Some Physiological Aspects
Of
Seed Germination

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INTRODUCTION

Physiology of seed germination has been a subject of a large number of investigators during the last half century.

Germination of seeds has been defined as the resumption of activity of the embryo resulting in the rupture of the seed coat and the emergence of the radicle (Meyer & Anderson, 1954). It is restricted to processes involving the resumption of development rather than the continuation of growth (Toole et al., 1956).

General reviews of the vast literature relating to the germination of seeds have included those of Crocker, (1948); Stiles, (1950); Crocker & Barton, (1953); Toole et al. (1956); Mayer & Poljakoff-Mayber, (1963).

The first change when seeds are placed to germinate is the imbibition of water. This is followed by cell enlargement and cell division (Toole et al., 1956). General observation shows that these sequences are the usual feature in the germination of seeds.

It would be of interest to refer to the chemical composition of seeds in a generalized form and brief picture to bind this with metabolic changes occurring during seed germination.

The chemical analysis of various seeds show a wide range of variation (Stiles, 1950; Crocker & Barton, 1953; Mayer & Poljakoff-Mayber, 1963). It is estimated that fat forms the chief food reserve in the seeds of about 80% of species of flowering plants, while starch forms the principal reserve in only [illegible] proteins occur in considerable quantity in still fewer species. In other seeds, complex carbohydrates other than sta as cellulose or hemicellulose constitute the main reserve of food. Frequently, not one substance but several different substances which may serve as food, are present in considerable quantity in seeds.

Various organic acids such as the tricarboxylic acid cycle intermediates have been also detected in seeds of many species (Crocker & Barton , 1953 and Dutcher et al., 1956).

Certain amounts of free amino acids and amides have been found in many seeds (Fowden, 1960 and Noe & Fowden, 1960).

Various phenolic compounds as coumarin, coumarin derivatives, chlorogenic acid and simple phenols such as ferulic, caffeic and sinapic acids are also present in many seeds (Mayer & Poljakoff-Mayber, 1963).

Seeds contain also certain amounts of minerals, usually comprising all the major and minor elements (Morse, 1950; Crocker & Barton, 1953 and FAO, 1954).

Most of the known vitamins have been shown to occur in some kinds of seeds (FAO, 1954).

Nucleic acids occur partly in their free form and partly in the form of nucleo-proteins in many seeds. The ratio of RNA to DNA, in many seeds, have been shown to be approximately 10:1 (Mayer & Poljakoff-Mayber, 1963).

It has been recently found as a result of the modern analytical methods, that many species of seeds contain a number of growth regulating substances comprising growth promoters and growth inhibitors (Evenari, 1949; Bonner, 1950; Bonner & Galaston, 1951 and Audus, 1963).

Dry seeds are characterized by a very low rate of metabolism. One of the early phases of the germination process is the activation of the enzymes in the region of the radicle and the increase in the respiratory rates (Toole _et al._, 1956). The requirement of energy for the onset of germination is satisfied by the increased rate of respiration. Thus, it has been supposed that, during the early stages of seed germination, there is a "grand period" of respiration during which the rate of respiration rises from approximately zero to a maximum, and then falls again (Stiles & Leach, 1932).

Concerning the chemical changes taking place during seed germination, they show a wide range of variation. But in all cases, the first chemical changes involved in germination, following water absorption, are the mobilization of food reserves contained in the seed, either in the endosperm, perisperm or in the embryo itself. These changes are of three main types : the breakdown of reserve material, the transport of materials from one part of the seed to another (from the endosperm to the embryo or from the cotyledons to the growing parts) and lastly the synthesis of new materials from the breakdown products formed.

Miller (1938) found that more than two thirds of the normal fat content of the sunflower seeds disappeared during the early stages of germination. Yamada (1955) found that total lipids decreased during the early stages of germination of castor-bean seeds, while reducing and non-reducing sugars in contrast, began to increase. In his openion, fats are converted to sugars as germination proceeds. The conversion of fats into carbchydrates has been also shown during germination of cotton seeds (Maclachlan, 1936 a & b).

Malhotra (1931 a & b; 1932 a, b & c; 1933 a & b and 1934) and Yamada (1955) showed that in seeds containing starch, a distinct fall in the latter is usually accompanied by a marked increase in soluble or simpler sugars. The changes in carbohydrates of barley during germination have been studied in detail because of its importance in malting industry. Glucose and fructose rise very considerably at 6-days germination and then begin to fall again. Maltose rises from about 1 mg/gm dry seeds to more than 55 mg/gm after 7-days of germination. Sucrose shows smaller and less regular increases, while the total trisaccharides stay more or less steady for the first 5-days of germination and then rise steeply; increasing 5-folds in the next two days (Mayer & Poljakoff-Mayber, 1963).

An interesting feature of metabolic changes taking place during *Phaseolus* seed germination is the formation of malonic acid which is nearly absent in the dry seeds. In the same seeds citric acid decreases, while malic acid accumulates during germination (Duperon, 1960). In *Zea mays*, citric, malic, and aconitic acids, all increase at different rates during germination (Duperon, 1958).

Concerning the metabolic changes in protein, it is observed that the chief loss in germination is in the protein, while the sugar content is actually increased (Stiles, 1950). In place of protein broken down, there appear free amino acids and amides (Mayer & Poljakoff-Mayber, 1963). Amino acids may be directly utilized for the production of enzymes, growth regulators or nucleoproteins or indirectly utilized through the formation of other intermediates (Dutcher *et al.*, 1956). Soluble nitrogen already present in the seeds may be utilized during germination. Egami *et al.* (1957) showed that the small amounts of nitrates present in *Vigna* seeds disappear as germination proceeds. They proved the existance of nitrate-reductase system in *Vigna* seedling. There is little change in total nitrogen content of the seed during germination, although slight losses may occur especially due to leaching of nitrogenous substances.

Seeds of many kinds of plants may be perfectly viable, but they fail to germinate, immediately after harvesting, when placed under environmental conditions that are ordinarly favourable for quick germination and vigorous seedling development. Such seeds are said to be in a state of dormancy.

Dormancy is a general phenomenon, shown by a variety of different plant organs such as seeds, buds, tubers, bulbs, corms and rhizomes ...... etc.

The problem of dormancy has been a subject of very considerable investigations by a number of plant physiologists. One may refer to the reviews of Crocker (1948), Evenari (1949), Porter (1949), Crocker & Barton (1953), Samish (1954), Evenari (1956), Toole _et al_. (1956), Mayer & Poljakoff-Mayber (1963) and Vegis (1964).

Some workers (Crocker, 1916; Crocker & Barton, 1953 and Mayer & Poljakoff-Mayber, 1963) attributed dormancy to one or more of the following causes:

(1) Impermeability of seed coats to water.

(2) Impermeability of seed coats to gaseous exchange.

(3) Mechanical resistance of seed coats.

(4) Immaturity of the embryo.

(5) Light or dark requirements.

(6) Temperature requirements.

(7) Excess or absence of growth-hormones.

(8) Occurrence of growth inhibitors.

(9) Inactivation of certain enzymes.

An account of some of these factors, which will be discussed in the present work, is given in the following sub-sections.

Temperature Requirements:

Seeds of many different species fail to germinate until after they have been exposed in a moist condition to low temperature for a few weeks to several months (Baldwin, 1930; Haut, 1941; Roe, 1941; Sharpe *et al.*, 1942; Barton, 1956; Black, 1959 and Villiers & Wareing, 1965). During this period of exposure to low temperatures, changes in metabolism take place, after the completion of which seeds will germinate promptly if placed under favourable conditions. These changes are commonly called after-ripening changes (Crocker *et al.*, 1918; Flemion, 1933 & 1934; Afanasiev *et al.*, 1942; Luckwill, 1952 a ; Hendershott *et al.*, 1955 and Allen, 1960).

Many of these seeds germinated best after the winter period and this led to the practice of stratification of seeds. Seed stratification was found many years ago to be effective in allowing for the germination of many seeds. After-ripening at low temperature is often accompanied by changes in acidity, changes in enzyme activity and changes in the rate of respiration (Ransom, 1935 and Crocker & Barton, 1953). Changes in nitrogen and phosphate contents during stratification of certain seeds were also observed (Olney & Pollock, 1960). Marked changes in amino acids, organic acids and phosphate compounds were noted during the stratification of peach seeds (Flemion & De Silva, 1960). Low temperature after-ripening may be responsible for the formation of some growth promoting substances or it may favour the destruction of some growth inhibitors (Luckwill, 1952 a;Villiers & Wareing, 1960 and Foda & Radwan 1962 a & b).

There is some evidence that gibberellins or gibberellin-like compounds may be involved during after-ripening at low temperature (Mayer & Poljakoff-Mayber, 1963).

Growth Hormones:

It has been suggested that excess of growth hormones may bring about dormancy and that their gradual decreases remove the growth inhibition. The evidences supporting this view are indirect. Guthrie (1939), prevented the sprouting of potato tubers in storage by naphthalene acetic acid (NAA). Denny (1942) found that rest breaking-agents such as ethylene chlorohydrin and thiourea counteracted the inhibitory action of the excess of NAA which had been applied to the buds. Michner (1942) was of the openion that ethylene chlorohydrin breaks the dormancy of potato tubers by antagonizing the supra-optimal hormone concentration. There is very little evidence , however, that normal dormancy is due to supra optimal concentration of naturally occurring hormones.

On the other hand, some workers suggested that absence of growth hormones may be responsible for dormancy.

Avery *et al*. (1937) and Bennet & Skoog (1938) found that auxins gradually appeared in the resting buds as the depth of dorancy decreased.

Samish (1954) succeeded in breaking the dormancy of apple buds by means of zinc sulphate sprays. In this connection, it may be of significance that zinc was found to be required directly for the synthesis of tryptophane and indirectly for the synthesis of indole acetic acid (Audus, 1963).

However, it has been proved difficult to relate the depth of dormancy either to low auxin level or conversely to the presence of a supra-optimal concentration (Kollar <u>et al</u>., 1962 and Vegis, 1964).

Growth Inhibitors:

In recent years, there have been increasing number of observations which lead us to suppose that naturally occurring growth inhibitors may play an important rôle in the origin and in the control of dormancy.

Evenari (1949) reviewed the subject of germination inhibitors togerther with a number of possible theories on this subject. He listed about 100 species of plants from which germination inhibitors have been isolated from fruits, seeds, leaves or roots. He referred to the natural growth inhibitors that have been identified as ammonia, hydrogen cyanide, ethylene, essential oils, aldehydes, mustard oils, alkaloids, unsaturated lactones and unsaturated acids.

Moewus *et al.* (1951) demonstrated the presence of germination inhibitors in 33 genera of 16 families from 16 different orders. In the majority such inhibitors are found in the juice of the fleshy fruits as in tomato and orange . They are also present in the fruits and seed coats as in cabbage, clover, coffee, sunflower, beet, oat ..... etc.

El-Shishiny & Thoday (1953) suggested that the retardation of the germination of *Kochia indica* seeds is due to a saponin-like inhibitor which is readily leached away in water.

Hemberg (1950, 1952 & 1954) demonstrated the presence of growth inhibitor in the peel of resting potato tubers, which was destroyed when the dormant tubers emerged from the rest period either naturally or by means of cold treatment, ethylenechlorohydrin thiourea or glutathione . Blommaert (1954), using paper partition chromatography, supported the view of Hemberg. Hendershott & Bailey (1955) observed that the inhibitors occurring in the dormant buds of peach greatly decreased when the rest was broken.

Some authors (Thornton, 1945 and Leggatt, 1948) suggested that some growth-inhibiting substances related to dormancy, are formed as intermediate products resulting from partial anaerobic respiration due to the impermeability of coats to gaseous exchange.

Wareing & Foda (1956) found that the 2 growth inhibitors which appear during the later stages of seed development of

Xanthium, disappear during the early stages of germination.

Varga and Ferenczy (1957) stated that coumarin and derivatives of cinnamic and benzoic acids are the inhibiting compounds occurring in lemons, strawberries and apricots. The same type of compounds have been also identified in clusters of sugar beet and it is suggested that these substances act also as germination inhibitors (Audus, 1963).

Foda & Radwan (1962 a & b) stated that the growth inhibitors present in dormant *Prunus armeniaca* seeds disappear during their after-ripening in dry storage or at low temperature.

Foda & El-Gazzar (1961) extracted from the pericarp of beet and spinach fruits, certain growth inhibitors, which seem likely to be unsaturated lactones. These inhibitors were found to inhibit the germination of certain seeds as well as the amylase activity, the inhibition of which can be relieved by sulphydryl reactivators such as cysteine.

Certain germination inhibitors have been extracted from light-germinating dormant *Oenothera* seeds and from dark-germinating dormant *Nigella* seeds (Foda, 1963).

Interaction Between Hormones and Inhibitors:

Some workers are of the openion that the emergence from and the onset of dormancy are due to an interaction between the natural growth inhibitors and the growth promoting substances of the