sleepy disease caused by *Peronosclerospora maydis* (Raciborski, 1897). Since that time, no organized and systematic work on maize diseases was carried out until the 1950s. In 1960, the Rockefeller Foundation established what was then known as the Inter Asian Corn Programme (IACP) based in Pantnagar (India) and from 1967 in Bangkok (Thailand). As a result of the initiation of cooperative research activities, understanding of maize diseases has increased significantly and valuable information regarding reduction of the damage has been amassed (Payak and Sharma, 1985). This review highlights the disease management strategies suitable for the region.

Diseases constitute a significant factor in lowering yield and productivity in maize in Asia, as they do elsewhere. On a global basis, there is an estimated yearly loss of 9.4% of the economic product (grain) due

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Table 1. Area, production and productivity of maize in the Asian region (1989–1991)[a]

Region	Countries	Area harvested (10^{-3} ha)	Yield (t ha^{-1})	Production (10^{-3} t)
Middle East	Afghanistan	264	1.6	436
	Turkey	513	4.0	2 067
	Iran	3	0.9	40
	Iraq	42	2.9	121
	Saudi Arabia	2	–	–
	Syria	59	2.7	158
South Asia	Bhutan	52	1.5	81
	Burma (Myanmar)	124	1.5	190
	India	5 856	1.5	8 975
	Nepal	760	1.6	1 222
	Pakistan	856	1.4	1 185
South-East Asia	Indonesia	3 037	2.1	6 445
	Philippines	3 699	1.3	4 677
	Thailand	1 644	2.5	4 035
	Vietnam	484	1.5	720
East Asia	China	20 804	4.3	89 922
	North Korea	710	6.3	4 450
	South Korea	24	4.3	105
	Taiwan	84	4.0	332

[a]Source: CIMMYT (1992)

Table 2. Distribution of important diseases in major maize-producing countries of Asia

Region	Country	Diseases
South Asia	India	Turcicum leaf blight (TLB) maydis leaf blight (MLB), common rust, sorghum downy mildew (SDM) maize, sorghum and maize + sorghum strains, Philippine DM, brown stripe downy mildew (BSDM), banded leaf and sheath blight (BLSB), bacterial stalk rot (BSR), pythium stalk rot (PSR), late wilt, fusarium stalk rot (FSR), fusarium ear rot (FER), head smut (HS)
	Nepal	TLB, MLB, BLSB, BSDM, Philippine DM, common rust, FER, HS
	Bhutan	TLB, MLB, BLSB, common rust, FER
	Pakistan	TLB, MLB, BLSB, BSDM, common rust, FSR, FER, HS
South-East Asia	Indonesia	MLB, BLSB, Java DM, FSR, FER
	Philippines	MLB, Philippine DM, BLSB, polysora rust, FSR, FER, BSR
	Cambodia	MLB, BLSB, FSR, FER
	Laos	MLB, BLSB, FSR, FER, SDM (maize strain)
	Thailand	MLB, SDM (maize strain), BLSB, FSR, FER, polysora rust, anthracnose stalk rot
	Vietnam	TLB, MLB, BLSB, Philippine DM, FER
East Asia	Taiwan	TLB, MLB, BLSB, sugar-cane DM, polysora rust, common rust, bacterial stripe, common smut, sugar-cane mosaic virus, maize dwarf mosaic virus
	China	TLB, MLB, BLSB, HS, common smut, common rust, FSR, FER, maize rough dwarf virus, maize mosaic virus, late wilt, anthracnose stalk rot, eye spot

to diseases. For the USA, a figure of 12% has been computed (Cramer, 1967; James, 1981), while in countries such as India an annual reduction in grain yield of at least 13.2% has been estimated (Payak and Sharma, 1985). Even if the lower figure, 9.4%, is assumed to be realistic, the annual reduction in grain yield in Asia (excluding Japan) is 9.1 Mt.

Table 2 lists the important diseases prevalent in major maize-producing countries in Asia. The spectrum of diseases has changed and some diseases which were considered minor are now more conspicuous. Since the incidence of downy mildews appears to have waned, *Rhizoctonia* (banded leaf and sheath blight) and stalk rots are now becoming the dominant disease groups in maize cultivation in Asia.

Seed and seedling blights

These diseases reduce plant stands in temperate and high-altitude areas where soil temperatures are low at planting time. This group of diseases does not constitute a serious threat in the lowland tropical environments, because of the rapid emergence of seedlings due to high temperatures. However, fungicidal seed treatment has led to an improvement in plant stands and seedling vigour. Yield increases of the order of 8–10% are possible to achieve through seed treatment alone (Laxminarayan *et al.*, 1967).

Although a variety of pathogens, including *Pythium*, *Fusarium*, *Acremonium*, *Aspergillus*, *Penicillium*, *Sclerotium*, etc., are associated with seed rots and seedling blights, no effort has been made to develop resistant cultivars because fungicide treatment is a simple and cheap method of protection against this group of diseases.

Foliar diseases

Although as many as 20 foliar diseases occur (Payak and Sharma, 1980), the following four are considered to be of importance in terms of geographical distribution and potential ability to cause significant yield reductions.

Turcicum leaf blight

This disease is caused by *Setosphaeria turcica* (Luttrell) Leonard & Suggs [= *Exserohilum turcicum* (Passerini) Leonard & Suggs]. It is a major problem in Pakistan, India, Nepal, Bhutan and China. Maize planted in the highlands where temperate conditions prevail and in winter plantings in the plains are more seriously damaged as the cool/moderate conditions favour development of this disease.

Monogenic sources of resistance possessing genes *Ht1* and *HtN* have been found to be susceptible at the adult stage. The race present in the Indian subcontinent has been determined to be race 2 (Payak *et al.*, 1974). Most of the early maturing and local germplasm is susceptible to the disease. Genetic studies on the inheritance of disease resistance, carried out in India, have shown that the inheritance of disease reaction is polygenic and is an additive character. Various sources of resistance in different backgrounds have been identified (Payak and Sharma, 1979). In at least two inbred lines, CM 104 and CM 105, 'durable resistance' was demonstrated (Sharma and Payak, 1990). In India, a double-top cross-hybrid, Ganga 11, that possesses a high level of resistance to this disease was released recently; Suwan 1 is one of the resistant parents. Fungicides belonging to the dithiocarbamates and Dithane M22 have been reported to be effective in reducing disease incidence in India and Taiwan, respectively. For high-value crops such as sweet corn or pop corn, two to three spray applications of these fungicides have been recommended.

Maydis leaf blight

This disease is incited by *Drechslera maydis* (Nishikado) Subramanian & Jain [= *Cochliobolus heterostrophus* (Drechs.) Drechs.] and presents a problem in Pakistan, India, Nepal, Kampuchea, the Philippines, Indonesia, Vietnam and China. The disease has the potential to cause significant yield losses in cultivars with a high level of subtropical or temperate germplasm.

Resistance to this disease is polygenically governed and most improved cultivars have a moderate degree of resistance. Indian scientists have demonstrated that resistance is expressed when the plants attain a growth stage of 35 days or more. Furthermore, different isolates vary in their degree of virulence.

Three races of the pathogen are present in the region. Race 'T' which is specific to Texas male-sterile cycytoplasm (Tems) was initially reported in the Philippines (Mercado and Lantican, 1961); it has since been reported also from India (Sharma, Lilaramani and Payak, 1978) and China (Wei and Chi, 1980). A new race C, virulent on charrua cms, has been detected in China (Wei *et al.*, 1988). However, race 0 remains the most prevalent and widely distributed race.

Hybrids and composites resistant to this disease have been released in India and Pakistan (Payak and Sharma, 1985; CIMMYT, 1989). Fungicidal control is also possible and is recommended in certain circumstances.

Common rust

This rust, caused by *Puccinia sorghi* Schw., develops on maize plantings in subtropical conditions in Pakistan, Nepal, Bhutan, South China and northern India. Aecial infection occurs infrequently on *Oxalis* spp. in Nepal. *O. corniculata* has been found to be susceptible under conditions of artificial inoculations with teliospores of *P. sorghi* in India. However aecial infections, so far, have not been observed in nature. Since the early 1970s in the state of Bihar, India, winter plantings have suffered epidemics of this rust, mainly because of the cultivation of the susceptible hybrids Ganga Safed-2 and Hi-starch. Losses in grain yield ranging from 6 to 32% have been reported (Sharma *et al.*, 1982). The inheritance of generalized or mature plant resistance has been studied by Sharma and Payak (1979) and has been established to be polygenic, with a small number of genes conditioning resistance.

Cultivars possessing resistance are available in most countries. For seed production and susceptible cultivars of pop corn and sweet corn, two to three spray applications of the fungicide zineb are recommended.

Polysora rust

Puccinia polysora Underwood occurs in Thailand and the Philippines. It is remarkable that, so far, it has not been observed in other countries. Of the three rusts reported on maize, this is the most destructive. Outside Asia one or two single dominant genes conferring resistance have been identified. Gene action includes complete, partial or no dominance (Scott, King and Armour, 1984).

Downy mildews

This group of pathogens constitutes one of the most important factors limiting maize production in South and South-East Asia. The important species causing downy mildew (DM) in maize in the region are the Philippine DM [*Peronosclerospora philippinensis* (Weston) Shaw], sorghum DM [*P. sorghi* (Weston & Uppal) Shaw], Java DM [(*P. maydis* Raciborski) Shaw], sugar-cane DM [*P. sacchari* (Miyabe) Shirai &

Hara] and brown stripe DM (*Sclerophthora rayssiae* var. *zeae* Payak and Renfro).

Coordinated research to study the aetiology, epidemiology of the pathogen and the breeding of downy mildew-resistant cultivars in Asia, was initiated by the Inter Asian Corn Programme (IACP), an informal association created and funded by the Rockefeller Foundation in the 1960s. Considerable information of a basic and applied nature was generated and useful exchanges took place through annual workshops. DM nurseries, and training of staff in national maize programmes, was also organized by IACP. The following is an updated account of these diseases.

Philippine downy mildew

This pathogen is widespread in the Philippines, plains of Nepal and northern India, Laos and northern Vietnam. The disease was first reported in India in 1912. This DM has also been found to possess the highest level of virulence: yield losses of 40–60% are frequent, and a disease incidence of 80–100% is not uncommon (Exconde, 1970). In Nepal, the disease developed in an epidemic form in 1987, with losses as high as 50%. It has been observed that late-sown plantings suffer greater damage (Shah and Tuladhar, 1971).

Infection on maize is traceable to the proximity of infected clumps of the wild grass *Saccharum spontaneum*. The grass not only grows wild but also is planted as fencing around cultivated fields. Its eradication helps to eliminate this DM.

Resistance in the Philippines is derived from indigenous open-pollinated varieties, particularly Tiniguib and Impa-Impa, others being Aroman White Flint, Kabacan WF, Bukidnon WF, Cadlan WF, Cebu WF, College WF and Bicol WF (Aday, 1975). The composites and varieties developed in the Philippines are based on crosses of local and introduced germplasm such as Tuxpeno, Eto Amarillo, Eto Blanco, Cupurico, Cuba Gr.1, and Tuxpantigua. A series of composites such as Phil DMR-1 and DMR-5 have been released for cultivation.

Sorghum downy mildew

This pathogen was first recorded in teosinte (*Zea mays* ssp. *mexicana*) from Pune in 1905, and in 1907 on sorghum from India (Butler, 1907; Uppal and Desai, 1932). Since the 1960s, damage on maize and sorghum has been observed to have a cosmopolitan distribution.

Three strains have been identified in *P. sorghi* – the sorghum strain (infecting only sorghum), the maize strain (attacking maize only) and a strain that infects both crops. In Thailand, only the maize strain of *P. sorghi* has been reported; in India, all three strains of the pathogen have been recorded (Payak, Sharma and Kalyani Menon, 1979). Bonde *et al.* (1984), on the basis of isozyme analysis, have reported that the Thai isolate has only four alleles out of 15 in common with those present in the five other isolates of *P. sorghi*. On the basis of isozyme analysis, the Thai isolate was more closely related to the '*P. sacchari–P. philippinensis* complex' than to *P. sorghi*.

The fungus can inflict serious damage in introduced germplasm with no resistance. The DM-resistant cultivar Suwan 1, released in Thailand in 1973, spread rapidly throughout most Asian countries where it continues to show a good level of DM resistance. Selections of Suwan 1 have been released in Bhutan, Burma, South China, India, Indonesia, Laos, Nepal, Philippines, Sri Lanka and Vietnam. In Thailand, 80% of the area planted to maize has been covered by this high-yielding DM-resistant improved open-pollinated cultivar. Recently, several CIMMYT maize populations (populations 22, 28, 31, 72, 75 and 78) have been selected by the CIMMYT–Asian Regional Maize Programme (CIMMYT, 1989); these combine desirable agronomic characters and a broader genetic base for DM resistance. Several other cultivars, such as Suwan 2 (early selection from Suwan 1), Suwan 3, Nakorn Sawan 1 (NSI), Rampur 8075, and Ganga 11 (male parent Suwan 1) have been released by national programmes in Thailand, Nepal and India.

In Thailand the agronomic practice of early planting in the rainy season is recommended for a low disease incidence. Late plantings are normally more damaged, mainly due to higher moisture and inoculum load.

Java downy mildew

Since the beginning of this century, this pathogen has affected maize cultivation in Indonesia, particularly in the islands of Java, Sumatra, Kalimantan and Madura. Where maize follows maize or sugar-cane, the disease incidence has been noted to be greater (Semangoen, 1970). Epidemics on a minor to moderate scale still occur in central Java and South Sumatra, and an incidence of 20–90% is not uncommon. The annual losses caused by the disease have averaged 40% (Frederiksen and Renfro, 1977). About five Bogor composites and three synthetics have been released. Many local cultivars, including Pendjalinan and Ganjah Kretek, have been rated as promising in Indonesia and Taiwan. Bogor Synthetic 2 was rated as having promising DM resistance material in Thailand and, together with Tainan Comp. 10, was released to farmers in 1972. The DM-resistant cultivar Arjuna with a background in Suwan 2, is planted over a large acreage.

Brown stripe downy mildew

This disease was first reported from India (Payak and Renfro, 1967). It has also been found in Burma, Nepal, Pakistan and Thailand (Frederiksen and Renfro, 1977), but is unknown outside South and South-East Asia. In the Himalayan area of northern India, the disease is limited to locations below 1500 msl (metres above sea level). Yield losses of up to 63% have been recorded in the *tarai* area of Uttar Pradesh.

As well as affecting maize, the disease has also been recorded on teosinte, *Digitaria sanguinalis*, in India and on *D. bicornis* in Thailand. Several cultivars possessing resistance to this DM have been identified. However, the most outstanding cultivar has been hybrid Ganga 5, widely grown in India. Genetic resistance to the disease has been identified with both additive and dominant gene actions. However, additive gene action plays a greater part in the expression of resistance (Asnani and Bhushan, 1970; Singh and Asnani, 1975).

Sugar-cane downy mildew

This DM occurs in India, the Philippines, Taiwan and Thailand. Recent reports indicate its presence in southern China. The disease has proved to be more destructive in Taiwan, where it is found on both sugar-cane and maize. The occurrence of the disease in Taiwan has been traced to sugar-cane cuttings brought from Australia. Control of this disease offers a good example of moderately successful breeding and eradication programmes. In India, the disease is restricted to the *tarai* areas of Uttar Pradesh, where it was first found in 1967 (Singh, 1968); its incidence in susceptible cultivars has ranged from 30 to 60%. Late plantings (mid-July or later) suffer greater damage (Payak, 1980).

Resistance to maize DMs in general has been determined to be polygenic (Mochizuki, 1975; Singburaudom and Renfro, 1982). An exception is sugar-cane DM in Taiwan where a resistance factor was also found to be monogenic and dominant (Chang, 1969).

Several fungicides have been tried for the control of DM in maize. Seed treatment with Demosan (chloroneb) was found to be promising against sorghum DM in Thailand (Titatarn, 1976) and in India (Dange, 1976), on brown stripe DM and sugar-cane DM in India (Lal, 1975) and on Java DM (Triharso and Kusdiarti, 1976). In the Philippines, economic returns for a schedule of three spray applications of Du-Ter (fentin hydroxide) followed by Dithane M 45 (mancozeb) was claimed to be cost effective and feasible for use against Philippine DM (Exconde, Raymundo and Soriano, 1975).

Among the systemic fungicides, acylalanines and the related compounds metalaxyl (Ridomil 25 WP, Apron 35 SD, Apron 30 FW), furalaxyl (Fongarid WP G), milfuram (Patafol, Caltan WP) and benalaxyl (Galben WP G) have been very effective in controlling DM incited by *Peronosclerospora* and *Sclerophthora* (Venugopal and Safeeulla, 1978; Exconde and Molina, 1978; Lal, Bhargava and Saxena, 1980; Renfro, 1983).

Sheath blights

Banded leaf and sheath blight

This disease caused by *Rhizoctonia solani* f. sp. *sasakii* Exner, was initially recorded in Sri Lanka (Bertus, 1927). Since then, it has been observed in Nepal, India, Bhutan, Bangladesh, Burma, Malaysia, the Philippines, Thailand, Vietnam, Kampuchea, Laos, South China and Taiwan. The disease has also been reported in various countries in Africa and the Americas. In the past the disease was regarded as of minor importance (Payak and Renfro, 1966; Renfro and Ullstrup, 1976). The occurrence of an epidemic in Mandi district (Thakur, Sharma and Munjal, 1973) in northern India attracted attention and currently it is rated to be one of the major diseases of maize, not only in India but also in other Asian countries.

In the southern Philippines, Vietnam and certain areas of Indonesia, the disease has caused great concern to maize growers; it is particularly destructive where the rice–maize rotation is practised. In nature, the disease makes its appearance at the preflowering stage (plants 40–50 days old); in some cases, younger plants may also be affected. Leaves and leaf sheaths in such plants appear blighted with prominent banding. The signs of disease are a white mycelium and irregularly rounded sclerotia, which develop on sheaths, husks, silks, cobs and kernels (Ahuja and Payak, 1982).

Indian scientists have amassed a considerable amount of information on this disease, including methods of creating disease epidemics, selection procedures and identification of sources of resistance. Sharma and Hembram (1990), have shown that stripping the lower two or three leaves and leaf sheaths considerably reduces the incidence of disease but does not affect grain yield adversely; this procedure is being followed on a large scale in Vietnam. The presence of the disease in Vietnam has been of concern in winter plantings along the Red River, where farmers are able to reduce disease incidence by removing the lower leaves and sheaths of infected plants.

Vertical banded blight

This disease has recently been reported from India (Payak and Sharma, 1986) and also observed in the Philippines by one of the authors (C.D.L.). *Marasmiellus paspali* (Petch) Singer causes a disease that is characterized by large, bleached, elongated lesions surrounded by irregular but vertically orientated bands or zonations. It is present during the summer crop season (*Kharif*) in northern India.

Redhead and Latterell (1988) reported that, for a similar disease from Mexico, Costa Rica and Nicaragua under the name of 'Borde Blanco' (= white margin) (Latterell and Rossi, 1984), the pathogen involved is *M. paspali* var. *americanus*. According to those authors, the pathogen occurring in Asia (India) is *M. paspali* var. *paspali*. As has been indicated by Payak and Sharma (1986), the disease is confused with the banded leaf and sheath blight and commonly occurs as mixed infections. The effects of the two therefore, can not be clearly demarcated.

Ear rots

Among the ear rots reported in the Asian countries, the most important are Fusarium kernel rot (*Fusarium moniliforme* Sheld. = *Gibberella fujikuroi*) and Gibberella ear rot [*Gibberella zeae* (Schw.) = *Fusarium graminaerum*].

Fusarium kernel rot

This is distributed throughout the maize-growing regions in the Asian lowland tropics. Maize farmers are not aware that in grain contaminated with fungus, toxic metabolites such as moniliformin and fumonisin are produced (Marasas, 1985). As a result farmers continue to consume the grain themselves, or use it as animal feed, leading to poisoning and death. The incidence of ear rot is especially high in India, Pakistan, Nepal, Bhutan, Vietnam, South China, Indonesia and the Philippines. The requirements of the pathogen appear to be peculiar: generally, its incidence rises with increased relative humidity, but the proportion of ears suffering from this rot is much higher in maize that has matured under conditions of moisture stress.

Farmers should be advised that ears showing this or any other rot should not be harvested for either human or for animal consumption. Elimination of contaminated ears, if regularly practised, in a few crop seasons may lead to virtual eradication of this fungal infection.

Gibberella ear rot

This problem is mostly found in highland areas where subtropical or temperate conditions prevail. Considerable damage has been observed in the hilly areas of northern Pakistan, India, Nepal and Bhutan. As with Fusarium kernel rot, no programme has been organized to select for resistance to this disease.

Stalk rots

This group of diseases is broadly divided into two categories, namely preflowering and post-flowering types. The former category includes stalk rots such as Pythium stalk rot [*Pythium aphanidermatum* (Eds.) Fitzp.] and bacterial stalk rot [*Erwinia chrysanthemi* pv. *zeae* (Sabet) Victoria, Arboleda & Munoz], whereas others, such as Fusarium wilt, late wilt, black bundle disease and charcoal rot, appear in the post-flowering phase.

Pythium stalk rot

This stalk rot is known to cause extensive damage to the crop in the lowlands of northern India. The incidence of disease is significantly influenced by both environmental and host factors. Temperature and relative humidity have been found to affect both the growth of the pathogen and disease development. The maximum disease development occurs within a temperature range of 30–35°C, with a relative humidity of 80–100%. Waterlogged, low-lying or poorly drained field conditions favour a high degree of disease development. Plant age (preflowering growth stage) and a large plant population ($\geq$ 60 000 ha^{-1}) favour a high incidence of disease (Diwakar and Payak, 1980).

Some resistant material has been identified. Hybrids Ganga Safed-2, Hi-starch, and composites Suwan 1 and Suwan 2, have shown resistance in India. An application of 75% captan (11.2 g a.i. per 100 l water applied as a soil drench at the base of the plant when the crop is 5–7 weeks old) can check this disease effectively (Payak and Renfro, 1974).

Bacterial stalk rot

In the *tarai* area of northern India, and in southern Nepal and the southern Philippines, this disease represents a serious problem for maize production. It has been observed that a high disease incidence is associated with the use of sewage water for irrigation; it is particularly favoured by high temperatures ($\geq$ 28°C) and high relative humidity, which prevails in most maize-growing areas 3–4 weeks after sowing.

In India, resistance in some inbred lines, single crosses and hybrids has been identified through artificial inoculations. Among these, CM 104, CM 600, hybrids Ganga Safed-2 and multiple disease resistant (MDR) populations MDR-1 and MDR-2 are known. This pathogen is highly sensitive to chlorine (Thind and Payak, 1972). Efficient control of the disease by using bleaching powder ($CaOCl_2.H_2O$ containing 33% chlorine), is achieved by drenching the basal stalk region when the plants are knee high.

Fusarium stalk rot

Stalk rots incited by *F. moniliforme* Sheld. and *F. graminearum* Schw. are known throughout Asia; however, the incidence of the former is more severe in lowland tropical areas, whereas the latter is present in the cooler highlands. The symptoms become conspicuous after flowering and towards maturity, when plants show premature drying. The pathogen commonly affects the roots, crown region and lower internodes. When split open, the stalks show a pink–purple discoloration with collapse of the pith region (De Leon, 1984). In old plants affected by *F. graminearum*, blue–purple ascomata of *Gibberella zeae* develop on the outer surface of the stalk rind. The diseases are known to occur in India, Indonesia, Pakistan, the Philippines, Thailand and Vietnam. They are observed more commonly if there is a period of drought during or shortly after pollination. Agronomically desirable stalk rot-resistant materials are available in Pakistan, India, Mexico and Zimbabwe, where selections against these diseases have been made. The 'stay green' character, in which plants remain green after attaining physiological maturity, has been associated with resistance to certain post-flowering stalk rots. There is evidence of mammalian toxicity where stalks infected with these pathogens were used as fodder (Cole and Kirksey, 1973; Bottalico *et al.*, 1985). In Asia this aspect deserves more attention and further study.

Black bundle disease

Acremonium kiliense Gams has been found to be associated with a disease in India and Pakistan. Conditions of water stress near the flowering stage favour this disease.

Purpling or reddening of the leaves and stalks is associated with plants infected with this fungus. The most characteristic symptom is blackening of the vascular bundles, extending through several internodes. The pathogen incites kernel streaking, a typical symptom in the ear rot phase. It seems that Fusarium stalk rot-resistant selections may also have resistance to this disease.

Late wilt

This disease, caused by *Cephalosporium maydis* Samra, Sabet & Hingorani, was first reported from Egypt (Samra, Sabet and Hingorani, 1962). It has also been reported in India and China. This is an important disease in many maize-growing regions, especially in areas where the crop is grown in light, sandy soils rather than in light, loamy soils. Avoidance of moisture stress and balanced potash application reduce the incidence of the disease. Resistance has been observed in several open-pollinated cultivars, inbred lines and single crosses. Hybrids Ganga 5 and Ganga 11 are recommended for cultivation wherever disease outbreaks are feared.

Charcoal rot

This disease, caused by *Macrophomina phaseolina* (Tassi) G. Goid, has been reported from India, Pakistan, Bhutan, Nepal, Thailand, the Philippines and South China. Outside India and Pakistan the disease has not been reported to be of economic significance. Characoal rot is more frequently present in maize plantings that have gone through a period of water stress at flowering time or slightly afterwards. Resistance to the disease is not fully understood, but some germplasm, such as hybrid Ganga 5 and single-cross CM 202 × CM 111, has been shown to possess adequate levels of genetic resistance to the disease.

Storage rots and aflatoxins

Aspergillus flavus Link ex Fries, the fungus responsible for aflatoxin contamination, occurs in maize kernels both at the preflowering and the post-flowering stage. Aflatoxin/mycotoxins can accumulate in maturing corn in the field and also when grain is transported and stored with a high moisture content. High relative humidity and temperature are favourable for the development of the fungus.

In 1975, an outbreak of hepatitis occurred in India, in which 100 adivasis (= tribals) died; the cause was thought to be the consumption of *A. flavus*-contaminated maize. In Vietnam, Thailand and the Philippines a great deal of grain has been reported to be spoiled by *A. flavus* when such grain is not dried properly after harvest.

Among the various methods employed in an attempt to reduce aflatoxin contamination, treatment of grain with propionic acid or ammonia gas has been found to be effective. However, proper drying of the grain immediately after harvest, good storage conditions and proper handling of the grain are recommended to avoid this hazard (Bungsawan, 1987).

Diseases caused by viruses

The viruses reported on maize in the Asian region are maize mosaic virus I, maize mosaic virus (MMV) and vein enation virus in India (Sharma and Payak, 1983), maize dwarf mosaic virus (MDMV), corn stripe and what is reported as 'leaf gall' (probably maize rough dwarf virus) in the Philippines (Exconde, 1983) and MDMV in China (Zhu *et al.*, 1983; Jingxiong, 1991).

Nematodes

Several nematodes have been found attacking maize. However, only the cyst nematode (*Heterodera zeae* Koshy, Swarup and Sethi) represents a serious problem in some maize-growing areas (Koshy and Swarup, 1971). Carbofuran at 2 kg a.i. ha^{-1} is recommended for effective control. *H. zeae* can be managed by eradication of *Setaria* sp., an alternate host of the nematode, and by crop rotation (mainly by planting a non-susceptible crop).

Notes

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