CHAPTER 2

REVIEW OF LITERATURE

Low temperature and photoperiod are amongst the most important environmental factors which affect the onset of flowering in plants. Substantial effort has been made to characterizing the ways in which different plant species sense and respond to these environmental factors, but the molecular mechanisms involved in floral induction remain unknown. The research on understanding the mechanism of flowering process has helped us to accumulate ecological data regarding separate crops, which are sufficient for wide agricultural application. A detailed study at molecular level might provide us the complete understanding of the whole mechanism of flower formation. In the present study, an effort has been devoted to understand some physiological and biochemical aspects related to flowering in radish.

VERNALIZATION

The control of flowering, besides being of academic interest is of crucial importance in agricultural and horticultural practice. For the reason man has since long tried to alter the
onset to flowering at will. From the several stages of flowering the actual switch from vegetative to reproductive development of plants has attracted first attention in the research, which deals with the physiology of flowering. Vernalization is the term applied to a prechilling or cold treatment given to the seeds before sowing, to hasten the time of flowering.

The necessity of low temperature for the development of certain plants was probably known long before any mention was made of it in literature. Some of the earliest known records on the effect of low temperature on cereals are those from Anonymus (1837) and from Allen (1850). Klippart (1857) was the first to undertake some systematic research and to describe this phenomenon more exactly and made it clear that winter wheat varieties could be made to behave like spring varieties by exposing the imbibed seeds to low temperature. The notion 'cold requirement' was introduced by Gassner (1910) and it was finally his work published in 1918 that initiated more systematic research by others as well. Particularly around this time a great interest in the effect of low temperature, specially on cereals, awakened in the USSR as the study of this phenomenon resulted in important practical implications in that country. From the many Russian scientists on this subject the name of Murinov (1914), Maximov (1929) and
Lysenko (1928) should be mentioned.

Lysenko introduced the notion 'vernalization' in the middle of 1929, when the seeds of winter wheat, following a suitable low temperature treatment, developed into plants which eared fully and uniformly after being sown in the spring under practical farming conditions. This method of pretreating seeds of winter cereal varieties for spring sowing was called yarovizatsiya ('Jar': meaning formerly fire, or god of spring), which has come to be known by its latinized equivalent 'vernalization' (from Latin 'vernus' meaning spring). Farmers in cold countries started implementing the practice of vernalization, since in this way they could raise two crops in one year.

Melchers (1939) coined the term 'vernalin' for the hypothetical active factor that was thought to accumulate during vernalization, and further demonstrated that the transmission of the vernalization stimulus across a graft union. Rapid flowering took place only when the embryos were cold-treated on a medium containing sucrose, although the subsequent vegetative growth was excellent even if the medium consisted of mineral salts (Gregory and DeRopp, 1938).

Taking the practical side, many workers in India looked forward to vernalization as a means of achieving better yield and
to escape drought. In the experiment on growth and flowering of *Brassica juncea* 'Type 27' Sen and Chakravarti (1938, 1942) have reported that low temperature treatment of seeds accelerates flowering. They have also recorded early flowering under 16 hours light in the above variety of mustard. Sen Gupta and Sen (1944) have observed shortening of vegetative period in mustard under increased light period and higher range of temperature. Workers at Calcutta, Delhi and a number of other places found that Indian wheat varieties are indifferent to presowing low temperature treatments. A slight earliness was noted in some varieties but the number of tillers was smaller and yield was correspondingly lower. Reports on other crops gave essentially similar results.

A close correlation between the magnitude of the vegetative growth and the rate of developmental process in a plant has been established (Chinoy, 1949a, 1950; Chinoy et al. 1969; Chinoy and Nanda, 1946, 1951a, b, c, 1952). Patel (1967) working with *Secale cereale* concluded that vernalization treatment when given during the seedling stage and appropriate photoperiod (LD), has a profound cumulative effect on growth and development. At a later stage, vernalization and long photoperiod hastened flowering of the plant compared to that of the control. In short-day condition the vegetative growth was accelerated.
Hartman (1964) from a study on the influence of day length on vernalization of winter rye concluded that winter rye showed both cold and short-day requirement. Short-day like cold, has both a direct and an indirect effect, in which the indirect may be considered as short-day vernalization. Since winter rye is a long-day plant, the acceleration in non-vernalized winter rye by a short-day period of six weeks after sowing is due to short-day vernalization and not to short-day induction. Hartman proposed that the cold vernalization and short-day vernalization are two different processes. Cold affects the apical meristem while short-day has influence when leaves have been formed.

Vora (1969) working with three varieties of oat concluded that processes involved in growth and development and differentiation are highly interrelated with one another. Also these processes are influenced by various environmental factors such as light and temperature. Gill (1979) reported improved yields in a short term wheat crop by vernalization treatment. Banerji and Kaushal (1980) also showed improved yield by presowing chilling treatment. An overall increase in the enzyme activities and metabolic contents were observed in vernalized seedlings of Plantago ovata as compared to control ones (Sarma, 1983). Vernalized seedlings of P. ovata after transplantation could not
survive due to higher temperature which prevailed after transplantation. In mustard radicle stage was found to be suitable for vernalization treatment as this evoked early flowering (Bhaskar, 1983). On the contrary, the plant took more days to flower when the treatment was given at cotyledon stage. Skariah (1988) observed in Raphanus sativus that vernalization treatment given at seedling stage caused early flowering irrespective of the photoperiods it received after the chilling treatment. Vernalized imbibed seeds took more days to flower as compared to seedling vernalized plants. Working with two varieties of carrot Archana Mankad (1990) concludes that though seed vernalization was unsuccessful, long-day and normal-day plants treated with GA$_3$ of cv. Early Nantes flowered in the long-day condition showing the initiation much earlier than the normal-day set. However, cv. Pusa Kesar flowered in all the conditions except in the short-day control condition.

Warm roots of Chinese cabbage had no influence on the vernalization effect but the soil heating can decrease the effect of vernalization by heat transfer into the growing point (Rietze and Wiebe, 1988). When grown in continuous fluorescent illumination, four mutants (fca, fe, ft. and fy) and the handsberg wild type of Arabidopsis thaliana exhibited a reduction in both
flowering time and leaf number following six weeks of vernalization (Jose and Chris, 1990).

SITE OF PERCEPTION OF LOW TEMPERATURE:

In most cold-requiring plants vernalization occurs at shoot tip. A response to localized chilling of the apex has been observed in celery (Curtis and Chang, 1930); beet (Curth, 1960) and in Chrysanthemum by Schwabe (1954). The site of chilling is at the growing points is also indicated by experiments with radish. When the growing points of a radish was removed immediately after chilling and an unvernalized one grafted in its place, flowering did not occur (Tashima, 1957). Wellensiek (1964) showed that not only apical meristems, but all dividing cells, including those in leaves, are potential sites for vernalization. Excise shoot tips and fragments of embryo consisting essentially of shoot tips are sensitive to a chilling treatment (Purvis, 1940). In annual and biennial races of Hyoscyamus niger, stem apex is the plant part that responds initially to cold treatment (Melchers, 1936 and 1937). In general vernalization only seems to occur in cells that are able to divide, or those about to undergo cell divisions.
DE-VERNALIZATION:

The possibility of de-vernalization, or loss of the vernalized condition is widespread and is probably ecologically significant. The most usual de-vernalizing agent is high temperature, i.e. temperature above which required for vernalization (30°C), but de-vernalization by SD has also been reported (Wellensiek, 1965). High temperature is usually most effective immediately following a vernalizing treatment, especially when the latter is sub-optimal.

Gregory and Purvis (1938) showed that vernalized grains of petkus winter rye can be de-vernalized by drying the grains and storing them under dry conditions for several weeks. The grains could retain the vernalized condition for six weeks but by eight weeks they were completely de-vernalized. The response to high temperature causing de-vernalization is not always seen and many a species are known to have a persistent effect. Sen and Chakravarti (1942) observed that in mustard, de-vernalization did not occur even at 30°C. Purvis and Gregory (1952) showed that complete reversal in winter rye could only be accomplished after a very brief vernalization period.

Wild lettuce (Lactuca serriola) can be de-vernalized only before germination and in the absence of light (Marks and Prince,
1979). Vora (1969) and Sarma (1983) reported de-vernalization of Avena and Plantago respectively by high temperature. Younger et.al. (1968) reported that destruction of the flowering stimulus in Dichondra from chilling to temperature above 21°C. Guttormsen (1981) and Wiebe (1984) found that short-day treatments given during the raising of transplants delayed bolting.

BIOCHEMICAL CHANGES DURING VERNALIZATION:

The biochemical processes during vernalization have been studied intensively but not completely understood till now (Devay, 1967; Hess, 1979; El-Antably and Hamed, 1976; Reda Fatma, 1976 etc.). During vernalization of barley, Sparmann (1961) found that the soluble protein fraction decreased briefly, then increased considerably while the amino acid content followed the opposite course. Pauli and Mitchell (1960) reported increases in the soluble protein nitrogen, soluble non-protein nitrogen and free amino acids fractions of winter wheat plant during the first two weeks of cold treatment. In 1964 Pavlov and Aukova reported higher protein levels in wheat during vernalization. Vernalization responses could be decreased by blocking the synthesis of protein and nucleic acid with chemical inhibitors (Chakravarti and Sreedevi, 1974). Low level of protein content in winter wheat
during vernalization was noted by Ishikawa and Usami (1975). Sarma (1983) and Bhaskar (1983) found increase in protein content in *Plantago* and *Brassica* respectively.

Qualitative studies of free amino acids of cold-grown winter wheat plants by Kirillova (1958) showed that some acids increased while others decreased. Pauli and Mitchell (1960) reported that total free amino acids in winter wheat plants increased during the first two weeks of cold treatment. Moskov and Bozova (1962) found that glutamic acid increased in a winter variety of barely during cold treatment but decreased the same in a spring variety; proline increased only in the winter variety. The total free amino acid level in wheat plants grown at 2°C changes dramatically during the middle portion of the vernalization period (Trione, 1966). Jones and Weinberger (1970) stated that changing pattern of alcohol soluble amino acids and amides with imbibition, grain variety and vernalization serve to indicate that a drastic change takes place in the content of amino acid and protein at distinct phases as a direct result of vernalization. Ishikawa and Usami (1975), Srivastava and Fowden (1972), Zech and Pauli (1962) and Markowski et al. (1962) could not find any qualitative or quantitative changes in total free amino acids and amino-nitrogen compounds in spring and winter wheat before or after
Many workers have reported the importance of nucleic acid metabolism associated with chilling treatment. Devay (1965) demonstrated with winter wheat that the biochemical mechanism was partially connected with the metabolism of nucleic acids. In 1967, he suggested that during germination specific RNA synthesis took place at the beginning of cold induction. There was no increase in the RNA content of winter rye embryo during vernalization (Finch and Carr, 1956). Tateyama et al. (1978), Bhaskar (1983) and Sarma (1983) observed an increased level of RNA content during vernalization.

Several workers have reported an increase in reducing sugars in winter wheat varieties during cold treatment (Aksenova, 1960; Valuta and Brad, 1960; Zech and Pauli, 1962; Kruzhilin, 1963; Sarma, 1983). Liashchenko et al. (1958) indicated that the winter varieties accumulated more soluble sugars than spring varieties when both were grown in cold environments. Highly significant differences in the level of sucrose, oligosaccharides and starch were reported in winter and spring wheat varieties grown at 12°C by Trione (1986).

The universal presence of ascorbic acid in actively metabolizing cells suggests that it has an important physiological
role in plant growth and metabolism. During vernalization ascorbic acid content increased (Chinoy and Nanda, 1959; Chinoy et al. 1967; Michniewicz, 1961).

Michniewicz (1961) determined the ascorbic acid content in grains and leaves of three varieties of winter wheat which had undergone vernalization treatment for 20, 40 and 60 days as well as in unvernalized plants. AA content found to be increased during vernalization up to its germination. Chinoy et al. 1967 have also shown an accumulation of AA at low temperature in embryo and endosperm of wheat. Even its bound form ascorbigen was also found in greater amount in vernalized seeds than in unvernalized seeds. Vora (1977) estimated the contents of ascorbic acid and sulfhydryl in apical organs and leaves of early and late cultivars of oat. Both AA and SH contents were low in leaves. In the apical organs, there was a parallel rise of AA and SH content during reproductive differentiation and declined during senescence stage (grain development). Increased SH and AA content during reproductive differentiation were correlated with more energy required for lying down of growth centres for floral primordia through enhancing ATP synthesis. Steeping the seeds in cold also increased ascorbic acid content (Sreenivasan and Wandrekar, 1950).

An increase in invertase activity during cold growth was
reported by Pressey (1969) and Rutherford (1977, 1981). Chinoy et al. (1989) found rapid hydrolysis of carbohydrates to sugars by amylase activity. In 1973 Tomita reported protease like enzyme as a cause of vernalization in winter wheat. Higher level of RNase activity in the embryo of winter and spring wheat varieties during vernalization was reported by Bigos and Maria (1979). Pavlov and Aukova (1964) reported that peroxidase activity was higher in non-vernalyzed seeds of winter wheat. Stimulation of peroxidase activity by vernalization treatment was observed in winter wheat (Stanesolowski, 1966).

The information concerning the influence of vernalization on the level of auxins are very scarce. In winter wheat the process of vernalization does not depend upon the changes in the auxin level during the chilling of kernels (Michniewicz and Kamienska, 1966). Cholodny (1936) and Peterfi et al. (1963) observed increase in auxin content due to the effect of vernalization. Paper chromatographic separation followed by bioassay with the Avena straight growth test demonstrated the presence of twice the amount of IAA in the acid fraction of the non-vernalyzed seedlings of lettuce as compared to that which was vernalized (Fuki, et al. 1958). Vernalization increased the level of native gibberellins in plants in long-day (Chailakhyan and Lozhnikova, 1962). El Antably
(1976), Fatima Reda et al. (1978) and Suge (1970, 1980) also reported higher levels of GA due to vernalization treatment. Jiann-Tshlin and Stafford (1987) compared the endogenous gibberellins in the roots and shoots of vernalized and non-ernalized Chinese spring wheat seedlings. Using HPLC, they have identified different GAs and found that the levels of GAs were lower in shoots of the vernalized wheat seedlings than in non-ernalized wheat seedlings. Metzger and Mardaws (1986) identified eleven endogenous gibberellins by combined gas chromatography - Mass spectroscopy in purified extracts from shoots of cold-treated field pennycress (*Thalaspi arvense* L.).

FLOWERING STIMULUS:

One of the unresolved question about low temperature vernalization is whether, chilling treatment leads directly to the production of a transmissible hormone Melchers (1939) has assumed the existence of a flower-forming hormone "vernalin" to explain the peculiar flowering behaviour of the biennial *Hyoscyamus niger*. Melchers and Lang (1941) suggested that a transmissible flowering stimulus vernalin is formed as a result of chilling in biennial plants. Working with *Nicotiana tabacum* cv. Maryland Mammoth (a SDP) they also proved that vernalin and florigen are independent,
and vernalin must be present if florigen is to be formed. A model proposed by Lang (1965) is as follows:

VERNALIN $\rightarrow$ FLORIGEN $\rightarrow$ FLOWER FORMATION

(Cold requiring plants (Photoperiodic plants only after cold) only in inductive photoperiods independent of day length)

The direct effect of vernalization is immobile and as cell divisions proceed the vernalization product will be distributed throughout the protoplasm of the new tissues and will eventually be so dispersed that insufficient product will be available to be effective (Margadant, 1951). Wycherley (1952) concluded that in three perennial grass species, a transmissible flower stimulus was formed after the vernalization Chouard (1960) emphasized that an autocatalytic transmission of the vernalization effect is entirely restricted to the meristematic cells derived from actually vernalized ones, but he disclosed the possibility of a substance diffusing from cell to cell.

The direct effect of low temperature in Lunaria biennis would be a "vernalized condition" which arises in dividing cells and
which is only transmissible from cell to cell by mitosis, while cells in the vernalized condition can produce a floral stimulus which can be translocated to cells which themselves need not be vernalized (Wellensiek, 1964). Moreover Wellensiek presented evidence for a competition between vernalized and unvernalized cells. Thus the ultimate effect of vernalization will depend on the ratio of vernalized and unvernalized cells. Kruzhilin and Schvedskaya (1960) have also reported the production of transmissible flower promoting substance as a result of vernalization in *Brassica napus* and *Daucus carota* respectively. An extract from vernalized rye seeds could substitute for cold treatment in the same plant (Purvis and Gregory, 1953).

Adenosine monophosphate (AMP) treatment can replace the cold treatment in winter wheat seedlings (Tomita, 1964a; 1964b, 1968). Cytokinins were also proved to substitute vernalization (Barabas and Csepely, 1978; Csepely and Barabas, 1979). Vooren (1971) and Wellensiek (1972) reported flower formation by high temperature treatment (40° - 50° c) under non-inductive conditions in *Silene armeria* L. and *Samolus parviflorens* respectively. According to Chailakhyan (1968), during low temperature treatment more sugars are synthesized which form the 'metabolites of vernalization'. Chailakhyan summarized his hypothesis as shown in Figure-2.

Fig. 2
CHAPTER 2

PHOTOPERIODISM

Photoperiodism is a phenomenon that enables plants to respond to day length so that they flower at a specific time of the year as determined by the length of the day. Following the invention of a practical incandescent lamp by Edison in 1879, experiments in "electrohorticulture" by Bailey and others showed that the flowering of several plants could be accelerated by extending the natural day length. Later in 1910 Julian Tournois realised the importance of day length as a controlling factor of flowering in hops and hemp (*Humulus* and *Canabis*). In Germany, at about the same time, Klebs (1913) made plants of *Sempervivum funkii* flower by exposing them to several days of continuous light. Klebs (1913) concluded that the additional light was acting catalytically and not as a nutritional factor. However, it was Garner and Allard (1920) who first clearly demonstrated the fact that seasonal changes in day length conditions profoundly affect the life cycle of many plants. In 1969, Hillman defined photoperiodism as a response to the timing of light and darkness.

In Kalanchoe very brief daily exposure to high intensity light causes flower initiation although it is photosynthetically insignificant (Schwabe, 1959). Long-day plants like *Spinacia* (Gentscheff and Gustaffson, 1940); *Beta vulgaris* (Fite and Price,
1953); *Triticum* (Sugino, 1957) and *Brassica* (Inoye and Kuo, 1981) flowered when grown on culture media with sucrose but without light.

Some barley varieties are virtually day-neutral, while others show a marked response to photoperiod (Takahashi and Yasuda, 1960) and similar differences have been found in spring wheat (Riddel and Gries, 1958). The progressive reduction in the life cycle which is brought about by longer photoperiods is associated with a reduction in the number of leaves formed before the apex changes to the floral condition. This rate of primordia initiation and apex elongation are also increased in long days (Aspinall and Paleg, 1963). The effects of light intensity on strawberry have been studied by Smeets (1955) and Went (1957). High light intensities were found to favour runner production and reduce flowering, although Went's observations suggested that flowering and runner production were independent processes.

Wellensiek (1970) was of the opinion that light intensity can not be directly important in floral bud formation. According to him, perhaps the low light intensity affects the photosynthetic efficiency of the plant and so may influence growth. Vince Prue (1960); Watson and Andrews (1953) had already reported that, long-day plants with high carbohydrate status failed to flower
when transferred to short days and low light intensities. So, in 1975 Vince Prue suggested that some immediate product of photosynthesis other than carbohydrate is important for photoperiodic induction of flowering.

The light break imposed in the middle of the dark period inhibited the development of the first initiated flower buds and reduced the production of open flowers in two day length-sensitive varieties of *Phaseolus vulgaris* (Morgan and Zehni, 1980). The effects were similar to those of a long photoperiod applied continuously. In radish (*Raphanus sativus* L.) the photoperiod and irradiance level had the major influences on storage organ development (Craker *et al*. 1983). Short photoperiods and irradiance delayed the initiation of storage organ development in radish. *Nicotiana tabacum* cv. Maryland mammoth plants grown continuously in short-days flowered after producing 31.4 ± 1.6 nodes, while plants grown in long-days did not flower and produced 172.5 ± 9.5 nodes after one year (Gebhardt *et al*. 1987). Heide (1988) reported that two species of *Festuca* i.e. *F. vivipara* and *F. ovina* responded to short days at low or moderate temperature with initiation of inflorescence primordia.
LIGHT QUALITY AND SOME LIGHT ON PHYTOCHROME:

Interaction between an endogenous timekeeper and a light sensor (photoreceptor) regulate floral induction. The experiments conducted by Borthwick et al. (1952) and Hendricks (1960) led to the discovery of an interconvertible photoreceptor system—the photochrome. Action spectra obtained by applying various durations and flux densities of monochromatic radiation near the middle of 12-h dark periods, show that R is the most effective region of the spectrum for promoting flower initiation in long-day plants (Borthwick et al. 1946; Parker et al. 1950). These action spectra indicate that a dark period interruption with any light source that converts most of the phytochrome to Pfr would be an effective means of controlling flowering.

Radiation from incandescent lamps induces of long-day plants more effectively than radiation from fluorescent lamps, when used to extend the day length (Borthwick and Parker, 1952; Downs and Thomas 1982). This increased effectiveness was caused by the high content of far-red radiation as compared with radiation from fluorescent lamps (Downs et al. 1958; Takimoto 1958). A day length extension using far-red radiation is more effective than a similar extension using red radiation of equal energy or quanta in Brassica, Nyoscyamus, Triticum, Lolium and other long-day plants.
(Wassink et al. 1950; Stolwijk and Zeevaart 1955; Friend 1964; Evans et al. 1965; Lane et al. 1965; Vince 1965; Schneider et al. 1967). Stolwijk and Zeevaart (1955) reported that effect of long periods of far-red radiation in promoting flowering of Hyoscyamus was not reversed by subsequent treatment with red radiation. A similar independence of the actions of long periods of far-red and red radiations was shown in wheat (Friend 1948a).

Phytochrome pigment exists in two forms, Pr and Pfr. The Pr form of phytochrome maximally absorbs red light at 660 nm and undergoes a phototransformation to the Pfr form. The latter maximally absorbs far-red light of 730 nm. Besides regulating the mechanism of flowering, photochrome pigment is known to regulate many metabolic reactions such as endogenous growth regulators, CO₂ flux, anthocyanin production, oxygen uptake, hook opening, leaf expansion etc. Short-day plants require phytochrome Pr form during the inductive dark period, while long-day plants require the presence of Pfr throughout the most diurnal cycle (Evans, 1975). For the induction of flowering in short-day plant Pfr is required at certain times in the daily cycle (Vince Prue, 1975; Thomas and Lumsden, 1984).

Oota (1985) could not find any red/far-red photoreversibility in the short-day duck weed Lemna paucicostata strain 6746. Light
has at least two functions in photoperiodism, the photoperiod set
the timer in one way, while a night break interact with the timer
to induce (LDP) or prevent (SDP) flowering at certain times
(Lumsden et al. 1982). In Albizia julibrissin, irradiation at 710
nm was most effective in delaying the dark closure of the pinnules
(Tanda, 1982, 1983b). Red, green and long far-red light were
ineffective. When longer wavelengths of far-red light were applied
with red light, the combination became effective. So it was
suggested that the phenomenon was due to interaction between
effects brought by red light absorbed by photochrome and far-red
light absorbed by an unidentified photoreceptor. This unknown
photoreceptor was postulated to absorb far-red light in one form
to become active and green light in another form to become
inactive. Tanada (1984) identified two photoreceptors in Brassica
campestris cv. Ceres which involved in flowering one is
phytochrome and the other an unknown pigment with far-red, green
photoreversible properties. Blue light was more efficient than red
or far-red light in induction of flowering in Brassica campestris
(Freinds, 1969) and Sinapis alba (Evans, 1975).

Knott (1934) was the first to demonstrate that perception of
the photoperiod takes place in leaves. Knott also hypothesied the
presence of some substance which was being produced in the leaves
and was then translocated to the growing points or apices causing the initiation of floral primordia. Sachs (1979) and Bernier et al. (1981a, b) reviewed the importance of photosynthetic assimilation for the floral transition. High intensity light level which induced flowering in *Sinapis alba* is very close to the level required for photosynthesis (Bodson et al. 1977). In association with the production of floral stimulus and floral initiation the biochemical changes can conveniently be divided into

(a) those occurring in leaves and lead to the production of floral stimulus - the process of 'induction'.

(b) those which take place at shoot apex by the arrival of floral stimulus - the process of 'evocation'.

The term photoperiodic induction is used for the process occurring at the shoot apex in response to the arrival of the floral stimulus and committing it irreversibly to the formation of flower primordia (Evans, 1969).
PROCESSES OCCURRING IN LEAF:

The photoperiodic stimulation of flowering involves events both in the leaves and the meristems. Flower induction takes place in the leaves in response to photoinductive light/dark cycles, while evocation occurs in the meristems in response to the arrival of the flowering stimulus and leads to morphogenesis. Flowering is a complex response to a variety of stimuli and interactions between environmental factors such as temperature and light as well as between light dependent processes such as photoperiodism and photosynthesis (Vince-Prue, 1984). With only a few exceptions flower induction requires some exposure to light (Vince-Prue, 1975). The leaf is the main site of the photoresponse for the control of flowering (Zeevaart, 1984).

Biochemical constituents of leaves grown in different photoperiods have been shown to vary widely (Vince-Prue, 1975). Much physiological evidence has emphasized the importance of photosynthetic assimilation for the floral transition (Sachs, 1979; Bernier et. al. 1981a, b). But in some plants including Pharbitis nil (Friend, 1975; King et.al. 1978), Brassica (Friend et.al. 1984) and Barley (Jabben and Deitzer, 1978) do not require the input of energy from immediate photosynthesis for floral induction. Therefore the role of photosynthesis in photoperiodic
induction is mainly to provide an energy source for the synthesis or control of promoters and inhibitors and their translocation from the leaf or to provide some more immediate products of the intermediary steps in photosynthesis that are essential for these processes (Friend, 1984).

Electrophoretic analysis of proteins synthesized in the leaves of Xanthium during a single inductive night showed no consistent differences from those synthesized in non-inductive leaves (Sherwood et al. 1971). Oota et al. (1970) detected additional proteins component in the cotyledons of Pharbitis nil during induction. Application of cyclohexamide on the leaves at the beginning or at the 16 hour inductive night inhibits flowering in Xanthium at a greater extent than at the intermediate time (Ross, 1970). However other inhibitors of protein synthesis like chloramphenicol and aminoacid analogues were not inhibitory to flowering when applied to leaves (Vince - Prue, 1975). Arzee et al. 1970 could find the suppression of flowering in Pharbitis when actinomycin D was applied to cotyledons. 5 - Fluorouracil also inhibited flowering in Pharbitis and Xanthium when applied to leaves (Zeevaart, 1962; Bonner and Zeevaart, 1962). But in short-day condition, application of 2 - Tu (2 - thiouracil) to leaves could induce flowering (Eichhoff and Rau, 1969).
Kumar and Nanda (1981) reported increase in the RNA content of leaf and stem of *Impatiens balsamina* under inductive photoperiod while no change was observed in plants growing under non-inductive conditions. An upsurge in RNA content during induction has also been reported by Bernier (1970); Stiles and Davies (1976) and Bhaskar (1983). Elevated sugar levels in leaves of *Sinapis alba* were observed by Bodson (1977).

Sironval (1958) observed about 20-30% reduction in chlorophyll content of herbaceous species like *Glycine*, *Lupinus* and *Cannabis* on transfer from long-day to short-day. The ratio of chlorophyll a and b was also changed with photoperiod. But in *Lollium multiflorum* the ratio increased under short-day (Reyss and Bourdu, 1971). Bidwell (1979) stated that higher level of chlorophyll, number and orientation of chloroplast and longer and thicker leaves with higher photosynthetic capacity are the important physiological mechanisms in plants adaptation to shorter light periods.

**EVENTS OCCURRING AT SHOOT APEX:**

Evocation has been defined as the initial events at the shoot apex in response to the arrival of the photoperiodic stimulus, which commit the plant to the subsequent formation of flower
primordia (Evans, 1971). Somewhat later stage of development, obviously new genes must be brought into play in order to specify the many kinds of inflorescence and flower structures (Evans, 1975). Histochemical techniques are employed to study the levels of various metabolites and zonations of shoot apex associated with the arrival of flowering stimulus.

The morphological changes preceding flower initiation are common, in most plants, whether or not they need a stimulus to flower. Preceding the floral stage, an increase in the mitotic index was observed in peripheral and central zones. A significant rise in apical volume, cell number, height and width, begins in the transitional stages and continue to the floral stage (Orr, 1981). In most plants the size of the apical dome increases just before flower initiation, usually in diameter, but mainly in length in the grasses and cereals (Evans, 1960; Horridge and Cockshull, 1979). However, in a few plants, such as petilla nankienensis (Nougarede et.al. 1964) and Humulus lupulus (Thomas and Schwabe, 1970), the apical dome clearly becomes smaller just before flowering. Increase in mitotic activity in Sinapis alba has been described as one of the initial steps of the sequential events in floral evocation (Bernier 1974). Shortening of life cycle and increased complexity of shoot meristems are the most
frequently described changes in apices undergoing transition and their significance has been reviewed by Bernier (1979).

The distinction between the central and peripheral zones of the apical meristems tends to disappear as RNA and ribosome density increases throughout the apex (Nougarede and Bronchart, 1965; Lin and Gifford, 1976). Cruciferae plant shows zonation pattern i.e. Tunica corpus, Central mother zone, Peripheral zone etc. in shoot apices both in vegetative and reproductive conditions (Bernier, 1974; Bhaskar, 1983 and Skariah, 1988). Changes in the size and number of starch grains in the apical meristem are also characteristic of transition to flowering (Bernier, 1971). Kanchanpoom and Thomas (1987) reported ultrastructural changes in tunica and corpus cells of shoot apex of *Nicotiana tabacum* during transition to flowering. Initial morphological changes at shoot apex might require early changes in the regulation of the expression of a few genes (Bonner, 1965; Salisbury, 1963; Searle, 1965 and Zeevaart, 1962). Francis and Lynden (1978a) and Francis (1981a) suggested a possible significance of the initial cell cycle events in *Silene* in transition to flowering from vegetative stage.

A rise in the RNA synthesis at the apex, is one of the earliest steps in floral evocation. Bonner and Zeevaart (1969)
stated that early RNA and protein synthesis are essential components of the flowering process. Novel RNA may or may not be required, but RNA synthesis takes place (Evans, 1975). Double labelling (P$^{32}$ and S$^{35}$) experiments (Evans et al. 1970) on Lolium temulentum indicated that there is a transient increase both in RNA and protein synthesis in the shoot apex at about the time when the floral stimulus arrives there. Bernier et al. (1967) described the changes in mitotic activity, DNA synthesis, cell and nucleolus sizes in the apical meristem of Sinapis following induction of flowering. Bernier (1971) documented the sequence of events during evocation in Sinapis alba. There is a first peak in mitotic index at 26 h, when RNA synthesis at a maximum, and a second peak of mitotic index at 62 h when first flower bud begins to become visible. Nucleolus volume, mitochondria and dictyosome number were maximum at the time of second mitotic peak (Bernier et al. 1967; Havelange and Bernier (1974); Havelange et al. (1974); Pryke and Bernier, (1978a, b); Jacquard, 1978 and Jacquard et al. 1972.

In a study Sadik and Ozbun (1967) dealing with histochemical changes occurring in the shoot tip of cauliflower, it was observed that starch accumulates during floral induction, whereas little starch is present in the shoot tips of vegetative plants. Again in 1968 Sadik and Ozbun reported that, flowering of cauliflower
plants could be prevented when carbohydrate synthesis was blocked during cold treatment. A positive relationship between increased carbohydrate level of the shoot tip and flower initiation was also established in photoperiodically induced and cold requiring plants (Bidhulph, 1935; Rodrigues, 1962; Shvedskaya and Kruzhllin, 1964). Increase in carbohydrate at the shoot apex is assumed to be the critical requirement for the transition from leaf to flower initiation (Sachs and Hackett, 1969; Babenko and Inkina, 1970; Fontes and Ozbun, 1972). The high level of carbohydrates induces preferentially the growth and multiplication of mitochondria (Sironval, 1967).

Considerable increase in the mitotic activity, meristem size and contents of total protein, RNA and DNA could be observed during transition of apex from vegetative to reproductive condition (Gifford and Jenson, 1971). Changes in protein composition of the apical bud or meristem of *Sinapis* and *Rudbeckia* during floral evocation have been described (Pierard *et al.* 1977, 1980; Milyaeva *et al.* 1979). Using immunological techniques, two antigenic proteins characteristic of the reproductive bud have been shown to appear in the apical meristem of *Sinapis* relatively early during the transition to flowering. This supports the hypothesis that a change in gene expression occurs at evocation
(Pierard et al. 1980). Changes in the complement of proteins being synthesized were also detected in the meristem of *Sinapis* during evocation by two-dimensional electrophoresis (Lyndon et al. 1983). RNA contents were also found to be increased after long-day treatment (Lance, 1957; Gifford and Tepper, 1962; Gifford, 1963; Knox and Evans, 1966; Bernier, 1970). Watson and Matthews (1966) found that floral induction at the meristem in *Chenopodium* is accompanied by the production of a new RNA component. This new RNA is associated with DNA, presumably as a DNA-RNA hybrid. 2-Tu (2-thiouracil) which inhibits floral induction in this species, too, prevents the appearance of this new RNA component, which has been called by Watson and Matthews the "floral messenger RNA". The incorporation of \([3H]\) uridine into RNA increased, immediately at the end of the critical dark period of 11 h, to twice that in the vegetative plants kept in long-day (Gressel et al. 1978).

FLOWERING STIMULUS:

So far, the floral stimulus is strictly a physiological concept. The evidence for the existence of a flower-forming substance is chiefly based on the fact that the green leaves are the organs which receive the stimulus under suitable photoperiods; the stimulus is transmitted to the growing points - where
flowering takes place after a certain critical concentration is reached. Sachs had conceived the idea of a flower-forming substance which is formed in the leaves and translocated to the terminal growing regions where flower formation occurs, as long as 1862. Chailakhyan (1937) has even gone so far as to name the substance as "florigen". The term florigen is restricted to the immediate product of leaves undergoing photoperiodic induction which causes evocation, the sense in which Chailakhyan introduces it. The remarkable ability of gibberellins to stimulate flowering prompted Chailakhyan to reconsider his earlier concept, and modify it as a combination of two complementary stimuli i.e. gibberellin and anthesin (Chailakhyan, 1958). Gibberellin is a limiting factor in short-day plants under long-days and anthesin is a limiting factor in long-day plants under short-days. Later, he (Chailakhyan, 1977) suggested that GA is only one of the components of florigen and can not induce flowering directly.

Wellensiek (1978b) has contradicted to Chailakhyan's theory and disagreed to the point that GA is one of the components of florigen. He suggested that GA is not a flowering hormone, instead cytokinins may be a part of florigen as it was shown by Bernier (1976).

Deblocking of a specific flower-forming DNA resulted in
floral induction in Silene armeria L. (Wellensiek, 1966b, 1969). According to him the flower forming genes are blocked under non-inductive condition and the appropriate photoperiod will deblock the genes initiating the synthesis of required substances. The reblocking genes were considered to be responsible for inhibitors. Wellensiek (1974) model of flower induction is given in Figure-3.

RELATIONSHIP BETWEEN PHOTOPERIODISM AND VERNALIZATION:

The process of vernalization shows a number of interactions with day length (Chouard, 1960; Napp-Zinn, 1961a, 1973; Purvis, 1961; Lang, 1965; Babenko et al. 1974; Marfet and Ried, 1974; Pressman and Negbi, 1980). It can be either the replacement, or modification of vernalization requirement by a day length treatment, or its converse, the abolition or modification of a photoperiodic treatment by an exposure to low temperature (Vince-Prue, 1975).

Short-day vernalization (i.e. the induction of ripeness to flower by SD instead of cold) has been discussed since the 1930's. Purvis and Gregory (1937) found short-day vernalization in petkus rye. Krekule (1964) also observed SD vernalization in some winter wheat varieties, and Mokhtare and Limberg (1977) did so in Iranian
Tentative general scheme of the mechanism of flower formation. A model for the process of flowering as proposed by Wellensiek (1976). Note 'Cytokinins' as floral hormone.

FIG. 3
winter barleys. Wellensiek (1953) was apparently the first to discover a similar phenomenon in *Campanula medium* a dicot plant. In many other cases SD vernalization was unsuccessful, e.g. in winter rye (Listowski, 1958); many varieties of winter wheat (Gott, 1961).

In several other plants long-day (continuous light) and vernalization may substitute for each other; e.g. *Scabiosa columbaria*, *Companiona longystyla* and *Campanula caespitosa* (Mathon, 1960a, b) and *Chondrilla juncea* (Cuthbertson, 1966). In wheat, as in many long-day plants, it has been reported that vernalization and photoperiod responses interact such that vernalization reduces the need for subsequent long days (Evans et al. 1975). McKinney and Sando (1935) found that the shorter the day length, during the first 54 days of growth in winter wheat the faster floral development proceeded when plants were transferred to photoperiod of 17.75 to 19 h. Levy and Peterson (1972), however, found significant interaction between vernalization and photoperiod in controlling days to heading in that vernalization could practically substitute for photoperiod.

In the experiment on growth and flowering of *Brassica juncea 'Type 27'* , Sen and Chakravarti (1938, 1942) have reported that low temperature treatment of seeds accelerates flowering. They have
also recorded early flowering under 16 hours light in the above variety of mustard. Zenker (1955) showed that vernalization of Arabidopsis led to earlier flowering when the plants were grown in long-day conditions, while no acceleration of flowering was observed when the plants were grown in short-day condition. Studies on the developmental physiology of Hordeum bulbosum (Koller and Highkin, 1980) have shown that its flowering was markedy stimulated by long (16-h) photoperiods if preceded either by seed vernalization or by a period of growth under short (8-h) photoperiods. The process of vernalization and photoperiodism are not physiologically interactive, i.e. vernalization does not reduce the need for subsequent long days and prolonged periods under short days do not remove the requirement for vernalization in wheat (Flood, 1984).

GIBBERELLIC ACID

Naturally - occurring growth regulators or hormones are chemical messengers which, unlike many other plant constituents occur in only very small quantities within plant tissues. Despite the low concentrations at which these substances occur, their effects on plant growth can be immense, and some of these effects are probably the result of direct action of the hormones at the
nucleic acid level in the plant. Using specialized techniques many different hormones can be extracted from plant tissues and their individual identity and quality determined. Thus, both quantitative and qualitative hormone variations can be detected which may often appear to be correlated with particular patterns of growth or responses to environmental conditions. These types of observations have sometimes indicated how a particular hormone may be used to produce specific growth effects. The natural growth regulators can be separated into four major groups, which are the auxins, gibberellins, cytokinins and inhibitors (Thomas, 1970). The simultaneous interaction of two or more of the five known types of growth regulators in regulating various aspects of growth and differentiation appears to be a general feature of higher plants. Although the behaviour of the plant as a whole is controlled by an interaction of all the natural regulators, there are some marked and specific effects of applying single growth regulators to plants.

In 1939, a major advance was made in the field of hormone research when the active substance which caused the symptoms of the Bakanae disease in rice was isolated by a group of Japanese chemists. At the time this work seemed to be of little importance and it was not until, 1955, when Brian and his colleagues isolated
pure gibberellic acid from cultures of the fungus *Gibberella fujikuroi*, that the full significance of this discovery was appreciated. The gibberellins show very marked effects on growth, in particular promoting the rapid extension of plant cells. In addition, gibberellic acid has been shown to induce flowering under non-inductive conditions, to break dormancy period of seeds and other dormant organs and induce fruit set.

The effect of gibberellic acid in stimulating cell extension has been shown to be of commercial significance in the production of celery, where yield increases of upto 40% and earlier harvests have been obtained following a spray treatment (Wittwer and Bukovac, 1957). Caufman (1965) found that gibberellic acid (GA₉) accelerates in both light and dark the rate of lengthening of stem segments isolated from intercalary meristem portions of next-to-last internodes of *Avena sativa*. Their response is primarily caused by an increase in the rate of cell lengthening in these segments. One of the possible mechanisms by which GA₉ accelerates this growth is through the promotion of invertase synthesis as it does with α-amylase (Hayashi et al. 1964; Paleg, 1960; Varner, 1964; Varner and Chandra, 1964). This would result in release of reducing sugars that could be used in polysaccharide biosynthesis in elongating cells of these internodal segments.
The involvement of gibberellin in the reproductive development of vernalizable, long-day plants has been studied extensively (Lang, 1965; Chailakhyan, 1968). One of the most pronounced effects of gibberellin in such plants is the stimulation of internode elongation, whether or not accompanied by flowering (Brian, 1959). In vernalized plants of *Hordeum bulbosum* L. prolonged application of gibberellin as a spray to the entire shoot promoted internode elongation and flowering, but the bulbs, normally found on flowering shoots, were missing (Roller et al., 1960). In *Hordeum bulbosum*, GA$_3$ was capable of enhancing bulb initiation only when the plants were exposed to photoinductive conditions (LD), even when the number of photoinductive cycles was insufficient by itself (Ofir, 1976). Application of GA$_3$ or GA$_7$, especially in higher dosages, increased stem length but inhibited flowering in pea (Hiroshisuge, 1980). The rate of growth of the GA$_3$-treated internodes in *Xanthium* was at least twice that of the control (Maksymowych et al., 1984). Though the emerging pattern of acropetal internode elongation was similar in both GA$_3$ treated and control plants, the rates of growth were significantly higher in the GA$_3$ treated ones. Working with *Actinidia chinensis*, Lionakis and Schwabe (1984) reported large increase of stem length and leaf number (but with smaller areas) with the application of GA$_3$. Other
work on GA$_3$-abscisic acid (ABA) interactions indicates that ABA and GA$_3$ may act synergistically to promote growth of rice mesocotyls (Takahashi, 1972, 1973); and Avena coleoptiles (Thomas et al. 1965).

The effect of gibberellic acid on flowering is perhaps of more importance than its effect on vegetative growth. GA$_3$ can induce flowering when applied to many rosette long-day plant and also to long-short-day plant under short-day. Lang (1956) was first to report the gibberellic acid caused floral induction. Silene armeria can be induced to the formation of flowers by the specific action of GA$_7$ in short-day (Michniewicz and Lang, 1962). Many workers observed a positive response of floral induction by long-day plants to exogenous GA (Harada, 1962; Langridge, 1967). In some other cases, however, it has been shown that gibberellins are able to cause or promote flower formation in short-day plants under long-day conditions. Such cases are Cannabis. (Razumov, 1960); Cosmos bipinnatus (Wittwer and Bukovac, 1958); Chrysanthemum morifolium (Barbat and Ochesanu, 1964; Pharis, 1972); Impatiens balsamina (Nanda et al. 1969) and Zinnia elegans (Sawhney and Sawhney, 1976). Flowering could also be induced by GA under short-days in long-short-day plant Bryophyllum diagrimonianum (Zeevaart, 1969b).
Working with two varieties of carrot (*Daucus carota* L.), Early Nantes, an European variety and Pusa Kesar, Archana Mankad (1990) observed that long-day and normal-day plants treated with GA₉ of cv. Early Nantes flowered in the long-day condition showing the initiation much earlier than the normal-day set, while the control set and the short-day set which was treated with GA₉ did not flower. This was not true, however, for cv. Pusa Kesar because this variety flowered in all the conditions except in the short-day control condition. Although long-day GA₉ treated set showed an early initiation and short-day GA₉ treated set showed a very late initiation.

The grain yields of cereals are often decreased by an application of gibberellic acid, although the growth of the leaves and stems are greatly promoted (Yamada, 1966). Takahashi *et al.* (1971) reported that, the grain yields of rice plants were increased with 10 ppm GA₉ applied repeatedly during the reproductive stage, while with higher concentrations (50 to 1,000 ppm) the grain yields were decreased because of a decreased total leaf area and of a smaller number of panicles with higher percentages of degenerated flowers and unripened grains.

Warm (1980) working with *Hyoscyamus niger* suggested that applied GA has two separate effects:
(a) it causes production of the floral stimulus in the leaves which results in flowering, and
(b) it acts in the shoot apex and causes stem elongation.

GROWTH AND YIELD

Variations in temperature and photoperiod bring about changes in the phasic development and growth of plants and consequently affect their yield. Besides flowering photoperiod influences many aspects of vegetative growth like tillering, leaf production, leaf size and bulb formation. The measurement of photosynthetic rate and the quantity of chlorophyll pigment gives an idea of growth. Calculations of growth parameters like relative growth rate (RGR), leaf weight ratio (LWR) leaf area ratio (LAR) and net assimilation rate (NAR) are important tools to study growth and development of a plant under varied environments (Blackman, 1919; Gregory, 1926; Purvis, 1944 and Nemchenko, 1984). Relative growth rate (RGR), i.e. the increase in weight per unit of original weight over a time interval $t$; Net assimilation rate (NAR), i.e. the rate of increase in dry weight per unit leaf area and leaf area ratio (LAR) i.e. the ratio of leaf area to whole plant dry weight.

Throne and Evans (1964) and Maggs (1964) interpreted the increase in NAR as the result of increased net photosynthesis. It
is well documented that NAR and RGR of annual plants usually decline with time, and this fall may depend upon light intensity and temperature (Friend et al. 1965; Throne, 1967). But Vora et al. (1977) found that both RGR and NAR followed a fluctuating trend of rise and fall rather than a declining trend in maize. Fall in the total daily light period causes increase in leaf area ratio in most plants (Hughes, 1965). Total dry matter production was accelerated by seedling vernalization (Sirohi et al. 1959). Nanda et al. (1959) observed that stem elongation, tillering and leaf production were markedly affected by differential vernalization and photoperiodic treatment of different varieties of wheat.

Interactions of light and temperature influence various yield components (Nanda and Chinoy, 1957; Ryle, 1966; Owen, 1968; Vora, 1977; Saini, 1988). Chinoy (1949, 1963) using winter wheat subjected to different vernalization treatments and photoperiods, illustrated the correlation between growth and development. In further experiments by Chinoy and Nanda (1951a, b, c), apical development, absolute and relative growth, absolute and relative leaf growth rate and water content were examined under short-day (6h), normal-day length (approx. 12h) and long-days. Ear emergence was earliest in LD and latest in SD. Dry weight, tiller number and
leaf area were greater under the ND than under LD or SD.

Long photoperiod reduces the leaf number before flowering and increases the rate of leaf emergence (Kirby and Eisenburg, 1966). Axillary shoot development was promoted under SD condition in tomato (Aung and Austin, 1971). Presowing chilling treatments to seeds induce enhancement in growth and yield especially branching and tillering in several crops (Anju Singh, 1983, 1984, 1985). The effect of day length upon floral initiation, flower position and associated features was measured in six white clover varieties (Norris, 1984). Most plants initiated flowers in the longest days (16h). Increasing day length increased the number of buds becoming inflorescence in all varieties. The number of leaves produced on stolon prior to inflorescence development was also significantly influenced by day length. In *Trifolium repens* short-day and chilling reduced peduncle length but increased ovule number, whereas long-days and chilling tended to increase floret number (Norris, 1987).

Vora *et al.* (1975) showed that flowering of maize, Var. Hyb. Ganga 5, was promoted under SD treatment which reduced all growth parameters viz. height, leaf production, dry matter accumulation etc. Working with two cultivars of oat (*Avena sativa* L.) N.P. Hyb. 1, an early Indian flowering cv., and Victory, a late Swedish
spring cultivar Vora (1977) reported that growth characters viz. height, tiller and leaf production as well as dry weights were considerably lowered under long-day treatment due to accelerated flowering. Growth was also suppressed under short-day treatment. Mean RGR and NAR were higher in long-day plants followed by normal-day and short-day; conversely, values of LWR were higher in short-day plants followed by normal-day and long-day. In grasses the rate of tillering is more in SD than LD (Stukey, 1942; Nittler et al. 1963).

Development of storage organ is an inductive process like flowering and its formation on or is accelerated by exposure of leaves to particular photoperiods (Vince-Prue, 1975). Bulb formation in onion is under the influence of day length and temperature and is a qualitative long-day plant. Craker and Seibert (1982) have demonstrated that the amount of energy required to grow a market size radish can be reduced by relative use of different photoperiods and irradiances.

Besides vernalization and photoperiodic response a third factor, basic development rate appears to exert an important influence on wheat development (Flood, 1983, 1984). Inanaga et al. (1979a, b) observed that in rape at the time of flowering the main photosynthetic system is leaves, but at the middle stage pods take
over it, thus the pods supply the dry matter required for the growth.

WORK CARRIED OUT IN THIS LABORATORY:

In Plantago ovata, as a consequence of acceleration of flowering in long-day condition all the growth parameters were reduced (Sarma, 1983). Total number of spikes/plant and number of seeds/spike were higher in the plants grown under normal-day, but 1000 grain weight was higher in short-day. The growth rate under short-day was almost equal to plants grown under normal-day although they were placed under restricted light hours. Bhaskar (1983) has also shown that the acceleration of development by long-day and GA₃ treatment, however, led to an overall reduction in yield of mustard due to the shorter vegetative growth.

Vernalization and photoperiodic treatment are important factors in the development of storage organ (root) in radish plant (Skariah, 1988). In vernalized plants and late transplanted non-vernalized plants which experienced natural chilling at the early stages of growth, roots were poorly developed. Normal-day condition during September to October were found to be suitable for the development of roots followed by long-day and short-day conditions. Longer the vegetative period the higher the dry matter
production. Archana Mankad (1990) concludes that GA$_3$ treatment, although enhances floral development in carrot, does not encourage root development. The yield in terms of number of seeds/plant was better in GA$_3$ treated plants.