Review of Literature
REVIEW OF LITERATURE

The literature on longevity and storability of seeds; the physiological, pathological and biochemical aspects of seed deterioration, and the control of loss of vigour and viability of stored seeds has been reviewed under the following heads:

I. Seed longevity and factors affecting storage life of seeds
   A. Seed longevity
   B. Effect of environmental factors
   C. Seed deterioration by storage microflora
   D. Effect of mechanical injury

II. Physiological, biochemical and cytological changes associated with seed deterioration

III. Control of seed deterioration and seed invigoration treatments
   A. Temperature and humidity control for extending storage life
   B. Control of pathological deterioration by storage microflora
   C. Physico-chemical treatments for controlling seed deterioration
      i) Hydration-dehydration treatments
      ii) Dry permeation of chemicals
   D. Seed hardening and invigoration treatments
      i) Presowing seed treatments for imparting resistance to stress conditions
      ii) Other treatments

IV. Loss of germinability and yield potential of the crop
I. SEED LONGEVITY AND FACTORS AFFECTING STORAGE LIFE OF SEEDS

A. Seed longevity

Ageing of seed actually begins from the moment the seed attains physiological maturity. At this point the seeds are at their fullest vitality and from then onwards their decline begins, in some species rapidly and in others relatively slowly.

There are various periods of seed longevity, from willow seeds - that lose their germination capacity within a few days, to various legume seeds - which maintain their germination potential for 50 years and more. Becquerel (1907, 1934) observed in the four families viz. Leguminosae, Nymphaeaceae, Malvaceae and Labiatae that the germination potential was quite well after 23-87 years of storage. Turner (1933) reported that the seeds of Anthyllis vulneraria and Trifolium striatum remained viable for 90 years and those of Cytisus scoparius, Melilotus alba, Lotus uliginosus and Trifolium pratense for 81 years. Candolle (1943) recorded the germination of 15-year-old seeds and concluded that the seeds of woody species could retain their viability longer than the seeds of biennials, which deteriorated more rapidly. It has been reported that seeds were viable after 250 and 149 years of storage respectively of Nelumbo and Albizzia julibrissin in the British Museum collection (Anon, 1942).
It is well known that low moisture content, cool temperature and low oxygen increase the longevity of seeds in storage (Barton, 1961). Candolle (1946) recorded the germination of 15-year-old seeds and concluded that the seeds of woody species could retain their viability longer than the seeds of biennials, which deteriorated more rapidly; seeds of Pinus taeda stored for eight to fifteen years at approximately \(-4^\circ C\) retained their germinability but viability decline after one year when the seeds were stored at room temperature.

The reported germination of approximately 3000-year-old seeds collected from an ancient Egyptian tomb (Anon, 1843) have, been refuted. Luthra (1936) and Barton-Wright et al. (1944) worked on that material and pointed out that barley from King Tutankhamen's tomb were completely carbonized; the germ with its scutellum and embryo components was, however, still intact.

B. Effect of environmental factors

The effects of environmental factors on seed ageing have been studied by many researchers from time to time.

The effects of moisture content, storage temperature and oxygen pressure on seed longevity have been reviewed by Owen (1956), Barton (1961), James (1967) and others. Roberts et al. (1967), Roberts and Abdalla (1969) pointed out that for most species the higher was the oxygen pressure, the shorter was the period of viability. The relative humidity of the air, which controls seed moisture content and temperature, which affects the rates of biochemical
processes in seeds (Gane, 1948; Toole et al., 1948; Ching et al., 1959; Simpson, 1942; Harrison, 1966) are of great importance. Barton (1943) in citrus, Rees (1963) in oil palm and Bagchi (1955, 1956) in the same found a relatively high moisture content optimum for maximum longevity. Furthermore, Barton (1965) noted that in cocoa, not only a high optimum moisture content but a storage temperature of 30°C was more suitable for longer storage life.

Harrington (1973) suggested two "rules of thumb" for the common dry-stored seeds of agricultural importance: (i) for each 1 per cent reduction in moisture content, the storage life of seed is doubled and (ii) for each 5°C lowering of the storage temperature the storage life of the seed is doubled. This rule is applicable in the temperature range of 0°C and 50°C. Below freezing temperature and above 50°C the available data are insufficient to test the rule. However, the above noted rules would act independently of each other. Koostra and Harrington (1969) found that the moisture content of 4-5 per cent or below was more harmful than 5-6 per cent probably because of damage due to lipid autoxidation. The cells containing unsaturated lipids may break, producing two free radicals at the double bonds. These free radicals would then react with other lipids destroying the structure of cell membranes; with proteins inactivating enzymes and with nucleic acids causing chromosomal abnormalities and even mutations. Schultz et al. (1962) pointed out that about 5 per cent moisture, the mono-molecular layer of water
which surrounds macromolecules in seeds ceases to be continuous and this facilitates the destruction of macromolecules such as enzymes and membrane proteins by free radical reaction. Nishiyama (1977) reported that storage of rice seed over calcium chloride at 18°C decreased germination activity and increased the electrolytic leakage. But there was no effect on germination, when the seeds stored over calcium chloride at 5°C.

Roberts (1973) established the viability nomograph based on the viability equations with temperature and humidity as the external factors. Recently Ellis and Roberts (1980a, 1980b) have changed their original basic viability equations and nomographs that would facilitate the determination of longevity period of seed lots differing in genotype, quality and initial viability.

C. Effects of microflora in seed deterioration

The microflora, bacteria and fungi which are closely associated with seeds during storage, resulting in the deterioration of seed, has been a matter of interest for a long decade. The major effects of storage fungi upon seeds are decrease in germinability, discoloration, production of mycotoxins, heating and total decay. It is evident from the previous information that storage of seeds under high humidity and high temperature conditions increase the rapidity of invasion of microflora on seed, resulting eventually in excess heating and mould growth.
Noble and Richardson (1963), Christensen and Lopez (1963) reported that the seed-borne pathogen or microflora would grow better on seeds with high moisture content, resulting in excess heating and deterioration of seed. Christensen (1955) carried out an experiment on the invasion by moulds on wheat seeds in room temperature for 16 months having moisture content 13.5 to 15 per cent. He concluded that *Aspergillus restrictus* invaded grains under such conditions, resulting in reduction of germination and increase in the brown colour of the germ, which was characteristic of "sick wheat". Christensen (1969) also studied the role of microflora and deterioration of germinability of sunflower seeds. He pointed out that invasion was proportional to increasing moisture content, temperature and time of storage period. Dorworth and Christensen (1963) and Christensen (1972) greatly emphasized the role of storage fungi belonging to *Aspergillus* group, in causing deterioration of stored seeds.

A regular association between storage fungi and some kind of grain infesting insects and mites has also been noted. A relatively high seed moisture content would favour invasion by storage fungi and insect whose larvae develop within the kernels of stored grains. Qasem and Christensen (1958) observed the influence of temperature upon invasion of stored corn by storage fungi and on reduction in germination of the seeds.

Cohn (1890) first observed that fungi and bacteria produced heat in the infested seed material. Ramstad and Geddes (1943) implicated fungi in
the heating of moist soybeans and Milner and Geddes (1945, 1946) established beyond question the cause of heating in moist-stored soybeans. Seed respiration could not possibly raise the temperature higher than the germinating seeds themselves could endure, which probably would not be above 30°C. Carlyl and Norman (1941), Carter (1950) and Christensen and Gordon (1948) also contributed evidence that microflora were principally involved in the heating of moist grains and other plant materials.

During seed germination the fungi which remained quiescent during seed dormancy become active, would kill seeds and produce decreased seedlings. The severity of fungal injury depends on the environmental condition during germination as well as on the locality of fungi mycelia in the seed (Wallen, 1964). Some fungi kill the seed before germination, probably while the seed is still attached to the mother plant (Wallace, 1959). It can be assumed that the damage caused by the pathogen to the seed germination potential is caused by metabolites secreted by the fungi which are apparently connected with endogenous biochemical and anatomical changes taking place in the seed tissues.

Harman and Cranett (1972) observed that the invasion of *Aspergillus ruber* caused an increase in the leakage of solute from pea seeds. The infested seeds revealed plasmalemma damage, shrinkage of the cytoplasm away from the cell wall, and a discolored ribosomal matrix. McGee and Christensen (1970) did not get any increase in the content of individual major fatty acids or total fat acidity in
the seeds of rice, barley, wheat, maize, soybean and sunflower with increased invasion by storage fungi (*Aspergillus* sp.) until the invasion had become visible. According to Harman and Mattick (1976) storage fungi, mainly *Aspergillus* sp., invade grains when the relative humidity is greater than 65% and causes physiological disorders that is similar to physiological ageing.

D. Effect of mechanical injuries

The presence of large quantities of damage seed during processing i.e., harvesting, threshing and handling may also cause a considerable decline in seed longevity. During storage, the injured areas serve as the centres of infection and result in accelerated ageing that shortens the longevity of the seeds. Injuries near or on the vital part of embryonic axis or embryo bring about a rapid loss of viability during storage with only a minor amount of additional deterioration.

Several methods of detecting internal injuries of seed have been developed. A study of fragmented embryos and seedlings, infections, mishapen seedlings, scar tissues etc. in growth tests provides a more realistic evaluation of mechanical damage. The X-ray method as used by Kamra (1967) provided another useful method for revealing internal injuries associated with immediate or premature loss of viability. The usefulness of tetrazolium test method in this regard have been discussed by Delouche et al. (1962) and Moore (1969).
The nature of injuries varies with crops and embryo structure. Flat seeds viz. sesame (*Sesamum indicum*) with very thin, flexible seed coats are extremely susceptible to critical mechanical injuries. Flax seeds (*Linum usitatissimum*) with a firm brittle seed coat are less susceptible than sesame. Seeds that are spherical in shape are usually better protected than elongated or irregularly shaped. Atkin (1958) noted that white seeds are more susceptible to injury than coloured seeds.

Kietreiber (1969) reported drought damage as the cause of many seed and seedling abnormalities which were referred to as water damage. Moore (1972) also supported the possibilities of water damage due to rapid uptake of water by different seeds.

II. PHYSIOLOGICAL, BIOCHEMICAL AND CYTOLOGICAL CHANGES ASSOCIATED WITH SEED DETERIORATION

A. Physiological and biochemical changes

Physiological manifestations of seed deterioration are changes in seed color, delayed germination, lower tolerance to adverse storage and reduction of growth of seedlings, etc. Germination conditions, higher sensitivity to radiation treatments. The biochemical changes are mainly in respiratory activity, activities of enzymes taking part in carbohydrate, fat and protein and changes in cellular membranes and other essential bioorganells (Anderson, 1970, 1973; Berjak and Villiers, 1972; Abdul-Baki and Anderson, 1970, 1972; Matthews and
Depletion of food materials: Depletion of the food materials supplied to the embryo has been thought by many researchers as a basic reason of loss of viability. Zeleny (1954) suggested that the deterioration of the seeds during storage might be due to gradual decrease of protein, non-reducing sugars and gradual increase of reducing sugars and free fatty acids. The direct relationship of food reserves in seed and maintenance of viability is, however, questionable. James (1967) mentioned that certain seeds with large reserve food materials deteriorated more rapidly than seeds with small reserves. Barton (1961) pointed out that there was no significant reduction in starch content and total amount of nutritional reserves in deteriorated seeds. There was a decrease in non-reducing sugar and protein content accompanied by increase in reducing sugar and free fatty acid content. Harrington (1967) suggested that lack of mobilization of oxidizable food materials to embryonic axis might cause deterioration even when the adjacent tissues such as cotyledon or endosperm still contained abundant food materials. According to Went and Muntz (1949), loss of viability might be the result of the depletion of respiratory substrate. Jones et al. (1942) and Ching and Schoolcraft (1963) reported that rates of protein loss depended on the severity of storage conditions. Significant reductions in
protein and increase in amino acids occurred during loss of seed viability.

Oxley (1948) suggested that the continued life of the seed depended on the use of some labile organic matter present in the embryo; as that substance is exhausted, the seed would lose viability. According to Owen (1956), the depletion of reserves such as non-carbohydrate respiratory substrates, lipids and proteins would not account for the loss of viability; age-dependent decreases were found in some specific compounds such as thiamine and ascorbic acid which had no direct relation with the loss of viability.

Accumulation of growth inhibitors: Schwemmle (1940) reported the accumulation of inhibiting or toxic materials in seeds as they aged. Stubbe (1935a, 1935b) suggested that the metabolic changes in seed in dry storage would lead to the accumulation of inhibiting or toxic substances. Crocker (1948) and Curtis and Clark (1950) reported that the loss of viability might be caused by the accumulation of the products of respiration and Wyttenbach (1955) suggested that loss of viability was due to the accumulation of lactic acid in Medicago sativa, Trifolium pratense and Lotus corniculatus seed. Another group of substances which accumulate when seed deteriorate are the fatty acids (Barton, 1961). It has been claimed by Sircar and Biswas (1960), Sircar and Dey (1967) that the loss of viability of rice seed is associated with the accumulation of supra-optimal concentrations of indoleacetic acid and other indole derivatives. Later on Dey et al. (1967) suggested that accumulation of phenolics including coumarin and ferulic acid as the most probable cause of loss of viability of rice seeds. They also reported that the accumulation of the inhibitor abscisic acid could
be responsible for the loss of rice seed viability (Sircar, 1967; Bey and Sircar, 1968; Chatterjee et al., 1976).

Polgar (1961) studied the inhibiting effect of the seed cluster of sugar and fodder beet on germination and concluded that dry treatment with 1 kg ferrous sulphate per 20 kg of clusters, in addition to ventilated storage for one month at 24°C is potentially valuable for improving yields and germination reducing the activity of inhibitory substances. Battle and Whittington (1969) reported a positive correlation between the germination and inhibitory substances of sugar beet seeds. Juntilla (1976) also supported with inhibitory substances in the water extracts of beet root clusters.

**Loss of enzyme activity:** Many attempts have been made to correlate enzyme activity and loss of seed viability. The activities of dehydrogenase and glutamic acid decarboxylase have been found to be correlated with seed viability. Important findings were made by Moore (1956, 1963, 1969) in respect of dehydrogenase and Linko and Sogn (1960), Linko (1961) and Grabe (1964) in decarboxylase activity. The changes in activity of amylase, cytochrome oxidase, glutamic acid decarboxylase and dehydrogenases have been investigated in deteriorating seeds (Throneberry and Smith, 1955; Fleming et al., 1960; Grabe, 1964; Anderson and Abdul Bari, 1972). McMargue (1920) reported peroxidase activity as a measure of seed viability. Davis (1931) pointed out that catalase and oxidases were frequently used as criteria of
metabolism and viability of seeds. In contrast to the above findings, Brocq Roussin and Gain (1908) reported higher peroxidase activity in 208 years old wheat seed. Similar observations were made by James (1968) on glutamic acid decarboxylase activity in non-viable bean seeds and a high activity of dehydrogenase in heat damaged barley seeds (McLeod, 1952). Abu-Shakra and Ching (1967) studied the mitochondrial activity of differentially aged seed lots of soybean and concluded that deterioration caused a visible increase in the density of the matrix of mitochondrial pellets.

Accumulation of mutagens: The relationship between loss of viability and accumulation of automutagenic substances during storage was first suggested by Stubbe (1935). D'Amato and Hoffman-Ostenhof (1956) pointed out that the most probable cause for the loss of germinability were either lethal chromosome changes brought about by automutagenic substances accumulated during seed ageing or a more general poisoning of the embryo due to the accumulation of autotoxic substances. Regarding this phenomenon some evidences were provided by James (1961), Lilly (1965) and D'Amato (1954). De Vries (1901) reported that higher percentage of abnormal plants were produced by old *Cepothera Lamarckiana* seeds than by new seeds which marked the beginning of mutational studies in seeds in relation to their deterioration. Jackson (1959) established that leachates of aged onion
seeds applied to fresh onion causes chromosome breakage. Nichols (1941),
and Sax and Sax (1964) showed that the frequency of aberrant cells in onion
increased with storage period. Harrison and Carpenter (1977) reported that
in low temperature storage, onion seeds did not lose germination and there
was no increase in cytological damage. Abdalla and Roberts (1968) also
failed to find any mutagenic activity in aqueous extract of old seed lots.

Floris (1966, 1970) and Floris and Anguillese (1974) showed that the
accumulation of toxic metabolites in seeds could cause a significant
depression of germination. Corsi and Avanzi (1969) reported that chromosome
damage in the embryo was not the result of senescence in the endosperm,
although low level of chromosomal damage could be induced by old endosperm.
Avalanche et al. (1967) and Maletti et al. (1968), however, noted that the
transmission of a mutagenic effect from an X-irradiated endosperm was much
greater.

Changes in respiratory rate: Woodstock and coworkers (Woodstock and Feeley,
1965; Woodstock and Pollock, 1965; Woodstock and Combs, 1967; Woodstock and
Justice, 1967; Woodstock, 1969) reported a high correlation between respiration
levels of the seed and seedling growth in corn, bean, pea seeds and wheat etc.
High respiratory quotient (R.Q.) values are often observed in deteriorated seeds
(Woodstock and Grabe, 1967; Anderson, 1970a). Reduction in oxygen uptake
occurred primarily during advanced deterioration (Thorneberry and Smith, 1955);
changes in activity of glutamic acid decarboxylase enzyme was reduced in deteriorated seeds of many species (Linko and Sogn, 1960; Linko, 1961; Bautista et al., 1964). Roberts and Abdalla (1968) established a deleterious effect of oxygen at a combination of temperature and moisture content at which respiration could be inhibited.

The decline in germinability and seedling growth of soybean seeds during accelerated ageing at 41°C and 100% RH has been found to be accompanied by increased level of acetaldehyde and ethanol in imbibing embryonic axes and seeds (Woodstock and Taylorson, 1981). They also pointed out that a similar inverse relationship between levels of acetaldehyde and ethanol with deterioration, when seeds were naturally aged for several years. During imbibition, increases of ethanol and acetaldehyde were high in low vigour seed than in high vigour. The increase of these substances in low vigour seed was less when water uptake injury avoided by osmotically decreasing water uptake rate with 30% polyethelene glycol. The embryonic axes of the deteriorated seeds were characterised by low rates of O₂ uptake and high R.Q. relative to the unaged controls and they concluded that, during ageing, an imbalance between tricarboxylic and glycolytic activities, present during early imbibition to some degree even in vigorous unaged seeds was more pronounced and would lead to accumulation of ethanol and acetaldehyde.
Changes in protein content: Robbins and Fetch (1932) reported that for the loss of seed viability denaturation of protein was one of the most important reason. Jones et al. (1942) investigated the changes in protein content of wheat during storage. Reduction in protein content and increase in amino acid content was attributed to loss of vigour and viability in crimson clover (Ching and Schoolcraft, 1968). Positive relationship of protein with seed vigour in terms of subsequent crop growth and yield was reported by several workers in wheat (Riss, 1971), in bean (Lopez and Grabe, 1971), and in barley (Riss and Everson, 1973).

Denaturation of nucleic acid: Denaturation of nucleic acid is one of the probable causes of seed deterioration. Roberts (1967) showed that with the progress of seed senescence, the number of breaks in the DNA increased. The damage to the nucleic acids would not require the production of stable mutagens during ageing but might involve reactions by free radicals which might be considered as short-lived mutagens (Roberts, 1972). Grzesiak and Kulka (1971) also suggested a direct correlation with age and decrease in quality of nucleic acid and greater activity of nuclease.

Measurement of membrane integrity: Pollock and Toole (1966), Matthews and Bradnock (1967), Takaanagi and Murakami (1968) reported the leakage of metabolites in larger amounts into the germination medium from aged, deteriorated and injured seeds than from vigorous seed due to membrane
permeability in lima beans, peas and rape seed respectively. Several tests such as electrical conductivity of leachates for different seeds (Hibbard and Miller, 1928; Follock and Toole, 1966; Matthews and Bradnock, 1968; Simson, 1974; Mallett and Wilkinson, 1979), leaching of sugar (Takayanagi and Murakami, 1968, 1969) and leaching of amino acids (Ching and Schoolcraft, 1968) were employed for evaluating the membrane integrity and correlating with seed vigour and viability. Hallion (1975) reported that there is no relationship between loss of viability and leakage of solutes in case of cotton seeds.

Denaturation of lipoprotein membrane: It is evident from the previous work that prolonged storage of seeds brings about some degenerative changes in cell membrane (Ching and Schoolcraft, 1968; Takayanagi and Murakami, 1968a, 1968b). Berjak (1968b) suggested that the loss of viability might be the result of the loss of integrity of cell membranes. Lipoprotein membrane contains high proportion of polyunsaturated lipids; in presence of oxygen, lipid the unsaturated/will form free radical intermediates and unstable peroxides, thus changing the semipermeable nature of the membrane (Roubal and Tappel, 1966).

Villiers (1972) suggested the deterioration of biomembrane in aged seeds due to peroxidation of phospholipid. Roberts (1972) supported the above view and reported that oxygen pressure may be the cause of loss of
membrane integrity in old seeds. Rudrapal and Basu (1979) have shown greater lipid peroxidation reactions in deteriorating wheat seeds.

The enhancement of membrane damage by lipid peroxidation have been attributed of the altered nature of phospholipid themselves which affect their packing in bilayer and indirectly to damage incurred by protein in the course of peroxidation (Roubel and Tappel, 1966). Harrington and Kostra (1969) were able to show a marked decline in quality of polar lipid in nonviable seed. Simson (1974) reported that peroxidation of membrane phospholipids and loss of membrane integrity are closely related. Sencer et al. (1973) have been able to identify products of the oxidation of some free fatty acid in stored seeds of Cichorium and Crepis.

Abdul-Baki and Anderson (1970) suggested that leachable glucose in rapidly aged seeds and so it was not related to the membrane integrity. Sterling et al. (1976) reported that rapid permeation of limiting membranes upon initial wetting with water was indicative of membrane disorder when dry. Mckersie and Thompson (1977) pointed out that substantial amount of the lipid in senescing membrane was crystalline even at physiological temperature.

Free radicals in seed deterioration: Free radical is one of the most important participants in causing oxidative damage of polyunsaturated lipids.
cell and cellular components in the biological system (Tappel, 1973; Demopoulos, 1973a, 1973b; Milvy, 1973; Myers, 1973). Pammenter et al. (1974) by adopting the technique of Molnar (1972), considerably extended the viability of maize seed by providing a source of free electron from outside, which would suggest the involvement of free radical in age-induced deterioration.

Direct evidences for the role of endogenous free radicals in seed deterioration are lacking, as they are very short-lived and accumulate in low concentrations not sufficient for detection. Dertinger and Jung (1970), Demopoulos (1973), Slater (1972) and other have shown the role of different radioprotecting chemicals in controlling free radical reactions. A number of antioxidants and metal chelating agents have been found to modify the damage due to X-irradiation (Demopoulos, 1973; Diluzio, 1973; Milvy, 1973; Heckly and Dimmock, 1967).

The radioprotective action of water has previously been reported by Ehrenberg (1961), Cook (1963) and Conger and Carabia (1972). It has been suggested by Ehrenberg (1972) that hydration of irradiated seeds might act by increasing the mobility of free radicals and facilitating their recombination into harmless non-radical product. Pre-irradiation soaking-drying treatment of barley seed, altered the molecular stability of the system resulting in decreased sensitivity to thermal and fast neutrons.
and to some extent to X-rays. Biebl and Mostafa (1965) recorded the optimum moisture content at which the radiosensitivity of barley and wheat seeds was minimum and found that a moisture content of 11.2% for barley and 12.9% for wheat were most effective against radiation damage. Kulzin et al. (1967) showed a recovery of post-irradiation damage in barley seeds after washing in water for several hours or in 2% urea solutions. Walf and Sicard (1961) also concluded the recovery of irradiation damage to dry seeds, when it was allowed to raise the moisture content of about 20%. Justice and Kulik (1970) suggested that increase of moisture content prior to irradiation significantly reduce the radiation damage in radish seeds.

Haber and Randolph (1967) pointed out that simple wetting-drying treatment could eliminate 92% of radiation-induced electron spin resonance signals in X-irradiated lettuce seeds. Joshi et al. also noted a very conspicuous recovery from X-irradiation injury by raising water content of barley seeds through storage at different humidity levels. Kalam et al. (1972) reported that treating X-irradiated barley, horse bean and maize seeds in water extract of mustard seed were effective in increasing germination, seedling length, the ratio of chlorophyll a, b and ascorbic acid oxidase activity in the seedling. Osborne and Bacon (1960), Justice and Kulik (1970) found that the seeds of Cruciferae were most resistant
Cook and Baneyan (1963, 1969) suggested that radiation damage could be minimized on application of 2-aminoethylisothiourea, a radioprotective chemical. Radical scavenging effect of cysteine, cysteamine and cystamine have been reported by Mkaelsen and Pedersen (1968). Sodium azide, as agent which enhances radiation damage, increased the seedling injury. Sanders and Muehlbeur (1977) reported that sodiumazide did not cause chromosome damage in pea. Conger (1973) observed that ascorbic acid, protected barley seeds against radiation-induced damage when given as a pre-irradiation treatment. Gaur et al. (1970) reported that the enhanced radiation damage caused by dinitrophenol treatment may be due to its effect on phosphorylation necessary for recovery or repair process. Radiosensitizing effect of caffeine was reported by Yamanoto and Yamaguchi (1969). Yamaguchi (1974) showed the inhibiting effect of EDTA on the repair of X-ray-induced lesions in germinating barley seeds. Witte and Bohme (1972) were of the view that binding of caffeine to DNA inhibited replication of DNA molecules and their reactivity was affected. Huystee and Cherry (1967) found that in pea nut seed, nucleic acid synthesis was stimulated just after X-irradiation but after storage for 2-4 weeks the X-ray enhanced nucleic acid synthesis was reduced. Inhibition of respiration rate was also pointed out in irradiated seeds by Woodstock and Justice (1967).
Vashrchenko et al. (1974) reported that seed treatment with gamma-rays at 1-4 KR plus soaking in 0.05% boric acid solution increased yield of red beet (Beta vulgaris) up to 21% and best results were obtained at 3 KR with boron. Sax and Sax (1964) found that X-irradiation and ageing effect are additive for chromosome damage. Bagchi (1974) also noted a similar correlation between ageing and irradiation damage in case of rice seed. Burov (1977) noted increased germination up to 4 KR but it decreased at 6-10 KR in onion seed. Dasgupta et al. (1977) showed parallelism between radioprotection and maintenance of seed viability which was suggestive of the involvement of free radicals in ageing of seeds.

Extension of longevity by imbibed storage

Villiers (1971, 1974) and Villiers and Edgcumbe (1975) reported that imbibed lettuce seeds were more viable than dry seeds. According to them, accumulation of damage to macromolecules and cell components and damage to the genome increased in air-dry storage. So, in seeds fully imbibed throughout the period before germination, repair of damage to cellular bioorganelles was possibly due to the operation of the cellular repair system and many degenerative changes might be correlated as and when they occur. Comes et al. (1978) observed the viability patterns of a range of weed and crop seed in water storage. Many of the seeds lost their viability before one year; few such as sunflower and Medicago retained germinability.
upto five years. But in no case storage in water was better than dry-storage.

B. Cytological studies

Cytological changes including chromosomal abnormalities, mutation and other disorders in cytoplasmic components as influenced by ageing have been studied over a long period. In 1901, De Vries pointed out that higher percentages of abnormal plants were produced by old seeds than fresh ones in Oenothera seed. Nilsson (1931), Nawashin (1933), Gunthardt et al. (1953) and others supported the above view. Nawashin (1933a, 1933b) observed that high frequencies of chromosome aberrations occurred in roots produced from old seeds. A number of other workers have subsequently reported increases in number of chromosome aberrations and cytological changes with increase in age of seed of a wide range of species; in durum wheat and common wheat, barley, rye and peas (Gunthardt et al., 1953), in lettuce (Harrison and Mcleish, 1954; Harrison, 1966), in onion (Nichols, 1941; Sax and Sax, 1964), in peas (D'Amato, 1951), in spring onion (Keto, 1951) and in maize (Barjak, 1963b). Blakeslee (1933 and 1934) noted that in Datura higher rate of pollen aberration mutation took place from old seeds. Excepting the chronological age of the seed, other factors such as temperature and moisture during storage would hasten the chromosomal damage. Barton and Blakeslee (1936) concluded that the mutation rate increased with
increase in moisture and temperature levels.

Peto (1933) noticed that treatment of barley seeds at 95°C for 25 minutes or at 40°C at high humidity for 30 days resulted in the appearance of chromosomal abnormalities. Montchen and Ehrenberg (1959) in broad bean and Jackson (1959) in onion seed noted that temperature, humidity, oxygen in normal storage environment could contribute to nuclear damage.

Observations were made by Roberts et al. (1967) and Abdalla and Roberts (1968) on the reduction of viability and the accumulation of chromosome damage in peas, beans and barley. Roberts (1970) also suggested that loss of 50% viability in barley seeds under any storage condition is equivalent to accumulation of genetic damage by treating fresh seeds with 10,000 of X-rays. Sax and Sax (1964) showed that the effects of normal ageing and X-irradiation were additive in their effects on the induction of chromosome aberrations.

Berjak (1968b) and Berjak and Villiers (1970, 1971) studied the chromosomal changes occurred in cell organelles during storage. Anderson et al. (1970) reported the ultrastructural changes in the embryonic axis of wheat embryos during storage. Sen (1977) also noted that ultrastructural and biochemical changes took place during ageing of seeds.
III. CONTROL OF SEED DETERIORATION AND SEED INVIGORATION TREATMENTS

A. Temperature and humidity control for extending storage life

Factors

Seed moisture content and temperature are the most vital for the maintenance of seed viability and a low moisture content and low temperature are the ideal storage conditions to prolong the life of the seeds. According to Harrington (1973), it is possible to keep seeds of most species for hundred of years, if the storage conditions are provided with relative humidity of 15%, low oxygen and high carbon dioxide concentration. Bass (1973) also reported that adequately dried seeds sealed in moisture impervious containers can be stored safely for 2-3 years at ordinary room temperature (21-30°C) and much longer at low temperature (5-29°C). Storage in a controlled atmosphere such as carbon dioxide, nitrogen etc. or in a partial vacuum may prolong seed life better than storage in air, where as storage in oxygen atmosphere tends to accelerate the loss of viability. He also concluded that small packages of seed lots require better moisture barrier than large packages, because, small packages contain fewer seeds per unit area of package surface than do large package. Therefore, seeds in a small package are exposed to vast environmental conditions and give up or absorb a large portion of moisture vapour transmitted through the package surface. Ghosh et al. (1951) reported that jute seeds stored in 7.2% moisture content in air tight glass bottle or polythene lined gunny
would retain germinability for longer period than the ordinary gunny bags. Obilsami (1972) observed that rice seeds kept at 12.5, 15 and 20 per cent moisture contents for 15 days showed 98, 97 and 0 per cent germination respectively after storage. Rocha (1959) found that the germination of onion seeds reduced by more than half in 10 weeks at 13 per cent seed moisture and 25°C, whereas Barton (1966) maintained onion seeds with almost no loss in germination for 18 years at below 6% moisture content and 5°C. Harrison et al. (1977) showed that onion seeds with 4 and 6 per cent moisture contents (on dry weight basis) can be stored for periods up to 3.75 years at -196°C and -20°C with no loss of germination or yield with no increase in cytological damage. Minkov et al. (1974) worked on commercial lots of onion, pea, bean and certain vegetables and concluded that seeds with lower moisture contents increased the viability of seeds. Bass (1975) reported that papaya seeds stored at 10°C and 50% RH in cloth bags and 5°C in sealed moisture-barrier packages, retained their viability reasonably well during 6 years storage.

Blockholt et al. (1969) suggested that storage/seeds of cotton, sorghum and corn in refrigerated condition was the best means followed by storage in partial vacuum, sealed glass bottle and paper envelops. Clark (1963) reported that effect of various seed storage bags on viability and vigour of seed and subsequent effect on yield. He concluded that maize seeds at 8.7% moisture content and sorghum seeds in 9.5% moisture
content stored in polythene bag proved to be the best. Conill (1974) reported that rice seeds stored in air-tight sealed polythene bag retained germinability better than in gunny bag. Ramayya (1972) observed that rice seeds stored in alkathene bag with reduced moisture content or with mixing in silica gel or calcium oxide without lowering the moisture gave 81-96% germination after storing for 8 months. Dasgupta (1978) reported that sealed glass bottle is the best for the preservation of wheat seed under warm humid conditions.

Roberts (1961) conducted an experiment in rice, sealed in ampoules in oxygen, air and nitrogen at various moisture content from 12-14.5% and temperature from 30-45°C and found there was a tendency of greater viability at decreased partial pressure of oxygen, particularly under low temperature and humidity conditions. Khan (1976) observed that 100-day-old rice seeds can retain their viability for 360 days when stored in paper bag in a vacuum desiccator at 2 x 10⁻³ mm Hg at 26°C. Rao (1976) noted that sunflower seeds stored under ambient conditions lost viability faster, accompanied by decrease in vigour, field emergence and oil contents. Bass and Stanwood (1978) stated that storage of seeds in an inert atmosphere did not show any encouraging results, though storage temperature and humidity affected the storability significantly.

B. Control of pathological deterioration by storage microflora

It is well known that most of the seed-borne pathogens are likely
to be detrimental to seed quality, especially with respect to germination potential. Certain pathogens—fungi, bacteria and viruses are borne on the seed surface and/or within the seed tissues, and they penetrate the seed while it is on the plant. Some pathogens invade the seed after harvest, mainly in storage period and it can be prevented with suitable fungicides during storage of seeds. Usually at a moisture content of 70-90 per cent, the storage fungi grows well on seeds or other plant with the increase materials. The activity of microflora increased of relative humidity rather than moisture contents of seeds because different seeds have different relationships between these two factors. Semenuik (1954) suggested that usually storage fungi are inactive below 62 per cent relative humidity. Milner and Gaddes (1954) also noted very little fungal activity below 75 per cent relative humidity. Semenuik (1954) reported that storage bacteria require 90 per cent relative humidity for growth and certain microorganisms would grow at a temperature at low at -8°C, others at a temperature as high as 80°C.

To check the storage microflora dry dressing with a systemic fungicide, carboxin, applied to the surface of barley grains could rid their embryos of loose smut fungus (Schmeding and Kulka, 1966). This was possibly due to the penetration of the fungicide or a fungitoxic byproduct deep into the seed tissues. Kumar et al. (1977) reported that miltox, dithane Z-78 (Zineb) and dithane M 45 (mancozeb) were equally
and significantly effective in enhancing seed germination of maize while unizeb had a profound effect on seedling growth and concluded that seed treatment with zineb, mancozeb and unizeb were equally effective in reducing the disease caused by H. turcicum (Setosphaeria turcica). Singh et al. (1974) showed that thiram and terrachlor super X both at 0.5% concentration significantly increased seedling emergence of barley after 6 months of storage. Similar beneficial effects of fungicides like thiram, captan, vitavax, benlate and Agrosen GN were noted by Agrawal et al. (1976). Grewal and Kapoor (1968) studied viability of fungicide treated wheat and barley in storage and found that different fungicide and types of containers used for storage influenced seed germination significantly.

Kommadahl et al. (1978) reported that Penicillium oxalicum was as effective as captan and significantly better than untreated control in greenhouse test and in the field, it improved stand and pod number over the control. Chinn (1978) reported that imazalil treated wheat seed in the field experiment showed the internodes of mature plants 14.7% larger than those from nontreated seed. Kommadahl and Mew (1975) coated kernels of corn (Zea mays) of with three hybrids Bacillus subtilis, Chaetomium globosum or captan and planted the seeds in the field. He found that stands increased 9 and 14 days after planting and at seasons end, for all hybrids with chaetomium
and captan treatment. Stalk rot and breakage were less with two organisms and captan treated than with non-coated kernels. He also reported that grain yield per treatment were higher for kernels coated with captan. Ellis et al. (1975) reported that high levels of internal seed and low percentage germination of soybean (Glycine max) seeds treated with captan, thiram and benomyl at 0.016, 0.033 and 0.033 g active ingredient/20 g seed respectively gave higher germination in vitro, and emergence in vermiculite and field soil than nontreated controls. He pointed out that internally seed-borne fungi were primarily located in seed coat (testa) tissues and only occasionally were found in embryo tissues. The fungicide captan and thiram moved into seed coat tissues, but did not penetrate the embryo, therefore, were effective only against fungi in the seed coat. Rowell (1976) noted that wheat seed treatment by 4-N-betyl-1, 2,4-triazole effectively prevented crop losses due to leaf rust. Jacobsen (1977) recorded that winter wheat yields (during 1974 and 1975) were reduced up to 15-20% by Septoria tritici, S. nodorum and Fusarium roseum f.sp. Cerealis 'Grazepearum' as measured by yield response to fungicides. Wheat yields were 20% higher in plots treated with mancozeb or mancozeb plus benomyl, and 15% higher when treated with benomyl alone. Test weights were also increased 1.2 to 2% by fungicide treatment.

Hampton (1979a) treated wheat and barley seeds with a number of fungicides.
and showed that the seeds could be safely stored for up to 12 months but the germination of barley seeds treated with carboxin and carboxin plus thiram was significantly reduced after 18 months of storage. Germination of captan treated wheat seed was significantly reduced after 24 months of storage. In another study, in which Hampton (1979b) gave greater emphasis on vigour testing, it was shown that wheat seed treated with mancozeb or mancozeb based fungicides could be safely stored for only 5-6 months after treatment. Glass house tests at 10°C suggested that storage of mancozeb treated wheat for more than three months resulted in weakened seedling as well as reduced emergence but the germination and vigour of similarly treated barley seeds was not affected by the length of storage.

Christensen and Lopez (1963) reported on the lack of satisfactory chemical methods of control of microorganisms in storage. The bacterial and fungal pathogens are more deeply seated and normal seed dressings are not effective and more penetrative treatments are required. Heat treatment of seed using hot carbon tetrachloride (Cruickshank, 1954) or wet heat using hot water (Bant and Storey, 1952) or steam air mixtures (Baker, 1962) have been employed against some seed-borne fungi. Haude et al. (1962) suggested that soaking seeds in 0.2% water suspension of thiram at 30°C for 24 hrs followed by rapid drying in a current of air at 25°C, can effectively control the invasion and growth of mould. Nofsinger et al.
(1977) reported that intermittent application of gaseous ammonia to freshly harvested maize grains of 20-25% moisture content was helpful in preserving the seeds for 6 months with no physical or microbial deterioration.

C. Physico-chemical treatments for controlling seed deterioration

(1) Hydration-dehydration treatments

Recently, the efficacy of soaking-drying treatments in the maintenance of vigour and viability of seeds have been put forward by Basu and coworkers (Basu et al., 1974; Basu and Dasgupta, 1974; Basu, 1976). This method of seed treatment differs from the conventional pre-sowing treatment in that the short-duration soaking-drying treatments were given to stored seeds allowing a sufficient time gap between treatment and sowing. The effect is spectacular and highly reproducible not only in maintaining vigour and viability but also for the productivity of the crop raised from the treated seeds (Dasgupta et al., 1976; Basu and Pal, 1978; Basu and Dhar, 1979; Mitra and Basu, 1979; Kundu and Basu, 1981).

The beneficial effects of physico-chemical seed treatment have been interpreted on the basis of control of free-radical pathology. Dasgupta et al. (1977) and Basu and Dasgupta (1978) reported that seed invigoration treatments could effectively reduce X-irradiation damage in wheat and jute seeds. Pre- and post-irradiation soaking-drying treatment effectively
counteracted the damaging effect of X-irradiation on growth of the seedlings, activity of amylase and dehydrogenase enzymes, membrane integrity and chromosomal aberrations. Radiosensitizing compounds such as caffeine, sodium azide and phenol etc. showed an adverse effect on germination and seedling growth, whereas treatment with antioxidants like salts and chelating compounds slowed down the loss of vigour and viability and effectively counteracted irradiation damage. Hydration of stored seed by moisture equilibration with a saturated atmosphere or a light aqueous spray followed by rapid drying back proved very effective in controlling age-induced and X-irradiation-induced seed deterioration. These findings suggest the involvement of free-radical reactions in seed deterioration.

(ii) **Dry permeation**

Organic solvents such as ethyl alcohol or acetone have been used for the purpose of germination improvement of hard-coated seeds as the solvents made the seed coats permeable (Cox et al., 1945; Anderson et al., 1953; Crocker and Barton, 1953).

Incorporation of bioactive chemical into the seeds via organic solvents was first suggested by Milborrow (1963). A number of workers have shown the potentiality of this method in improving the seed quality.
Tao et al. (1974) successfully prevented seed deterioration by using antiageing compounds like actinomycin-D, antibiotics, chloramphenical in a medium of different organic solvents. Khan et al. (1976) have shown the potentiality of this technique in improving seed vigour and good performance under field conditions. Joshua and Heydecker (1971); Heydecker and Joshua (1977) showed that the chiling temperature for lettuce seed germination could be raised appreciably by infusing kinetin into seed for 15 minutes through dichloromethane.

Recently, studies in the present laboratory also have indicated that several chemicals, such as potassium iodide, p-hydroxybenzoic acid, tannic acid etc. introduced into the mustard seed via acetone significantly reduced the loss of vigour and viability (Basu et al., 1980). It has also been noted that iodine in vapour form significantly reduced the loss of seed deterioration (Basu and Rudrapal, 1979; Rudrapal and Basu, 1980).

D. Seed hardening and invigoration treatments

1) Pre-sowing seed treatments for imparting resistance to stress conditions

Pre-sowing seed treatment with dilute solutions of salts, primarily with the idea of imparting resistance to sub-optimal edaphic and climatic conditions was advocated by Henckel (1967). The germination and emergence
of tomato, onion, pepper and carrot seeds were accelerated by pre-soaking the seeds in various salt solutions (Traverse and Riekels, 1973). The beneficial effect of pre-sowing wetting-drying treatments on the enhancement of germination and seedling emergence of a number of species have been putforwarded by Austin et al. (1969), Hegarty (1970), Berrie and Drennan (1971), Heydecker (1972) and others. A number of evidences suggest that such treatments may improve the performance of seed and seedling under sub-optimal conditions (Henckel, 1967; Cole and Wheeler, 1974) and improve seed production (Corleto et al., 1974; Thomas and Christiansen, 1971; Heydecker, 1974). On the other hand May et al. (1962), Evenari (1964); Salim and Todd (1968) noted that in many cases the effects of seed treatments on crop stand and productivity were marginal or non-significant.

The effects of micronutrients, growth regulators or seed protectants were evident when seeds were treated to meet the subsequent plant needs (Roberts, 1948; Khan et al., 1978; Heydecker, 1978). Johnson et al. (1966) reported that soybean seed treatment with molybdenum could be safe for cleaning operation. McCoy and Harrington (1970) reported that emersion of lettuce seeds in a solution containing kinetin enhanced the germination ability of the seed under high temperature conditions as well as under drought stress conditions (Kaufman and Ross, 1970) and under salt stress conditions (Odegbaro and Smith, 1969). Choe (1972) pointed
that pre-soaking of pea seeds in solutions of growth substance (GA, IAA, kinetin) improved the germination rate.

Leo et al. (1976) observed that pre-soaking treatments improves the seedling vigour without disturbing the final germination of the seed. Heydecker and Coolbear (1977) made an extensive survey of the work on pre-soaking wetting-drying treatments and concluded that the seeds could be invigorated successfully for improving seedling vigour and better crop stand.

Henckel (1968, 1972) explained the pre-sowing soaking-drying treatment in terms of formation of high energy compounds, increased DNA and RNA activity in growing regions, higher mitochondrial activity and better preservation of cellular ultrastructure. Osborne (1972), Kory et al. (1972) and Savino et al. (1976) pointed out that hydration itself activated a number of metabolic processes that were necessary for cell division to start. Osborne et al. (1974) reported that hydration-dehydration pre-treatment of embryo initially enhances the ability of the embryo to synthesize protein and RNA compared to the non-treated control. It is suggested that the first phase of germination is characterised by the synthesis of protein and RNA which is activated on soaking-drying treatment resulting in an advantage of being ready for the subsequent phases of growth (Dell'Aquila et al., 1977; Savino
et al., 1979) much earlier.

The pre-enlargement of the embryo is suggested to be the cause of the beneficial effect of the wetting-drying treatments (Austin et al., 1969). Hutchinson (1969) and Hegarty (1970) also supported the improved field emergence of carrot to embryo enlargement. Hanson (1973) showed that an increased $^{14}$C-leucine incorporation in aleurone layers of pretreated wheat seeds. Heydecker (1974) suggested that during the initial phase of hydration the seeds undergo certain changes associated with germination, which are compatible with drying back. This advancement on the part of the treated seed would be of great advantage in tiding over inimical edaphic and environmental conditions.

Studies on seed germination under salt stress conditions were reported by many workers. Bhardwaj and Rao (1955) examined the effect of salt solutions on the germination of gram seeds. Sarin and Rao (1956) reported deleterious effect of sodium sulphate on seed germination and seedling growth of wheat. Bhardwaj (1961) noticed that sodium chloride at 0.2 and 0.6% levels depressed seed germination and growth of wheat seedling. Odegbaro and Smith (1969) reported that emersion of lettuce seeds in a solution containing kinetin enhanced the germination ability.
of the seed under salt stress conditions. Dwivedi (1980) reported a drastic depression in germination percentage and delay in seedling emergence of barley and wheat seeds in saline soil.

Exposing the seed to repeated wetting and drying is likely to enhance its ability to withstand drought, high temperature, low temperature and salinity as noticed by Austin et al. (1969), Hegarty (1970), May et al. (1962), Alejar (1978) reported that saline conditions (sodium chloride) retarded barley seed germination and seedling growth but increased the amount of ethylene released by the seedlings. He concluded that these deleterious growth effect increased as salt concentration was increased but they were alleviated and sometimes eliminated by treatment with 3,5-diiodo-4 hydroxybenzoic acid.

Drastic reduction in growth and yield of crops due to salt stress has been recorded by many workers in this country (Maliwal et al., 1967; Serin and Narayana, 1965; Dwivedi, 1979). However, effective means of controlling the same are yet to be standardised.

(ii) Other treatments

Seed treatments has also been attempted with various forms of energy i.e. heat, light, magnetic fields, electrical treatments, ultrasound, noise, ionising radiation and shock. Heydecker and Coolbear
(1977) have reviewed the literature on such treatments.

The germination of oil palm seeds has been improved by storing them for 90 days at 39.5°C (Wonky-Appiah, 1974) and that of okra seeds by exposure to 45°C for 10 hours (Onwueme, 1975). Wesley found that microwave drying increased the germination of cotton seeds. The beneficial effects of high energy flashes of light on the yield and quality of maize, wheat, sugar beet, cotton and other crops were reported by Shakhov (1972). Babuchkin et al. (1974) reported that the irradiation of seeds with concentration sunlight improved yield and quality of the resulting crops.

Pittman and his colleagues have reported the beneficial effects of magnetic pre-sowing treatments using fields of 1500-1800 oersteds and exposure times of upto 240 hours in several species. There was significant improvement of seedling growth of winter wheat (Pittman, 1967; Pittman and Ormrod, 1970), improved yield of Phaseolus vulgaris (Pittman and Anstey, 1967) and improved germination of barley (Pittman and Ormrod, 1971). Generally X-ray and γ-ray were disadvantageous, whilst electromagnetic fields alone, of upto 300 oersteds, produced growth advantages in the plants, and there was evidence that electromagnetic treatments alleviated the effects of ionising radiations on buck wheat (Zolyneck and Bicu, 1972; Zolyneak and Fonór, 1972). Mukhamedkhanov and Shermukhamedov (1971) reported that seed treatment with ultra-sound
Holm and Miller (1972) found that a hot water soak, infra-red radiation and ultrasound could equally well improve seed germination of many weak species. Singh et al. (1974) found that X-rays and thermal shocks (as well as thiourea and ascorbic acid) could both improve germination. Such evidences reinforce the impression that it may not be the specific treatment but the energy input and its 'shock' effect that may 'trigger' germination.

IV. LOSS OF VIABILITY AND CROP YIELD

The deterioration of seeds leading to loss of viability can effect the yield of a crop either by decreasing the plant population per unit area or due to poorer performance of the individual surviving plants. It is obvious that the decreased vigour of seedlings would show lower field emergence than could be obtained from fresh seed. The relationships between plant population and yield are now reasonably well understood and the subject has been reviewed by Willey and Heath (1969). According to them cereal crops have remarkable compensatory power, therefore, are less sensitive to planting density and display a wide range of negative correlations among the yield components.
Harrison (1966) demonstrated the effects of different ageing treatments on the field performance of lettuce and onion. In rapid ageing treatments he observed a significant decrease in growth once the viability had dropped down to about 50 per cent, whereas in slow ageing, even a small loss of viability resulted in a severe loss of yield in plants derived from the surviving seeds. Barton and German (1946) reported that if there had been loss of viability then decreased yield from the surviving plants of the deteriorated seed lot would be expected.

Roberts (1972) reported that in a number of crop plants, seed deterioration associated with a reduction of viability to 50% would have significant effect on final yield. He also pointed out that the loss of vigour during storage had little effect on yield potential as the early effect of low vigour tended to disappear during growth, thus final yield might not be affected considerably due to decrease in seedling vigour.

Hydecker (1972) quoted the work of several researchers in mentioning that a small loss in vigour and viability effects the final yield remarkably. According to Delouche et al. (1967), Crabe (1964,1973) and Delouche (1969)
the sequence of deterioration is back to front. Yield declined first, growth second and field establishment and germination last. It has been pointed out that deterioration may set in much before the same could be detectable in the germination test. The effects of decreased vigour and viability on yield potential were also studied by Perry (1977), Tekrony and Egli (1977) and Wu (1977). They concluded that the ageing response was closely associated with emergence potential of seeds, growth and development of seedlings raised from the surviving plants and finally on the productivity of the plants.

Recently, Dasgupta et al. (1976), Basu and Pal (1978), Basu and Dhar (1979), Mitra and Basu (1980), and Kundu and Basu (1981) reported that small losses in viability were reflected in significant yield reduction. However, in the aforesaid studies the difference in vigour and viability of different treatments were attributable to the effects of different physico-chemical treatments.