2 Diseases and Injuries of Seed

2.1 DEFINITIONS

The fact that seeds are both vehicles and victims of disease calls for some clarification of concepts. So do the facts that seeds, without being diseased, may be vehicles of pathogens, as well as they may be victims of detriments other than disease, such as insect damage.

First, the following tentative definitions of disease and injury may be considered.

Disease is a factor that interferes with the normal functions or structure of a plant. It may be physiogenic, caused by the direct effect of unfavourable environmental factors, or biogenic, caused by the effect of pathogens, including animal parasites and viruses.

Injury is damage to the structure of a plant, brought about by physical, chemical or animal force: wounding, mechanical injury, insect injury, frost injury.

The concepts of disease and injury may overlap: 'cold', encountered in thermophilic plants by low temperatures, for instance in orchids, would be regarded as a physiogenic disease, frost damage usually as an injury. Mercury injury to seeds may lead to seedlings that are abnormal due to induced chromosome disorders, and it may be justified to consider such seedlings as diseased.

There has been some controversy about the use of terms such as 'seed-borne disease', 'seed-transmitted disease', and 'seed-borne' and 'seed-transmitted' pathogen. The writer holds views that are in agreement with those of Leach (1940), expressed in his definition of insect transmission of plant diseases. Leach found ample justification, both etymological and traditional, for the use of the expression 'disease transmission' and accepts this term. On the other hand, he reserved 'dissemination' for the use only in connection with the pathogen. He holds the concept that the pathogen may be disseminated widely but the disease is not transmitted until inoculation and infection have occurred. Insects — and seeds — may disseminate a pathogen without transmitting the disease. Moreover, a disease is 'borne' in the seed in the sense that potentially it is brought forth or given support by the seed. Here the sense of 'bear' is by tradition broad enough to make 'borne' acceptable as a general indication of seed

as an agency potentially conveying disease. Distinction is thus implied between seed-borne disease, the seed being an agency, and seed disease, the seed being itself a victim of disease, not necessarily conveying this disease to the subsequent crop. For distinction between 'seed-borne pathogen' and 'seed-transmitted pathogen', see Part II, Introduction.

2.2 PHYSIOGENIC SEED DISEASES

2.2.1 Deficiency diseases

Nitrogen deficiency. The so-called 'yellow berry' of wheat is an important degrading factor in this cereal. Grains of wheat are normally translucent but kernels suffering this anomaly have light yellowish spots affecting part or all of the grain (Fig. 2.1). The affected parts are high in starch and low in protein content, and the grains are low in specific gravity. The disease is prevalent in soils high in potash and phosphorus and is prevented by application of nitrates and by crop management favouring the nitrogen level of the soil, such as including legumes in rotations, introducing green manure crops and by using nitrogenous fertilisers. The disease is economically important, lowering the market value of grain. It is common in North America, Argentina and North Africa.
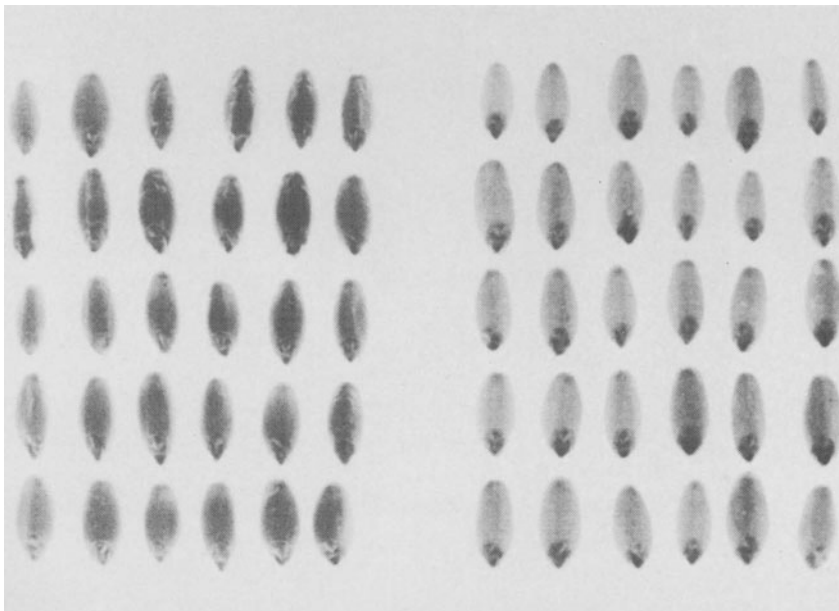

Fig. 2.1. Yellow berry of wheat, nitrogen deficiency. Left, affected kernels; right, unaffected kernels. Photographed by transmitted light. Note semi-transparency of healthy kernels

  Potassium deficiency. This may cause substantial quantitative yield reduction of seed (Eckstein, Bruno and Turrentine, 1937; Stapel and Bovien, 1943) and may also affect the quality. Seed often fails to mature and becomes small. De Bruijn (1933) regards potassium deficiency as a factor contributing to development of marsh spot in pea, discussed below. Hoffman (1933) has shown that shortage of potassium may cause seeds of cucumber to assume an abnormally tapering shape.

Fig. 2.2. Marsh spot, manganese deficiency, in pea

Manganese deficiency. This is a rather common disorder in pea seed, to a less extent in bean seed. Symptoms appear as an extended internal brown necrosis in the seed, the central part of the cotyledons being affected (Fig. 2.2). When these are severely affected cracks may appear. Some seeds may show brown, sunken spots in the seed coat and these necroses continue into the two cotyledons beneath. The internal symptoms are detectable two to three days after the seeds have been sown. The seedling is weak and will later develop poorly; once the plumule has emerged, the top dies and a double replacement plumule develops. The parent plants, on the other hand, often show only a slight chlorosis, even when they yield severely affected seeds.

The disease has been known since the past century and described by Mansholt (1894); later the disease was studied in the Netherlands by De Bruijn (1933), in Britain by Lacey (1934), and in Finland by Jamalainen (1936). Manganese deficiency was first detected as cause of the disease by Löhnis (1936) and Pethybridge (1936), and manganese sulphate as a measure of control was established by these and other authors (Koopman, 1937; Ovinge, 1937; Von Berenberg-Gossler, 1943). Von Berenberg-Gossler recorded 41 mg manganese per kg dry matter in healthy seed but only 13 mg in affected seeds. She found that all or only some of the seeds in one pod may be affected, and that the last developed pods yielded the highest percentage of diseased seeds.

Marsh spot is common in pea grown in the polder districts of the Netherlands (Ovinge, 1935; Doyer, 1938). Marrow-fat peas are very susceptible, particularly in alkaline soil which is rich in humus as in Romney Marsh, England (Furneaux and Glasscock, 1936), hence the name 'marsh' spot, and in newly reclaimed sea silt soils in the Netherlands (Ovinge, 1935, 1937). In England late maturing pea cultivars with large seeds have been found to be more severely affected than early maturing cultivars with small seeds (Glasscock, 1941). De Bruijn (1933) observed that a protracted ripening period encouraged the development of marsh spot, while the trouble was less in the seeds of plants in which maturation had been hastened. The disease is only rarely encountered in North America (Cuddy, 1959).

Marsh spot in Phaseolus bean and broad bean is milder and less frequent (Hewitt, 1945). This condition has been confused with hollow heart, see below.

Boron deficiency. This is known in Florida, U.S.A., as cause of a type of 'hollow heart' in groundnut, leading to discoloration and rotting of the seed. Soil amendments with boron eliminates the defect (Harris and Gilman, 1957).

Pea seeds appearing normal may suffer boron deficiency; seedlings develop pale stunted shoots without plumule bud. Addition of boron

completely overcomes the abnormality (Leggatt, 1948).

Molybdenum deficiency. In New South Wales, Australia, interveinal mottle, 'scald' or necrosis of interveinal and marginal regions of the leaves developed in plants of Phaseolus bean, grown from seed, produced in plants grown in acid soil and sown in similar soil. The plants were cured by application of sodium molybdate (Wilson, 1949).

Calcium deficiency. Wallace (1951) showed, in his colour atlas of deficiency diseases, the effect of calcium deficiency in broad bean pods and seeds. Pods are deformed, wilted and blackened, and seeds fail to develop. In general, calcium deficiency occurs most commonly in strongly acid soils. Often deficiency of manganese and magnesium may be involved.

2.2.2   Temperature effects on seed

Low temperature effects. Dry seed withstands extremely low temperatures (-185 to $-192°C$) but wet seed will usually be killed at a few degrees below zero. This effect of temperature applies also to fungi and bacteria. Frost damage on seed crops during maturation may reduce or destroy the viability of unripe seed. The damage induced may appear as symptoms on the seedlings such as necrotic spots in the cotyledons.

In North Europe (Germany) late frost in spring may cause severe damage to maturing seeds of winter crops. The siliquas of rape, *Brassica napus,* may, after frost, still look normal but the seeds inside are brown, shrunken and dried-up. Yield losses may be up to 100 per cent (Pape and Härle, 1943). Frost may cause reduced germination in seeds of lupin and beets, and early autumn frost injures or destroys maturing of seeds of crucifers, particularly in cauliflower (Stapel and Bovien, 1943). In Norway frost damage is rather common in seeds of barley, oats and rye. Seedlings from damaged seeds often have a stunted, swollen root and a curled sprout (Overaa, personal communication, 1973).

High temperature effects. Air-dried seed tolerates rather high temperature of dry heating, e.g. barley 64°C, rye and wheat 67°C, pea 71°C, but in water or after soaking, seed may be killed at temperatures of about 50°C (Ferdinandsen and Buchwald, 1936a). Self-heating of seed during storage, particularly when the seed is moist or insufficiently mature, may lead to serious damage. The seed may become brownish, wrinkled, the embryo weakened, brown, and roots of the seedling may not develop root hairs, or the embryo may be killed.

Hot water treatment (Subsection 21.3.1) may reduce the germination capacity of seed; only a few degrees separate *dosis tolerata* and *dosis curativa.*

2.2.3 Humidity effects on seed

The 'normal' water content of seeds varies from one plant species to another and depends greatly on the chemical composition of the seed. While 14 per cent water content is low for oats it is high for cabbage and radish. The maximal limit for seeds of grass, beet and spinach is 15 per cent, but for cabbage and radish only 9 per cent (Franck, 1940). Onion seed must be dried down to 8 per cent water content to keep well in storage.

The air humidity during storage of seed is an essential factor for keeping the viability of seed, see Section 20.1.

High humidity effects. At high relative atmospheric humidity the lifetime of seed is substantially reduced. The germination capacity
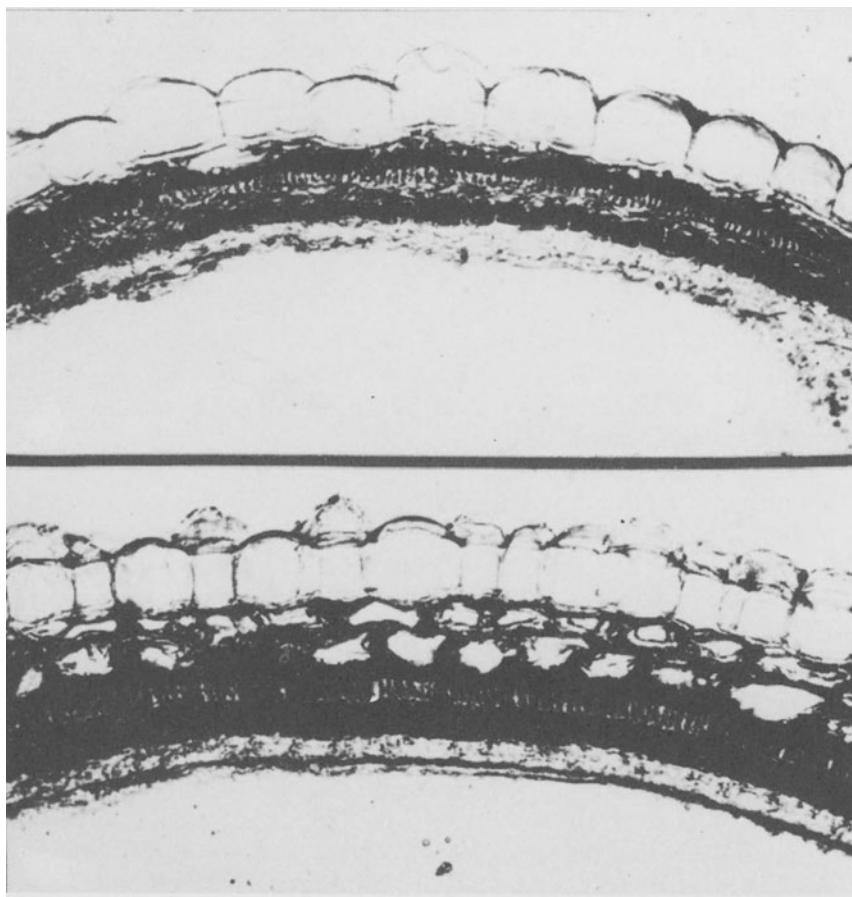

Fig. 2.3. Transverse section of the seed coat of white mustard, *Sinapsis alba*. Above, normal seed coat; below, seed coat with swollen parenchymatous cells from seeds showing grey discoloration. ×150. (Jørgensen, 1967)

decreases while the number of abnormal seedlings increases. In cucumber, lettuce, spinach and other crop seeds such poorly developed seedlings, induced by high humidity, include 'stubbed roots' involving development of a secondary root (Toole, personal communication, 1958). Voisenat (*fide* Doyer, 1938) produced abnormal seedlings with stubbed roots by keeping lettuce seed for some time in humid air, then drying it. Such seedlings cannot survive in the field.

In Denmark grey discoloration of seeds of radish, *Raphanus sativus* (Neergaard, 1945), and white mustard, *Sinapis alba* (Jørgensen, 1967), is very common. Jørgensen demonstrated that the direct cause of the discoloration is swelling of the subepidermal parenchyma of the seed coat which leads to a distortion or breaking of the epidermis (Fig. 2.3). The swelling occurs under humid conditions. In the field the disorder occurs only when the crop is close to maturity and the weather humid. The breaking of epidermis may facilitate invasion of *Alternaria* spp. which may penetrate deeply into the seed. *A. brassicae* is particularly frequent in affected white mustard seeds (Jørgensen, 1967), *A. raphani* in affected radish seeds (Neergaard, 1945). The quality of grey seeds of white mustard in terms of oil quality (per cent fatty acids), germination capacity and seed weight, is lower than that of normal, yellow seeds. The effect on oil quality may be due to easier access of oxygen to the outer cell layers of affected seeds.

Low humidity effects. A common phenomenon in spinach is 'broken seedlings'. However, close examination reveals no true rupture; the necrosis is caused by a drying effect, not by mechanical damage (Toole, personal communication, 1958).

McCollum (1953), Pirson (1966), Pollock, Roos and Manalo (1969) and Kietreiber (1969) have described seedlings of bean and pea, abnormal due to the effect of drought. The cotyledons may have transverse cracks and the primary leaves may be small and deformed. The defect resembles mechanical damage. The tetrazolium test reveals a thin untinged layer at the outer and inner sides of the cotyledons and untinged spots of the primary leaves of the embryo. Affected seeds show poor emergence, and the seedlings are very weak. Dickson (1973) believes that this disorder is due to a combination of factors: the genotype, the rate of seed drying at maturation and imbibition rate at germination. In the U.S.A. transverse cracking is common in most Phaseolus bean cultivars and can occur as much as 100 per cent in some cultivars. Dickson classed a number of cultivars in consistently resistant, intermediate and susceptible cultivars.

Another drought reaction is 'physiological drought' resulting in necrotic spots in cotyledons of lettuce due to moisture stress at temperatures of 32°C and above, over an extended period. In extreme cases the entire embryo may be killed. In Idaho, U.S.A., lettuce seed fields may be kept

very dry and not irrigated because of the danger of losses due to *Sclerotinia sclerotiorum*. The etiology of the malady was experimentally confirmed (Finley, 1959).

In soybean, cracking and wrinkling of the seed coat may be due to desiccation during the maturation of the seed; field emergence of such seeds is lower than in seeds with sound coat (Moore, 1960). Agraval and Menon (1973) observed that rapid desiccation during the last one to two weeks of crops maturity results in cracking, moderate desiccation in wrinkling. Some cultivars were highly resistant, others highly susceptible to cracking, whereas none of the cultivars were resistant to seed coat wrinkling.

Hollow heart or *cavitation* in pea closely resembling marsh spot was first described by Myers (1948) in New South Wales, Australia, who knew that it was not marsh spot, and later work has confirmed that the two disorders are distinct.

Seeds with hollow heart are usually normal in outward appearance but have sunken or cracked areas in the centre of the adaxial cotyledon face; there is no discoloration as in marsh spot (Fig. 2.4). However, the cells lining the hollow are abnormal (Moore, 1964; Perry and Howell, 1965), and these are readily colonised by pathogenic and saprophytic fungi. Gane and Biddle (1973) found that affected seeds often were triangular in cross-section, rather than square, and the seedlings were less vigorous and more readily killed in adverse conditions and weather. Affected seeds usually germinate well on blotter but produce weak plants in pot tests. In
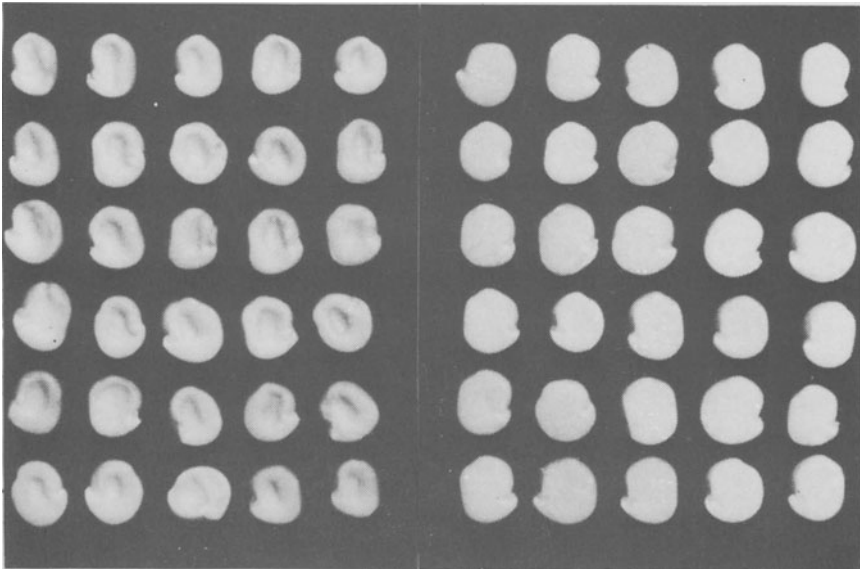

Fig. 2.4 Hollow heart or cavitation. Adaxial cotyledon face of affected seeds (left) and healthy seed (right)

the field the affected cotyledons quickly rot. Myers established that hollow-hearted seeds yield plants of significantly lower weight than normal seeds, Perry (1967) that seed lots with a high incidence emerged less well than normal seeds, and Harrison and Perry (1973) found that the disease delayed germination and reduced the size of seedlings in a sterile medium; in glasshouse experiments it was associated with smaller plants which flowered later and yielded 32 per cent less than plants from normal seed. Heydecker and Kohistani (1969) did not obtain such effects. Perry and Howell (1965) found the disorder in seeds from many countries and that it was prevalent in seed stocks received for sowing in Scotland.

It has been suggested that hollow heart in pea may be due to too quick drying of immature seed, such as may be caused by hot dry winds, confirmed by Perry and Harrison (1973) who showed experimentally that predisposition to hollow heart may be caused by high ambient temperatures during maturation of the seeds on the plant, and by drying them when immature. The incidence of hollow heart increased with increasing drying temperature from 35 to 45°C and decreased as seed maturity advanced. They found also, in accordance with R. P. Moore (1964) and Heydecker and Feast (1969), that the incidence of hollow heart ultimately depends on the rate and quantity of water imbibed by dry seeds, rapid softening increasing the condition; high soil moisture increases the damage when affected seed is sown.

Damage in seeds may be due to improper drying. Wheat grains damaged during the process of drying may produce abnormal seedlings (Wellington, 1968), see Table 2.1 later in the chapter.

2.2.4   Effects of poisons on seed
Chemical damage to seed is common because of the wide use of chemical seed treatment. Phytotoxicity of some seed fungicides is discussed in Section 22.4; and the importance of condition of seed to be treated, in Section 22.7. Some aspects of injuries due to seed fungicides will briefly be discussed here, pertaining to two categories of classical seed germicides: copper sulphate (blue vitriol) and formaldehyde.

Injury caused by copper sulphate solution has been studied already by Nobbe (1872) and Kühn (1873). Hurd (1921) found that in mechanically damaged wheat kernels the radicle was injured by seed treatment much more frequently than the embryo, resulting in 'stunted roots', because threshing usually caused wounding of the pericarp just above the radicle. The detrimental effect of copper sulphate may not be completed until after a period of storage. Jørgensen (1934) improved germination of celery seed immediately after 24 hours of treatment, as compared with untreated, but after storage the germination capacity of the treated seed went down, and after three years the germination was half of that of untreated seed.

Formaldehyde has a similar or even worse effect. When treated seed is dried, formaldehyde is converted to paraformaldehyde which persists on and in the seed coat or pericarp. If the seed is sown immediately under humid conditions, there is no injury at adequate dosage (Hurd, 1921; Braun, 1922). Jørgensen (1934) recorded almost total loss of germination capacity in celery seed treated in 0.25 per cent formaldehyde for six hours and then stored for three years.

The effect of mercury compounds in producing abnormal seedlings is dealt with in Subsection 22.1.4.

Growth substances. Detrimental effects of plant hormones applied to seed crops have sometimes been encountered in germination of seed. For instance, treatment of a seed crop of cotton with 2,4-D resulted in poor germination and abnormal seedlings, exhibiting swollen root tip and hypocotyl. The young seedlings were not much damaged but the first and second true leaves were substantially malformed, partly filiform, and the growth of the seedling was much slower than normal (Dunlap, 1948). Kjær (1950) reported damage to germination of pea seed from a lot which had been stored close to a leaky jar with P.46 (4 chloro-2 methyl-fenoxyacetic acid). One sack of the pea lot had been moistened at the bottom. Laboratory testing showed that the presence of only a few of the hormone-treated seeds was enough to prevent the other seeds from germinating.

In grass seed crops, in England, application of herbicides often causes damage to seeds, resulting in abnormal seedlings (Mary Noble, personal communication, 1968).

2.3 SEED DISEASES CAUSED BY VIRUSES

Tomato aspermy virus is the best known example of a virus producing seed abortion, and barley stripe mosaic virus may cause seed abortion or flower sterility in wheat (Inouye, 1962) and barley (Inouye, 1962; Sandfaer, 1973). A mite-transmitted virus, pigeon pea sterility mosaic virus, which is not seed-transmitted, causes sterility in pigeon pea, *Cajanus cajan* (Capoor, 1952; Seth, 1962). Some amount of abortion is produced by several viruses, e.g. bean common mosaic virus in bean (cf. Schippers, 1963) and Prunus necrotic ringspot virus in cherry (Attafuah, 1965). Seed abortion also occurs in several types of citrus infected with citrus stubborn disease virus which is not seed-transmitted (Calavan and Christiansen, 1966).

Embryo-borne viruses provide many examples of effects reducing the viability of seeds, particularly in leguminous seed. Seeds of pea, infected by pea early browning virus, become wrinkled, the seed coat showing a greenish-grey discoloration (Bos and Van Der Want, 1962), cowpea seeds infected by cowpea aphid-borne mosaic virus are small and shrivelled

(Phatak and Summanwar, 1967), pea seeds, infected by pea seed-borne mosaic virus, become small and cracked, the seed coat subsequently healing, and generally only such abnormal seeds transmit the virus (Stevenson and Hagedorn, 1969, 1973). Soybean seeds, infected by soybean mosaic virus, have a brown or blackish mottled seed coat and are substantially smaller than healthy seeds (Koshimizu and Iizuka, 1963; Ross, 1963; Van Niekerk and Lombard, 1967; Kennedy and Cooper, 1967; Phatak, 1974), see Colour Plate IV; frequency and intensity of seed mottling vary according to strain and temperature, and effects on seed size and mottling are increased by added infection of bean pod mottle virus which is not seed-borne (Ross, 1969*a*, 1969*b*). Soybean seeds infected by soybean stunt virus also have a discoloured seed coat mottled with concentric rings (Koshimizu and Iizuka, 1963).

Seed of mungbean may become wrinkled and shrivelled due to mungbean mosaic virus (Phatak, 1974). Kuhn (1965) established that groundnut mottle virus occurs more frequently in small and in discoloured seeds than in normal. Barley seeds infected by barley stripe mosaic virus are also abnormally small and shrivelled (Inouye, 1962; Błaszczak, 1963; Phatak and Summanwar, 1967). In barley this virus causes a considerable number of triploid and aneuploid seeds; the frequency of triploids seems to depend on the rate of infection. The triploid seeds are very light, shrivelled, and all or nearly all of them will be discarded in a normal seed-cleaning procedure. The triploid plants are usually a few days later in germination, they are weak in the initial stages and are unlikely to survive to maturity (Sandfaer, 1973). In sorghum the sugarcane mosaic virus (strain maize dwarf mosaic virus) causes panicle necrosis and shrunken, undersized seeds in plants that otherwise are symptomless. Affected seeds are light, have chalky endosperms, break easily and are more heavily attacked by *Alternaria* and *Fusarium* than normal seeds. Reductions in yield may be as high as 40 per cent (Edmunds and Niblett, 1973). Also seeds of squash, *Cucurbita pepo*, infected by squash mosaic virus, are lighter than healthy seed, poorly filled and deformed (Middleton, 1944). Other examples of reduced seed size are onion seed infected by onion dwarf virus (Härdtl, 1960), and beet seed infected by beet yellows virus which is not seed-transmitted (Sŭtić, Jončić and Djordjević, 1959; Blaszyk, 1963).

In England broad bean stain virus produces a stain (called 'Evesham Stain') or dark discoloration in the form of peripheral, brown necrosis of the seed coat, see Fig. 2.5 (Lloyd, Smith and Jones, 1965). The presence of the disease renders affected crops unsuitable for processing, and the disease is therefore of considerable economic importance.

Stones of apricot, infected by plum pox virus, which is not seed-transmitted, show distinct brown ringspots (Baumann, 1958; Kegler, 1962; Bojnansky *et al.*, 1963).

An attempt to separate out lettuce seeds according to weight in order to remove seeds infected by lettuce mosaic virus failed (Grogan and Bardin,
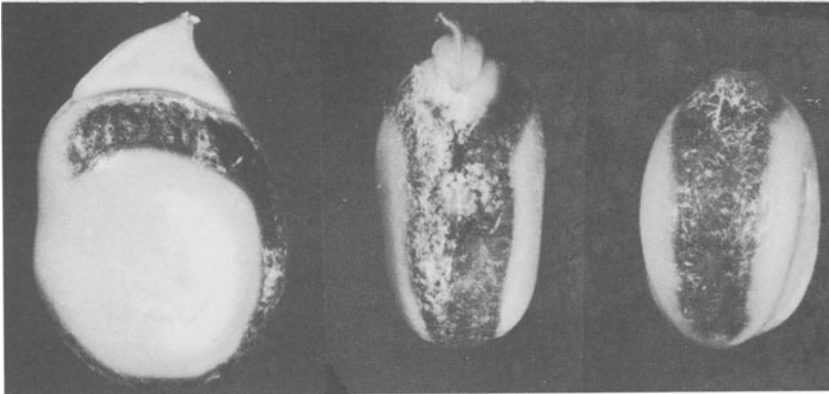
Fig. 2.5. Broad bean seeds showing brown necrotic, peripheral bands typical of 'Evesham Stain', caused by broad bean stain virus. (Lloyd, Smith and Jones, 1965)

1950). Rohloff (1962) also found that large, well-developed seeds in an infected sample did not yield fewer infected seedlings than did small seeds. In many cultivars, however, the virus produces necroses in the seeds which then have much reduced germination capacity (Szirmay, 1957).

In *Lupinus luteus,* infection of cucumber mosaic virus as well as bean yellow mosaic virus results in a different effect on seed size. The viruses cause shredding of flowers, few pods are formed, and as a consequence these contain few big seeds which largely carry the virus (Troll, 1957; Blaszczak, 1963).

Tobacco mosaic virus (tomato strain) may cause necroses in tomato seeds which become black (Broadbent, 1965).

The longevity of many viruses in seed is remarkable, see Subsection 20.2.4, but there seems to be no information on the effect of viruses on the longevity of seeds and there is little information on the longevity of virus in seeds which have lost their germination capacity. However, Pierce and Hungerford (1929) established that bean common mosaic virus was infective after 30 years of storage of bean seed, and Laviolette and Athow (1971) found that soybean after five years of storage at 16–32°C lost most of its germination capacity, whereas a high infection percentage of tobacco ringspot virus remained constant, outliving the seed.

Some viruses may directly influence the viability of seed, as in lettuce mosaic virus. A mild strain of seed-transmitted hop virus (which may have been Prunus necrotic ringspot virus) caused a reduction of 20 per cent in germination, while a severe strain reduced germination by no less than 90 per cent (Blattny and Osvald, 1954). Seeds of spurrey, *Spergula arvensis,* infected by tomato black ring virus, germinate more slowly than do healthy seeds but there is little or no effect on the seedlings (Lister and Murant, *fide* Cadman, 1963).

2.4   SEED DISEASES CAUSED BY BACTERIA

The direct pathogenic effect of bacteria on seeds may be referred to the following four types of disease condition: (1) seed abortion, (2) seed rot, (3) seed discoloration, and (4) 'slime disease'. According to pathogen and weather conditions during seed maturation one or another of these disease conditions may be prevalent in the seed or may occur in combinations.

Seed abortion. Black chaff of wheat, *Xanthomonas translucens* f.sp. *undulosa,* may reduce seed yield heavily, being very serious in some localities. Seed formation may be totally stopped or seed formed but much reduced in size, and the seeds shrivelled (Bamberg, 1936; Wallin, 1946*a*, 1946*b*; Boosalis, 1952). A disease caused by *X. panici* prevents seed formation of millets in Hungary (Klement, 1954).

Seed rot. Angular leaf spot or black arm of cotton, *Xanthomonas malvacearum,* produces water-soaked lesions on the boll, and the bacteria may penetrate from this position into the seed primordia, often effectively assisted by rot fungi, including *Colletotrichum gossypii*. The bacteria may cause a general rotting of the young seed which decomposes in bacterial slime but it is usually only present in the seed coat of mature seeds. Young seedlings are rapidly decayed, the cotyledons showing first water-soaked, then dead lesions. Fibres of infected seeds are often discoloured by bacterial ooze (Tarr, 1961; Brinkerhoff and Hunter, 1963; Schnathorst, 1964).

Seeds of cabbage and cauliflower may be so affected by black rot, *X. campestris,* that they are completely rotted or the embryo so infected that on germination typical black rot lesions become apparent in the cotyledons (Srinivasan, Neergaard and Mathur, 1973).

In Japan *X. itoana* has been found to produce a black rot of rice grain (Tochinai, 1932).

Seed discoloration. Discoloration of the seed coat may be due to lesions produced by pathogenic bacteria. This is common in bean infected by bacterial blight, *Xanthomonas phaseoli,* and halo blight, *Pseudomonas phaseolicola*. On the pods reddish-brown, water-soaked slightly sunken lesions are formed, and from these there is subsequent invasion of the bacteria into the developing seeds. If bean seeds are infected, for instance by fuscous blight (*Xanthomonas phaseoli* var. *fuscans)* at a very early stage, they completely rot while later infections produce discoloured seeds in the form of yellow patches, readily seen in white-seeded cultivars. In this disease also a small yellowish resin-like mass of bacteria is sometimes present at the hilum.

Slime disease. In many developing countries, including India, Egypt and China, yellow slime disease, or in India 'tundu disease' involving also *Anguina tritici* or 'tannau disease', *Corynebacterium tritici*, is widespread and important in wheat (Sabet, 1954*a*, 1954*b*). A similar disease, yellow slime disease or Rathay's disease, *C. rathayi*, is prevalent in Denmark in seed crops of cocksfoot, *Dactylis glomerata* (Skou, 1965) but has been encountered occasionally also in New Zealand (Johnston, 1956) and the U.S.A. Both pathogens which perhaps are identical or varieties of one species (Sabet, 1954*c*; Vasudeva, 1957) cause rotting of developing seeds and produce excessive amounts of bacterial slime which on drying becomes a varnish-like cover of the seed. A third yellow slime disease has been encountered on wheat in Iran, *C. iranicum*, where it causes abortion of grain and bacterial slime in embryos (Scharif, 1961). On *Agropyron smithii*, yellow gum disease, *C. agropyri*, is similar to the above diseases, and the pathogen may be identical with *C. rathayi* (Elliott, 1951).

2.5 SEED DISEASES CAUSED BY FUNGI

The direct impact of fungi on seed is considerable. Many fungi are serious parasites of seed primordia and maturing seeds and reduce yields of seed both quantitatively and qualitatively. Other fungi, including saprophytes and very weak parasites, may lower the quality of seeds by causing discoloration which may seriously depreciate the commercial value of seeds, particularly of grain when graded for consumption. The following types of disease and disorder are encountered, often in combination: (1) seed abortion; (2) shrunken seeds, reduced seed size; (3) seed rot; (4) sclerotisation or stromatisation of seed; (5) seed necrosis; (6) seed discoloration; (7) reduction or elimination of germination capacity; (8) physiological alterations in seed.

Seed abortion. The most prominent examples of fungi producing abortion are the smut fungi that infect cereals and grasses systemically, and the ergot fungi. The flower organs of the hosts are replaced by the fructifications of the parasites.

Certain parasitic fungi, belonging to Fungi Imperfecti, are particularly pathogenic to flowers and young seed structures, but lose their infectivity as seeds approach maturity; other parasitic fungi of this group attack maturing seeds and may be of little or no importance as pathogens in the first stages of development (e.g. *Drechslera sorokiniana,* cf. Section 11.3). Still other of these fungi may have little or no preference. Parasites of the first category are those that cause deterioration of ovules and young seed primordia, thus reducing seed yield quantitatively. Important exam-

ples are *Gloeotinia temulenta* causing 'blind' (ungerminating) seed in ryegrass and other grasses (Section 11.5), different species of *Fusarium*, particularly in cereals, including *F. culmorum* (Section 11.5), *F. graminearum* in wheat, maize and rice (Section 11.4) and *F. moniliforme* in maize. In flax, seed formation may be prevented by *Aureobasidium lini*, stem-break or browning (Section 11.5), and *Septoria linicola*, pasmo (Section 11.5); in California poppy, *Eschscholtzia californica*, *Acroconidiella eschscholtziae* (Section 11.5), and in chickpea, *Ascochyta rabiei* (Section 11.9) may kill the young seeds. In brome grass and in wheat, *Pyrenophora semeniperda* (perf. state; imp. state: *Podosporiella verticil-*
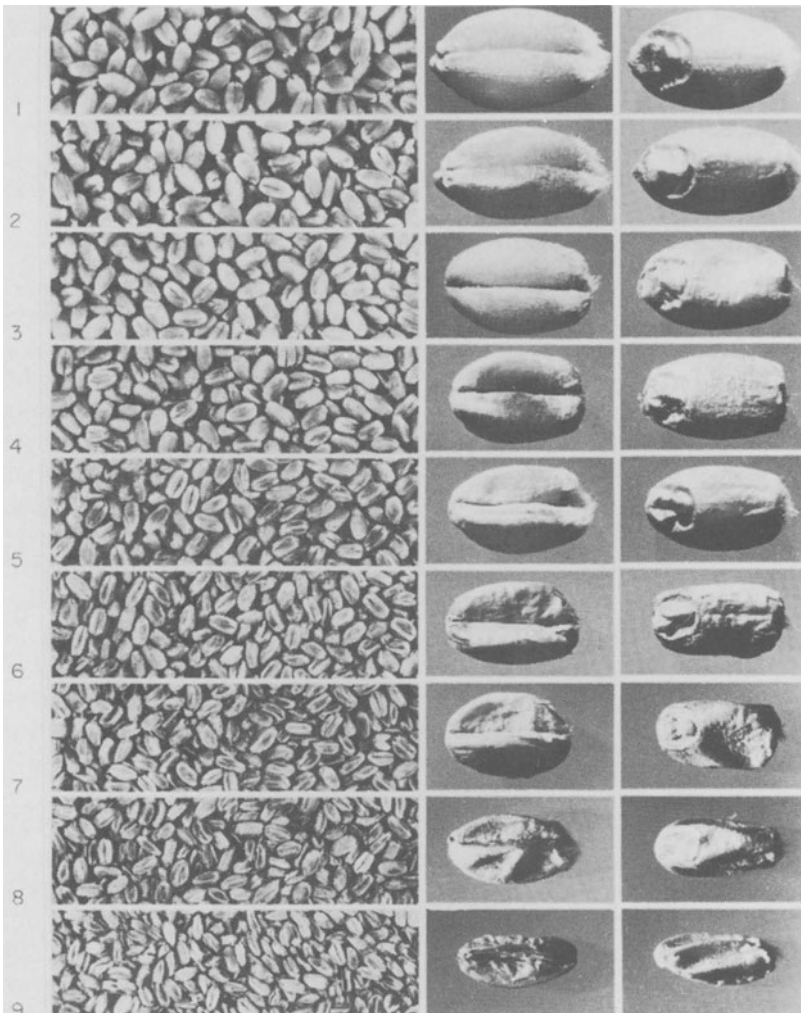

Fig. 2.6. Key to evaluation of grain quality, according to Brönnimann (1968), used in his studies on glume blotch of wheat, *Septoria nodorum*. (Courtesy of A. Brönnimann)

lata) causes death of seed primordia, hence the name of the perfect state of the fungus, and the vernacular name of the disease, 'sterility disease' (Cooke and Shaw, 1952). *Sclerospora sorghi,* downy mildew of sorghum, infects maize systemically, and usually causes sterility (Jones, Leeper and Frederiksen, 1972).

Shrunken seeds, reduced seed size. Examples of more or less heavy reduction of seed size have been given in the discussion on seed processing, including removing of poorly developed shrivelled seeds from seed lots (Section 19.9): *Alternaria brassicicola* and *Phoma lingam* in crucifers, *Ascochyta rabiei* in chickpea (Halfon-Meiri, 1970), *Phoma medicaginis* in lucerne, *Septoria linicola* in flax, *Drechslera teres* in barley (Smedegård-Petersen, 1974), and *Septoria nodorum* in wheat (Brönnimann, 1968), cf. Fig. 2.6.

Reduction of yields as a result of poor development of seeds is caused by many fungi, which are not necessarily seed-transmitted. Pathogens attacking foliage may severely impair photosynthesis with adverse consequences to seed development. Important examples are black stem rust, *Puccinia graminis,* and other rust fungi in cereals, grasses and other crops; downy mildew, e.g. *Peronospora destructor* in onion, *Sclerophthora macrospora* and *Sclerospora philippinensis* in maize, *S. sorghi* in sorghum, *Albugo candida* in crucifers; powdery mildews, e.g. *Erysiphe graminis*, in cereals and grasses; *Puccinia helianthi, Plasmopara halstedii* and *Verticillium alboatrum*, reducing also the oil content in sunflower (Zimmer and Zimmerman, 1972).

Seed rot. Many seed-borne fungi produce seed rot either in the crop or during germination. Examples are *Fusarium* in cereals, including *Fusarium avenaceum, F. culmorum, F. graminearum, F. moniliforme, F. nivale* and *F. semitectum* [Fig. 2.7(1)]. The last fungus may cause dry rot in rice grains. *F. avenaceum* is a common seed rot organism in a wide range of hosts of different families. Many species of *Drechslera* cause seed rot, e.g. *D. oryzae* in rice, *D. maydis* in maize, *D. sorokiniana* in cereals and in many other kinds of crop seed, *D. papaveris* in poppy. *Diplodia maydis* and *Fusarium graminearum* produce seed rot in maize (Ullstrup, 1961), *Trichoconis padwickii* in rice, and *Curvularia penniseti* in pearl millet. *Alternaria porri* f.sp. *dauci* and *Alternaria radicina* are causes of seed rot in carrot, *Colletotrichum graminicola* in soybean [Fig. 2.7(2)], *Phoma lingam* in cabbage, *Phoma medicaginis* in lucerne and clover, *Mycosphaerella pinodes* in pea, *Diaporthe phaseolorum* in soybean (Wallen and Cuddy, 1960), *Botrytis cinerea* in seeds of many hosts, including forest trees. Seed rot is produced in oak by *Ciboria batschiana, Sclerotinia sclerotiorum, Phomopsis quercella, Valsa intermedia* and *Gloeosporium quercinum* (Urošević, 1961a). In cacao, seed deterioration is caused by *Monilia roreri* and *Botryodiplodia theobromae* (Wellman, 1954).
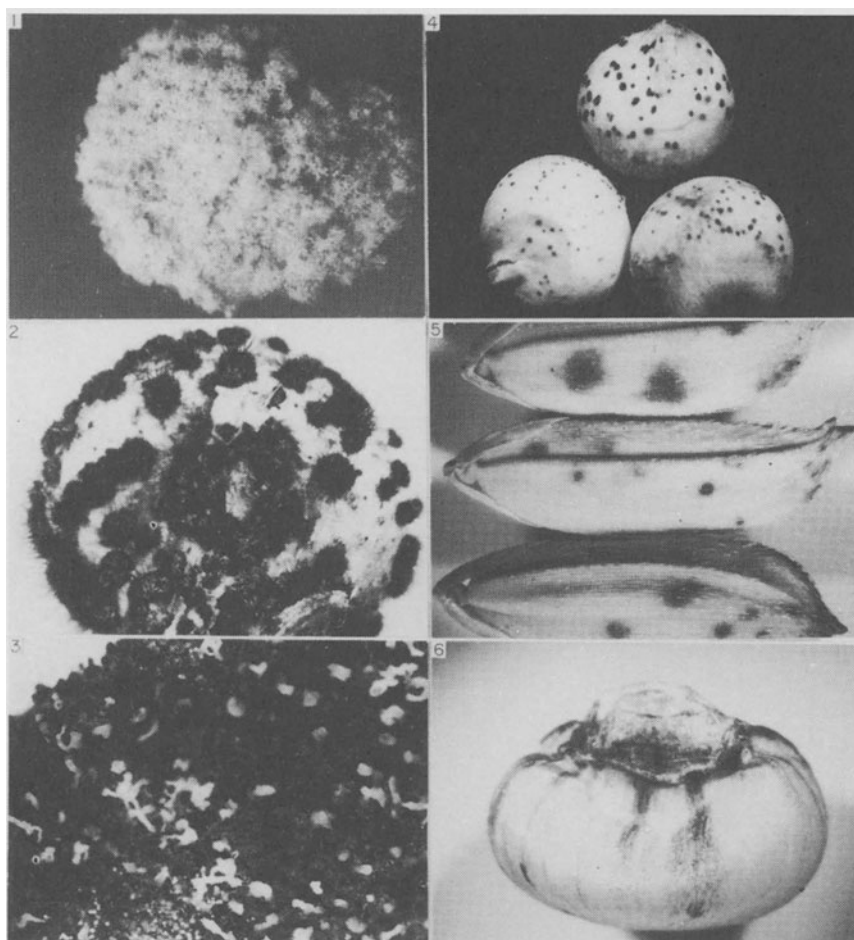
Fig. 2.7. Examples of seed rots and seed discolorations. Seed rot in (1) eggplant (*Fusarium semitectum*); (2) soybean (*Colletotrichum graminicola*); (3) *Phaseolus mungo* (*Macrophomina phaseolina*). Seed discoloration in (4) sorghum (*Colletotrichum graminicola*); (5) rice (*Drechslera oryzae*); and (6) maize (*Drechslera maydis*)

Trichothecium roseum causes rot in Scots pine, *Pinus sylvestris,* Norway spruce, *Picea abies*, black locust, *Robinia pseudacacia*, ash, *Fraxinus excelsior,* birch, *Betula*, spindle tree, *Euonymus*, European beech, *Fagus sylvatica*, and oak, *Quercus robur* (Urošević, 1961*b*). *Schizophyllum commune (Agaricaceae)*, a common wood-destroying fungus, produces rapid deterioration of cones and seeds of Douglas fir, *Pseudotsuga taxifolia* (Shea and Rediske, 1964). Also, acorns may be infected (Urošević, 1957). Under unfavourable conditions of collecting seeds and in storage *Mucor mucedo* and *M. racemosus* contribute to deterioration of seeds of oak and beech. The

fungi may originate from the ground and penetrate through cracks in the fruit coat. Seed rot produced by storage fungi is discussed in Chapter 7.

Sclerotisation, stromatisation. Transformation of floral organs or seed into sclerotia or stromata is an important disease condition in certain categories of fungi and hosts. Ergots produced by *Claviceps purpurea* and other species of *Claviceps* in cereals and grasses exemplify sclerotia of this type. Different species of *Ciboria* stromatise forest seeds and seeds of grasses, e.g. *C. alni* in alders, *Alnus incana* and *A. glutinosa*; *C. batschiana* in oak, *Quercus robur*, and chestnut, *Castanea vesca*; *C. betulae* in birch, *Betula pubescens* and *B. verrucosa*; *C. carunculoides*, known as popcorn disease in mulberry, *Morus* spp.; and *C. granigena* in brome grasses, *Bromus* spp. (Buchwald, 1949). Closely related to these fungi is *Gloeotinia temulenta*, cause of blind seed disease in different grasses, particularly in *Lolium perenne*. Another example of sclerotisation or stromatisation of seed is *Phomopsis viterbensis* in chestnut, *Castanea vesca*.

Seed necroses. Many seed-rotting fungi produce superficial necroses in the seed; other fungi never penetrate deeply into the tissues, most seed-borne fungi usually not beyond the protective layers, the seed coat or pericarp. In leguminose seeds anthracnose fungi, *Colletotrichum* spp., as well as *Ascochyta* spp., often penetrate into the fleshy cotyledons, producing conspicuous necrotic lesions in seeds of bean, soybean, pea, chickpea, cowpea and other hosts.

Seed discoloration. Discoloration of seeds is a very important degrading factor. In seeds for sowing, such disorders may indicate that seed-transmitted parasites are present, although it must be emphasised that this is not necessarily so; in seeds for consumption (e.g. grain) or for industrial purposes (e.g. oil seed) it may be a general indication of poor quality. Although in many cases blemishes in seed have no real effect on the quality of seed for sowing, they usually do depreciate, often seriously, its market value. There are at least three categories of seed discoloration when causes and effects are considered: (1) superficial necrotic lesions, (2) fungous coatings and (3) pigmentation.

Many seed-borne parasitic fungi infect the seed coat causing conspicuous necrotic black, brown to grey discolorations. Well-known examples are the effects of *Ascochyta pisi* in pea; *Colletotrichum lindemuthianum* in bean; *Drechslera oryzae* in rice, 'pecky rice' [Fig. 2.7(5) and Colour Plate IV] in which the grain not only becomes poor in appearance but also low in milling quality. Other examples are *Fusarium equiseti, F. semitectum* and *Macrophomina phaseolina* in mungbean, *Phaseolus aureus* (Ram Nath, Neergaard and Mathur, 1970); *Phaesisariopsis griseola* in bean (Orozco-

Sarria and Cardona-Alvarez, 1959); in sorghum dark brown to black spots on the seeds are associated with *Colletotrichum graminicola* [Fig. 2.7(4)], *C. gloeosporioides* and *Phoma* spp.; and in maize white streaks, often radiating from the embryo part of the seed, have been found due to infection of *Fusarium moniliforme* and *Cephalosporium acremonium,* while greyish, dark brown to black streaks are associated with *Drechslera maydis* [Fig. 2.7(6)], *Macrophomina phaseolina* and *Botryodiplodia* sp. Black streaks or specks beneath the pericarp of maize may be caused by *Physalosporazeae,* grey ear rot (Ullstrup, 1961).

   'Black point' or 'kernel smudge' in cereals is a combination of profuse contamination of fungi, as discussed below, and discoloration of the tissues of the pericarp and testa due to infection. In certain parts of the world, e.g. Canada, *Drechslera sorokiniana* is the dominant infection. Dark brownish spots prevail at the pointed end and/or the crease near the round end, as it has been shown for wheat. Under the microscope the attacked tissues appear yellowish-brown, while the aleurone cells underneath are not damaged (Kietreiber, 1972). Affected kernels are, surprisingly, heavier than normal (Brentzel, 1944; Crosier, 1953; Karpejuk, 1969; Kietreiber, 1972). Kietreiber found for 96 samples of durum wheat an average of 49 g for normal, 53 g for discoloured kernels. Affected kernels are also larger, but there is practically no difference in specific gravity. The number of discoloured kernels may increase during storage. Kietreiber (1972) studied in Austria the development of discoloured kernels in the field and found the condition caused by *Alternaria tenuis*, infection beginning at the stage of milk-ripening, about one month before harvest. The discoloration started later, at the stage of yellow ripening, about 10–14 days before the harvest. She showed that a short advance of the harvest date reduces the percentage of discoloured kernels appreciably. Cultivars exhibited marked differences in susceptibility to the condition.

   The second category of seed discoloration, coatings by mycelium and sporulating structures of fungi, often saprophytes, is another degrading factor of utmost importance. In cereals this kind of contamination is frequent and known as part of the syndrome in 'black point' or 'kernel smudge'. The disorder is caused sometimes by profuse growth of pathogens such as *Drechslera sorokiniana* in different cereals, *D. teres* in barley, *D. oryzae* in rice (Kondō and Okamura, 1927), as well as by common saprophytes such as *Alternaria tenuis* and *Cladosporium cladosporioides*, to a less extent by *Curvularia* spp., particularly in rice, and *Nigrospora* spp. Contaminations of *Alternaria tenuis* and *Cladosporium cladosporioides* are common also in many kinds of seeds other than cereals and may depreciate their market value heavily, because of their sooty appearance.

   Pathogenic fungi may be so profusely present in seeds that these appear discoloured: heavy sporulation of *Fusarium graminearum*, scab or head

blight in wheat, makes the kernels pink or orange; other examples are the blackening effect of heavy smut or bunt contaminations in grains, and oospore crusts of *Sclerospora sorghi* on the seed surface and glumes of sorghum. Machacek (1953) reported loss in Canada from a lowering of grade in grain due to heavy smut contaminations; at that time about three carloads of wheat out of each thousand inspected at Winnipeg were so degraded.

Finally, pigments produced by various fungi may indicate the presence of pathogens or saprophytes. *Cercospora kikuchii* produces a purple stain in seeds of soybean, see Colour Plate IV, and clusterbean, *Cyamopsis tetragonoloba* (Kilpatrick, 1957; Johnson and Jones, 1962; Laviolette and Athow, 1972), *Fusarium moniliforme* a pink discoloration in seeds of maize, *Stemphylium botryosum* a condition of red discoloration, 'red nose', in bean seeds in the region around the micropyle (Brinkman, 1931), and *Trichoconis padwickii* a pink stain in rice (Ou, 1963). However, not all seeds that are infected or contaminated with these fungi show discoloration. The capacity of producing pigments varies markedly from strain to strain, as shown for *Fusarium moniliforme*, and may probably also vary according to environmental conditions. *Alternaria* (probably *A. tenuis*) produced a blue strain on the lint in cotton.

Reduction or elimination of germination capacity, lowered viability. Obviously, necroses or more deeply penetrating rots in seeds reduce the viability of seeds, their longevity in storage and their emergence in field. But also infections which do not cause rot are known to lower the viability of seeds. Seeds of barley or wheat in which *Ustilago nuda* and *U. tritici* are present as dormant mycelium in the embryo, show less resistance to severe adverse field conditions such as excessively deep sowing or excessive high seeding rate, germination and seedling development being prevented (Mathur and Hansing, 1962); see Subsection 19.6.2. Barley seeds infected by *U. nuda* are slightly smaller than healthy ones, another indication that infection interferes with normal development of the seed. Wheat kernels, infected by *Podosporiella verticillata* fail to germinate, or they produce stunted seedlings, possibly due to a toxin produced by the fungus (Wallace, 1959).

Physiological alterations or effects in seed. Metabolic products of seed-borne microorganisms may affect the seed itself or may have other sometimes serious consequences such as toxicity to animals and human beings. *Aspergillus flavus*, which produces aflatoxin both toxic and carcinogenic in groundnut (Brook and White, 1966) and other seeds, may cause albinism in seedlings of citrus (Durbin, 1959) and virescence in seedlings of maize (Koehler and Woodworth, 1938); *Penicillium oxalicum* causes yellowing of the leaves in maize (Johann, Holbert and Dickson,

1931). The implications of mycotoxins, etc., produced by seed-borne pathogens are discussed in Chapter 8.

2.6   SEED DISEASES CAUSED BY NEMATODES

The genus *Anguina* includes some species which are specific endoparasites of flower primordia and produce 'seed-galls'. Most important is *A. tritici* in wheat, the seed galls of which are known under a variety of vernacular names: earcockles, purples, peppercorns, cockle wheat, hard smut, eelworm galls and nematode galls (Leukel, 1924; Thorne, 1961). Also rye, *Secale cereale*, emmer, *Triticum dicoccum*, and spelt, *T. spelta*, are hosts. The galls are produced mainly from undifferentiated flower buds (Marcinowski, 1910). Leukel (1924) showed that up to five galls may replace one kernel. The galls are different from kernels by shape and colour. They are usually 3.5–4.5×2–3 mm — some, however, are smaller; others may be larger than wheat kernels. They are almost black, often with beaklike projections, furrowed on one side. Galls formed in rye are longer in proportion to their width and more irregular in form. The life-cycle of *Anguina tritici* is described in Section 14.8.

   Seed galls are also produced by *A. agrostis* (Fig. 6.3) in different species of *Agrostis*, *Arctagrostis*, *Dactylis*, *Dupontia*, *Festuca*, *Holcus*, *Koeleria*, *Phalaris*, *Phleum* and *Poa* (detailed list in Chapter 6, on Nematodes) and by *Anguina agropyronifloris* in western wheatgrass, *Agropyron smithii* (Lakon, 1953; Norton and Sass, 1966) and in golden oatgrass, *Trisetum flavescens*, up to 28 per cent by weight (Lakon, 1953). The seed galls in grasses are very conspicuous and much bigger than the seeds.

   Undetermined nematode seed galls have been encountered in western wheatgrass, *Agropyron smithii* (Collins, 1966), *Arrhenatherum elatius* (Mühle, 1953), *Bromus inermis* (Mühle, 1953), and golden oat grass, *Trisetum flavescens* (Goodey, 1959).

   Lesions and discolorations on seeds or fruits, caused by nematodes, characterise another possible category. *Pratylenchus brachyurus* has been associated with injury to peanuts in several southern States of the U.S.A. Minton, Hammons and Parham (1970) reported lesions and discolorations in peanut of six cultivars grown in soil infested with the nematode.

2.7 EFFECTS OF AGEING IN SEEDS

In Subsection 20.2.1 longevity of seeds is discussed. Old seeds gradually decline in germination capacity and develop plants of reduced vigour. Categories of abnormal seedlings encountered in testing aged seeds for germination, according to Wellington (1968), are listed in Table 2.1.

2.8 SEED DISORDERS DUE TO UNKNOWN FACTORS

Disorders similar to hollow heart (Subsection 2.2.3) have been recorded in the U.S.A. in groundnut (Harris and Gilman, 1957) and in Venezuela in cacao (Cifferi, 1951).

In cacao the cavity is recognisable only in sections of the fresh bean. It is found only in Cirollo subspecies or in high-quality hybrids. All pods from a single diseased tree contain abnormal seeds. Dry seasons seem to be favourable to development of the disease. Affected cacao beans fail to germinate.

2.9 MECHANICAL INJURIES IN SEEDS

The *primary sources* of mechanical damage are the operations of (1) harvesting, (2) threshing, (3) processing, including cleaning and transportation within the warehouse, and (4) handling during planting (drilling).

Three levels of mechanical damage are recognised (Pollock and Roos, 1972): (1) slight injuries in the form of microscopic breaks, particularly in the seed coat, which make the seed susceptible to attack by microorganisms; (2) gross damage to seed and seed coat, easily visible; (3) internal damage, often injury to the embryo, being visible usually only after the seed has germinated.

Factors in the seed affecting susceptibility to mechanical damage include: (1) genetic constitution, (2) growth conditions of the seed crops, (3) moisture content of the seed.

Consequences of mechanical damage are primarily: (1) loss or damage of tissues and hence of viability, (2) loss of capacity in regulating the water content of the seed, (3) increased susceptibility to invasion by microorganisms, and (4) increased susceptibility to phytotoxic effects.

Classification of abnormal seedlings. In germination tests seriously damaged seedlings are classed as 'abnormal'. Wellington (1968) described categories of abnormal seedlings with reference to mechanical damage of the seed, listed in Table 2.1.

Table 2.1. Types of abnormal seedlings according to Wellington (1968)
Causal factors: desiccation = D, ageing = A, mechanical = M

Host	Root (r.)	Coleoptile	Hypocotyl (h.)	Cotyledons (c.)	Plumule epicotyl, primary leaves
Bean			Open splits, lesions and breaks in h. (M)		No primary leaves (M)
Beet	No primary r. (AM) Stunted primary r. (AM) Stunted r. (M)		Short h. (M)	Decayed c. (A)	Completely decayed or blackened seedlings (M)
Cabbage	No primary r. (A) Radicle with no root hair (A) Weak and spindly primary r. (A)		Short h. (A) Split h. (A) Decayed h. (A)	Decayed c. (A)	Watery seedlings (A)
Carrot	Stunted primary r. (A) Watery r. (A)		Short h. (A) Brown h. (A) Watery h. (A)	Decayed c. (A)	
Flax	No primary r. (A) Stunted primary r. with and without secondary r.s. (A) Stunted r. (A)		Short h. (A)	Decayed c. (A)	
Italian ryegrass	No seminal r.s (A) Stunted r. (A) One weak spindly seminal r. (A)	Coleoptile or leaf split (A)			Decayed plumule (A) No green leaf within coleoptile (A) Short leaf less than half way up coleoptile (A)
Lettuce	No primary r. (AM) Stunted primary r. (AM) Stunted r. (A)		Short h. (A)	No c. (AM) Discoloured c. (AM)	Decayed seedlings (AM)
Lupine	No primary r. (M) No well-developed secondary r.s (M)		Open splits, lesions and breaks in h. (M)		Open splits, lesions and breaks in epicotyl (M) Decayed epicotyl (M)
Onion	No primary r. (M) Stunted primary r. (AM)			Decayed c. (M) Short c. with poorly developed crook (A)	Completely decayed seedlings (M)

Table 2.1 *continued*

Host	Root (r.)	Coleoptile	Hypocotyl (h.)	Cotyledons (c.)	Plumule epicotyl, primary leaves
Radish	No primary r. (M) Stunted primary r. (M) Weak and spindly primary r. (M)		Short h. (M) Split h. (M) Decay at point of attachment between h. (M)	Spots on c. (M) Decay at point of attachment between c. (M) Decayed c. (M)	
Red clover	No primary r. (AM) Stunted primary r. (AM) Weak and spindly primary r. (M) Primary r. with longitudinal split (M)		Short h. (M) Decay between c. and h. (A)	Decayed c. (AM) No c. (A) Enlarged c. (M) One c. and damage to shoot apex (AM)	Watery seedlings (AM) Completely shattered seedlings (M)
Wheat	No seminal r.s (DM) Stunted seminal r.s (D) One spindly seminal r. (DM)	Coleoptile or leaves split (DM)			Decayed plumule (DM) Leaves less than half way up the coleoptile (D)

2.9.1 Injuries in seed due to threshing

Leguminous seeds are particularly sensitive to thresher injury which in beans may produce up to 30 per cent abnormal seedlings (Harter, 1930). 'Baldhead' or 'snakehead' is a type of abnormality caused by such injury, the epicotyl being fractured just below the plumule. Similar damage occurs in pea and clover. Cultivars with hard thick coats are more resistant to thresher injury (Zaumeyer and Thomas, 1957). Baldhead rarely occurs in seed threshed by hand (Harter, 1930; Borthwick, 1932). Bainer and Borthwick (1934) showed for lima beans that by increasing the speed of the revolving cylinder threshing was improved but mechanical damage increased, and they showed that the higher the moisture content is, the less is the damage. Troelsen (1947), however, found in Denmark, where harvest conditions often are humid, that seeds of pea, bean, lupin and similar kinds of seed are easily damaged by hard threshing when the moisture content of the seed is high. Injured seeds have poor keeping quality. The more injured are Phaseolus bean seeds, the more rapidly they lose viability in storage (Toole and Toole, 1960). During the threshing operation the machinery should be adjusted according to the moisture content of the seed.

In dry regions in the U.S.A. Phaseolus bean may become too dry for combining without damage to the seed coat. To prevent this, bean windrows may be sprayed with water to prolong or induce seed coat toughening, and after combining, any desired amount of moisture may be added by mixing damped sawdust with the beans, followed by screening after some intervals. This precaution protects bean during the processes of unloading, conveying, screening and binning (Dexter, 1966).

Flax seeds are also sensitive to thresher injury. The seed coat is brittle and may easily rupture when the seeds are knocked against a hard surface. The seed coat may be cracked or fractured, injuries are visible as scratches or splits, or the seeds may be more or less broken (Kommedahl *et al.*, 1955). Injury is caused by high rotation speed of the drum treater. Forsyth and Vogel (1945) found that the amount of injury increased with cylinder speed, and Van Es (1959) that the speed should not be above 500 rotations per minute. He established other factors that contributed to damage: wrong shape of the cylinder, the fact that seeds are thrown with high velocity against metal parts of the machine, and fall during the pneumatic transport of the seeds within the machine. Flax seeds are particularly easily injured after dry weather during the maturing and harvesting period; the fractures are generally minute and invisible to the unaided eye and, consequently, their presence does not affect the market grade of the seed (Machacek and Brown, 1945). They also found that large seeds were more injured than smaller, and that injury was more serious in large-seeded flax cultivars. Frederiksen (1948) emphasised that evaluation of flax seed should be based on normal seedlings — abnormal and weakened seedlings are unable to penetrate a soil layer 2 cm thick and are therefore worthless. In the purity test all severely injured and broken seeds should be referred to inert matter (Härtel, 1936).

Burema (1959) investigated the influence of the peripheral speed of the threshing drum on seed damage and germination of various crop seeds. He established that the adequate peripheral speed was 18–22 m/sec for cabbage seed and 20–22 m/sec for poppy seed (Fig. 2.8); higher speed results in damage. The speed of the drum had hardly any influence on the seed quality of meadow grass, *Poa trivialis*.

In most seeds thresher injury increases with decrease of the moisture content but in maize injury to the pericarp increases with seed moisture content from just above 12 per cent. Generally, to reduce risk of damage threshing is often carried out in the early morning while the seeds are still moderately moist, as is especially so for California flower seed crops.

In cereals broken and bruised kernels may considerably reduce the market value of seed grain. This was already pointed out many years ago and modern threshing machinery is still the cause of seed damage, especially when improperly used. Damage occurs particularly when the grain is threshed after a dry period of maturation and harvesting (Zundel, 1921).

% 90 80 70 60 50 — Germ. energy and germ. capacity

Cabbage seed

| o • x August 1956 |
| □ ■ + August 1957 |
| o □ Germ. energy |
| • ■ Germ. capacity |
| x + Damage |

| Rotation per minute | 500 | 600 | 700 | 800 | 900 Rot./min |
| Rotation speed | 15 | 20 | 25 | 30 m/sec |

Hand threshed

Poppy seed

| Δ ▲ August 1955 |
| o • August 1956 |
| □ ■ August 1957 |
| Δ o □ Germ. energy |
| ▲ • ■ Germ. capacity |

| Rotation per minute | 500 | 600 | 700 | 800 | 900 Rot./min |
| Rotation speed | 15 | 20 | 25 | 30 m/sec |

% 90 80 70 60 50 40 30 20 10 — Germ. energy and germ. capacity
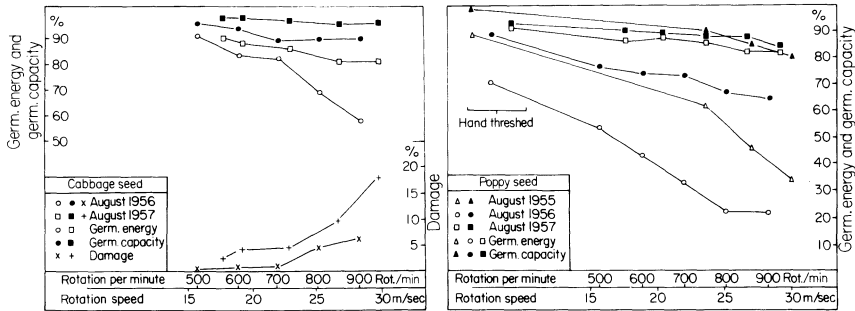
% 20 15 10 5 — Damage

Fig. 2.8. Influence of the thresher cylinder speed on the germination energy and germination capacity of cabbage and poppy. (Burema, 1959)

Walldén (1916), Machacek and Greaney (1933) and Koehler (1957) demonstrated that mechanically injured grains are much more susceptible to moulds, saprophytes as well as pathogens, than are uninjured seed, both during storage and under field conditions. Already Nobbe (1872) and later Hurd (1921) have shown that machine-threshing injury in the seed leads to chemical injury after treatment with copper sulphate, and this still holds true for modern chemical treatments (cf. Section 22.7). The localisation of the injury in the seed is important. Hurd showed that if the injury of the pericarp in wheat is above the endosperm there is 100 per cent fatal infection when *Penicillium* and *Rhizopus* spores are present, while if the rupture is above the embryo the kernel is practically unaffected. Mechanical damage, moreover, shortens the storage life of seeds as Alberts (1927) has shown for maize. Seeds with injured pericarps are subject to excessive exchange of water vapour and they are more susceptible to storage fungi.

2.9.2   Injuries in seed during cleaning and other seed processing

Preparing seed for marketing comprises a series of separate processes: separating by air blast, specific gravity, sorting according to size and colour, polishing, and other processes (Harmond, Klein and Brandenburg, 1961). Seeds may be handled more than a dozen times in plants fully equipped for processing and treating. This involves transportation, often from the top of a multistoreyed building, the seeds flowing by gravity through several machines to the lower floors. When processing is on one level the seeds may be elevated through a tank, then passed through a machine by gravity and then re-elevated for the next process. As seeds may be mechanically damaged by minor falls and increasingly so by repeated falls (Asgrow, 1949) the effects accumulate during such transportation. Much has been done to reduce handling injuries by improving cleaning and conveying equipment in seed-processing plants. A rather recent development is dense-phase or fluidised conveying of seeds (Bran-

denburg and Harmond, 1964). In this pneumatic operation seed move-
ment consists of aerated seed sludge that form, move, dissipate and
reform in a cyclical manner throughout the pipe run. In this way easily
damaged seed can be transported at low velocities, without damage,
through flexible small-pipe systems.

2.9.3   Injuries in seed inflicted during planting (drilling)

While damage to seeds inflicted during harvesting and processing is
assessed in seed testing, assessment of damage which may occur during
sowing cannot of course be anticipated. Hulbert and Whitney (1934)
found up to 10 per cent injury in large and smooth seeded pea during
drilling and they recommend mixing seeds with graphite. Bean seeds with
low moisture content may be severely damaged during planting. Dexter
(1966) obtained, by increasing the seed moisture content from 11 to 16 per
cent, increased emergence from 39 to 78 per cent.

2.10   CONGENITAL DISORDERS

In seeds of maize, particularly those of certain inbred lines which have a
weak pericarp, two types of disorder may occur. 'Popped kernels' appear
as irregular breaks over the crown of the kernel, a condition resembling
partially expanded popcorn kernels (Fig. 2.9). 'Silk cut' is characterised
by a horizontal cut or split in the pericarp over the sides of the kernel (Fig.
2.10). Both break the seed at the weakest point, exposing the starch of the
endosperm which then may be subject to infection by fungi, e.g.
Fusarium moniliforme (Ullstrup, 1961).

  In flax the seed coats split because of a genetic disorder (Fig. 2.11); the
two halves separate at the small end of the seed, exposing the cotyledons.
The percentage of affected seed may be considerable — seed lots with
10–60 per cent 'split seeds' have been common in Minnesota, U.S.A. The
anomaly is worst in yellow-seeded cultivars (Kommedahl *et al.*, 1955).
The same type of disorder is encountered in some cultivars of bean
(Zaumeyer and Thomas, 1957).

2.11   INSECT INJURIES

2.11.1   Embryoless seeds

Various umbelliferous crops, including carrot, celery, coriander, dill,
fennel, parsley and parsnip, often produce normal-looking but embryoless
seeds, i.e. seeds in which the embryo is replaced by a cavity, while the
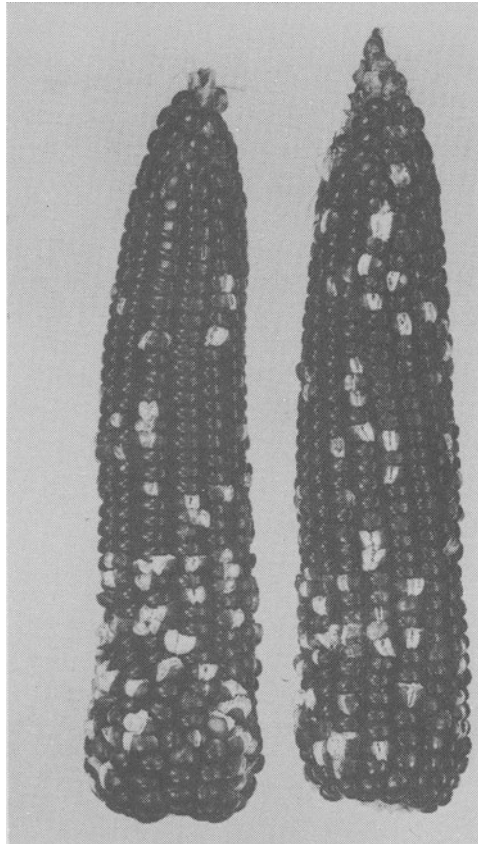
Fig. 2.9. 'Popped kernel' in maize.
  (Courtesy of A. J. Ullstrup)

endosperm and seed coat is undamaged (Flemion and Waterbury, 1941; Flemion and Uhlmann, 1946; Flemion and Olson, 1950). Handford (1949) and Flemion and Olson (1950) have shown that this injury is produced by various species of *Lygus*, including *L. campestris*, *L. elisus*, *L. hesperus*, *L. oblineatus* and *L. sallei*. In carrot similar damage has been observed in Denmark, due to *L. calmei*, *L. campestris*, *L. pratensis*, *L. pubescens* and *Echoris norvegicus* (Wagn, 1954), and in Holland due to *L. campestris* (Kho and Braak, 1956).

Lygus bugs feed preferentially on meristematic tissues. When the insects, nymphs or adults, are allowed to feed on the developing seeds they destroy the embryo at almost any stage, without affecting other parts of the seed. When they feed on flowers or ovaries, the entire fruit is destroyed and the seed yield thereby reduced. Flemion, Weed and Miller (1951) and Flemion, Ledbetter and Kelley (1954) demonstrated that secretions are injected by the insects into the tissues but they did not determine whether these were phytotoxic. Sorenson (1939) showed that *L. hesperus*
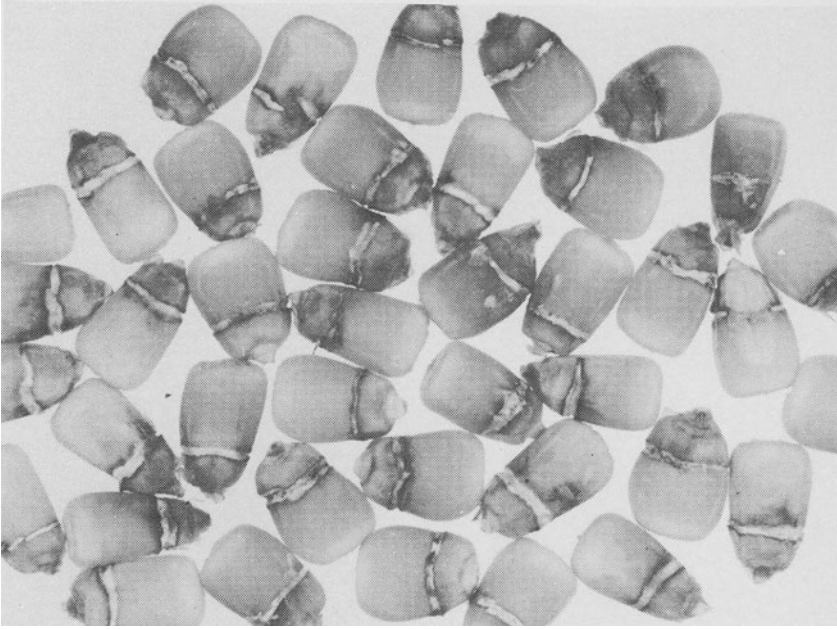
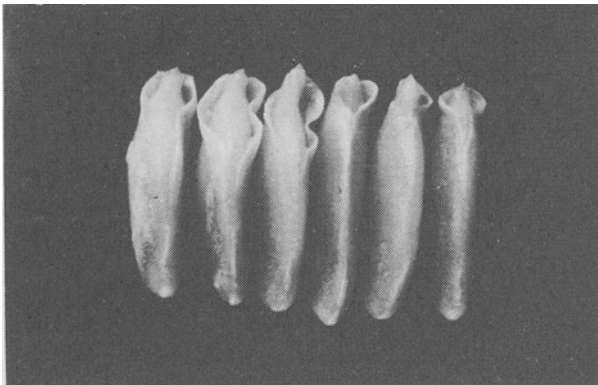Fig. 2.10. 'Silk cut' in maize. (Courtesy of A. J. Ullstrup)

Fig. 2.11. Split seed coats ('split seed') in flax. (Kommedahl, 1975)

and *L. elisus* may attack immature seeds within the pods of lucerne caus-
ing them to become misshapen or shrivelled. Also in beet different species
of *Lygus* may cause severe damage of the seed, involving loss of viability
(Hills and Taylor, 1950; Carlson, 1961).

2.11.2   Seed pitting (stigmatosis)
In the U.S.A. and other regions *Lygus hesperus* and *L. elisus* have been

shown to cause destructive pitting of several kinds of bean, including lima bean, also in cowpea (Davis, 1897; Hawley, 1922; Shull, 1933; Baker, Snyder and Holland, 1946). Young pods may be shed as a result of their feeding; insect punctures through older pods produce lesions varying from tiny sunken pinpoints to large, irregular crater-like yellow or brown lesions in the cotyledons over which the seed coat is destroyed. A brown granular mass of dead cells fills the cavity.

'Stigmatomycosis', sunken necrotic lesions produced on seeds of cotton and legumes, has been ascribed to certain yeast fungi of the genus *Nematospora*, claimed to be inoculated by different plant bugs, in particular southern green stink bug, *Nezara viridula* (Wingard, 1925). The lesions may, however, be produced independently by the insects (cf. Section 16.2). *Nezara viridula*, southern green stink bug, produces 'black pit' in pecan, *Carya illinoensis*, causing the nuts to drop prematurely if injured before the shells have become hard, and later 'kernel spot', in which the spots are decidedly bitter (Demaree, 1922; Weber, 1933; Phillips and Cole, 1945; Phillips, Large and Cole, 1960).

2.11.3 Damage caused by insects feeding in seeds

The larvae of a considerable range of insects destroy seeds by feeding in immature or mature seeds. Many are important storage insects. Well-known examples of world-wide importance are the corn earworm, *Heliothis zeae*, in maize; the pink bollworm, *Pectinophora gossypiella*, in cotton; various species of *Dioryctrya*, coneworms, in pines and firs; boll weevil, *Anthomonus grandis*, in cotton; alfalfa seed chalcid, *Brucophagus roddi*, in lucerne; pea weevil, *Bruchus pisorum*, in peas; bean weevil, *Acanthoscelides obtectus*, in stored seeds of bean, cowpea, vetch, clover, lentil and lupine; bean weevil, *Bruchus granarius*, in beans and lentil; lentis bruchid, *Bruchus lentis*; the embryo-eating beetle, *Cryptolestes ferrugineus*. In peanut the principal pest is *Carydon serratus*. *Sitophilus* spp., including grain borer, *S. granarius*, and rice weevil, *S. oryzae*, attack many kinds of seed in warehouses; the lesser grain borer, *Rhizopertha dominica*, is an important pest of paddy rice; the Khapra beetle, *Trogoderma granarium*, probably native to India, is excluded by quarantine from most of the world — it has spread in South Asia and most of Africa, but has been kept out of South America, North America and Australia.

Secondary grain pests can be serious in stored grain. Most granivorous insects are tropical or subtropical species and breed over a fairly wide range of temperatures, with optima from 30 to 38°C. They can cause heating in stored grain bulks. Important are saw-toothed grain beetle, *Oryzaephilus surinamensis*; grain weevil, *Sitophilus (Calandra) granarius*; rust-red flour beetle, *Tribolium castaneum*; confused flour beetle, *Tribolium confusum*; rust-red grain beetle or embryo-eating beetle,

Cryptolestes ferrugineus; flat grain beetle, *Cryptolestes pusillus*; and Khabra beetle, gram borer, rice weevil and lesser grain borer, *Rhizopertha dominica*.

Various moths are serious pests; *Sitotroga cerealella*, which attacks barley, wheat, maize and sorghum, is prevalent in warmer parts of the world, and different species of *Ephestia*, which eat the embryo of stored wheat, are common in most tropical produce, including peanut and maize.

Reviews on seed-damaging insects have recently been given by Howe (1972) and Bohart and Koerber (1972).