FLOWERING OF BRASSICA SPECIES IN KENYA

ESTHER MURUGI KAHANGI

A Thesis submitted in fulfilment for the Degree of Master of Science in Agronomy (Vegetables) in the University of Nairobi.

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with our approval as University supervisors.

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SUMMARY

Seeds of Brassica oleracea L. and other temperate vegetables are not produced in Kenya where the chilling temperature requirement for flowering in these crops is lacking in the low altitudes or is not low enough in the high altitudes. Because of the increasing costs of importing seeds of these crops, there has been a great need to start producing them locally. Experiments carried out in this work therefore, were to determine whether GA could replace the chilling temperature requirement for flowering in Brassica oleracea L., mainly cabbage and kale in the low and high altitudes of Kenya, and to investigate whether there exists cultivars which can flower naturally in the high altitude. The effect of head splitting on enhancing flowering was also studied.

Kabete (1941 m) and Molo (2554 m) were selected as the experimental sites to represent the low and high altitude sites respectively. Each of the cabbage and kale GA experiment in both sites was carried out in 4 replicates of a complete randomized block factorial design involving 2 GA rates (100 and 250 ppm) and 3 cultivars of cabbage and 2 of kale. GA application was started when the plants had reached stem diameters of 1cm or over in cabbage, and 7-8 leaves in kale. The commercial GA known as 'Pro-Gibb' was used and spraying was done by a hand pump. GA sprays were repeated weekly for eight weeks. The experiment to determine the natural flowering potential of eight cultivars of cabbage in Molo and the effect of head

splitting on flowering was carried out as a split plot design laid out in 4 replicates in a completely randomized block. In each plot, half of the plants were split and the other half was not split. In all the experiments dates of flowering were recorded in each treatment every day for a period of 3 months. Percent flowering was calculated for each treatment from the collected data. For statistical analysis, which was done for each of the 3 months recorded, the percentages were converted into arcsin in degrees.

Results of the GA experiments indicated that GA at 250 ppm induced flowering in some cultivars of cabbage and kale in the low altitude site at Kabete although the induction was not complete. This indicated that more investigations should be made to find optimum GA rates and frequencies of spraying which could induce 100% flowering in different cultivars of cabbage and kale in the lower altitudes. For seed production low altitudes have advantage over the high altitudes which have high amounts of rainfall throughout the year. Seed production programmes should be started on Collards in the low altitudes as this cultivar of kale flowered well with GA 250 ppm.
GA did not induce flowering in the high altitude site Molo and any flowering which occurred in this altitude was not due to GA. This was attributed to the fact that the high rainfall in the high altitude could have diluted the GA applied or the temperatures in Molo (7-15°C) might not be high enough for flower bud initiation in some cultivars (Flowering in cabbage occurs only when the induced plants are exposed to warmer temperatures

18-21 °C). This was supported by the fact that some cultivars bolted without flowering. GA experiment in the high altitude also showed that there is no need to use GA to induce flowering in Sugar Loaf as this cultivar of cabbage flowers well without GA. Seed production programmes in this cultivar should be started immediately in the high altitudes. Research to find optimum GA rate and frequencies of spraying for maximum flowering in different cultivars of cabbage and kale should also continue in the high altitudes.

In the experiment to test natural flowering in different cultivars, Sugar Loaf and Savoy cabbage showed natural flowering potential under Molo conditions. This suggested that more cultivars should be tested for natural flowering in the high altitudes. Head splitting did not increase flowering but there was a tendency for this method to increase flowering in Savoy Drumhead.

FLOWERING OF BRASSICA SPECIES IN KENYA

1. INTRODUCTION

Brassica oleracea L. includes the following botanical varieties: Cabbage, Cauliflower, Brussels sprouts, Sprouting broccoli, Kohlrabi and Kale; all known as cole crops. These crops originated from temperate countries where they grow as biennials. During the first year they grow vegetatively and in the second year they flower and produce seeds. Several workers have reported that flowering is induced when mature plants are exposed to chilling temperatures of about 4 - 7°C for a period of 6 - 8 weeks. Flower initiation of floral parts which follows induction occur when these plants are exposed to temperatures of about 18 - 21°C. In the temperate zones, planting of seed crops is done in summer so that the plants receive the cold treatment necessary for flower induction in winter. In spring the plants flower and produce seed stalks when exposed to warmer temperature.

Flowering of *Brassica oleracea* L. in the tropics is limited in that there are no areas where temperatures stay around 4 - 7°C for 6 - 7 weeks continuously to fulfil the chilling requirement. However, flowering has been observed in the high altitudes of Kenya (2000 - 3000 m) where some cultivars of cabbage bolt when the heads are mature. Some varieties, such as Sugar Loaf, sometimes flower in the first season without formation of the head. This phenomenon also occurs in temperate zones when early crops planted before the winter sometimes bolt in the spring without heading (Nieuwhof, 1969). Kales grow vegetatively in the first year and flower in the second year when grown in the high altitudes (2000 - 3000 m), but remain vegetative all the time when grown in the lower altitudes.

Lang (1956 b) demonstrated that Gibberellic acid (GA) may replace chilling requirement for flowering of biennial henbane (*Hyoscyamus niger* L.). Flower induction or hastening of flowering with GA treatment of other biennial crops has also been reported by several workers (Bukovac and Wittwer, 1957 ; Van Marrewijk, 1976). GA has only been used to induce flowering in *Brassica* species on an experimental basis under controlled environments. However, if this could be applicable in the field, then it could be beneficial in the tropics where low temperatures necessary for flower induction are lacking in the low altitudes. In the high altitudes the temperatures are not low enough to promote satisfactory flowering especially in the cultivars having the highest cold requirement.

The Government of Kenya has given a high priority to research on seed production of temperate vegetables because all seeds of these vegetables are imported. Among the temperate vegetables, *Brassica oleracea* L., mainly cabbage and kale are the most popular in the diets of the Kenyan people. A study on flowering of *Brassica* species in Kenya is important in that it would show whether seeds of these species could be produced locally.

The objectives of this study were to determine whether exogenous GA could substitute for the chilling requirement for flowering in cabbage and kale in the low altitudes (1000 - 2000 m) of Kenya where temperatures are much above those required to induce flowering by chilling; to determine whether exogenous GA could improve or accelerate flowering of cabbage and kale in the high altitudes (2000 - 3000 m) of Kenya where temperatures approach those required for chilling and to investigate the rate of natural flowering in different cultivars of cabbage and the effect of head splitting on hastening flowering in these cultivars after flower induction by chilling in the high altitudes.

2. LITERATURE REVIEW

2.1. Physiology of flowering as related to chilling requirement

The earliest work on chilling requirement, which has been called vernalization was undertaken by Klippart (1958) who showed that winter cereals when subjected to cold temperatures for a few weeks in winter flowered soon after the return to warm temperatures. Later Gassner (1918) reported that the flowering of winter rye depends on its going through a cold period either during germination or later. This work was followed up by Lysenko (1928) who showed that seeds of winter wheat that had been previously soaked in water to allow slight germination of the embryo and then exposed to cold treatment flowered in the same season if sown in spring.

Purvis and Gregory (1937) demonstrated that vernalization changes occurred in the embryo itself and not in the endosperm of the seed of winter cereal as had been suggested by other workers. Moreover, they showed that vernalization could be effective in young embryos only 5 days after fertilization. The time required for vernalization both in mature and immature embryos or seedlings was about 40 - 45 days. In winter cereals, the minimal chilling time required to vernalize mature plants decreased with age (Purvis, 1961). All the growth which developed from the vernalized apical meristem of the embryo was vernalized, e.g. the tillers which are formed after the chilling treatment (Hänsel, 1953).

In some plant species, vernalization of the moistened seed is not possible like in winter cereals, but flowering can only be induced when the whole growing plant is chilled. Vernalization of the whole plant was discovered simultaneously for two horticultural crops, cabbage and celery (Boswell, 1929; Miller, 1929; Thompson, 1929). These workers noted that as plants became older they responded more readily to a low - temperature stimulation for flower induction and that there was a juvenile phase during which low temperatures were without effect.

Plants requiring vernalization for flower induction are usually winter annuals or biennials. They remain vegetative in the first season of growth and flower in the following season in spring or early summer in response to a period of chilling received during winter (Wareing, 1970). Many perennial species also show a chilling requirement and will flower only when exposed to cold each winter (Wareing; 1970).

Many species which require vernalization also have photoperiodic sensitivity for flowering (Leopold, 1975). The most common combination is that of species requiring low temperature and long days (LDP), such as henbane (Hyoscyamus niger L.). When henbane is subjected to low temperature, flower induction takes place, and under the long days of summer flowering is initiated. Some plants require low temperatures for flower induction and short days for flower initiation such as certain varieties of chrysanthemum

(Leopold, 1975). But the latter combination is not very common.

In most species, the most effective temperatures are just above freezing 1 - 2°C, but temperatures ranging from - 1°C to 9°C are almost equally effective. From the work of Wollensiek (1961), it is now known that the dividing cells (active meristems) are the sites of vernalization. Once a meristem has been vernalized, all growth that develops from that source is vernalized (Leopold, 1975).

Duration of cold treatment seems to affect the rate of flowering as demonstrated in winter rye. The longer the cold treatment, the shorter the period from sowing to flowering up to a certain limit, beyond which further cold treatment has no effect (Wareing, 1970). The vernalization process can be reversed which is known as 'devernalization'. This was first noted by Thompson (1929) in celery and by other horticulturists working with low temperature response of biennials (Miller, 1929). When vernalized grains were exposed to 35°C for even one day, the vernalization effect was erased (Purvis and Gregory,1937). The plants were not damaged since devernalized plants could be revernalized effectively by cold treatment. Devernalization also occurred under anaerobic conditions (Purvis and Gregory, 1937).

Other researchers working on the flowering stimulus of vernalization gave two different explanations. First, that a flowering hormone is involved in vernalization is implied by the finding that gibberellins could replace low temperatures in some biennials (Lang, 1956 b). This model was supported by the fact that vernalization took place only under aerobic conditions, which indicated that an aerobic metabolic process was involved. A second explanation was that vernalization did not involve a metabolic process whereby a hormone was produced but rather a physical change. This was supported by the fact that gibberellins could not replace the cold requirement for flowering in some species. Graftage experiments also suggested that translocation of the products of vernalization did not occur. Also, active meristems of one plant could be vernalized while inactive meristems on the same plant remained unvernalized, indicating that the product of vernalization was immobile, or that the process did not involve synthesis of a new substance. It could be that with the low temperature stimulus, active meristems underwent a physical change which persisted in all growing tissues originating from them (Leopold, 1975).

2.2. Physiology of flowering as related to gibberellic acid

Among the endogenous plant hormones, only gibberellins consistently replace the environmental requirements for flowering in a large number of plants belonging to different categories (Lang, 1965; Phinney and West, 1960).

2.2.1. Exogenous gibberellins and flowering

Lang (1956a, and b) demonstrated that a rosette LD and cold requiring biennial henbane (*Hyoscyamus niger* L.) could be induced to flower by applying GA_3 to plants grown under non-inductive photoperiods. Since then, a number of plants belonging to these two categories have responded similarly to GA application. However, some LD and some cold requiring rosette plants failed to flower in response to GA treatment. Examples are *Lactuca scariola* L. and *Mimulus luteus* L. among the LD and *Geum urbanum*, *Reseda*, *lutoola* and *Scrophularia vernalis* L. among the cold-requiring plants. In some of these plants, GA application resulted in stem elongation without flower formation e.g. *Lactuca scariola*, *Mimulus*, *Scrophularia* and in others even the rosette growth was not broken e.g. *Geum*, *Reseda* (Lang & Reinhard, 1961). In some of the negative responses to GA the duration of the treatment and the dose or the method of application may have been inadequate. Experiments with different gibberellins (GA_1, G_3, GA_5) on dwarf maize mutants showed that the activity of different gibberellins in vegetative growth was different and exhibited certain specificities depending on the genetic characteristic of the treated plant (Lang and Reinhard, 1961). It was therefore likely that similar differences existed with regard to the flower-inducing activity of the various gibberellins in different plants and that the absence of a flowering response in certain plants may have been due to the use of the wrong GA (Lang and Reinhard, 1961).

GA can substitute for the cold requirement but not the LD condition in plants requiring both cold and LD treatments for flowering.

In long-short day and short-long day plants exogenous GA replaces the LD requirement but not the SD requirement for flowering.

In short day plants, GA generally fails to induce flowering under non-inductive conditions. However, there are exceptions where GA had induced flowering under strictly non-inductive conditions in *Impatiens balsamina* L. (Nanda, et al, 1967), some varieties of *Chrysanthemum moriforium* Ram. (Pharis, 1972), *Zinnia elegans* Jacq. (Sawhney and Sawhney, 1976) and *Paniam miliacem* L. (Lang, 1956a). In contrast, GA inhibits flowering in some SD plants maintained under optimal inductive conditions (Guttridge, 1964; Harder and Bunsow, 1958).

2.2.2. Endogenous GA and flowering

Research done on the role of endogenous GA in plant growth showed that when a plant was made to switch from vegetative to reproductive growth by proper inductive treatment, this transition was accompanied by great changes in the endogenous GA level (Lang and Reinhard, 1961), as explained below.

Exposure of LD plants to long days resulted in a gradual increase in endogenous GA level (Baldev and Lang, 1965). In *Samolus*, at least eight long days were required to build up an optimum GA level required to induce flowering. *Lolium temulentum* L. could be induced to flower by a single long day. This requirement could be met by treating with exogenous GA_3, GA_4 or GA_7 (Evans, 1964).

In long-short day plants flowering and GA levels are closely related. Zeevart (1969), working with Bryophyllum daigremontianum Hamet and Part, concluded that levels of GA appeared to be a limiting factor for flowering in this plant under SD conditions. Exposing the plant to LD condition led to increased levels of endogenous GA.

In SD plants, GA was not the limiting factor for flowering. Vegetative SD plants under LD conditionshad more gibberellin-like substances than flowering plants under SD condition (El-Antably and Wareing, 1966). Therefore, GA could have an indirect role in flowering of SD plants.

In cold requiring plants, endogenous GA increased with vernalization (Suge, et al., 1968; Harada and Nitsch, 1959; Fontes et al., 1970). Summer cultivars of wheat, rye and rape (Brassica napus L.) had higher GA content than corresponding winter cultivars. However, when the latter was vernalized for 45 days at 3-4°C, endogenous GA level was similar to that of the summer cultivars (Chailakhyan and Lozhnikova, 1962).

Although gibberellins show a substantial control on flower induction, their precise mode of action in plant growth is not clear.

2.3. Flowering of Brassica oleracea L.

Brassica oleracea L. belongs to the group of biennial plants which require chilling temperaturesfor flower induction. Knott (1925) concluded that environmental factors occurring in the later stages of growth might be responsible for inducing reproductive phase in cabbage

(B. *oleracea* var. *capitata* L.) after failing to induce bolting by chilling germinating cabbage seedlings and other *Brassica* seeds. This indicated a juvenile phase during which the plants could not be induced to flower by vernalization.

2.3.1. The influence of juvenility on flowering

Boswell (1929) described juvenility in cabbage by the size of the plant. He reported that plants with stem diameters of 6 millimeters or larger readily could be induced to flower by chilling. Miller (1929) found no possibility of distinguishing "juvenile" from "adult " plants by size which was supported by Lysenko (1935) and Whyte (1946) who made a distinction between growth in size and development. The actual size of plants at maturity varies depending upon the genetical constitution and environmental factors.

Stokes (1951) vernalized Brussels sprouts plants of different ages in weeks in order to define juvenility. He concluded that with such variable material, age expressed in number of weeks is not a meaningful criterion for defining when a plant is mature to flower.

Juvenility in *Brassica* *oleracea* L. may be distinguished by the morphological and physiological characteristics of the plant (Stokes, 1951; Nieuwhof, 1969). In the juvenile phase, the apex of the stem is somewhat flat and the growing point very small. There are about 4 rudimentary leaves and 3 primodia present in case of Brussels sprouts (Stokes, 1951) and in cabbage only petiolate leaves are formed (Nieuwhof, 1969). There is a progressive accumulation of carbohydrate material in the stem which reaches a maximum at maturity. In the latter stage the growing point enlarges, becomes raised and pointed (Stokes, 1951). In the case of Brussels sprouts lateral buds appear in the axils of the larger green leaves in the central section of the stem (Stokes, 1951). Maturity is reached when the number of green leaves is approximately 15 in Brussels sprouts, but this is only a general indication and is not a fixed number (Stokes, 1951). At maturity, the plants would flower when subjected to cold.

All botanical varieties of Brassica oleracea L. show a juvenile phase with exception of some cultivars of Kohlrabi: (Brassica oleracea var. Gongylodes L.).

Stambera (1972) and Rossger (1947) found that plants of some early cultivars of Kohlrabi were already sensitive to cold directly after germination. Nieuwhof (1969) indicated the possibility of seed vernalization in the quick bolting Kohlrabi cultivars. Nakamura (1961) experimenting on seed vernalization concluded that seed vernalization in itself was never sufficient for complete flower induction. Seed vernalization induced flowering only when interacted with plant vernalization.

2.3.2. Vernalization and flower induction

Flowering in cabbage is induced when plants which have passed the juvenile stage are exposed to chilling temperatures of 4 - 7°C for 6-8 weeks Nieuwhof, 1969; Heide, 1970). This characteristic is common in all botanical varieties of Brassica oleracea L. The only exception is found in the very sensitive kohlrabi cultivars which have the lowest cold requirement (12-14°C). These cultivars must be cultivated at temperatures of at least 15°C to prevent premature bolting (Nieuwhof, 1969). In many plant species requiring vernalization for flower induction, flower initiation takes place when these plants are exposed to high temperatures after chilling. Botanical varieties of Brassica oleracea L. follow this pattern since flowering occurs when the induced plants are exposed to temperatures of 18 - 21°C. Temperatures above 25°C during flowering cause poor fruit set (Nieuwhof, 1969). If plants do not receive the chilling temperatures, they continue growing vegetatively. Botanical varieties of Brassica oleracea L. are not sensitive to day length (Nieuwhof, 1969, Sadik, 1967).

The duration of cold has an influence on flowering of Brassica oleracea L. Parham (1959) working with Georgia cultivar of Collards (Brassica oleracea var. Acephala L.) found that 50 percent of the plants exposed to cold for 4 weeks, and all the plants exposed to cold for 6 weeks, flowered. Plants exposed to cold for 4 weeks flowered at a higher node and required more time after cold treatment for flowering but produced more than twice as many flower stalks as those exposed for 6 weeks. Haide, (1970), working on cabbage found that increasing the length of cold treatment also increased the number of plants that flowered.

Though the plants that had passed the juvenile stage flowered after being exposed to chilling temperatures, the size and the age of the plant at the time of cold treatment had an influence on the percentage of flower stalks formed and seed yield (Chroboczek, 1955).

When Lang (1956a and b) demonstrated that GA could replace the cold requirement for flowering in biennial henbane, physiologists were inclined to believe that a hormone was involved in the vernalization process. However, Kagawa (1956) failed to demonstrate the translocation of the "flowering stimulus" from cold treated to non-cold treated cabbages. Also, Sadik (1967) could not induce flowering by a graft union from flowering to vegetative plants or from cold treated to non-cold treated cauliflower plants. Researchers have shown that whenever cold-treated plants which were definitely known to be day neutral were used as donors to non-cold treated biennials such as cabbage, flowering was not induced (Kagawa, 1955 and 1956). When photoperiodically sensitive LD or SD plants were used as donors, flowering could be induced in cold requiring non-treated plants. Kruzilin (1954) succeeded in inducing non-chilled cabbage plants to flower by grafting them to either spring rape or white mustard plants whose photoperiod requirement had been satisfied. It seemed therefore, that the 'flowering stimulus' produced by cold treated plants lacked mobility from its site of synthesis, unlike the 'flowering stimulus' produced by photoperiodically sensitive plants whose translocation has been demonstrated by grafting experiments.

Flowering of Brassica species in the tropics, as already mentioned, is limited because of lack of chilling temperatures for flower induction. In the high altitudes (about 2000 - 3000m) of Kenya however, flowering of Brassica species does occur. The only literature available to support this is by Hawkins (1944) who demonstrated production of seeds of Brassica species and other temperate vegetables in Kenya around Turi area which lies over 3000m. There is otherwise no recent research done of flowering of Brassica species in Kenya and yet such knowledge would be very useful for seed production purposes.

2.3.3. The influence of GA on flowering of Brassica oleracea L.

Several workers have reported that GA can replace the cold requirement for flower induction in Brassica oreracea L. (Van Marrewijk, 1976; Lang and Reinhard, 1961; Bukovac and Wittwer, 1957). Bukovac and Wittwer induced flowering with GA on cultivars of cabbage (Golden Acre and Ferrey's Round Dutch), kale (Dwarf Blue Curled and Siberian) and Collards (Georgia and Louisiana Sweet) grown at temperatures of 10-13°C, which is slightly above the critical temperature for flower induction.
Among other biennial vegetable crops which responded to GA treatment were carrots, beets and rutabagas.

All non-treated plants remained vegetative when grown at a night temperature of 10-13^{o}C. When grown at 15-18^{o}C, either no flowering occurred with GA treatment (beets, turnips, rutabagas and kale) or only a small percentage flowered (cabbage, celery and collards). In the case of cabbage and kale, 100 ppm GA_3 applied weekly for 8 weeks to the apices of the plants produced greatly elongated stems which preceded the appearance of flower buds in the plants which flowered. From these observations, Bukovac and Wittwer (1957) concluded that GA definitely promoted flowering in those biennials which have a chilling requirement for flowering. However, complete induction of flowering did not occur unless the plants were grown at temperatures approaching those normally inductive for flowering (10-13^{o}C). Such a means of controlling reproductive growth in biennials, previously regulated by temperature, could likely extend boundaries where many flower and seed crops may be grown commercially (Bukovac and Wittwer, 1957). Van Marrewijk (1976) experimented on GA application and flowering response of Kohlrabi (<u>Brassica</u> <u>oleracea</u> L. var. Gonglodes). He concluded that GA application (250 or 500 ppm applied three times) after an incomplete cold treatment promoted bolting and flowering even in the slow-bolting high cold requiring 'Traro' cultivar. He also noted that GA treatment increased and improved the number and quality of the flowers.

2.3.4. Promotion of flowering by head splitting method

Cutting across the cabbage heads when fully mature to facilitate the emergence of reproductive shoots is a method which is commonly practiced in many countries (Hawthorn and Pollard, 1954). There are 2 different techniques of making the head incision. One of the most commonly practiced methods is giving two cuts at right angles to each other with a sharp knife on the compact head (Singh, 1954). In so doing all the leaves must be cut leaving the flowering shoots intact. The other method is to cut across the compact head right down to the stem (though not deeply into the heart) and wrench the tight mass of leaves apart with one's hands (Hawkins, 1944). This operation may be repeated several times at intervals. In obstinate cases the whole head is cut off to allow the flower shoots free to emerge from the stump (Hawkins, 1944). The stump method has the advantage over other methods in producing flower stalks at a much shorter time, plus added income from sale of marketable heads after decapitating which could meet some seed-production costs. By the stump method, more seeds can be produced than in the head-splitting method which is an advantage for breeding purposes (Miller, 1932).

3. MATERIALS AND METHODS

The seeds of various cultivars of cabbage and kale used in this work were bought from the East African and Kirschhoff seed companies. These companies import seeds from the U.S. and various parts of Europe.

3.1. Sowing seeds in the nursery:

All the seeds used for the various experiments were first started in a nursery in each location. Raised beds 1m wide of convenient length were used. Manure and double superphosphate (46% P_2O_5) were added into the beds and mixed thoroughly with the soil. Drills 10 cm apart were made across the beds. Seeds were sown in those drills and covered lightly with soil. Late cultivars were sown 1 week earlier than early cultivars in order to have uniform seedlings. The beds were watered regularly. Seedlings were transplanted when they had attained five true leaves.

3.2. Transplanting seedlings in the field:

Uniform seedlings were selected and transplanted at a spacing of 60 by 60 cm. During planting, 40g of double superphosphate were added in each planting hole. Nitrogen fertilizer in the form of calcium ammonium nitrate (26% N) was top dressed at the rate of 20g per plant when the plants were 20cm high, followed by 40g per plant 3 weeks later. The spacing and fertilizer rates used were according to those recommended in Horticultural Handbook (Anonymous 1976). Other routine field maintenance was carried out like weeding, spraying against insects pests and fungus diseases etc.

3.3. Experiment I: To determine whether GA could be a substitute for vernalization requirement for flowering in cabbage in the low altitudes between 1500 - 2000 m.

The experiment was carried out during the short-rain season in 1977. Two low altitude sites were used, Thika which is 1548m (37^{o} 04 'E, 0^{o} 59'S) and Kabete 1941m (36^{o} 44'E 1^{o} 15'S). The soils in Thika are red to strong brown friable clays medium humic (2 - 3% carbon) with pH varying from 4.5 to 5.4, and in Kabete Kikuyu friable loams.

The temperatures shown in Table 1 are above the chilling temperatures required to induce flowering in cabbage and kale, and therefore no natural bolting would occur in these altitudes.

Uniform seedlings were selected and transplanted on 26th May and 15th June 1977 in Thika and Kabete respectively. The design used was a factorial experiment laid out as a randomized block in which each of the three cultivars of cabbage used in the experiment (Sugar loaf, Golden Acre, and Giant Drumhead) was sprayed at three different stages (heading stage, heading plus 3 weeks and heading plus 6 weeks) with 2 rates of GA (100 and 250 ppm). This added up to 18 treatment combinations. Three controls for each cultivar were added. The experiment was replicated 4 times using 30 plants per plot. Out of these, 9 were recorded and the rest were guard rows.

GA Sprays:

A commercial GA was used which contains 10% of active GA_3 isomer known as Pro-Gibb. Since Pro-Gibb is not soluble in water, it was first dissolved in some absolute ethanol (about 99.8%) and then made up with water to the required concentrations of 100 and 250 ppm. Agral 90, a wetting agent was added into the prepared GA solution at 2 drops per litre just before spraying to improve the absorption of the GA solution into the plants. The spraying was done with a hand pump (compressed Air Sprayer) to ensure an even distribution of the spray over the whole plant. Each plant was sprayed until the solution dripped through. The spraying was done only once for each of the three stages mentioned above. The following were the spraying dates for Thika and Kabete.

Thika	Kabete
Heading stage - 29/6/77	Heading stage - 21/7/77
Heading stage plus 3 weeks 19/7/77	Heading stage plus 3 weeks - 12/8/77
Heading stage plus 6 weeks - 11/8/77	Heading stage plus 6 weeks - 1/9/77

Observations were made twice a week when the crop was still young and later every day after the GA sprays. The data taken was date of flower and the number of plants that flowered in each treatment. Meteorological data was recorded which included maximum and minimum temperatures.

The Kale experiment was the same as that of cabbage but 2 cultivars (Collards and Thousand Headed) were used adding up to 12 treatment combinations. Two controls for each cultivar were added. Transplanting was done on 26/5 and 15/6/77 in Thika and Kabete respectively. The three different spraying stages were the 10 leaf stage and the other 2 stages at 3 weeks interval after the first. The following were the spraying dates in Thika and Kabete:-

Thika	Kabete
10 leaf stage - 15/7/77	10 leaf stage - 4/8/77
3 weeks after - 5/8/77	3 weeks after - 25/8/77
6 weeks after - 26/8/77	6 weeks after - 19/9/77

The same data was taken as in cabbage experiment (Exp. 1).

3.4. Experiment 11: To determine whether GA can accelerate or improve flowering of cabbage in the high altitudes (2500 - 3000m).

The experiments were carried out during the long and short rain seasons of 1978 in Molo (2554m latitude 0.3^{o}S, Longitude 35.8^{o}E. The soils in Molo are volcanic in origin, mainly sandy loams. The temperatures in this location (shown in Table 1) approach those required for chilling and the aim of the experiment was to see whether GA would improve or hasten flowering in this location.

Experiment 1 was repeated during the same period in Kabete. Thika site was eliminated because the temperatures there (Table 1) are much above the chilling temperatures. According to Bukovac and Wittwer (1957) GA induces flowering in cabbage and kale only when the plants are grown at temperatures approaching those normally inductive for flowering (10-13^{o}C). For the same reason no experiment was carried out in Kabete during the short rains as the temperatures during this season are too high.

Sugar Loaf, Golden Acre and Giant Drumhead were transplanted during the long rains on 15/3 and 17/4/78 in Kabete and Molo respectively and on 3/9/78 in Molo during short rains. The design used was a factorial experiment laid out in randomized blocks. Each of the three cultivars of cabbage used was sprayed with two rates of GA (100 and 250 ppm) adding up to 6 treatment combinations. Three controls were added. The experiment was replicated 4 times using the same number of plants for recording and guard rows as in Experiment 1.

GA Sprays

The preparation of the GA solution and the method of spraying was carried out in the same way as that described in Experiment 1 (1977). However, there were some modifications made on time and frequency of spraying. Instead of spraying only once as in Experiment 1 (1977), the GA sprays were repeated weekly for 8 weeks on the plants which had reached stem diameters of over 1 cm. (The 3 different spraying stages in Experiment 1 were eliminated) This method was reported by Bukovac and Wittwer (1957) to induce flowering in cabbage plants which had been grown at temperatures approaching those normally inductive for flowering (10-13^{o}C). The first spraying dates during the long rains were 26/4 and 12/5/78 in

Kabete and Molo respectively and on 5/10/78 in Molo in the short rains experiment. The sprays were repeated weekly for 8 weeks.

In kales the experimental design and the spraying method was the same as that of cabbage but two cultivars (Thousand Headed and Curled Scotch) were used, adding up to 4 treatment combinations plus two controls which were not sprayed.

The two cultivars of kale were transplanted on 15/3/78 and 17/4/78 in Kabete and Molo respectively. The first spray was applied when the plants had attained seven to eight leaves (Bukovac and Wittwer, 1957) which was 17/5 and 26/5/78 in Kabete and Molo respectively. Sprays were then repeated weekly for 8 weeks.

The data taken was the same as that taken in Experiment 1 (1977).

3.5. Experiment III: To determine the rate of natural flowering in different cultivars of cabbage and the effect of head splitting in these cultivars on hastening flowering in the high altitudes 2500 - 3000m.

The experiment was set up during the long and short rain seasons of 1978 in Molo. No trial was carried out in the lower altitudes because the temperatures there are much above the chilling temperatures and therefore no natural bolting would occur. Eight cultivars of cabbage were selected for the trial. These were, Sugar Loaf, Savoy Perfection, Giant Savoy, Prize Drumhead, Early Drumhead, Brunswick, Copenhagen Market and Main Crop.

The experiment was a split plot design laid out in a complete randomized block with 4 replicates. The main plot treatments were the eight cultivars and the sub-plot treatments were the head splitting and without head splitting.

Uniform seedlings of the eight cultivars were transplanted on 17/4 and 5/10/78 during the long and short rain seasons respectively. Each plot had 24 plants. Out of these,12 plants were selected at random for head splitting and the other 12 were not split. Head splitting was carried out as heads matured. Cuts were made across the mature heads with a sharp knife right down to the stems (though not too deeply to damage the hearts) and the tight mass of tissues was wrenched apart by hand. This operation was repeated several times at intervals where there was a tendency for the plant to form another head. The same data was taken as in other experiments.

3.6. Data analysis

The method used to analyse the data was from Snedecor and Cochran (1973). The percentages of the number of plants which flowered 5, 6 and 7 months after planting were calculated in each cabbage experiment and for kales 6, 7 and 8 months for the different treatments. These percentages were then transformed into arcsin expressed in degrees to improve the quality of variance - Snedecor and Conchran (1973). A statistical analysis was carried out for each of the 3 months using the transformed data.

Curves were drawn to show the flowering pattern at 10 day intervals for each treatment from planting to first date of flower up to maximum flowering using percentage means.

TABLE 1: TEMPERATURE DATA IN THE DIFFERENT EXPERIMENTAL SITES DURING THE TIME THE EXPERIMENTS WERE IN THE FIELD.

MONTH	THIKA 1977		KABETE 1977		KABETE 1978		MOLO 1978		MOLO 1979	
	MAX.°C	MIN.°C	MAX.°C	MIN.°C	MAX.°C	MIN.°C	MAX.°C	MIN.°C	MAX.°C	MIN.°C
JANURAY	28.6	14.7	23.2	12.1	23.6	11.7	14.3	7.4	14.6	7.0
FEBRUARY	28.3	13.6	25.8	13.3	24.4	11.5	15.4	8.9	15.0	7.6
MARCH	27.9	14.3	24.2	14.3	23.0	14.3	15.6	10.1	14.8	8.4
APRIL	24.8	15.9	23.0	14.6	22.9	15.0	15.4	9.8	14.2	8.0
MAY	23.8	15.7	22.7	13.7	21.8	12.8	14.4	7.3		
JUNE	27.8	15.6	20.9	11.6	21.0	11.9	14.3	8.0		
JULY	22.8	12.8	20.2	11.5	20.3	11.2	13.7	8.3		
AUGUST	25.7	13.6	21.7	10.7	21.1	11.1	14.3	8.6		
SEPTEMBER	26.1	12.1	23.2	11.2	23.7	11.7	14.0	7.4		
OCTOBER	28.9	13.8	25.6	13.0	23.5	13.1	14.5	8.5		
NOVEMBER	24.7	15.4	22.0	13.7	22.6	13.8	14.5	8.8		
DECEMBER	23.8	14.4	22.3	13.1	22.1	13.6	15.3	9.9		

4. RESULTS 1

Experiment 1

4.1. Cabbage and Kale experiments in Kabete and Thika

The results of the 1977 long rains experiments which were carried out in the low altitude sites(Thika and Kabete) showed that GA did not induce flowering in the three cultivars of cabbage used at both sites, nor did the controls of these cultivars produce any flowers.

GA also did not induce flowering in the two cultivars of Kales tried in Thika and their controls also did not flower. In Kabete however, as shown in Table 2, a small percentage of the Collards flowered with the two rates of GA treatments as well as the controls. The number of flowering plants was significantly higher in plants treated with GA at 250ppm than in plants treated with GA at 100 ppm. There was no significant difference between the three different spraying stages, or between the interraction of the latter and the different rates of GA used. The Thousand Headed cultivar did not flower in Kabete with any of the treatments.

Experiment 1 repeated in 1978

Experiments were repeated during the long rains of 1978 in Kabete with modifications made on the time and frequency of spraying.

As shown in Table 3, GA induced flowering in Sugar Loaf and Giant Drumhead but not the Golden Acre cultivar of cabbage. The number of flowering plants in each of the 3 months analysed was significantly higher in plants treated with GA at 250ppm than in those treated with GA at 100 ppm in 'Sugar Loaf' and 'Giant Drumhead'. About 10% of the control plants in each cultivar flowered but this was not significant. As shown in Figures 1 and 2, the highest percent flowering reached with GA 250 ppm was 78% and 50% in 'Sugar Loaf' and 'Giant Drumhead' respectively. The first flowering with both rates of GA occurred at 130 and 140 days after planting in Sugar Loaf and Giant Drumhead respectively.

As shown in Table 4, flowering in kale occurred in both GA treated and control plants of the Collards cultivar but Thousand Headed did not flower. The number of flowering plants was significantly higher in the plants treated with GA at 250 ppm than in those treated with GA at 100 ppm and the controls in the 6th and 7th months after planting. In these two months there was no significant difference between the number of flowering plants in the 100 ppm GA treatment and the controls. In the 8th month after planting there was no significant difference between the number of flowering plants with the GA 100 ppm and GA 250 ppm treatments.

The two GA rates were significantly higher than the controls. As shown in figure 3, plants treated with GA at 250 ppm started flowering 20 days earlier than those treated with GA at 100 ppm and 30 days earlier than the controls. The highest flowering was with GA 250 ppm which was 91.5%.

TABLE 2: EFFECTS OF DIFFERENT RATES OF GA AND SPRAYING STAGES ON PERCENT FLOWERING OF COLLARDS (B. Acephala) IN THE LOW ALTITUDE SITE KABETE DURING THE LONG RAINS EXPRESSED AS TRANSFORMED DATA (Arcsin).

TIME OF APPLICATION (Leaf stage)	RATES			
	0ppm	100 ppm	250 ppm	MEAN
7 weeks leaf stage	23.10	24.78	28.90	26.84
" 3 weeks	23.10	20.95	35.61	28.28
" 6 weeks	23.10	21.32	42.82	32.07
Mean	23.10	22.35	35.77	
	Rate(R)***	Stage(S)NS	R X S NS	
LSD .05	11.62	-	-	
LSD .01	16.07	-	-	
SE	±5.45	±6.68	±9.45	
CV	45%			

*** F= significant at .001 NS = not significant.

Table 3: The effects of different rates of GA on percent flowering of 3 cabbage cultivars (B. Capitata L.) during the long rains at Kabete expressed as transformed data (arcsin).

Cultivars	5 months after planting				6 months after planting				7 months after planting			
	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean
Golden Acre	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Sugar loaf	9.98	17.19	22.97	16.71	9.98	29.12	33.52	24.21	9.98	46.44	58.09	38.17
Giant Drum-head	9.98	14.99	27.63	17.53	14.13	18.74	27.63	20.17	14.13	18.74	36.94	23.27
Mean	9.98	14.05	20.19		11.36	19.28	23.71		11.36	25.05	35.00	
	Rate***	Var.***		VxR*	Rate**		Var.***	VxR*	Rate***		Var.***	VxR***
LSD .05	4.70	4.70		8.15	6.43		6.43	11.14	6.85		6.85	11.87
.01	6.37	6.37		-	8.72		8.72	-	6.28		9.28	16.08
.001	8.84	-		-	-		11.67	-	12.43		12.43	21.42
SE	±2.28	±2.28		±3.9	±3.12		±3.12	±5.39	±3.32		±3.32	±5.75
CV	37.8%				42.12%				34.2%			

Note: *** F significant at .001; ** at .01; * at .05.

Table 4: The effect of different rates of GA on percent flowering of 2 kale cultivars (B. Acephala L.) during the long rains at Kabete, expressed as transformed data (arcsin).

Cultivars	6 months after planting				7 months after planting				8 months after planting			
	0ppm	100ppm	250ppm	Mean	0ppm	100ppm	250ppm	Mean	0ppm	100ppm	250ppm	Mean
Collards	17.19	19.56	45.36	27.37	26.51	33.87	55.82	38.73	39.44	59.36	68.63	55.81
Thousand Headed	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Mean	13.59	14.78	27.67		13.25	21.93	32.90		24.71	34.67	39.30	
	Rates***		Var.***	VxR**	Rates***		Var.***	VxR**	Rates***		Var.***	VxR**
LSD .05	7.80		6.37	11.03	8.33		6.80	11.78	7.91		6.46	11.19
.01	10.78		8.81	15.25	11.52		9.41	16.29	10.94		8.93	15.47
.001	-		12.17	-	-		13.00	-	-		12.34	-
SE	±3.66		±2.99	±5.18	±3.91		±3.19	±5.53	±3.71		±3.03	±5.25
CV			39.2%				32.1%				22.6%	

*** F significant at .001; ** at .01; * at .05

FIGURE 1: THE EFFECTS OF GIBBERELLIC ACID ON FLOWER INDUCTION OF B. CAPITATA 'SUGAR LOAF' PLANTED ON 15.3.78 AT KABETE, KENYA (Altitude 1951 m)

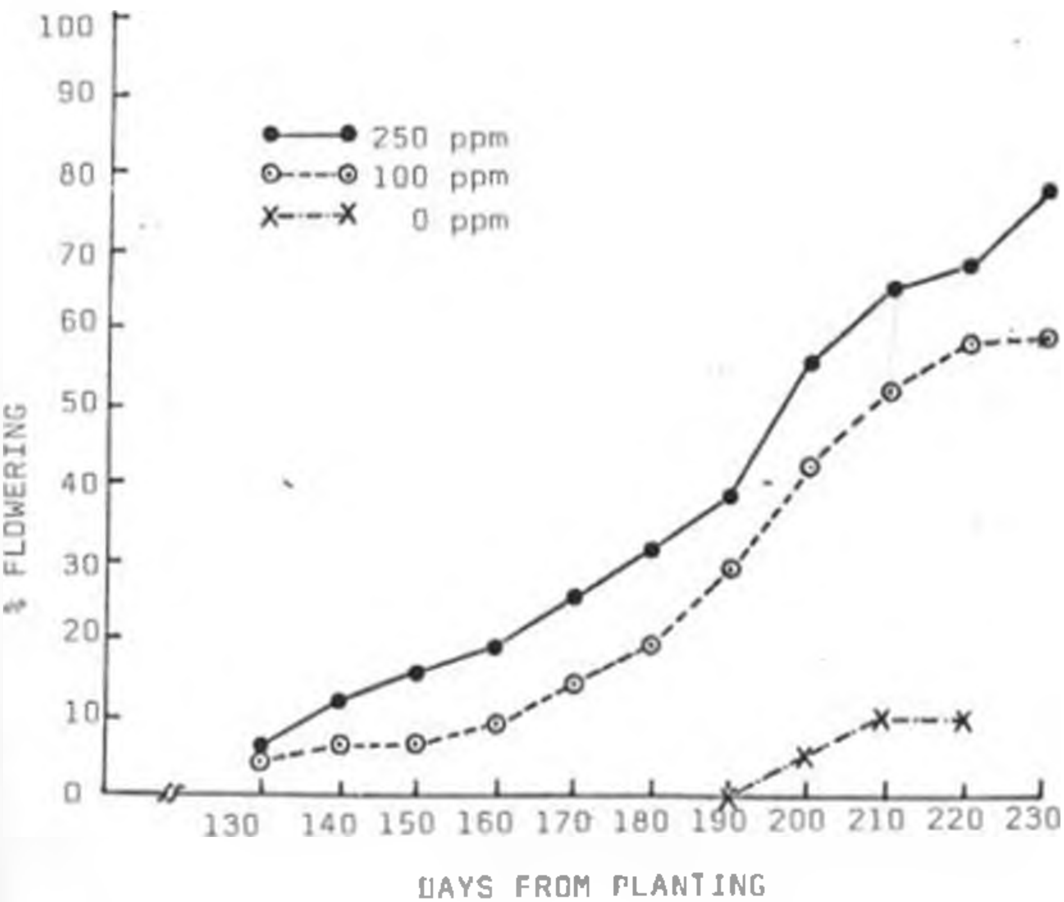


FIGURE 2: THE EFFECTS OF GIBBERELLIC ACID ON FLOWER INDUCTION OF B. CAPITATA 'GIANT DRUMHEAD' PLANTED ON 15.3.78 AT KABETE, KENYA (Altitude 1941 m)

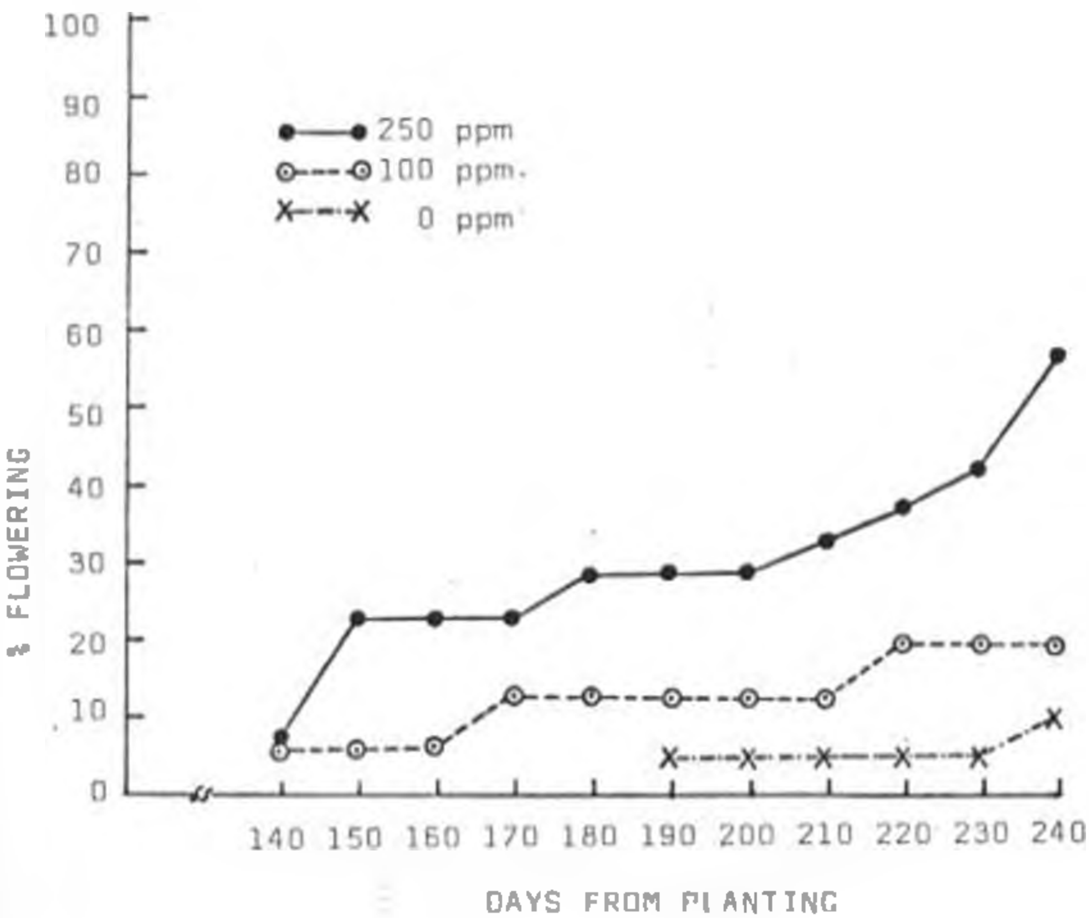
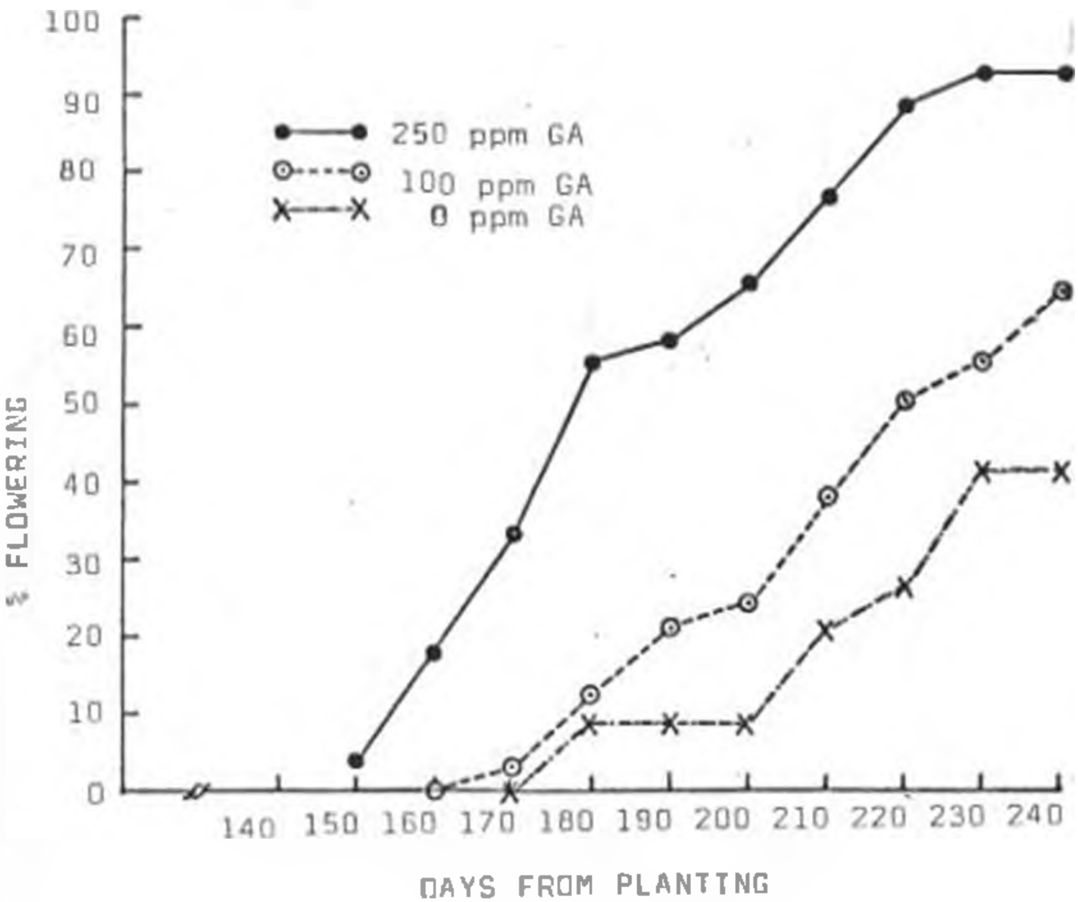


FIGURE 3: THE EFFECTS OF GIBBERELLIC ACID ON FLOWER INDUCTION OF B. *ACEPHALA* 'COLLARDS' PLANTED ON 15.3.78 AT KABETE, KENYA (Altitude 1941m)



4.2. Experiment II

In the high altitude site at Molo, as shown in Table 5, only 'Sugar Loaf' with and without GA treatment flowered, but 'Giant Drumhead' and 'Golden Acre' did not flower during the Long Rains season. Five months after planting 'Sugar Loaf' plants which were treated with GA at 100 ppm had significantly higher number of flowering plants than those treated with GA at 250 ppm and the controls. Six months after planting, there was no significant difference between the number of flowering plants in response to GA at 100 ppm and the controls. Seven months after planting, there was no significant difference between the number of plants flowering among all treatments. As shown in Figure 4, plants treated with GA at 100 ppm started flowering 20 and 30 days earlier than those treated with GA at 250 ppm and the controls respectively, and reached 100% flowering 10 and 20 days earlier than the controls and those treated with GA at 250 ppm respectively.

During the short rains season the same cultivar (Sugar Loaf) flowered as in the long rains experiment. As shown in Table 6 there was no significant difference between the number of flowering plants in all the treatments (controls included). The first flowering occurred at 120 days after planting in all treatments (Fig. 5). In 'Giant Drumhead' and 'Golden Acre' neither the GA-treatment nor the controls plants flowered. However, about 6% of the 'Giant Drumhead' flowered with GA at 250ppm but this was not significant. Some plants in each of these two cultivars bolted but produced no flowers (Plate 1).

As shown in Table 7 the two cultivars of kale tested during the long rains (Thousand Headed and Curled Scotch) in the high altitude site at Molo flowered poorly for all the treatments. No flowering occurred in the 6th months after planting. There was no significant difference between the number of flowering plants with GA at 100 ppm and GA at 250 ppm and between these two GA rates and the controls in the 7th and 8th months after planting.

Flowering plants from all the treatments had normal flowers and set normal seeds after pollination (Plates 2, b and c). In some plants flowering occurred without formation of the heads. This was most common with the GA treated Sugar Loafs (plate 3).

Table 5: The effect of different rates of GA on percent flowering of 3 cabbage cultivars (B. Capitata L.) during the long rains at Molo, expressed as transformed data (arcsin)

Cultivars	5 months after planting				6 months after planting				7 months after planting			
	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean
Golden Acre	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Sugar loaf	35.44	50.34	25.30	37.03	67.24	72.78	49.34	63.12	75.92	79.50	78.98	78.13
Giant Drumhead	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Mean	18.47	23.43	15.09		29.07	30.91	23.10		31.96	33.15	32.98	
	Rate*		Var.***	VxR**	Rate*	Var.***		VxR*	Rate[NS]		Var.***	VxR[NS]
LSD .05	5.68		5.68	9.84	6.40	6.40		11.07	-		2.4	-
.01	-		7.83	13.66	-	8.81		-	-		3.31	-
.001	-		10.76	-	-	12.11		-	-		4.55	-
SE	±2.68		±2.68	±4.64	±3.02	±3.02		±5.22	±1.25		±1.13	±3.85
CV			29.9%			23.1%					7.35%	

NS = Not significant

Note: *** F significant at .001; ** at .01; * at .05.

Table 6: The effect of different rates of GA on percent flowering of 3 cabbage cultivars (B. Capitata L.) during the short rains at Molo expressed as transformed data (arcsin).

Cultivars	5 months after planting				6 months after planting				7 months after planting			
	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean	0 ppm	100 ppm	250 ppm	Mean
Golden Acre	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Sugar Loaf	38.19	39.41	40.28	39.30	64.11	62.55	61.64	62.77	79.63	79.63	79.63	79.63
Giant Drum-head	9.98	9.98	9.98	9.98	9.98	9.98	12.33	10.77	9.98	9.98	16.85	12.26
Mean	19.38	19.80	20.08		28.02	27.50	27.98		33.20	33.20	35.48	
	Rates^{NS}	Var.***		VxR^{NS}	Rates^{NS}		Var.***	VxR^{NS}	Rate^{NS}	Var.***	VXR^{NS}	
LSD .05	-	5.83		-	-		6.04	-	-	2.43	-	
.01	-	7.91		-	-		8.19	-	-	3.29	-	
.001	-	10.58		-	-		10.96	-	-	4.42	-	
SE	$\pm$1.99	$\pm$1.99		$\pm$3.46	$\pm$2.07		$\pm$2.07	$\pm$3.58	$\pm$0.83	$\pm$0.83	$\pm$1.44	
CV		35.04%					25.76%			8.5%		

NS = Not significant

*** F significant at .001; ** at .01; * at .05

Table 7: The Effect of different rates of GA on percent flowering of 2 kale cultivars (B. Acephala L.) during the long rains at Molo, expressed as transformed data (arcsin).

Cultivars	7 months after planting				8 months after planting			
	0ppm	100ppm	250ppm	Mean	0ppm	100ppm	250ppm	Mean
Thousand Headed	17.02	12.33	12.33	13.89	17.02	14.68	16.83	16.17
Curled Scotch	25.82	24.97	14.68	21.82	34.34	39.37	25.49	33.06
Mean	21.42	16.65	13.50		25.68	27.02	21.16	
	Rate^{NS}	Var.***	VxR^{NS}		Rate^{NS}	Var.***		VxR^{NS}
LSD .05	-	5.57	-		-	7.73		-
LSD .01	-	7.70	-		-	10.69		-
LSD .001	-	-	-		-	14.77		-
SE	±3.19	±3.20	±4.52		±4.44	±3.62		±6.28
CV		32.2%				36.09%		

NS = Not significant

*** F significant at .001; ** at .01; * at .05

FIGURE 4: THE EFFECTS OF GIBBERELLIC ACID ON FLOWER INDUCTION OF B. CAPITATA 'SUGAR LOAF' PLANTED ON 17.4.78 AT MOLO, KENYA (Altitude 2554m)

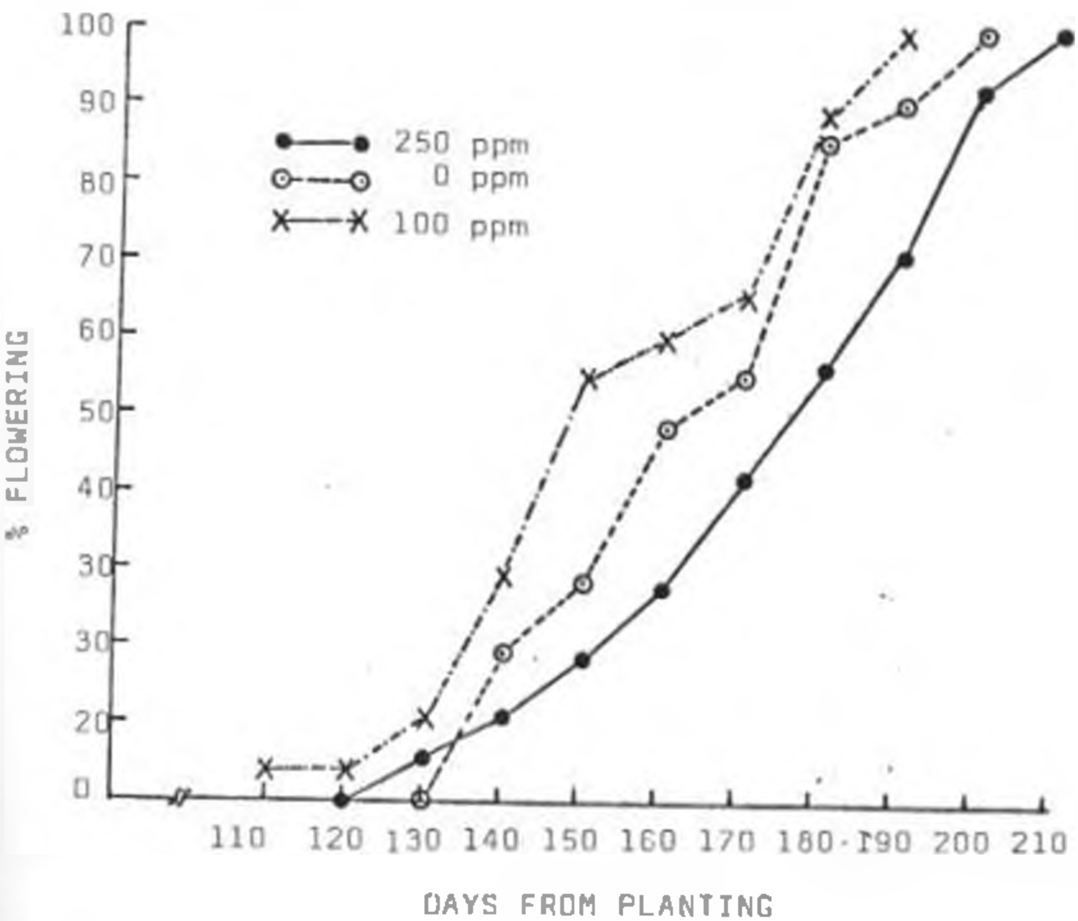


FIGURE 5: THE EFFECTS OF GIBBERELLIC ACID ON FLOWER INDUCTION OF B. CAPITATA 'SUGAR LOAF' PLANTED ON 3.9.78 AT MOLO, KENYA (Altitude 2554m)

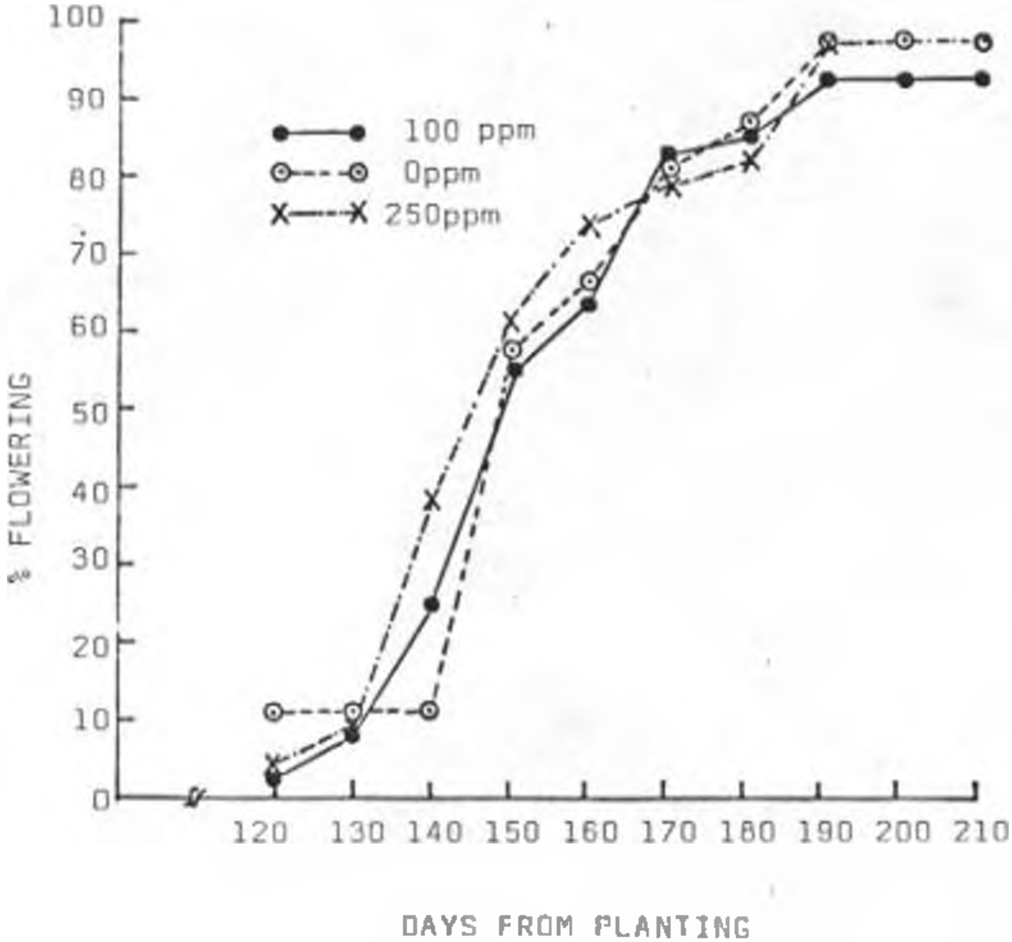


Plate 1: Bolting without flowering in Golden Acre cultivar of cabbage in the high altitude site Molo.

Plate 2, b and c: Plants from GA treatments and controls set normal seed after pollination.

a. Control

b. 100ppm GA

c. 250ppm GA

Plate 3: Flowering without formation of the head occurred in some plants of Sugar Loaf cultivar in Molo.

4.3. Experiments III

This experiment was to test the natural flowering of different cultivars of cabbage and the effect of head splitting in accelerating flowering in the same cultivars at Molo. In the experiment carried out during the long rains season, only two cultivars (Sugar Loaf and Savoy Perfection) flowered naturally. The other six cultivars, Giant Drumhead, Price Drumhead, Brunswick, Main Crop, Savoy Drumhead and Copenhagen Market, did not flower. As shown in Table 8, natural flowering was significantly higher in 'Sugar Loaf' than in 'Savoy Perfection' in all the three months tested after planting. There was no significant difference between the flowering plants of the head split and non head split plants of the Sugar Loaf and Savoy Perfection cultivars. In the 7th month after planting however, the number of flowering plants of the head split treatments in 'Savoy Perfection' plants was significantly higher than that of the plants that were not split.

During the short rains season, 3 cultivars (Sugar Loaf, Savoy Perfection and Savoy Drumhead) flowered naturally. As shown in Table 9, 'Sugar Loaf' had the highest natural flowering followed by the 2 Savoy cultivars. The number of flowering plants was significantly higher in the head split than in the non head split Sugar Loaf and the 2 Savoy cultivars in the 5th month after planting.

About 6% of the head split plants of the 'Early Drumhead' flowered, but this was not significant. Figures 6 and 7 show the flowering pattern of the head split and non head split cultivars in the 2 seasons.

Table 8: Natural flowering of eight cultivars of cabbage in Molo and the effect of head splitting on enhancing flowering during the long rains, expressed as transformed data (arcsin).

Cultivars	5 months after planting			6 months after planting			7 months after planting		
	Not split	Heads split	Mean	Not split	Heads split	Mean	Not split	Heads split	Mean
Golden Acre	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Main crop	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Sugar loaf	30.68	30.81	30.75	62.06	64.39	63.23	76.63	78.63	77.43
Brunswick	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Savoy Drumhead	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Savoy perfection	11.56	25.24	18.40	31.19	42.83	37.01	44.87	55.28	50.08
Giant drumhead	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Price drumhead	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13	8.13
Mean	11.38	13.10		17.75	19.50		21.24	22.84	
	Var.***	Split^{NS}	VxS^{NS}	Var.***	split^{NS}	VxS^{NS}	Var.***	split^{NS}	VxS*
LSD .05	10.15	-	-	5.44	-	-	5.76	-	4.69
.01	13.81	-	-	7.39	-	-	7.84	-	-
.001	18.64	-	-	9.97	-	-	10.58	-	-
SE	±4.88	±1.86	±5.27	±2.61	±1.36	±5.46	±2.77	±0.80	±2.27
CV_1					28.07%			25.12%	
CV_2		60.87%			41.43%			14.59%	

NS = Not significant

*** F significant at .001; ** at .01; * at .05

Table 9: Natural flowering of eight cultivars of cabbage in Molo and the effect of head splitting on enhancing flowering during the short rains, expressed as transformed data (arcsin)

Cultivars	5 months after planting			6 months after planting			7 months after planting		
	Not split	Heads split	Mean	Not split	Heads split	Mean	Not split	Heads split	Mean
Golden Acre	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Main Crop	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Sugar Loaf	24.74	32.78	28.76	48.61	57.59	53.10	73.31	68.37	70.84
Brunswick	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Savoy drumhead	8.33	33.40	20.40	12.54	48.35	30.44	37.28	56.02	46.65
Savoy perfection	12.54	25.34	18.94	21.72	33.63	27.67	39.12	41.57	40.35
Giant drumhead	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Early drumhead	8.33	8.33	8.33	8.33	10.43	9.38	8.33	14.38	11.36
Mean	10.91	16.65		15.56	22.91		23.92	26.71	
	Var.***	Split***	VxS***	Var.***	Split***	VxS NS	Var.***	Split NS	VxS NS
LSD									
.05	5.57	1.69	4.78	7.24	2.34	-	9.64	-	-
.01	7.59	2.29	6.48	9.85	3.19	-	13.12	-	-
.001	10.23	3.07	8.68	13.29	4.26	-	17.71	-	-
SE	±1.90	±0.58	±2.32	±2.46	±0.80	2.27	±3.28	±1.19	±3.36
CV_1	38.89%			36.19%			36.64%		
CV_2	23.78%			23.63%			26.55%		

NS = Not significant

FIGURE 6: Natural flowering of 2 cabbage cultivars (B. Capitata) in Molo (Altitude 2554m) and the effect of head splitting on flowering during the long rains.

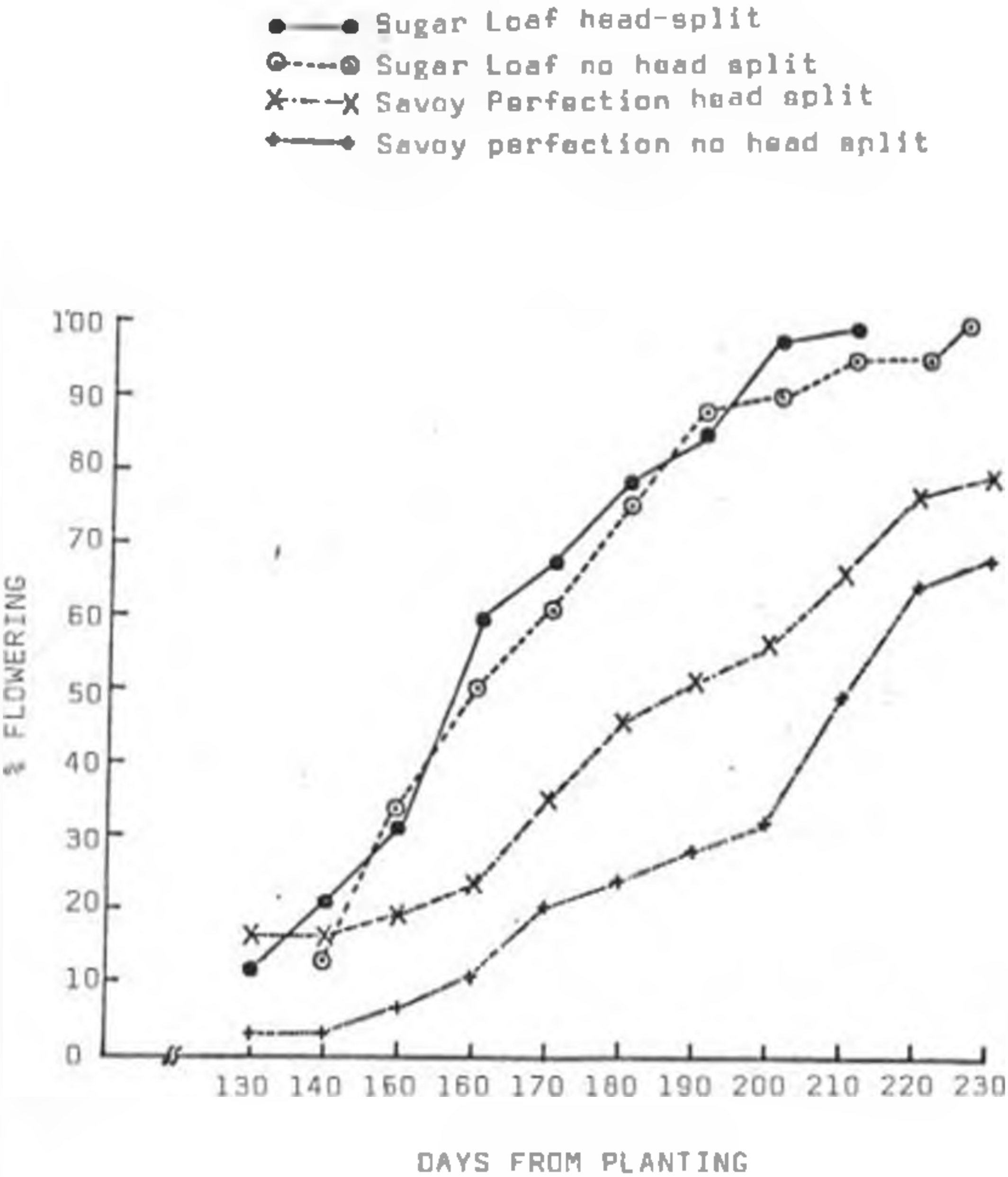
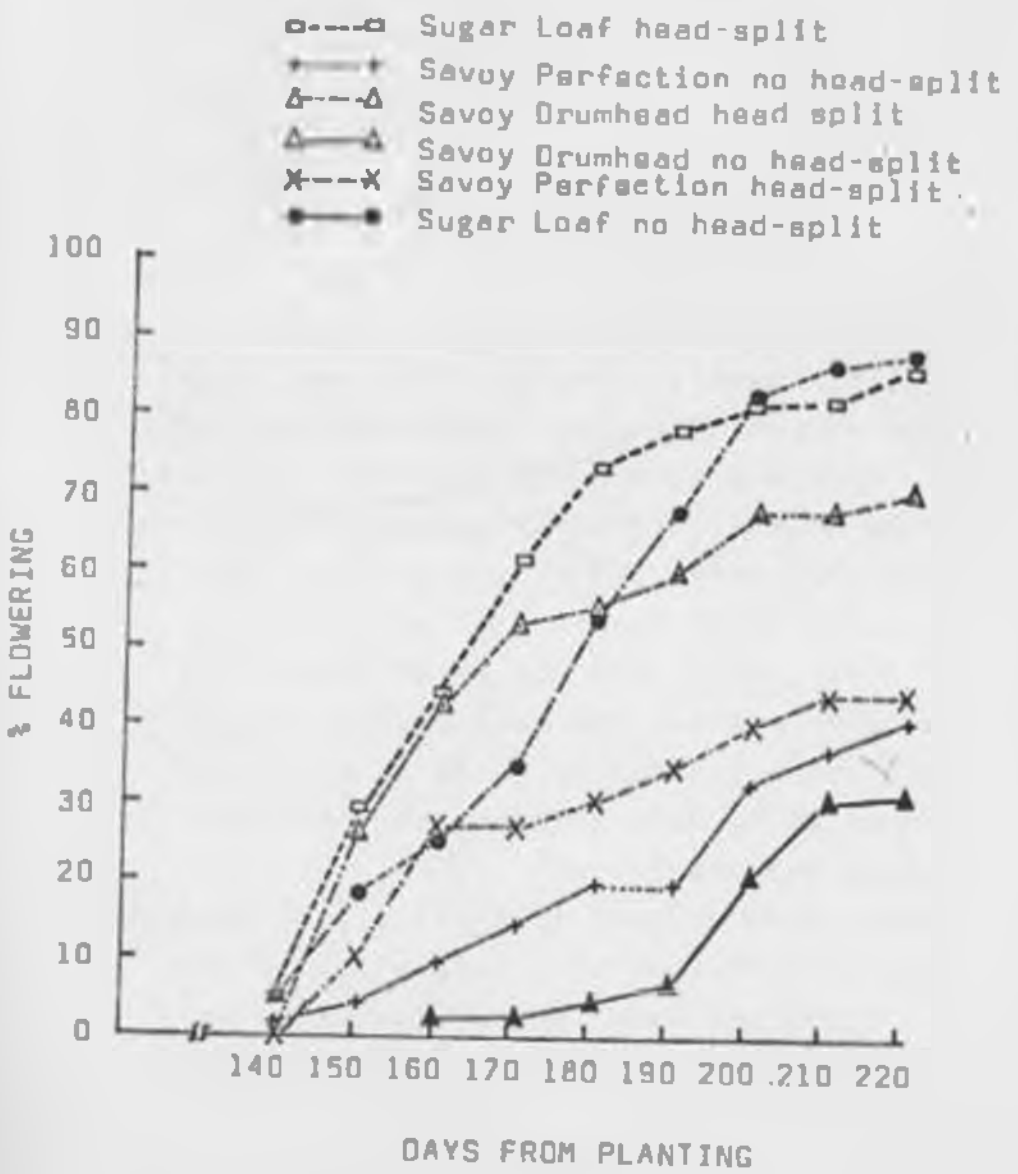


FIGURE 7: NATURAL FLOWERING OF 3 CABBAGE CULTIVARS (B. CAPITATA) IN MOLO AND THE EFFECT OF HEAD SPLITTING ON FLOWERING DURING THE SHORT RAINS.



5. DISCUSSION

Results of the GA experiments which are summarized in Table 10 show that GA replaced the vernalization requirement for flowering in some cultivars of cabbage and Kale in the low altitude site at Kabete, but failed to promote flowering in the high altitude where temperatures are close to those required to induce flowering by chilling.

The highest percent flowering in the low altitude occurred with GA at 250 ppm, whereas GA at 100 ppm induce flowering in 'Giant Drumhead'. However, it was not possible to obtain 100% flowering with GA at 250 ppm but if higher GA concentrations were used, complete induction might have been achieved in the lower altitudes. Bukovac and Wittwer (1957) reported that GA did not induce flowering in cabbage and kale plants which were grown under temperatures much above the required chilling range, after failing to obtain any flowering in some cultivars of cabbage and kale using GA at 100 ppm at 15 - 18°C. Their report differs from the results obtained in the low altitude study at Kabete, where flower induction was possible with GA at temperatures about 18 - 22°C. The differences could have been due to the fact that in this work higher GA concentrations (250 ppm) than those used by the two workers (100 ppm) were applied. This suggests that GA could replace the vernalization requirement for flowering even when plants of cabbage and kale are grown under temperatures much above those required to induce flowering, if higher

GA concentrations than 250 ppm are used. This agrees with Van Marrewijk (1976), who demonstrated that GA at 250-500 ppm applied 3 times induced flowering in Kohlrabi (B. oleracea L. Var. gongylodes). However, since vernalization process can be reversed at very high temperatures (Thompson, 1929 and Miller 1929) there could be a maximum temperature limit above which GA cannot be used to induce flowering.

As shown in Table 10, a varietal response to GA was observed in the lower altitude, since the Golden Acre and Thousand Headed cultivars of cabbage and kale, respectively did not respond to GA by flowering. It could be that those cultivars needed higher concentrations of GA than those applied, or more extended treatment period. According to Lang and Reinhard (1961) different varieties require different GA concentrations and duration of the treatment in order to induce them to flower.

As mentioned above, GA did not induce flowering in any variety in the high altitude site at Molo. Flowering that occurred in 'Sugar Loaf', 'Thousand Headed' and 'Curled Scotch' was not due to GA treatment since the controls flowered equally well. These results differ from reports by Bukovac and Wittwer (1957) and Van Marrewijk (1976), which show that GA induces flowering in Brassica oleracea L. only after incomplete cold treatment or when plants are grown under temperatures slightly above the induction temperatures.

Since in the high altitude it was assumed that the temperatures (7-15°C) were close to those required to induce flowering in cabbage and kale (4-7°C for 8 weeks) GA was expected to induce complete flowering in the cultivars tried. Moreover, Giant Drumhead flowered when treated with GA in the low altitude, but failed to flower with or without GA in the high altitude. One possible explanation why GA did not work where it was expected to induce flowering, could be that in the high altitude, the temperatures are too low for flower bud initiation in some cultivars. This is supported by the fact that some plants of the cultivars that failed to flower (Giant Drumhead and Golden Acre) bolted without forming flowers (Plate 1). Researchers have reported that flowering in Brassica oleracea L. occurs only when the induced plants are exposed to warmer temperatures 18-21°C (Nieuwhof 1969). In the high altitude site at Molo, night temperatures are always below 10°C and day temperatures never exceed 15.5°C which are quite below the flower initiation temperatures in cabbage. It could be that in Kabete the temperatures (18-22°C) were high enough for flower initiation after flower induction by GA in Giant Drumhead. Sugar Loaf which flowered well in the high altitude with and without GA, might have a lower temperature requirement for flower bud initiation than the cultivars that did not flower. The other possible reason why these results differ from those reported by Bukovac and Wittwer (1957) could be due to the fact that these two workers carried out their experiments in a green house under controlled conditions. In this work environmental factors in the field might have interferred with the treatments. For example, the high rainfall in the high altitude could have diluted the GA applied, or washed it off after application since rains occur daily.

In Thousand Headed cultivar of kale, higher GA rates might have induced flowering in both low and high altitude site, since this cultivar did not flower in the low altitude and flowered only poorly in the high altitude with and without GA. The same explanation applies to Curled Scotch cultivar of kale.

Results of the experiments to test natural flowering and the effect of head splitting in eight cultivars of cabbage are summarized in Table 11. These results show that cultivars of cabbage differ in their natural flowering. 'Sugar Loaf' and the 2 'Savoy' cultivars of cabbage flowered naturally under Molo conditions, although with 'Savoy Drumhead' this was only true during the short rains.
These cultivars could have a lower chilling temperature requirement for flowering than the cultivars that did not flower. This agrees with Nieuwhof, 1969; Oetjen, 1933; Miller, 1929 and Sutton, 1924 who observed that bolting in cabbage was inherited and that some cultivars have lower or higher chilling temperature requirements for flowering than others. Different workers have reported that head splitting increased flowering in cabbage as it allows the flower stalks to come out with ease without having to grow through the compact heads in which they usually rot and die (Hawkins, 1944; Hawthorn and Pollard, 1954 and Singh, 1954). In this work, head splitting did not increase flowering in the cultivars that flowered naturally. However, in Savoy Drumhead there was a trend for head splitting to enhance flowering (Table 9). The failure for head splitting to improve flowering in

'Sugar Loaf' and the 'Savoy' cabbage could have been due to the fact that these cultivars have loose heads through which the flower stalks can grow with ease.

About 8% of 'Early Drumhead' flowered with head splitting and about 10% of the same variety, 'Giant Drumhead' and 'Golden Acre' bolted but produced no flowers during the short rains. This may be related to the higher flower initiation temperatures requirements for these cultivars as explained earlier.

Results of the GA experiments obtained in the low altitude site at Kabete call for further work to find optimum GA rates and frequencies of application which would induce 100% flowering in different cultivars of cabbage and kale. As mentioned earlier, a study of flowering of Brassica species is of primary importance for seed production of temperate vegetables in Kenya which is becoming increasingly important to Kenya Government because of the high prices of the imported seeds. The high amount of rainfall which occurs throughout the year in the high altitudes could interfere with the drying of seeds. The low altitudes could be therefore more suitable for seed production than the high altitudes if it could be possible to induce 100% flowering with GA. Although GA is expensive it could be still cheaper than the costs of imported seeds. Seeds of the Collards cultivar of kale can be produced by the use of GA to induce flowering in the low altitudes (1000-2000m) as 91.5% flowering was obtained with GA at 250 ppm. However, an optimum GA rate that would induce 100% flowering in this cultivar should be found. Further investigation on response of different cultivars to GA should be continued in the low altitudes.

Seeds of 'Sugar Loaf' can now be produced in the high altitudes of Kenya without the use of GA. Although GA at 100ppm accelerated flowering in one season, it would be uneconomical to use GA to accelerate flowering in 'Sugar Loaf' as it flowers so readily. Seeds of the 'Savoy' cabbage can also be produced in the high altitude areas. However, further investigations with GA and head splitting techniques are required in order to obtain 100% flowering in 'Savoy Perfection' and 'Savoy Drumhead'. Further work should be done to determine whether the low temperatures which are experienced throughout the year in the high altitudes contributed to lack of flower bud initiation in the cultivars that bolted without flowering. This would mean putting the plants induced in the field in warmer temperatures to observe whether they would flower. More work to find optimum GA concentrations for different cultivars of cabbage and kale should continue in the high altitudes.

Table 10: Summary of GA effects in comparison to controls on flowering of different cultivars of cabbage and kale in low and high altitude sites at final observation

Cultivars	Kabete (low altitude)		Molo (high altitude)		Explanation of symbols
Cabbage	100 ppm	250 ppm	100 ppm	250 ppm	0 No GA effect
Golden Acre	0	0	B	B	• GA induced flowering
Sugar loaf	•	•	0	0	B Some bolting without flowering
Giant drumhead	0	•	B	B	(See plate 7)
Kales					
Collards	•	•	-	-	- No data
Thousand headed	0	0	0	0	
Curled Scotch	-	-	0	0	

TABLE 11: Natural flowering and the influence of head splitting on flowering of eight cultivars of cabbage in the high altitude at Molo.

Cultivars	Natural flowering	Head splitting	Explanation of symbols
Golden Acre	0	B	0 No flowering
Giant drumhead	0	B	++ Flowering occurred both seasons
Early drumhead	0	B	+ Flowering occurred during short rains
Sugar loaf	++	++	B Some bolting without flowering occurred in splitting treatment only (See plate 4)
Savoy Perfection	++	++	
Savoy drumhead	+	+	
Main Crop	0	0	
Brunswick	0	0	

Plate 4: Bolting without flowering in Giant Drumhead cultivar in the high altitude at Molo in the head-split treatment.

6. CONCLUSION

GA induced flowering in Sugar Loaf and Giant Drumhead cultivars of cabbage and Collards cultivar of kale in the low altitudes (1000-2000 m). In the same altitudes GA did not induce flowering in Golden Acre and Thousand Headed cultivars of cabbage and kale respectively. In the high altitudes (2000-3000 m), GA did not induce flowering in any cultivars of cabbage and kale tested. Natural flowering occurred in Sugar Loaf, Savoy Perfection and Savoy Drumhead cultivars of cabbage in the high altitudes. Head splitting had no effect on increasing flowering in any of the cultivars. 'Sugar Loaf' flowered 100% in the high altitude without GA and 'Collard' above 90% with 250 ppm GA in the low altitudes indicating seed production of these 2 cultivars could start immediately.

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