

# FLOWER BUD DIFFERENTIATION IN BANANA

By

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THESIS

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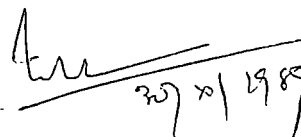
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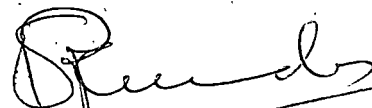
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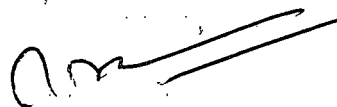
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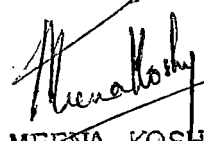
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# INTRODUCTION

## 1. INTRODUCTION

Banana is the most important of the tropical fruits of the World. The demand for this fruit in the international market is increasing and it fetches substantial foreign exchange to the tropical region. Because of its export potentialities, food value and status as a fruit of the common man, the area under this crop is increasing year after year. Its cultivation is widespread, covering all the states in India, along the coastal belt and some in the interior. The area under banana in India is estimated at 2.7 lakh hectares (Anon., 1988). India holds the second position in the World banana production.

Its performance as a commercial crop has been varying, according to the environment. The banana growing areas in India have varied agroclimatic conditions, ranging from the rainfed hill slopes of Tamil Nadu and north-eastern states, the wet paddy lands of Andhra Pradesh, Kerala and Tamil Nadu, to the heavy rainfall areas of the West coast, to the relatively dry South-East coast and to the central arid/semi-arid zones of Andhra Pradesh and Maharashtra. As a consequence, the performance of the crop, in terms of growth, production and quality, has varied greatly.

Despite its agricultural importance, surprisingly little is known about the growth and development of the banana plant in general, and about the shoot apex in vegetative and flowering condition, in particular (Barker and Steward, 1962). The subtle differences, if any, among the clones, have not been adequately studied. Consequently, some of the recommendations made on the cultural and other aspects, have been arbitrary. The leading workers like Alexandrowicz (1955) Barker and Steward (1962) and Simmonds (1966) have pointed out several gaps in our knowledge of banana culture as applicable to the tropical countries.

One example is the current schedule for manurial and irrigation practices, which is based on experiences rather than on scientific evidences. At present, the doses prescribed for the different cultivars are recommended to be split into two, the first to be applied at the 2nd month and the second, at the 4th month after planting (Anon., 1986). This is on the notion that in banana, flower buds differentiate by the 5th month. The folly of this recommendation can easily be appreciated when one considers the duration of the different clones (10 to 12 months for Palayankodan, Nendran, Njalipoovan, etc., as against 18 months for Red Banana).

How the morphological features manifest under strictly tropical conditions and how the external morphology, in turn, influence floral initiation are subjects on which there is practically no information, particularly under Indian conditions.

Although India can boast of the varietal wealth in banana, commercial cultivation is restricted to only a few. Among these Nendran, Robusta, Palayankodan and Red Banana occupy prominent places, with respect to Kerala. The need to rationalize the recommendations on the agro-techniques, before streamlining production, has been emphasised by several workers. To achieve this objective, fundamental information on the growing point of the plant to show how the plant grows and produces the bunch, requires to be elucidated.

Flower bud differentiation is an important event in the life of a flowering plant. Information on the site and time of differentiation, and on the stages of differentiation will provide valuable tips for scheduling the package of practices for successful crop production. Hence, it was felt that flower bud differentiation studies should be conducted in the three banana cultivars of South India, namely, Palayankodan, Red Banana and Robusta.

# REVIEW OF LITERATURE



## 2. REVIEW OF LITERATURE

The edible bananas are bispecific in origin. They originated from two wild ancestors, Musa acuminata Colla and Musa balbisiana Colla. Simmonds and Shepherd (1955) evolved a scoring method to indicate the relative contribution of the two wild parents to the constitution of any given cultivar. On the basis of origin and ploidy level, Simmonds (1966) classified the known cultivars of Eumusa into genomic groups and designated them by the letters which indicate their ploidy and genomic composition with respect to the two parent species.

### 2.1. The growth of the plant

The corm grows from a "cambial-like" region located beneath the vegetative growing point (Simmonds, 1966). Like in many other monocotyledons, the aerial plant or pseudostem consists of a structure of concentric, overlapping leaf bases, the older being outside and the younger, inside. The growing point is a very minute structure situated at the base of the pseudostem, at about the soil level.

The rate of emergence of leaf is influenced by temperature, wind velocity and relative humidity (Turner, 1971). It is reduced by low temperatures (Summerville, 1944) and

decreases with increasing plant age (Champion, 1961). The rate of leaf production is influenced by mineral elements, especially nitrogen (Murray, 1960). Leaf production at the growing point ceases with its conversion to the floral apex.

The size of pseudostem has a significant bearing, as the growth index, on crop yield. Many workers observed strong correlation between the circumference of the pseudostem at the time of emergence of the inflorescence on the one hand and bunch weight (Teaotia et al., 1970), as well as bunch weight and number of hands/bunch (Fernandez et al., 1972) on the other. Influence of the circumference of the pseudostem on the height of the pseudostem and the number of leaves produced was found to be negligible (Teaotia et al., 1970). The height and the circumference of the pseudostem is largely a function of the leaves.

The corm and the pseudostem increase in size until the emergence of the inflorescence. The internodes, produced during the vegetative phase, are very short. After the vegetative apex is transformed to floral apex, elongation of the true stem commences (Summerville, 1944; Barker and Steward, 1962b; Turner, 1972).

Though Summerville (1944) and Champion (1963) divided the vegetative stage into substages, the course of development of banana plant can be divided on morphological terms into three stages, the vegetative, the floral and the fruiting phases (Simmonds, 1966). Turner (1972) divided the growth cycle of banana plant into five arbitrary stages, where the first three stages covered the vegetative stage of Simmonds (1966).

## 2.2. Leaf number and leaf area

The number of leaves borne by the shoot at any one time is the resultant of two processes—production and loss. Healthy banana plants normally have about 10 to 15 (exceptionally, 20) green leaves, the number falling towards maturity of the bunch, at a time when leaf loss is no longer balanced by leaf production (Simmonds, 1966; Wardlaw, 1972). The last one or two leaves may be much reduced in size than the others.

As regards the total number of leaves produced before floral initiation, different schools of thought exist. Some workers suggest that a reasonably constant number of leaves emerge prior to floral initiation (Ticho, 1960; Wardlaw, 1972; Champion, 1963) whereas according to others, the number of

unemerged leaves at floral initiation is fairly constant (Summerville, 1944; Champion, 1961). The estimates vary, being 35 to 50 (Summerville, 1944) and 45 (Barker and Steward, 1962a) in Gros Michel, 30 to 36 (Oppenheimer, 1960) and 23 (Ticho, 1960) in Dwarf Cavendish and 23 to 45 in Poyo (Champion, 1961). Reviewing the above data, Simmonds (1966) concluded that depending upon the varieties and the growing environment, a plant might produce 60 to 70 leaves including the juvenile leaves. The leaf number is greatly controlled by the specific origin of the clone (Nambisan, 1972) who observed the highest leaf number in Musa balbisiana and the lowest, in pure acuminata clones.

### 2.3. Leaf function hypothesis

Summerville (1944) attempted an arithmetic method of determining the time of floral initiation, although he could not find any single factor that determined the induction of flowering. After observing the development of many plants, he regarded flowering as a function of the total expanded leaf area, the exposure of each leaf to sufficient hours of daylight and the mean temperature during the functional life of each leaf. When the product of these (Ts) reached a certain threshold value ( $T_s = 56,000$ ), the stimulus to flowering occurred. This empirical relationship, however, was applicable only to the varieties and conditions in Queensland

(Alexandrowicz, 1935). In any case, it only states in arithmetical terms, that the banana plant flowers when it is large enough to have had sufficient number of leaves, sufficiently active during a long enough period. Simmonds (1966) regards the Ts concept as a crude measure of net assimilation of some metabolic state.

#### 2.4. Climate and banana growth

The banana is strictly a tropical plant. Except a few, all the important banana growing countries are situated between  $30^{\circ}$  N and  $30^{\circ}$  S latitudes. Heavy rainfall and high temperature are ideal for banana cultivation. Prevalence of 4.0 inches of average precipitation per month and  $80^{\circ}$  F temperature throughout the crop growth have been fixed by Simmonds (1966) as the effective rainfall and temperature.

Banana is thermosensitive. It can tolerate neither very high nor very cold temperature. In India, the regions where climate can be called excellent for growing banana are Kerala, parts of Tamil Nadu, Maharashtra and West Bengal.

Green and Kuhne (1970) reported that growth of banana was closely related to air temperature and the growth estimate could be made from temperature alone. He fixed lower threshold temperature as  $11^{\circ}$ C. Growth was more sensitive to the

fluctuations in temperature during the day than that during the night; but sunshine did not limit the growth (Green and Kuhne, 1970).

## 2.5. Nutritional factors

The carbohydrates formed in the process of photosynthesis and the nitrogenous compounds introduced through the plant roots were considered to be of primary importance in Kleb's theory. Kraus and Kraybill, the pioneer workers on this aspect of flowering, stressed the importance of carbon/nitrogen ratio, as early as in 1918. But there is very little information on the carbohydrate metabolism in banana plant. The carbohydrate changes that occur in the banana leaf were studied long ago by Belval (1932), as quoted by Steward et al. (1960). Loesecke (1950) reported the total carbohydrates and related substances in leaf to be 16.21 per cent of the dry matter; but the changes at the different stages were not mentioned. Shantha et al. (1970) studied the starch content in the pseudostem and found that during the growth of the plant, starch accumulated in the pseudostem and reached its maximum at the time of flowering and remained practically constant thereafter, until harvest.

As regards nitrogen metabolism, Steward et al. (1960) were the first to study some of the biochemical constituents in the different parts of banana plants.

The relationship between C/N ratio and flowering has not been studied thoroughly in banana. Summerville (1944) observed a wider C/N ratio in banana during initiation of flowering. Chakrabarthy (1977) has shown that in banana the pattern of changes of nitrogen content envisaged a gradual decrease from vegetative stage to reproductive stage. He also found marked increases in carbohydrate at the transition stage which registered a peak, followed by a slow decrease thereafter.

Vasanthakumar (1986) observed high status of carbohydrates at the panicle initiation and flower bud development stages of cardamom. This accumulation of carbohydrates favoured the development of flower buds in cardamom.

Rajan (1985) recorded an accumulation of carbohydrates and a build up of C/N ratio prior to peak differentiation, in black pepper. However, he did not observe any significant correlation between the carbohydrate content, the C/N ratio and flower bud differentiation.

High starch reserves, total carbohydrates and C/N ratio in shoots favoured flower bud differentiation in mango (Naik and Shaw, 1937; Mallik, 1953; Singh, 1960; Sen et al., 1963). However, Suryanarayana (1980) observed that though there is a general increase in the C/N ratio of leaves from April to November, its peak level did not synchronise with the time of flower bud differentiation in the six varieties studied.

Bai and Ramadasan (1982) found that the number of female flowers produced were maximum during March-April in coconut, when the starch content in stem and leaves was also maximum.

## 2.6. Histology of flower bud differentiation

When a plant reaches the reproductive stage of development, some or all of the apical meristems on its shoot cease to initiate foliage leaves and begin to produce floral parts according to a sequence characteristic of the species, with a variable number of bracts intervening the leaves and the flower. In this process, the apical meristems change from indeterminate to determinate growth, because the formation of flower is usually the final event in the activity of a given apical meristem. In annual plants, the advent of the reproductive stage means also the approaching completion of the



entire life cycle. In perennials, flowering is repeated a variable number of times, depending on the longevity of the plant.

#### 2.6.1. The vegetative shoot apex

Any study of the apical growth of banana must take into account the diversity of vegetative shoots which are formed. Holttum (1955) described the growing point of the members of the Musaceae as a rhizomal sympodium. Simmonds (1966) reviewed some of the old reports of Skutch (1927, 1930 & 1937) on the developmental anatomy of the axis and leaf; but could not give a detailed interpretation of all the actual growing regions. In an undisturbed banana plant, several leading shoots may be in approximately the same stage of dominant growth and in addition, each of these may have several basally formed followers as well as a number of concealed buds that are in various stages of development (Barker, 1959). Alexandrowicz (1955) has thrown some light on the apical growing regions of the banana plant; but the histological information is wanting. Although this plant is large, the actual vegetative growing point is relatively small, its main and central portion being, in fact, of the same order of size as that of many other herbaceous shoots (Wardlaw, 1953).

Essentially, the apical meristem in banana consists of the central domeshaped structure familiar in the angiosperms (Gifford, 1954; Wardlaw, 1957). Barker and Steward (1962a and b) gave detailed information on the growing region of the vegetative shoot and the different changes that occur in the growing point during and after the transition stage. The leaf primordium originates as a protuberance on the flank of the apical dome. Subsequently, it elongates by combining a peripheral growth around the apex and ultimately encircles the whole growing point. Thus, a displacement of young leaf from the growing point to make room for its expansion and development, occur laterally and the successive leaves build up a flattened crown.

From the point of internal organisation, the vegetative shoot apex of banana can be grouped with the opuntia type of Popham (1951). The opuntia type differs from the usual angiosperm type in its cambium-like transitional zone. A similar cytohistological structure is found in other monocotyledons such as date and other palms (Ball, 1941).

The different zonations in the vegetative apex of banana fits the description of the apices of certain other monocotyledons Stant (1952), except that the rib meristem

is inconspicuous or absent and that the flank meristem is only represented by the divisions which initiate the leaf primordia (Chakrabarty, 1977).

Stant (1952) described the shoot apex of monocotyledons in terms of tunica-the rectangular cells dividing regularly and anticlinally to form a distinct layer of cells, and the corpus - a central core of meristem, similar in appearance and properties to the tunica initials. As regards the different zones laid out, the banana apex exhibits the general tunica - corpus organisation like in other monocotyledonous plants (Stant, 1952; Barnard, 1960). Stant (1952) described the corpus as a composition of two zones. The rib meristem, the central zone of the corpus with successive transverse divisions leading to the production of the rib meristem and the flank meristem a cylinder of peripheral meristem with increased density of staining. Stant (1952) observed mostly one layer of tunica. Barker and Steward (1962a) observed two layers of tunica in the vegetative apex of banana. Mohan Ram et al. (1962) observed even three layers of tunica at the transition stage of banana apex.

The lateral or adventitious bud of banana is unusually placed (Skutch, 1927), almost  $180^{\circ}$  from the usual axillary

position. Skuteh (1927) even included the possibility that sympodial habit might be the true growth pattern of the species and suggested that the terminal apex was pushed aside and replaced by the development of each lateral bud.

In monocotyledons, which lack secondary growth brought about by a well-defined cambium, the intercalary meristem, situated at the base of the leaves, makes an important contribution to the total growth of the shoot. Barker and Steward (1962a) have shown that the intercalary growth at the base of the banana leaf is of two kinds. The first, cuts off cells formed by tangential longitudinal division permits growth in girth and the second, presumably after the first is almost complete, adds, by transverse division, many cells to the length of the leaf.

Barker and Steward (1962a) observed that a striking feature of the mature leaf of banana is the number of lacunae or air chambers which may be filled with water, a clear 'mucilage' or with air. Investigations on the physiology of flowering in banana by Chakrabarty (1977) showed that in vegetative stage, the apical meristem was a flat dome-like structure. The important features observed by him in the development of the vegetative shoot apex were spiral leaf

arrangement, complete absence of lateral buds and extreme reduction of internodes.

In many crop plants, the vegetative apex is characterised by a conical shape, as observed in mango (Singh, 1960), grapes (Chadha and Cheema, 1971) and jasmine (Subramonian and Shanmugavelu, 1980). Shukla and Bajpai (1974) found that prior to differentiation in litchi, the apical bud of a vegetative shoot is dome-shaped, with a uniform curvature and surrounded by leaves. Rajan (1985) found that vegetative bud in black pepper was conical and surrounded by leaf primordia. Histological studies on the flower bud differentiation of cardamom by Vasanthakumar (1986) showed the apical meristem to be broadly conical during the initial stages, with prominently nucleated cells.

#### 2.6.2. The transition from vegetative to floral shoot

In several dicotyledonous plants, the first visible effect that follows the perception of flowering stimulus, is a change in the shape of the central dome of the apex which tends often to become broader and flattened. It has been suggested that, this is consistent with the need of the apex to accommodate many more floral parts at a given level than the need of the vegetative apex to accommodate the leaves.

Steward and Mohan Ram (1961), however, observed that some monocotyledonous plants have individual floral shoot apices in which the central dome may be more tapering and less broad, than in the corresponding vegetative shoot apices. The French school led by Buvat (1955) held the view that the so-called quiescent zone in the sub-apical region, which is relatively dormant with few cell divisions during vegetative growth, springs into activity when flowering occurs. This region is then absorbed, as it were, into the modified structure of the flowering shoot apex. This aspect has been re-examined with some success by Wetmore et al. (1959) with respect to some photoperiodically sensitive plants. These facts, therefore, have formed the background against which the special case of flowering was examined by Barker and Steward (1962b). Alexandrowicz (1955) recognized the first step towards flowering in banana growth by elongation of the axis, as the transitional one from vegetative to flowering stage. Stoler (1960) suggested that in banana, the transition from the vegetative to the reproductive stage is marked by an upward elongation of the top of the corm, which represents the initiation of the flowering shoot. Fahn et al. (1963) found that the cyto-histological changes involve a gradual disappearance of the zones that were present in the

vegetative apex and the appearance of two zones—an outer, many-layered one composed of small intensively staining cells with dense protoplasts, and an inner zone of highly vacuolated, weakly staining cells. According to them, the outer zone represents the meristem from which the bracts and hands of the inflorescence develop. They further observed that these changes resemble those described by Wetmore et al. (1957) in Chenopodium album, Xanthium pensylvanicum, Glycine max, Hyoscyamus niger and Papaver somniferum.

Barker and Steward (1962b) observed that with the onset of flowering, the vegetative apex commences to grow in the following way: First, the axis grows in length. Then, the peripheral growth of the leaf bases becomes progressively less pronounced. Bracts which form instead of leaves do not fully encircle the stem, and their internal structure is different. Lateral growing regions or buds appear in the axils of the bracts, even very close to the central apical dome of the meristem, whereas, in the vegetative shoot, buds were conspicuously absent from these axillary positions. Chakrabarty (1977) found that at the transition stage, the previously flattened dome in banana started elongation to become conical.

Histological studies on the flower bud differentiation of cardamom by Vasanthakumar (1986) showed that the panicle (inflorescence) meristem was a flattened zone. Later, this assumed an arc-like structure. The raceme initials that appeared on the panicle primordia were larger than those of the leaf primordia that appeared on the shoot meristems.

Rajan (1985) observed a change in the shape, from conical to hemispherical, as the transition from vegetative to floral phase occurred in black pepper. The change of shape was accompanied by high meristematic activity.

Broadening and flattening of the apical meristem with two lateral protuberances, one on either side, was established as the phenomenon of blossom bud differentiation in citrus (Abbot, 1935; Randhawa and Disna, 1947; Singh and Dhuria, 1960 and Misra and Yamadagni, 1968). In mango, Singh (1958) observed high meristematic activity marked by the origin of broad conical protuberances in the axils of the scales, as the sign of fruit bud differentiation. In litchi, Shukla and Bajpai (1974) observed that the bud flattened and broadened with a rapid elevation on both the sides of the growing point.



### 2.6.3. The origin of the inflorescence and development of the flowers

The fruiting inflorescence or the 'stem' of the banana, is a familiar object. It, nevertheless, presents botanical problems and is the end-result of a remarkable sequence of growth events. The origin and development of the banana inflorescence was first studied by White (1928). Wardlaw et al. (1939) reported some of the observations relating to the elongation of the axis and the post-emergence growth of the inflorescence. The studies of Fahn et al. (1963) on the development of flower primordia in the flower cluster of Dwarf Cavendish have been summarised by Simmonds (1966). Fahn et al. (1963) found that the flowers in one cluster developed in a sequence from right to left, the observer facing the axis. The sequence of development alternated between the two rows and vascularization followed approximately at the same sequence, as the flower cluster represented a condensed cincinnus. He drew attention, for comparative purposes, to Holttum's statement that cymose inflorescences are common in the allied families. Lane (1955) gave an alternative interpretation that the flower clusters represent condensed racemes.

White (1928) found that the flowers originated as dome-shaped bumps on the cushions and soon became roughly square or pentagonal in section as a result of compression between the neighbours. He observed that at an early stage, a depression developed on the top of the bump and the annulus of tissue so formed differentiated into three tepals.

Barker and Steward (1962b) observed that the bract primordium, which arose as a small mound, showed both periclinal and anticlinal divisions of the sub-epidermal layers. The epidermis kept pace with the increase in volume by anticlinal divisions. The bract elongated and grew almost at right angles to the apex of the inflorescence. Transverse sections below the apex showed the bract as a crescent-shaped organ. As it grew, the bracts pushed outward in a radial direction. They found that due to greater growth on the abaxial side, the bracts became boat shaped. As they grew upward and outward, the bracts over-arched and enclosed the position which the flowers will later occupy in their axils.

Fahn et al. (1963) found that two cytohistological zones occurred in the reproductive apex also when the primordia of "hand"-subtending bracts were being formed. Remnants of the tunica could be observed in the outer zone, not only in

the young reproductive apex but also in the summit of the developing inflorescence.

Chakrabarty (1977) observed that production of bract and hand primordia occurred simultaneously. The hand primordia were acropetal in succession and the initiation could be seen first as a cone-like structure. Soon, the tip became flattened and the two regions of growth formed with a gap in between them to form the two rows of a hand. Each row, again by further division, formed the fingers. These two, the abaxial and the adaxial rows of the hands, could be seen in transverse sections.

### 2.7. The flowering stimulus

Turner (1972) reviewed the earlier work on the flowering stimulus in banana. As most plants, banana also becomes reproductive under the influence of age and environment. According to him, age is probably the dominant factor in banana, as flowering cannot be induced by changing the day-length or by vernalization.

Three approaches have been put forward so far, regarding flowering in banana. The first approach is based on the number of leaves produced by the plant. One aspect of this

approach is the assumption that a fixed number of leaves is produced prior to flower bud differentiation. But the number of leaves vary with the locality and the cultivar. Barker and Steward (1962) recorded 45 leaves for 'Gros Michel' in Central America while 23 leaves were considered critical for Dwarf Cavendish in Israel by Ticho (1960). Another aspect is the assumption that a fixed number of leaves remains in the pseudostem at flower bud initiation. If the date of bunch emergence is known and leaf emergence rates measured, it is possible to estimate the occurrence of initiation retrospectively in this way.

The second approach is based on the leaf function hypothesis put forward by Summerville (1944). Barker and Steward (1962) did not favour it as a generally applicable hypothesis.

The third hypothesis put forward by Champion (1963) pointed to an interaction between the corm and the leaves. He observed that while in the development of any one plant, a certain leaf area must be produced before initiation occurs, in a population, the vegetatively largest is not necessarily the first one to bunch. He, therefore, considered that while the function of the leaf system is important,

the corm must have developed sufficiently to receive the flowering stimulus.

For offering a suitable hypothesis for the mechanism of flowering, Mohan Ram et al. (1962) took the histological changes which occurred at the growing point during the change from the vegetative to the floral phase. They further opined that gibberellin-like substances would cause elongation of the true stem in banana. That a translocated factor is involved in the flowering process has been demonstrated by Barker (1962b). In South India, Pillai (1975) and Chakrabarty (1977) studied the histological and biochemical changes occurring at the time of transition from the vegetative to floral phases in some cultivars of banana.

# MATERIALS AND METHODS

### 3. MATERIALS AND METHODS

The studies on "Flower bud differentiation in banana" were carried out at the College of Agriculture, Vellayani in three cultivars of banana, Musa (AAB Group) 'Palayankodan', Musa (AAA Group, Cavendish Sub-group) 'Robusta' and Musa (AAA Group) 'Red Banana'.

#### 3.1. Layout

Three-month old suckers (of apparently uniform age) were planted according to the layout plan given in Fig. 1. Eventhough the study included three cultivars, the suckers were planted at a general spacing of 2.4 m x 2.4 m. A common border was given in between the observational rows so that uniform microclimate would be experienced by the observational plants. Otherwise, non-uniform conditions would prevail as the plants were uprooted for microtomy. Uprooting of the plants was done at fifteen-day interval, beginning from the first observational row. However, since the uprooted suckers did not show the developmental stages in sequence at 15-day interval, the uprooting schedule was modified.

Fig. 1. LAYOUT PLAN

Row No.

1	-	x	x	x	x	x	x	x	x	x	x	x	x	
2	-	x	b	b	b	x	a	a	a	x	c	c	c	x
3	-	x	x	x	x	x	x	x	x	x	x	x	x	x
4	-	x	c	c	c	x	b	b	b	x	a	a	a	x
5	-	x	x	x	x	x	x	x	x	x	x	x	x	x
6	-	x	a	a	a	x	c	c	c	x	b	b	b	x
7	-	x	x	x	x	x	x	x	x	x	x	x	x	x
8	-	x	b	b	b	x	c	c	c	x	a	a	a	x
9	-	x	x	x	x	x	x	x	x	x	x	x	x	x
10	-	x	a	a	a	x	b	b	b	x	c	c	c	x
11	-	x	x	x	x	x	x	x	x	x	x	x	x	x
12	-	x	c	c	c	x	a	a	a	x	b	b	b	x
13	-	x	x	x	x	x	x	x	x	x	x	x	x	x
14	-	x	b	b	b	x	c	c	c	x	a	a	a	x
15	-	x	x	x	x	x	x	x	x	x	x	x	x	x
16	-	x	a	a	a	x	b	b	b	x	c	c	c	x
17	-	x	x	x	x	x	x	x	x	x	x	x	x	x
18	-	x	c	c	c	x	b	b	b	x	a	a	a	x
19	-	x	x	x	x	x	x	x	x	x	x	x	x	x
20	-	x	b	b	b	x	a	a	a	x	c	c	c	x
21	-	x	x	x	x	x	x	x	x	x	x	x	x	x
22	-	x	c	c	c	x	a	a	a	x	b	b	b	x
23	-	x	x	x	x	x	x	x	x	x	x	x	x	x
24	-	x	a	a	a	x	c	c	c	x	b	b	b	x
25	-	x	x	x	x	x	x	x	x	x	x	x	x	x

- x - Palayankodan (Common border)  
a - Palayankodan (Observational)  
b - Robusta (Observational)  
c - Red Banana (Observational)



### 3.2. Cultivars

A brief description of the characteristics of the three cultivars is given below:

Musa (AAB Group) 'Palayankodan'

Synonyms: 'Poovan' (Tamil Nadu), 'Karpura Chakkarakeli' (Andhra Pradesh), 'Lal Velchi' (Maharashtra), 'Mysore' (Trinidad), 'Fill Basket' (West Indies)

A tall and stout variety with large leaves and heavy bunches. The common variety cultivated throughout South India.

The distinguishing characters are the rose pink colouration on the outerside of the midribs (when young) and the heavy bunches with closely packed fruits hanging down vertically. The peduncle is glabrous and pedicel short. The bract is deep purple and glaucous outside; dark red and polished inside. The apex is rounded. The male flowers are pigmented and deciduous. The hands are very compact with 11 to 18 fingers per hand. The fingers are terete, cylindric, four to five ridged, with two ridges rather prominent. The fruit is small to medium in size, held firmly in the bunch and has distinct mammillary tip. The rind is thin and the

pulp, cream with an agreeable sub-acid taste. The rind is golden-yellow with a tinge of rush-red colouration. An average bunch weighs 15 kg.

This, being a triploid belonging to the AAB group, is intermediate in sucker production between the diploids and the tetraploids. On an average, sucker production of this cultivar ranges between 4 and 5 (Lekha, 1986).

Musa (AAA Group, Cavendish Sub-group) 'Robusta'

Synonyms: 'Bombay Green' and 'Harichal' (Maharashtra), 'Pedda pachcha arati' (Andra Pradesh), 'Pisang buai' (Malaya), 'Tall Mons Mari' (Queensland).

Semi-tall mutant of Dwarf Cavendish. It possesses desirable export qualities and is priced much in the international market. Because of the high yield potential, the area under this cultivar is rapidly expanding. As there are good markets within the State and outside for Robusta, steps at present are being taken to increase its production further by intensive and extensive methods of cultivation.

The fruit retains the green colour of the rind even when ripe. The average bunch weight ranges from 12 to 13 kg. The fruit is long and large with a thick rind.

It is poor in suckering habit, producing only two to three suckers/plant (Lekha, 1986).

Musa (AAA Group) 'Red Banana'

Synonyms: Lal Kela (Maharashtra), Chenkadali and Sevvazhai (Tamil Nadu), Anupan (Bihar), Red Banana (Trinidad).

This is popular in Kerala, especially towards the South. The colour of the pseudostem, petiole, midrib and fruit rind is deep purplish red. The bunch is compact with attractive red-rinded fruits. The fruit is of good size, cylindrical, thick, with a blunt apex. The rind is thick. The ripe fruit has a characteristic flavour.

It is a long duration variety and takes about 15 to 18 months from planting to harvest.

The cultivar is poor in suckering habit (Lekha, 1986).

### 3.3. Climatic factors

From the data collected at the Meteorological Observatory in the campus, monthly averages of maximum temperature, minimum temperature, rainfall, relative humidity and sunshine hours were computed. These parameters were examined for their possible role in flower bud differentiation.

### 3.4. Observations on morphological attributes

Observations were made three months after planting at monthly intervals as detailed below:

#### 3.4.1. Pseudostem height:

Height of the plant was measured from the base of the trunk to the axil of the youngest leaf and expressed in cm.

#### 3.4.2. Pseudostem girth:

Girth of the pseudostem was measured at 20 cm height from the ground level and expressed in cm.

#### 3.4.3. Number of functional leaves:

The number of functional leaves were recorded at monthly intervals by counting the green and healthy leaves, discarding the senescent leaves [ When more than three fourth of the total leaf surface became yellowish, either by natural ageing or due to the attack of leaf spot disease, the leaves were regarded as senescent ].

#### 3.4.4. Area of leaf:

Leaf area was calculated in the case of 'Palayankodan' by multiplying the length, the width and the factor 0.8 (Murray, 1960)

Determination of the leaf area in 'Robusta' and 'Red Banana' was done by fitting the regression equation

$$y = a + bLB., \text{ where}$$

$$a = \text{intercept}$$

$$b = \text{regression co-efficient}$$

$$y = \text{area in cm}^2$$

$$L = \text{length of the leaf in cm}$$

$$B = \text{breadth of the leaf in cm}$$

### 3.5. Carbohydrate and nitrogen reserves

Plant samples were analysed at monthly intervals to determine the levels of carbohydrates and nitrogen.

The third leaf from the apex (counting the top most fully emerged leaf as the first) was taken (Hewitt, 1955; Murray, 1960) for collecting the samples. Samples were taken from the middle portion of the lamina to a width of about 45 cm on both the sides of the midrib. The samples were labelled and dried in an oven at 80°C for 48 hours.

Nitrogen in the samples was determined colorimetrically, as suggested by Snell and Snell (1967).

Total carbohydrates in the samples were determined colorimetrically, as per the method suggested by Deiraz (1961).

### 3.6. Histological studies

To determine, at least approximately, the time of floral initiation and differentiation within the pseudostem and to unravel the course of development until the emergence of the inflorescence out of the pseudostem, histological studies were carried out. The investigation consisted of

- a) collection of the bud samples from the pseudostem
- b) preparation of the bud samples
- c) sectioning, staining and mounting for microscopic examination.

#### 3.6.1. Collection of the bud sample

Bud samples were collected from three months after planting till the anticipated date of shooting.

The whole plant along with the corm was dug out carefully and the base of the pseudostem, trimmed. Then, the leaf sheaths were removed one by one from the pseudostem by making a slit with a small knife at the middle of the distal end of the leaf sheath at the top and tearing down the two halves by pulling them apart. With the removal of the sheath of the last fully opened leaf, the pseudostem became very pliable and brittle. Utmost care was, therefore, necessary for the removal of the remaining sheaths. The pliable sheaths

of the leaves inside the pseudostem were removed carefully one by one with the help of a blade. After the removal of the sheaths of five or six unemerged leaves from this pliable stem (depending upon the age of the plant), either a cylindrical apical bud with a long filiform apex or a small plumpy apical bud with a slightly pointed apex was obtained. These were preserved for histological study.

### 3.6.2. Preparation of the bud samples

### 3.6.3. Killing and fixing

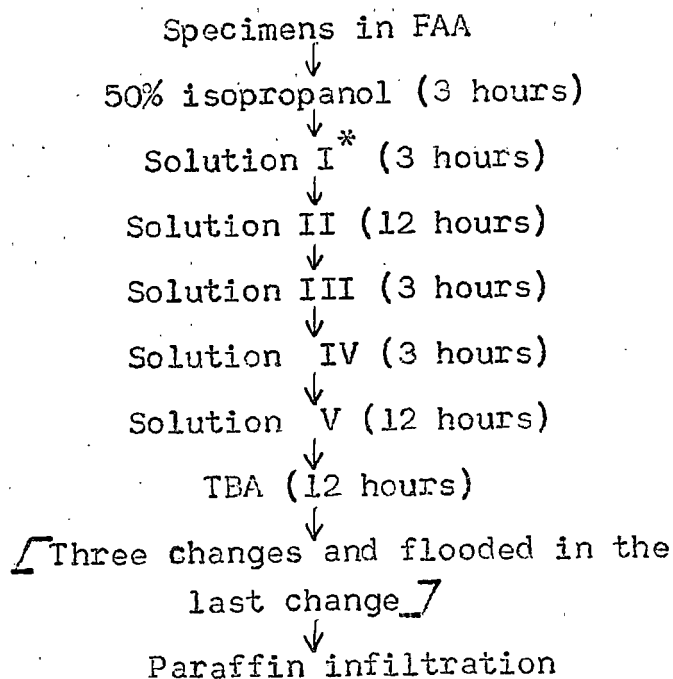
FAA (formula given below) was used for killing and also as a fixative in which the specimens were kept immersed in corked specimen tubes. The specimens could be stored in FAA (Table 1) without any damage to the tissue organisation or shrinkage of the cells.

Table 1. Composition of the Formalin - Aceto - Alcohol (FAA)

Ingredient	Quantity (ml)
Ethyl alcohol	50
Glacial acetic acid	5
Formaldehyde (37-40%)	10
Distilled water	35

### 3.6.4. Dehydration

The buds were gradually dehydrated in isopropanol - tertiary butyl alcohol series after a minimum storage period of one week in FAA.



\* Details furnished in Table 2

Table 2. Composition of the dehydration series

Solu- tion No.	95% Isopropanol (ml)	Absolute Isopropanol (ml)	TBA (ml)	Water (ml)
I	50	--	10	40
II	50	--	20	30
III	50	--	35	15
IV	50	--	50	--
V	--	25	75	--



### 3.6.5. Paraffin infiltration

After dehydration, infiltration was done using paraffin with ceresin (M.P. 60°C), as described by Johansen (1960).

### 3.6.6. Embedding

Paraffin with ceresin (M.P. 60°C) was used for embedding. Embedding was carried out as per the procedure described by Johansen (1960).

### 3.6.7. Microtomy

Sections were taken at a thickness of 10-12  $\mu$  using a Rotary Microtome, as per the standard procedures for microtomy (Johansen, 1960).

### 3.6.8. Staining

The sections affixed to glass slides were stained by immersion in specific reagents in staining jars. Saffranin, Saffranin-aniline blue combination and Eosin Yellow were tried.

The schedules adopted for staining are given below:

#### Staining chart for Saffranin

Xylene (5 min)

↓  
Absolute ethyl alcohol (1 min)

↓  
95% ethanol (1 min)

↓  
70% ethanol (1 min)

↓  
50% ethanol (1 min)

↓  
30% ethanol (1 min)

↓  
Distilled water (2 min)

↓  
Aqueous Saffranin (2 hours) →

Dried and mounted  
in Canada balsam

↑  
Xylene (1 min)

↑  
Absolute ethyl alcohol (30 sec)

↑  
95% ethanol (30 sec)

↑  
50% ethanol (30 sec)

↑  
30% ethanol (30 sec)

↑  
Distilled water (2 min)

Staining chart for Saffranin - aniline blue

Pre-staining operations and intervals were the same as for Saffranin staining

Aqueous Saffranin (2 hours)

↓  
Distilled water (1 min)

↓  
30% ethanol (1 min)

↓  
50% ethanol (1 min)

↓  
70% ethanol (1 min)

↓  
95% ethanol (1 min) →

↑  
Dried and mounted  
in Canada balsam

↑  
Xylene (1 min)

↑  
Absolute ethyl alcohol (30 sec)

↑  
95% ethanol (15 sec)

↑  
Aniline Blue (1%)

Staining chart for Eosin Yellow

Xylene (5 min)

↓  
Absolute ethyl alcohol (1 min)

↓  
95% ethanol (1 min)

↓  
70% ethanol (1 min)

↓  
50% ethanol (1 min)

↓  
30% ethanol (1 min)

↓  
Distilled water (2 min)

↓  
Eosin (30 min) →

↑  
Dried and mounted  
in Canada balsam

↑  
Xylene (1 min)

↑  
Absolute ethyl alcohol (30 sec)

↑  
95% ethanol (30 sec)

↑  
70% ethanol (30 sec)

↑  
50% ethanol (30 sec)

↑  
30% ethanol (30 sec)

↑  
Distilled water (2 min)

### 3.6.9. Microscopic examination

The slides were initially examined through a binocular monoobjective microscope (Olympus KICBI) with 10x or 15x objective and 10x eyepiece. Critical examinations were done at higher magnifications using the trinocular 'Nikon Optiphot' microscope available at the Central Instruments Laboratory, National Agricultural Research Project (Southern Region), College of Agriculture, Vellayani.

### 3.6.10. Photomicrography

Photomicrographs of the selected sections were taken using the photomicrography system (Nikon Optiphot with Fx-35A) available at the Central Instruments Laboratory, National Agricultural Research Project (Southern Region), College of Agriculture, Vellayani. Colour negative films (100 ASA, Kodacolor) were used for taking the photomicrographs.

# RESULTS

#### 4. RESULTS

The morphology of banana plant is very complicated. Its inflorescence develops from the terminal vegetative meristem that is located within 30 cm of the ground and within the cylinder of sheathing leaf bases (the pseudostem). The plant is perennial and the flower buds form without regard to season and without any external symptoms.

On dissection, for removal of the leaf bases, an outgrowth, representing the lateral bud was located on the true stem, opposite to the axil and just above the two overlapping margins of the mature leaf bases. Outwardly, the growing apex was seen to be a conical structure covered by a number of leaf primordia. Each immediate older leaf was fitted upon the younger as an inverted funnel formed by the encircling leaf bases, projecting a filiform appendage at the tip, enclosed by the next primordium.

Median longitudinal sections of the apical meristem were examined to unravel the histological features of development of the growing point of banana.

##### 4.1. Early vegetative phase

The plates 1(a) and (b) show the apical meristem with

a broad base. The internal corpus cells are seen covered by the tunica which is a few cells deep. The leaf primordia formed, can be seen completely encircling the apical meristem, which appears as a low mound in the plate 2, with the tunica covering the internal corpus cells. In the plates, the initial increase in size is evident when successive leaves are compared. The arrangement of leaf bases, as a series of cones, each fitting over the next one, can also be seen. The leaves appear on all the sides of the meristem. It can be observed that the basal half is thicker than the apical half. In the leaves which have been cut transversely, the cuts have occurred at the basal portion.

In the plates 3(a), 3(b) and 3(c) also, the apical meristem appears as a low mound. There is evidence of greater stainability throughout the apical meristematic region.

#### 4.2. Late vegetative phase

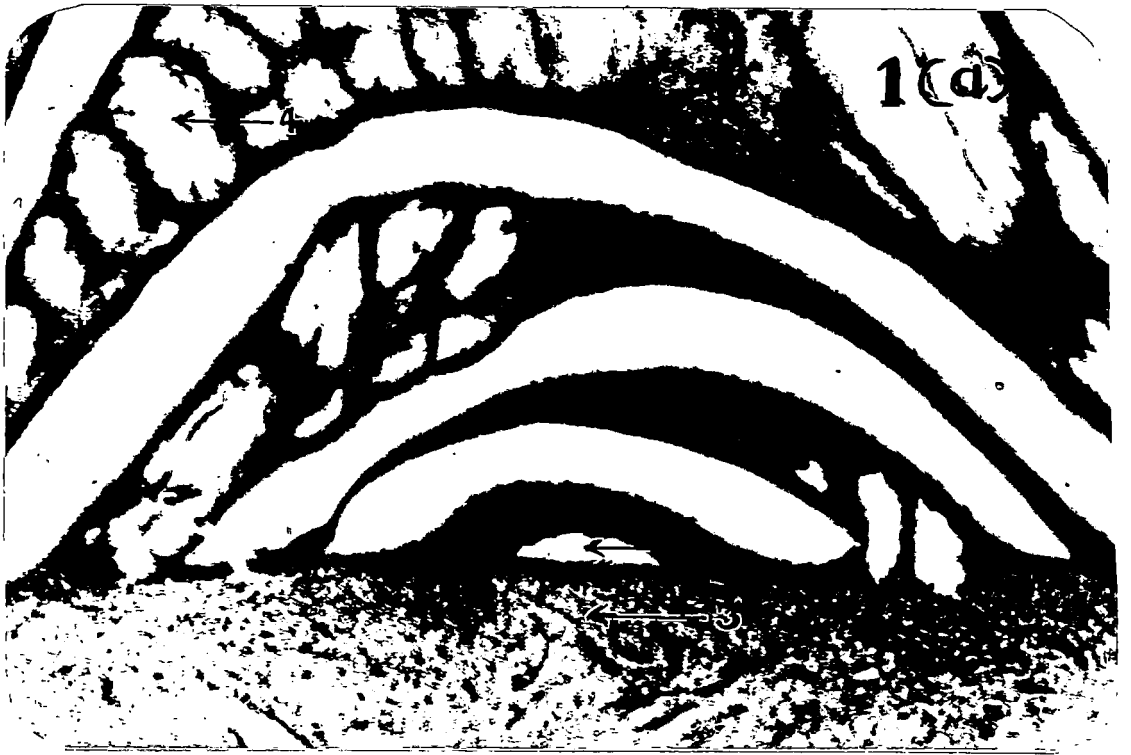
In the plates 4(a) and 4(b) the tunica or mantle can be seen, three or four-cell layers deep. Below this, in the mother cell zone of the corpus, the cells are less dense and more vacuolated. In the plate 4(c), the less dense and more vacuolated nature of the corpus cells can be clearly seen.

Plate 1(a), L.S. of the shoot apex (Red Banana) showing the apical meristem and the encircling leaves (below 334 days approx.) x 10

1. apical meristem
2. tunica
3. corpus
4. air chambers

Plate 1(b), L.S. of the shoot apex (Robusta) showing the apical meristem and the encircling leaves (below 228 days approx.) x 10

1. apical meristem
2. tunica
3. corpus
4. air chambers





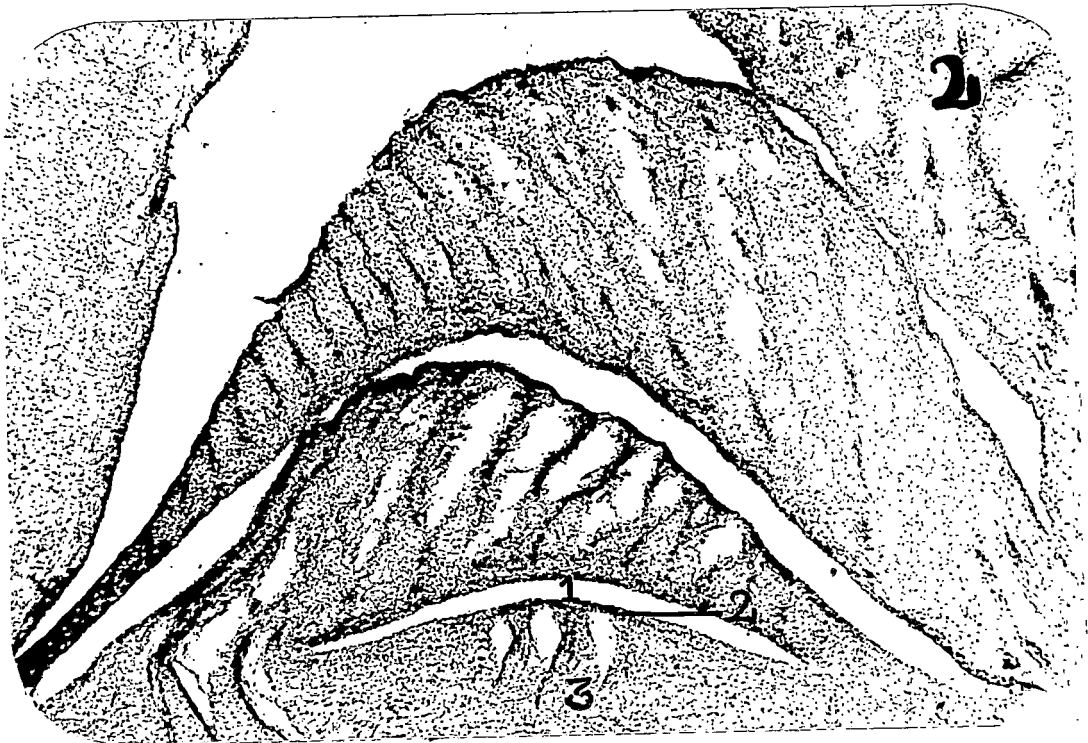


Plate 2, L.S. of the shoot apex (Palayankodan)  
showing the central apical dome and the encircling  
and overarching leaves (below 250 days approx.) x 10

1. meristem (low mound)
2. tunica (single layered)
3. corpus

Plate 3(a), L.S. of the shoot apex (Robusta)  
showing the low mound and formation of new  
leaf primordia (below 228 days approx.) x 10

1. meristem (low mound)
2. leaf primordium

Plate 3(b), L.S. of the shoot apex (Red Banana)  
showing the apical meristem as a low mound  
(below 334 days approx.) x 10

1. meristem (low mound)

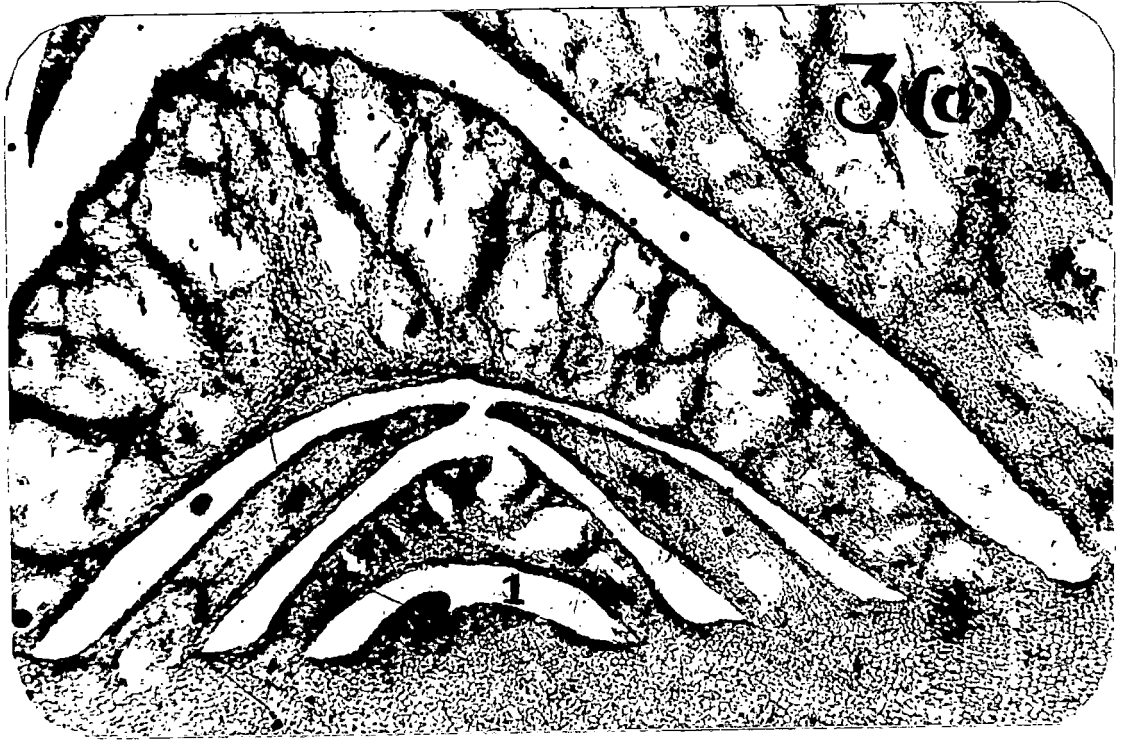


Plate 3(c), L.S. of the shoot apex (Palayankodan)  
showing the apical meristem as a low mound and the  
separating leaf primordia (below 250 days approx.) x 25

1. meristem (low mound)
2. leaf primordium

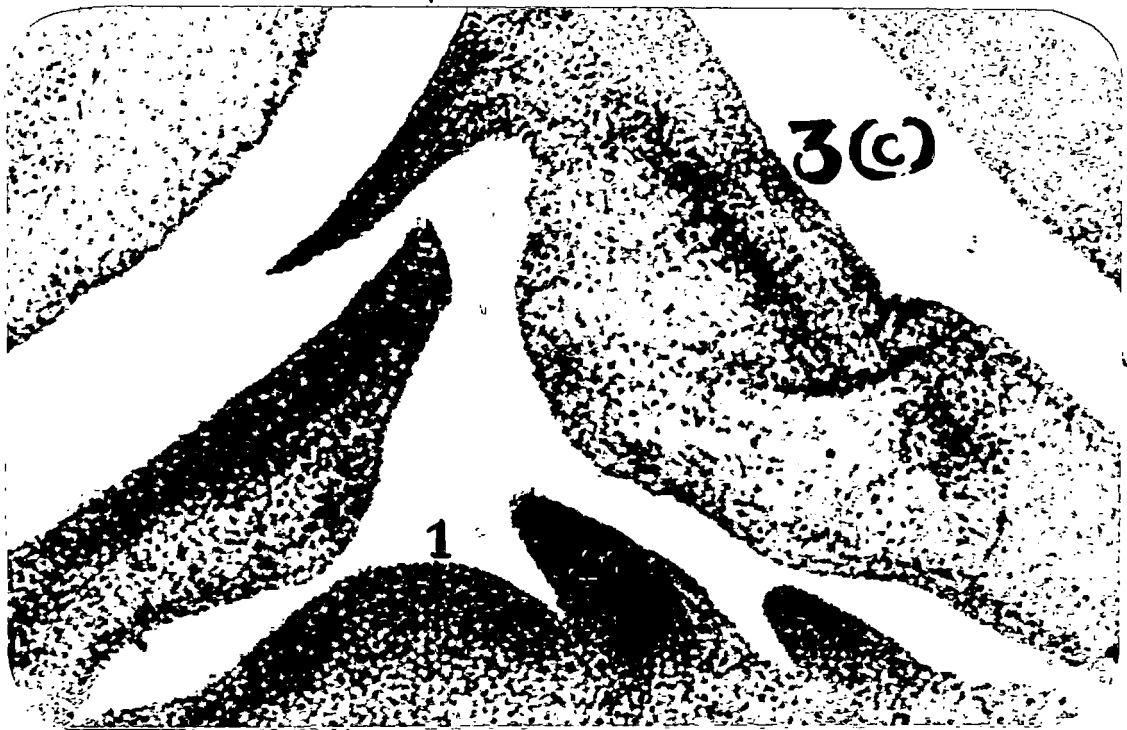


Plate 4(a), L.S. of the shoot apex (Palayankodan)  
at late vegetative phase (below 250 days approx.) x 25

1. meristem (low mound)
2. tunica (4 cell layered and deeply stained)
3. corpus (lightly stained vacuolated cells)

Plate 4(b), L.S. of the shoot apex (Red Banana) at  
late vegetative phase (below 334 days approx.) x 10

1. meristem (low mound)
2. tunica (4 cell layered and deeply stained)
3. corpus (lightly stained vacuolated cells)

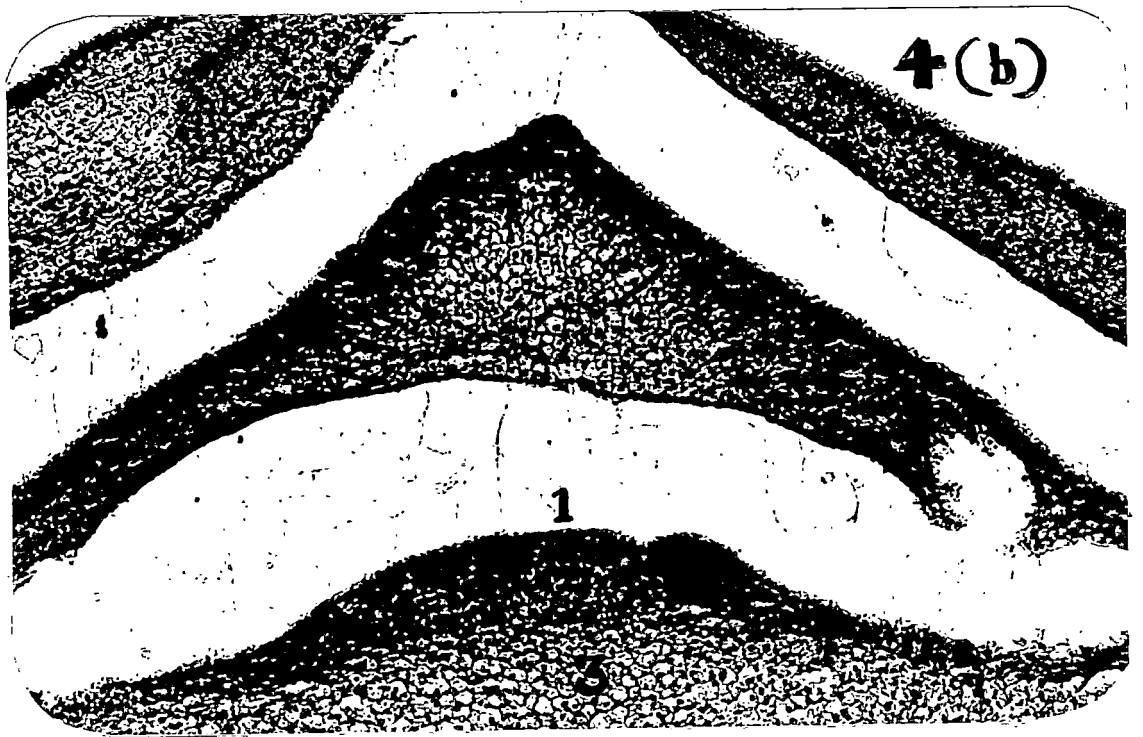
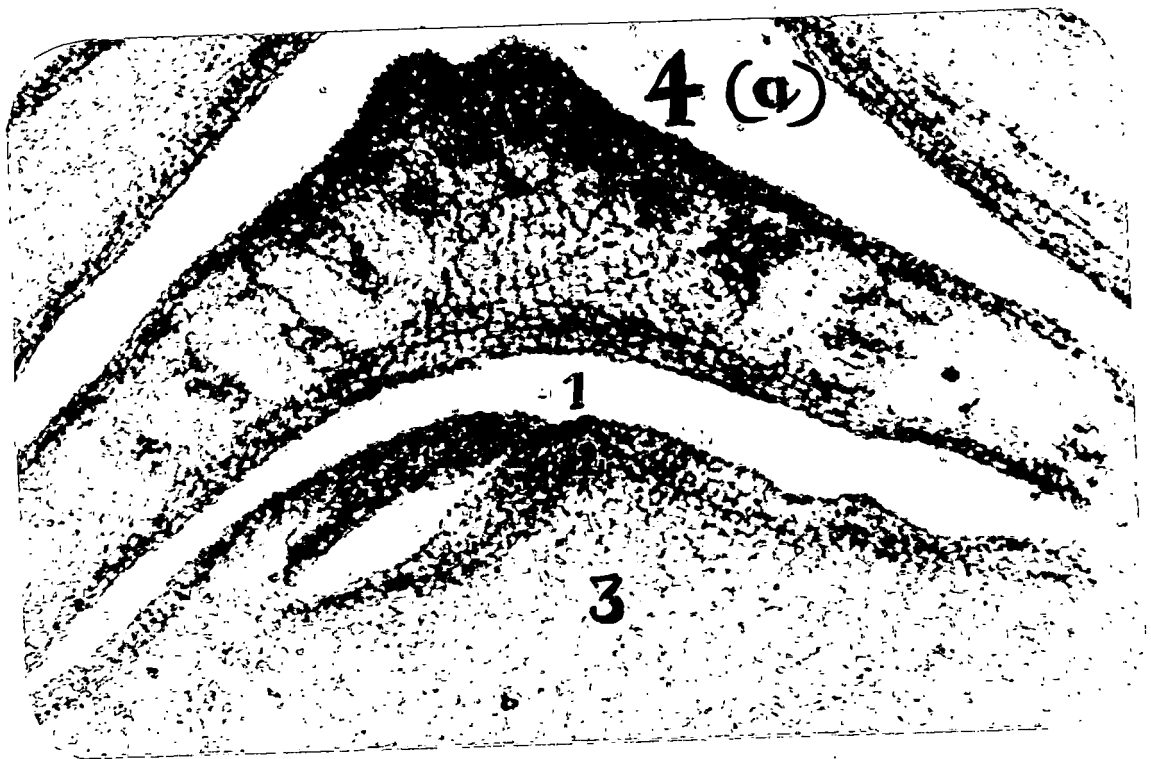




Plate 4(c), L.S. of the shoot apex (Palayankodan)  
illustrating the terminal portion of Plate 4(a)  
enlarged (below 250 days approx.) x 50

1. tunica (4 cell layered and deeply stained)
2. corpus (lightly stained vacuolated cells)



The tunica layer is deeply stained and the corpus layer, more vacuolated and lightly stained.

#### 4.3. Differentiation and initiation of bract primordia

In the plates 5(a), 5(b) and 5(c), the apical dome is seen more elevated than the surrounding primordial leaves. But the extent of elevation varies with the cultivar and the stage. The first bract primordium can be seen arising as a small mound in the plates 5(a) and 5(c); but separated in 5(b) and (therefore) in 5(d). The apical meristem portion has been magnified in the plates 5(d) and 5(e), clearly indicating the small mound. In the plates 5(d) and 5(e), the bract primordium has taken deep stain. The second bract primordium can be seen as a small mound on the other side in the plate 5(b) and in the magnifications 5(d) and 5(e). A zone of differentiating cells also can be seen in 5(b) and in the magnifications 5(d) and 5(e).

#### Development of the bract primordium

The dome has become more elevated in the plates 6(a), 6(b) and 6(c) and the bract primordium can be seen growing at right angles to the apex. The dome is seen raised well above the surrounding leaf bases. The plates 6(d), 6(e) and

Plate 5(a), L.S. of the shoot apex (Palayankodan)  
at transition from the vegetative to the reproduc-  
tive state (250 days approx.) x 50

1. bract primordium (small bulge)

Plate 5(b), L.S. of the shoot apex (Red Banana)  
at transition from the vegetative to the repro-  
ductive state (334 days approx.) x 25

1. 1st bract primordium (separated)
2. 2nd bract primordium (deeply stained)
3. zone of differentiating cells

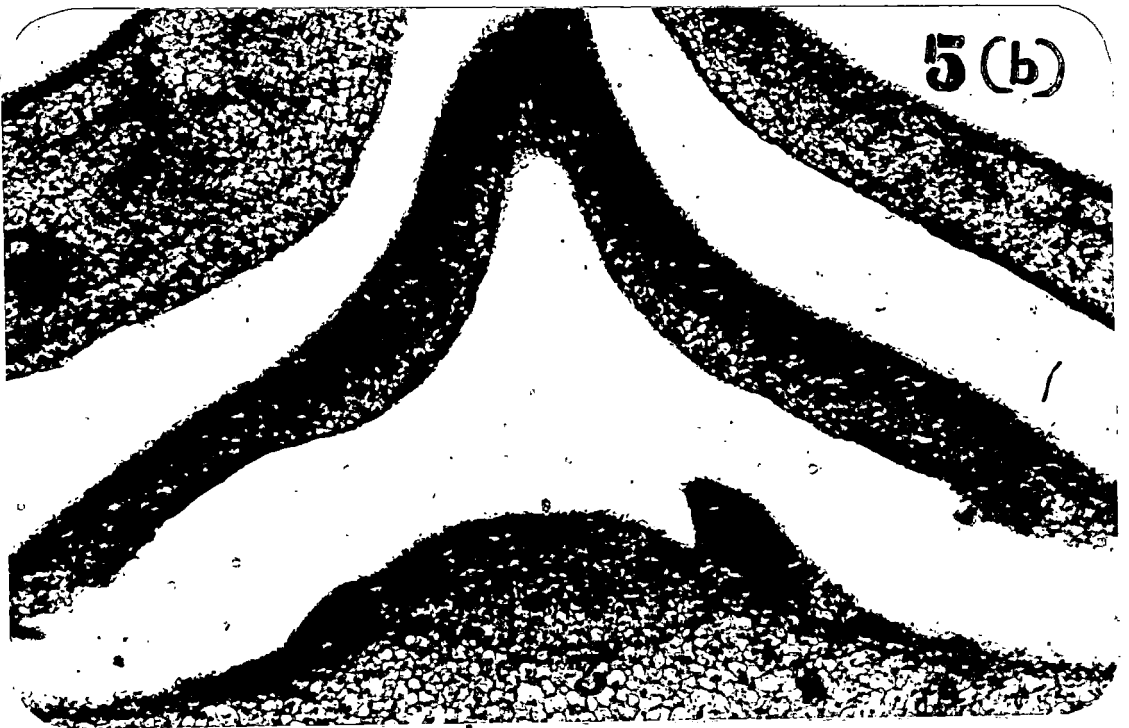
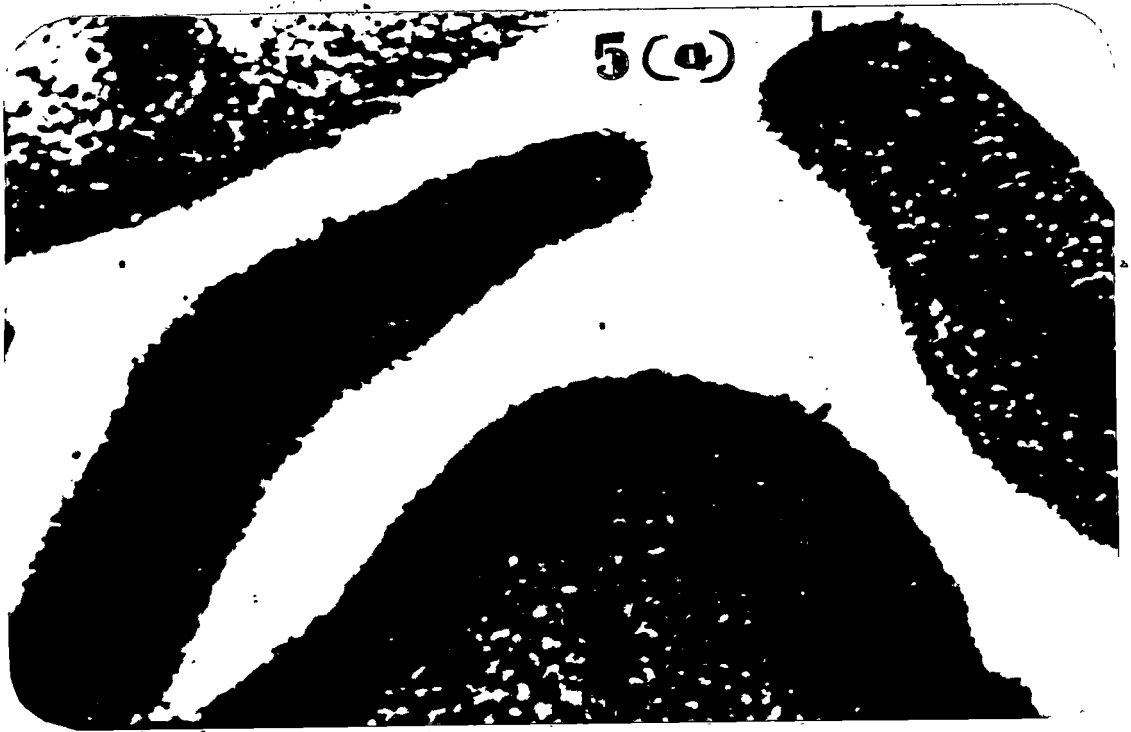


Plate 5(c), L.S. of the shoot apex (Robusta) at transition from the vegetative to the reproductive stage (228 days approx.) x 25

1. 1st bract primordium (small bulge)
2. 2nd bract primordium (deeply stained)

Plate 5(d), The terminal part of the Plate 5(b) (Red Banana) enlarged to show the dense mantle layers, the subapical region and the bract primordium (334 days approx.) x 50

1. 1st bract primordium (separated)
2. 2nd bract primordium (deeply stained)
3. zone of differentiating cells

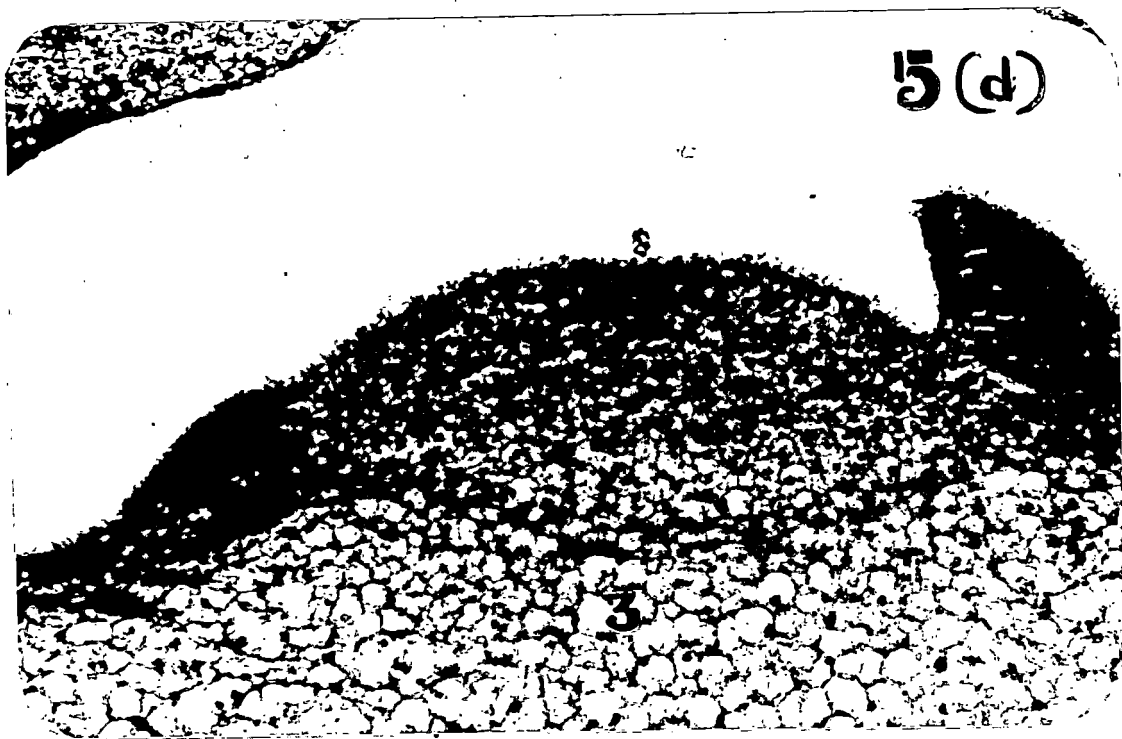
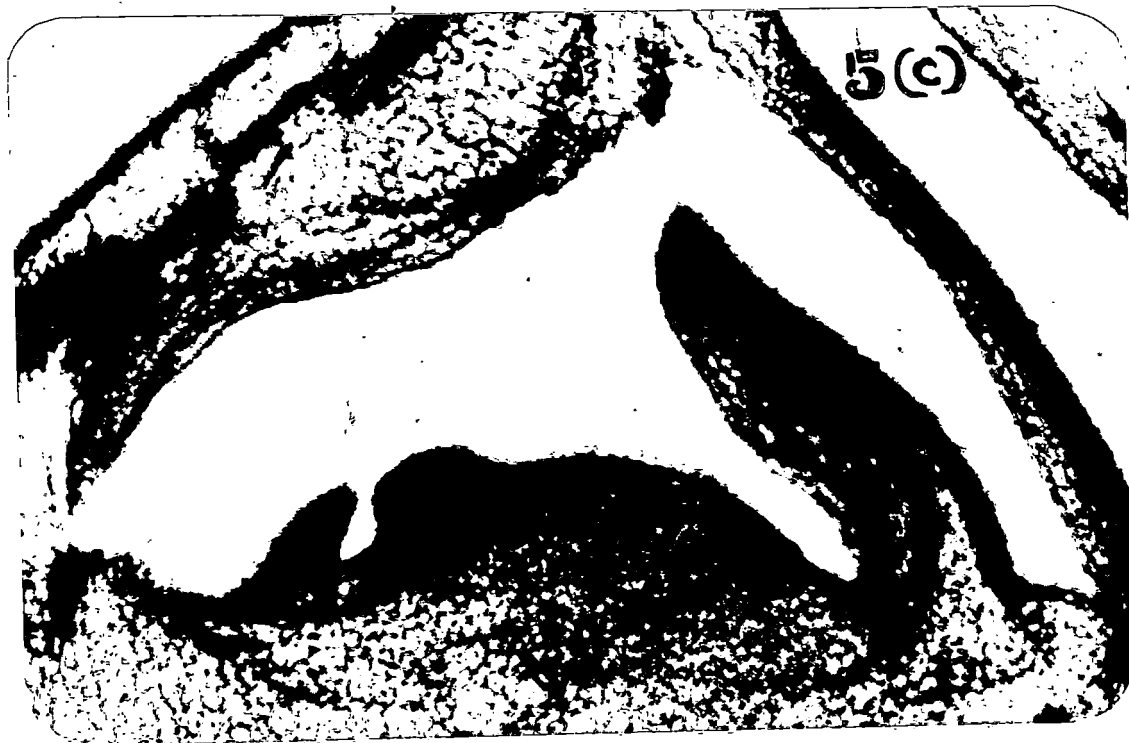


Plate 5(e), The bract primordium alone enlarged (Red Banana) to illustrate the meristematic activity of the subepidermal cells in the initiation of the bract (334 days approx.) x 100

1. bract primordium (deeply stained)



5(e)

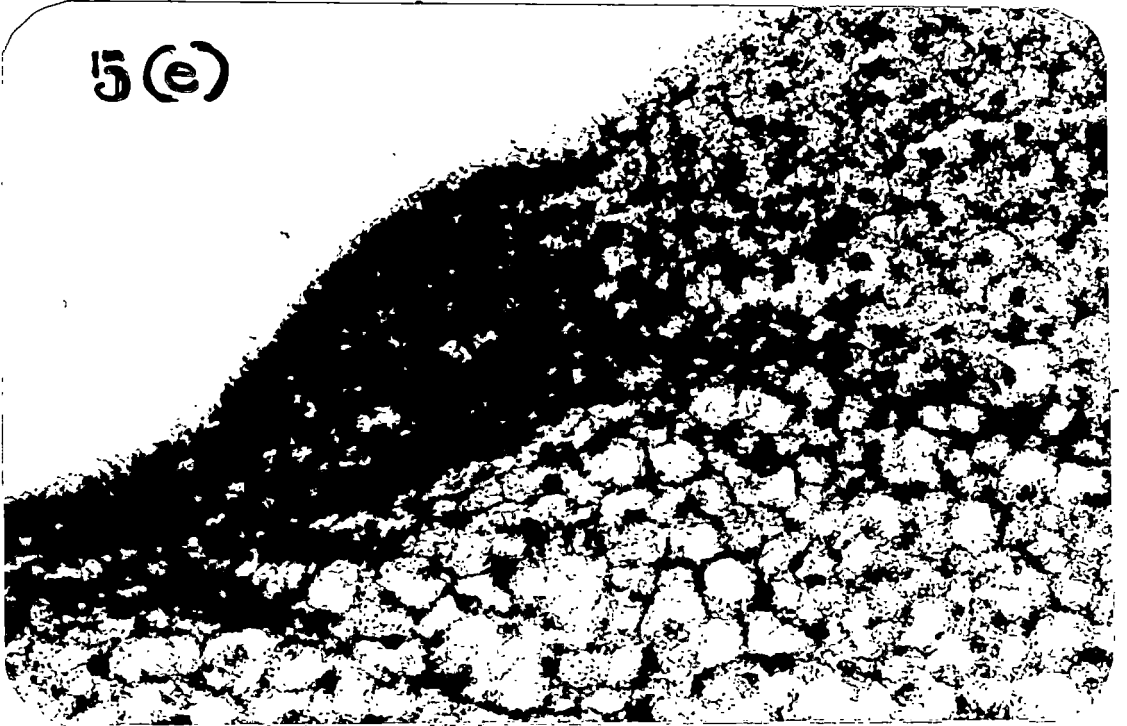


Plate 6(a), L.S. of the shoot apex (Palayankodan) showing the dome becoming more elevated and the bract primordium growing at right angles (250 to 311 days approx.) x 10

1. meristem (raised dome)
2. separated bract primordium

Plate 6(b), L.S. of the shoot apex (Red Banana) showing the dome becoming more elevated and the bract primordium growing at right angles (334 to 365 days approx.) x 10

1. meristem (raised dome)
2. separated bract primordium

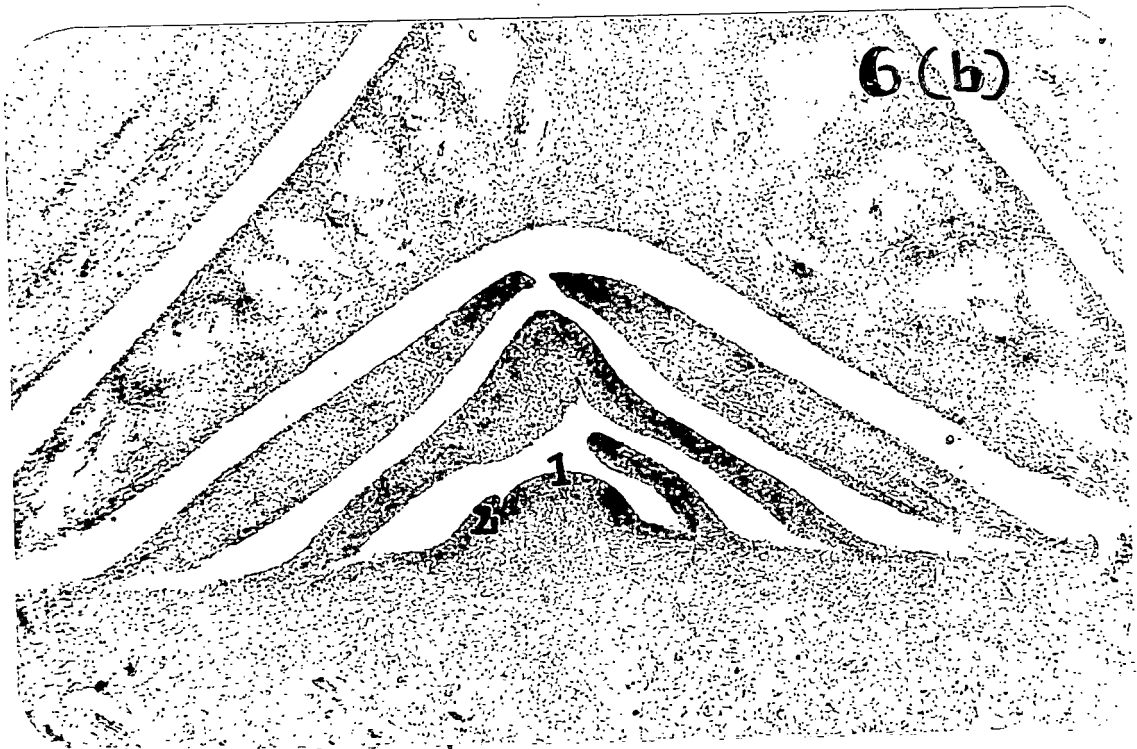
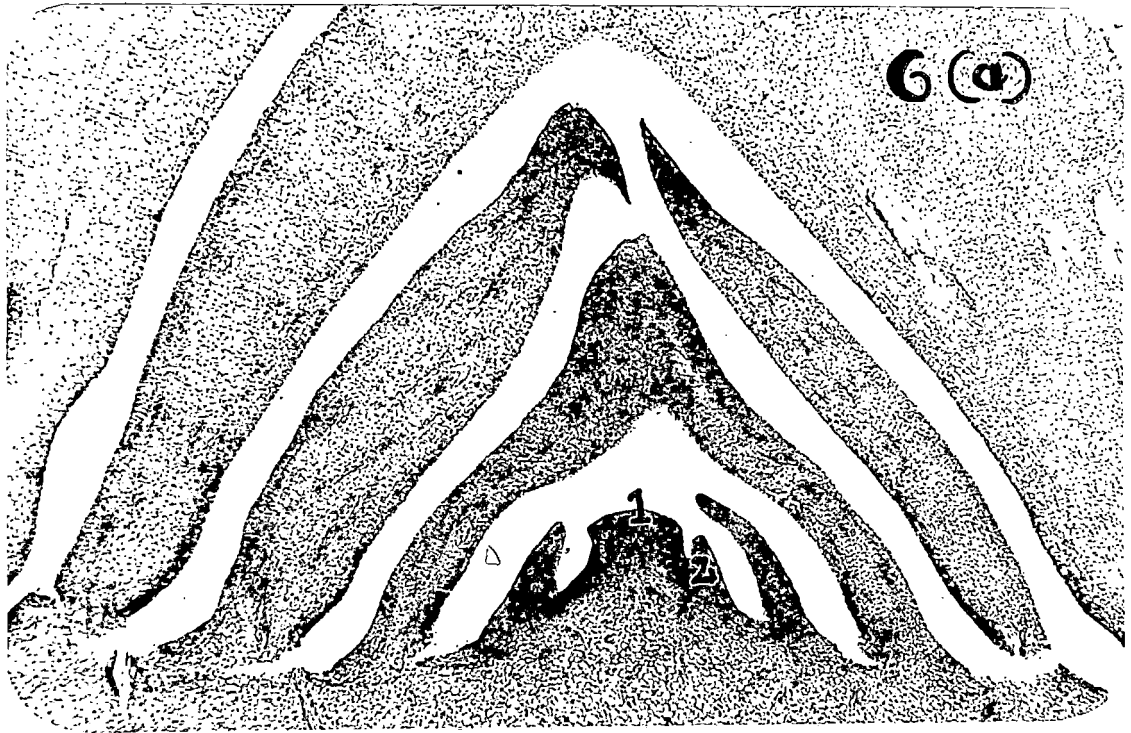


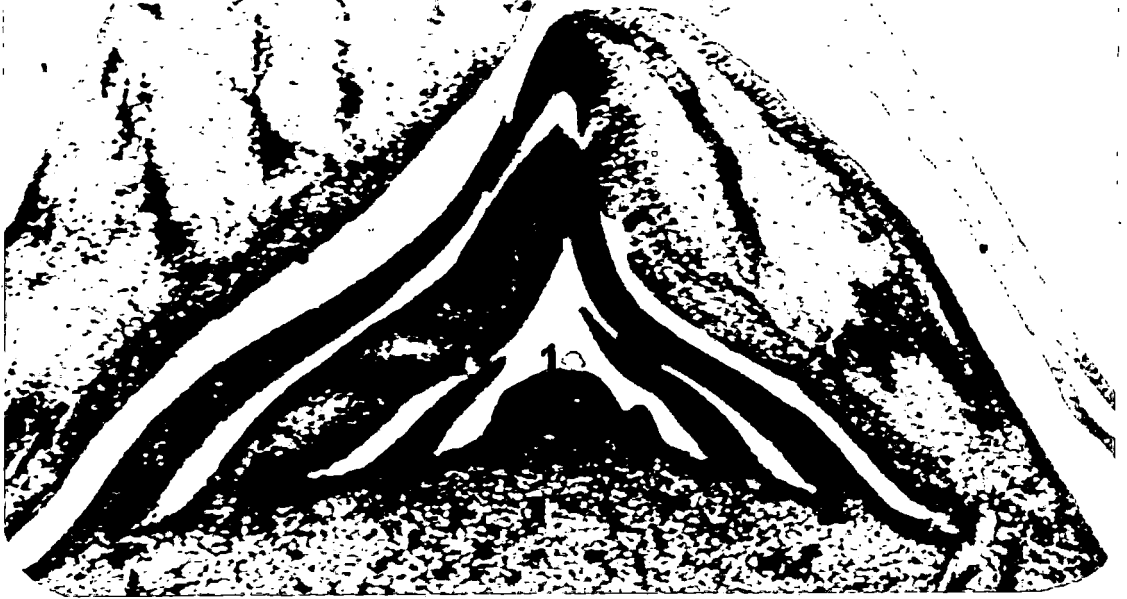
Plate 6(c), L.S. of the shoot apex (Robusta) showing the dome becoming more elevated and the bract primordium growing at right angles (228 to 278 days approx.) x 10

1. meristem (raised dome)
2. separated bract primordium

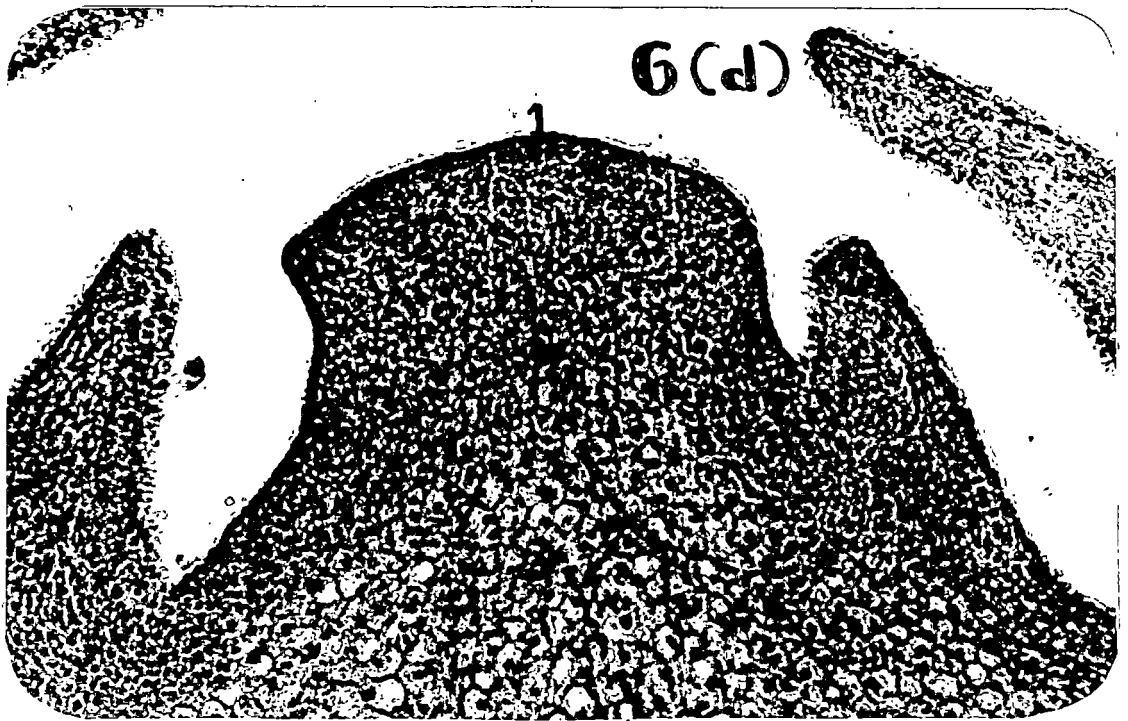
Plate 6(d), The terminal portion of Plate 6(a) (Palayankodan) enlarged to illustrate the separation of the bract (250 to 311 days approx.) x 50

1. meristem (raised dome)
2. separated bract primordium

6(c)



6(d)



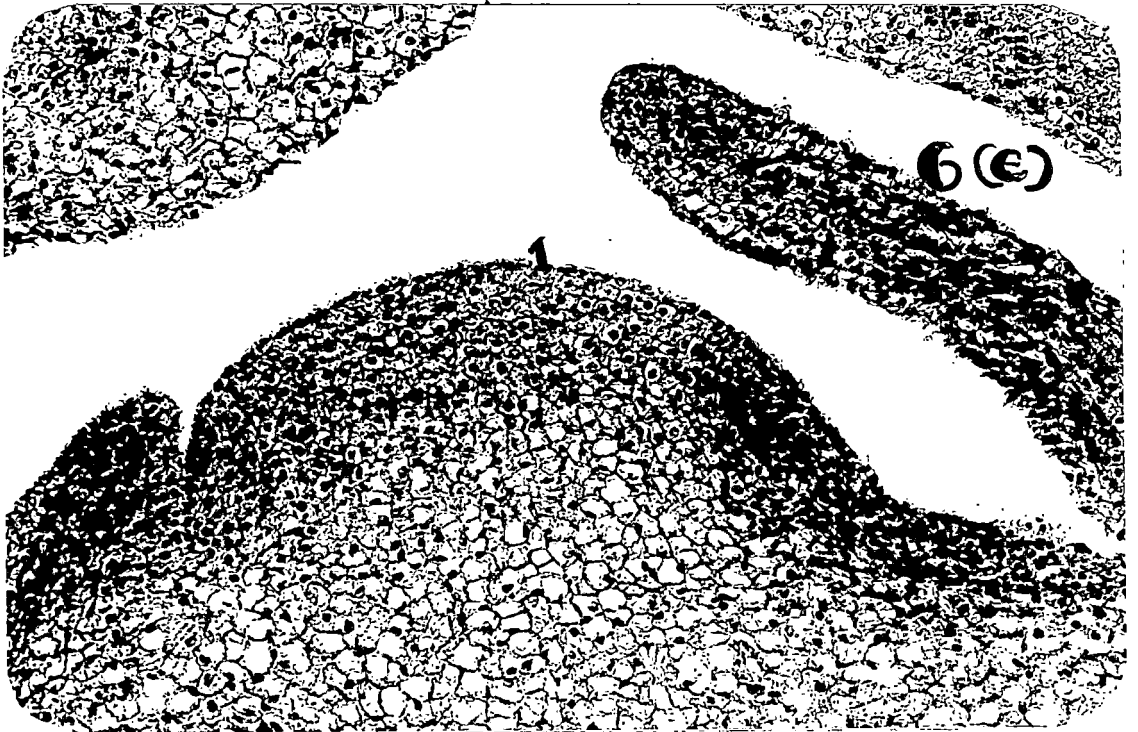
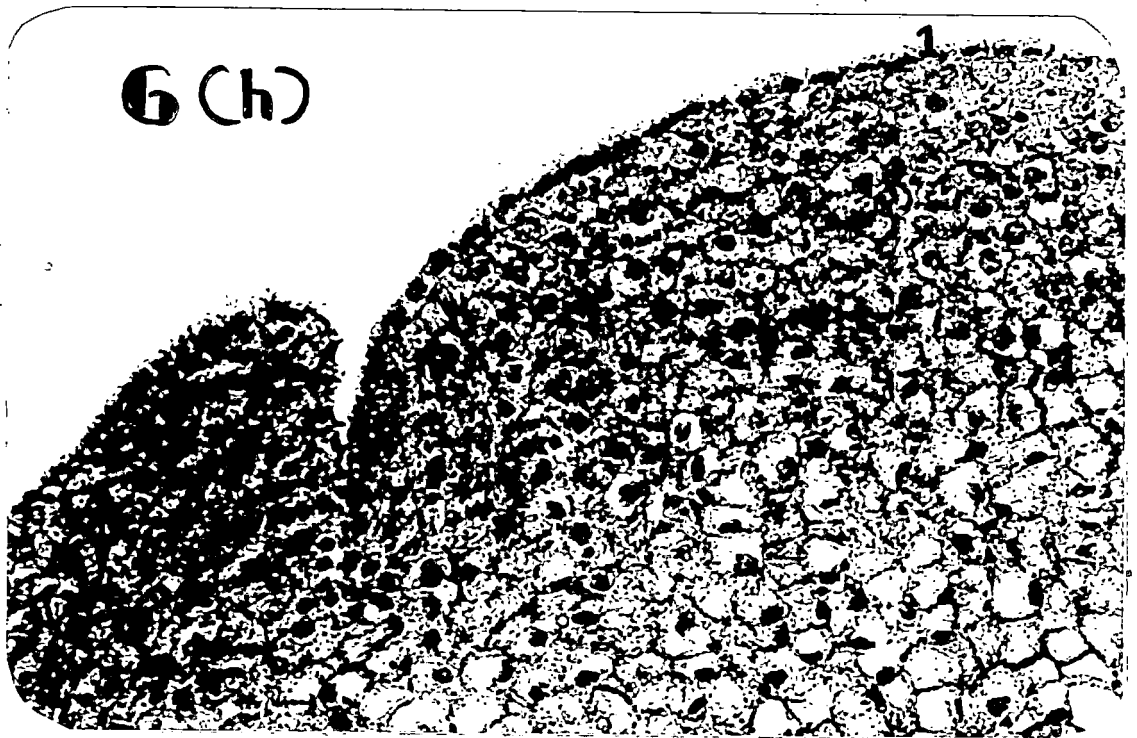
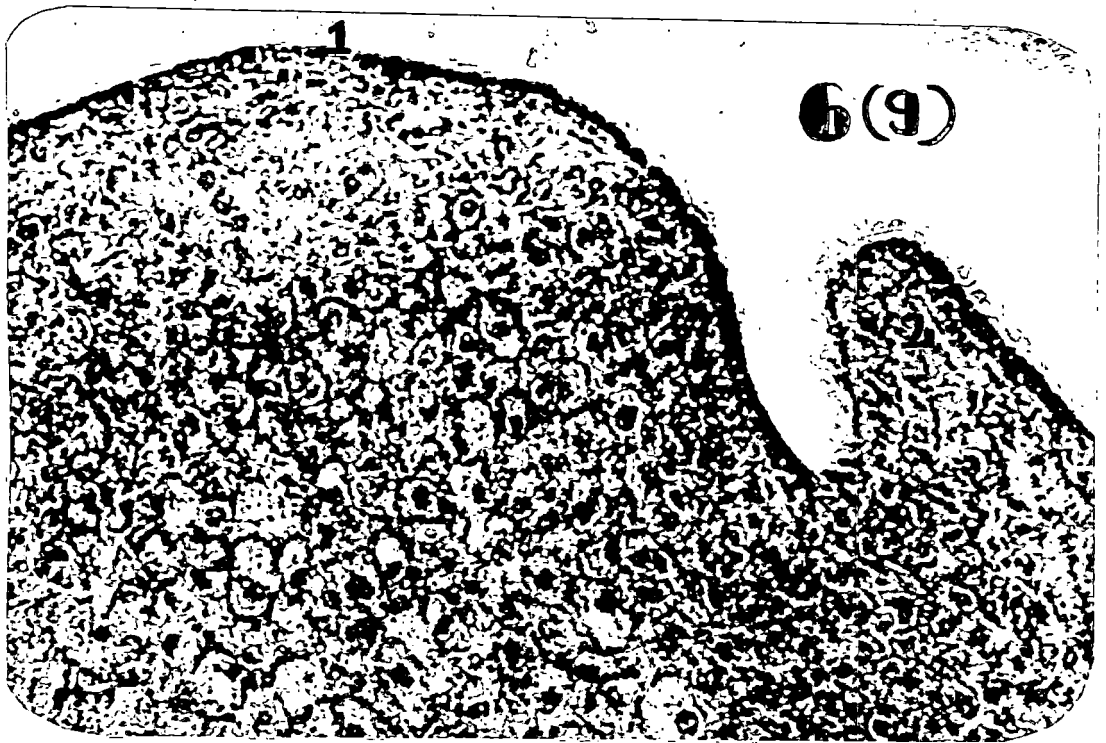


Plate 6(e), The terminal portion of Plate 6(b)  
(Red Banana) enlarged to illustrate the  
separation of the bract (334 to 365 days approx.) x 50

1. meristem (raised dome)
2. 1st bract primordium (separated)
3. 2nd bract primordium (densely stained)

Plate 6(f), The terminal portion of Plate 6(c)  
(Robusta) enlarged to illustrate the separation  
of the bract (228 to 278 days approx.) x 25

1. meristem (raised dome)
2. separated bract primordium





6(f) show magnified views of the apical meristem portion of the three cultivars. The elevated apex with the separated bract primordium can be seen. The region of separation of the bract is seen deeply stained in the plates 6(g) and 6(h).

The number of bracts have increased and the conical apex has become more raised in the plates 7(a) and 7(b). The bracts are boat shaped and converge towards the apex. The central mother cell zone and the rib meristem seem to merge to form a single inner zone of vacuolated weakly stained large cells. The flank meristem is seen thickened and densely stained around the periphery.

#### 4.4. Differentiation and initiation of hand primordium

The plates 8(a) and 8(b) show a number of bracts on either side of the dome. Since the full sections are not in view, all the bracts which enclose the apical dome, cannot be seen. Highly protoplasmic, crescent shaped zones (hand primordia) can be observed on the flank meristem, at the axes of the bracts. These zones are heavily stained.

In the plates 9(a), (b) and (c), the apex has become more conical. Hand primordia are seen in the axils of the bracts, in all the three plates. But the shape and size of the dome vary in the three cultivars.

Plate 6(g), The separating region of the bract of Plate 6(a) (Palayankodan) enlarged to show the dense staining (250 to 311 days approx.) x 100

1. meristem (raised dome)
2. bract primordium (separated)

Plate 6(h), The separating region of the bract of Plate 6(b) (Red Banana) enlarged to show the dense staining (334 to 365 days approx.) x 100

1. meristem (raised dome)
2. bract primordium (separated)

Plate 7(a), L.S. of the transformed shoot apex  
(Red Banana) (365 to 374 days approx.) x 50

Note: the gradual elongation of the apex with  
the numerous bract primordia

1. bract (boat shaped)
2. deeply stained peripheral zone
3. inner vacuolated region

Plate 7(b), L.S. of the transformed shoot apex  
(Palayankodan) (315 to 323 days approx.) x 25

Note: the gradual elongation of the apex with  
the numerous bract primordia

1. bract (boat shaped)
2. deeply stained peripheral zone
3. inner vacuolated region

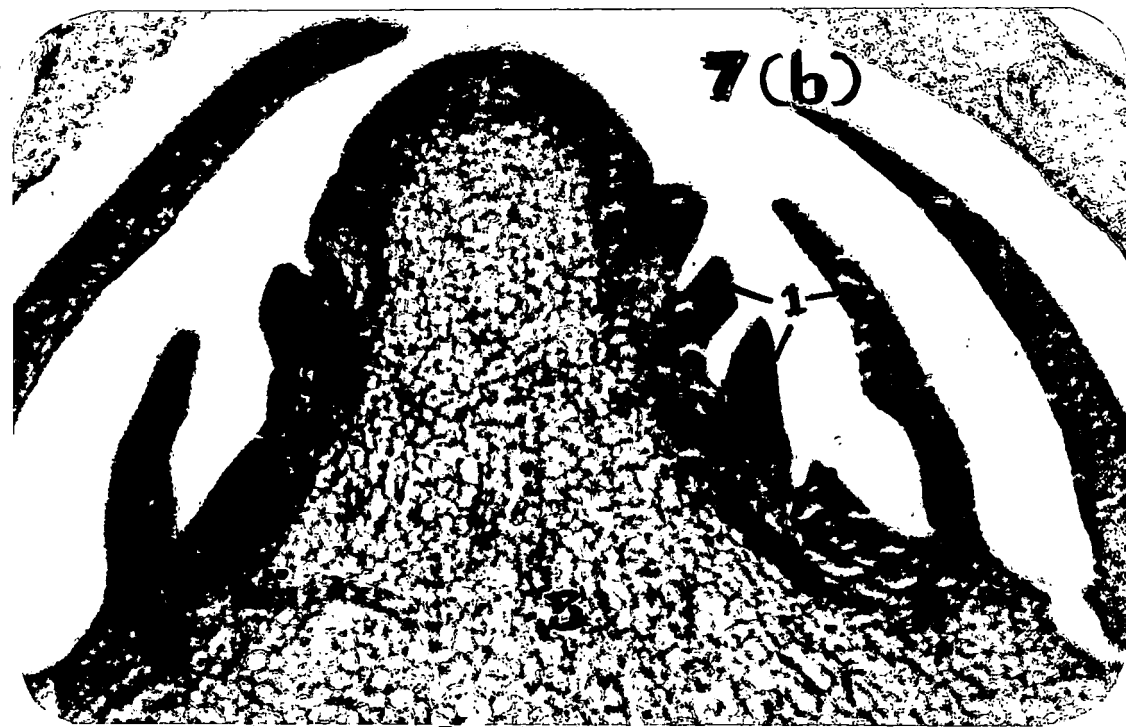


Plate 8(a), L.S. of the shoot apex (Robusta)  
showing the further elongated apex and the  
bracts with axillary meristematic region  
(305 days approx.) x 10

1. bract (boat shaped)
2. hand primordium

Plate 8(b), The terminal portion of Plate 8(a)  
(Robusta) enlarged to show clearly the diffe-  
rentiation of hand primordia (305 days approx.) x 25

1. bract (boat shaped)
2. hand primordium



#### 4.5. Differentiation and initiation of the flower primordium

In the three plates 9(a), (b) and (c) bracts are seen converging towards the apex. The hand primordia can be seen more advanced at the basal portion than towards the apex, indicating that the development occurs in acropetal succession. In the advanced hand primordia at the base, meristematic bulges are seen arranged one within the other. These meristematic bulges are the flower primordia. The acropetal succession of flower development is clearly seen in the plates 9(d) and 9(e). The meristematic bulges formed, later show cleavage, which is seen in the lower most primordia. A zone of meristematic tissue can be seen at the base of the well developed hand primordia in the plates 9(a), (b), (d) and (e).

#### Development of flower primordia

In the plate 9(f), two perianth lobes can be seen differentiated on the margin. A club shaped structure is seen enclosed within the perianth lobes which indicates that it is a functionally female flower.

The plate 9(g) shows that flower primordium formed at the base has two well developed perianth parts with the club shaped structure within. The one just above this has well

Plate 9(a), L.S. of the shoot apex of young inflorescence (Palayankodan) (340 to 345 days approx.) x 10

1. bract (boat shaped)
2. hand primordium (deeply stained)
3. flower primordium (seen as bulges)

Plate 9(b), L.S. of the shoot apex of young inflorescence (Red Banana) (380 to 382 days approx.) x 10

1. bract (boat shaped)
2. hand primordium (deeply stained)
3. flower primordium (seen as bulges)



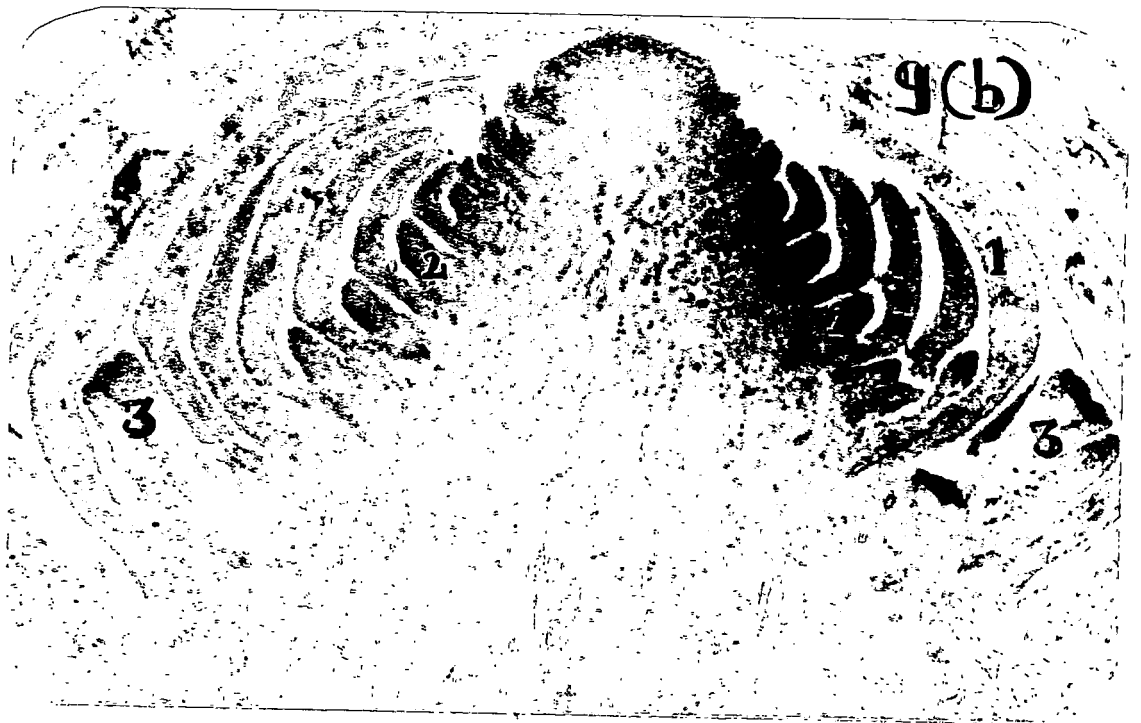
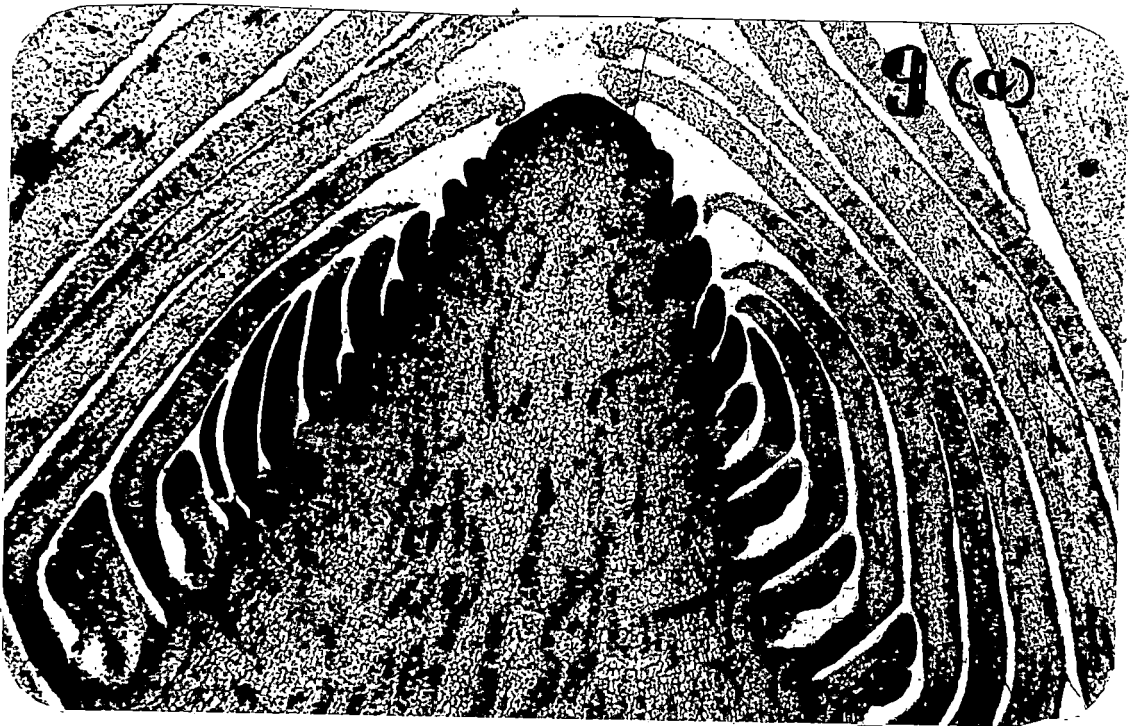


Plate 9(c), L.S. of the shoot apex of young  
inflorescence (Robusta) (285 to 312 days  
approx.) x 10

1. bract (boat shaped)
2. hand primordium (densely stained)



Plate 9(d), L.S. of shoot apex (Palayankodan)  
illustrating the acropetal development of hand  
primordium (340 to 345 days approx.) x 10

1. bract (boat shaped)
2. hand primordium (deeply stained)
3. flower primordium (seen as bulges)
4. meristematic cells



Plate 9(e), L.S. of shoot apex (Red Banana)  
illustrating the acropetal development of  
hand primordium (380 to 382 days approx.) x 10

1. bract (boat shaped)
2. hand primordium (deeply stained)
3. flower primordium (seen as bulges)
4. meristematic cells



Plate 9(f), L.S. of the functionally female  
flower (Palayankodan) (340 to 345 days approx.) x 25

1. perianth parts
2. club shaped structure





9(†)

Plate 9(g), L.S. of the basal portion of young  
inflorescence (Palayankodan) enlarged (340 to  
345 days approx.) x 10

1. female flower
2. intercalary meristem



developed perianth parts; but the club shaped structure is yet to develop.

In plate 9(h), the inner structure is different from that in plate 9(f). Here also the two perianth lobes are seen differentiated on the margin. Three structures with a cavity in between is seen here, indicating the possibility of this being a male flower.

The differentiation of the flower primordium is seen in plates 9(i) and 9(j). The adaxial primordium has elongated considerably faster than the abaxial one.

The plate 10 shows the termination of the differentiation process in which the apical dome has ceased to be active to accommodate more number of bracts.

#### 4.6. Duration taken by the three cultivars for completing the sequential stages in the flowering process

Initially, the plants of the three cultivars were uprooted every month and examined (anatomically) to identify the developmental stage vis a vis the age and morphological features of the plants. From the data so obtained, the precise duration taken for the key developmental processes and the exact morphological features were to be determined. This

Plate 9(h), L.S. of the male flower (Red  
Banana) x 50

1. stamen primordium
2. ovarian cavity

9(b)



Plate 9(i), L.S. of the shoot apex of young inflorescence (Red Banana) showing the distal differentiation of the flower primordia.

Note: that the adaxial primordium has elongated more than the abaxial one (382 days approx.) x 25

Plate 9(j), L.S. of the shoot apex of young inflorescence (Robusta) showing the distal differentiation of the flower primordia.

Note: that the adaxial primordium has elongated more than abaxial one (312 days approx.) x 25





Plate 10, The terminal portion which has ceased to  
be become active (Robusta) (312 days approx.) x 10

1. meristem (which has ceased to become active)



regular uprooting and examination could not be maintained as the plants from the experimental plot showed out of sequence development. As such, instead of precise data on duration, height of the plant, girth of the plant, number of functional leaves and leaf area Vs developmental stages, the range exhibited by the plants with respect to the characters alone could be obtained.

The data presented in Table 3 with respect to Robusta indicate that the vegetative phase terminated and transition occurred between 228 and 278 days. In the case of Palayankodan and Red Banana, the transition occurred between 250 and 311 days and between 334 and 365 days, respectively (Table 3).

Table 3. Duration for the developmental processes in different cultivars

	Robusta	Palayankodan	Red Banana
Transition	228-278	250-311	334-365
Floral phase	254-305	315-323	365-374
Completion phase	285-312	340-345	380-382

The formation of bract primordia, hand primordia and flower primordia in Robusta occurred between 254 and 305 days. In the case of Palayankodan, these were observed between 315 and 323 days and in Red Banana, between 365 and 374 days.

Between 285 and 312 days, the flower bud differentiation was seen completed in Robusta. Palayankodan, took 340 to 345 days and Red Banana, 380 to 382 days to complete the process.

The data on morphological parameters [height of the plant (cm), girth of the plant (cm), number of functional leaves, leaf area ( $m^2$ )] are presented in Tables 4 to 7. It can be seen from the data presented in Table 4 that the

Table 4. Comparison of height (cm) in different stages in different cultivars

	Robusta	Palayankodan	Red Banana
Transition	165-212	227-274	270-340
Floral phase	200-232	265-273	305-340
Completion phase	234-248	265-282	340-350

termination of the vegetative phase and the initiation in Robusta occurred when the plants were 165 cm to 212 cm tall. The Palayankodan plants were 227 cm to 274<sup>cm</sup>/tall and the Red Banana plants 270 cm to 340 cm tall at the stage. The different floral stages (formation of bract primordia, hand primordia and flower primordia) were observed by the time the Robusta plants reached 200 to 232 cm height. These occurred when the height of the Palayankodan plants were 265 to 273 cm and that of the Red Banana plants, 305 to 340 cm. The flower bud differentiation was seen completed in 234 cm to 248 cm tall Robusta plants, 265 to 282 cm tall Palayankodan plants and 340 to 350 cm tall Red Banana plants.

By the time the vegetative phase was completed and initiation occurred, the Robusta plants had a girth of 41 to 58 cm, Palayankodan plants, 52 to 64 cm girth and Red Banana plants, 76 to 90 cm girth (Table 5). The different floral

Table 5. Comparison of girth in different stages in different cultivars

	Robusta	Palayankodan	Red Banana
Transition	41-58	52-64	76-90
Floral phase	55-62	67-69	80-90
Completion phase	56-64	68-70	85-95

stages were observed in plants having a girth of 55 to 62 cm in Robusta, 67 to 69 cm in Palayankodan and 80 to 90 cm in Red Banana. The flower bud differentiation process was seen completed in Robusta plants with 56 to 64 cm girth, in Palayankodan plants with 68 to 70 cm girth and in Red Banana plants with 85 to 95 cm girth.

By the time, the vegetative phase was completed and initiation occurred, Robusta plants retained 8 to 11 functional leaves (Table 6) with 0.4771 to 0.9175 m<sup>2</sup> area (Table 7). Palayankodan plants at this stage had 9 to 11 functional leaves with 0.6960 to 1.3608 m<sup>2</sup> area and Red Banana plants, 8 to 12 functional leaves with 1.4751 to 1.9364 m<sup>2</sup> area. The various stages of flower bud differentiation occurred in Robusta plants having 8 to 12 functional leaves (Table 6)

Table 6. Comparison of the number of functional leaves in different stages in different cultivars

	Robusta	Palayankodan	Red Banana
Transition	8-11	9-11	8-12
Floral phase	8-12	9-11	10-12
Completion phase	9-11	8-12	10-12

Table 7. Comparison of leaf area ( $m^2$ ) in different stages  
in different cultivars

	Robusta	Palayankodan	Red Banana
Transition	0.4771-0.9175	0.6960-1.3608	1.4751-1.9364
Floral phase	0.7564-1.2136	1.0780-1.3760	1.5885-1.7992
Completion phase	0.8358-1.1668	0.9112-1.2960	1.7992-2.0642

with 0.7564 to 1.2136  $m^2$  area. Palayankodan plants with 9 to 11 functional leaves and 1.0780 to 1.3760  $m^2$  area and Red Banana plants with 10 to 12 functional leaves and 1.5885 to 1.7992  $m^2$  area showed the various developmental stages. At the time of completion of flower bud differentiation, the Robusta plants had 9 to 11 functional leaves with 0.8358 to 1.1668  $m^2$  area, Palayankodan plants had 8 to 12 functional leaves with 0.9112 to 1.2960  $m^2$  area and Red Banana plants had 10 to 12 functional leaves with 1.7992 to 2.0642  $m^2$  area.

#### 4.7. N content in the leaves

In the vegetative phase, the Robusta plants had a N content of 2.00 to 2.50 per cent, the Palayankodan plants

1.93 to 2.10 per cent and the Red Banana plants 2.94 to 3.21 per cent (Table 8).

Table 8. Mean total N content (%) in the leaves of the three cultivars at different stages

Stages	Robusta	Palayankodan	Red Banana
Vegetative	2.00-2.50	1.93-2.10	2.94-3.21
Transition	2.42-2.51	2.11-2.51	2.28-2.36
Floral	2.39-2.40	2.78-2.91	2.01-2.20
Completion	1.99-2.01	1.61-1.69	1.93-2.10

In the transition phase, the Robusta plants showed a N content of 2.42 to 2.51 per cent, the Palayankodan plants 2.11 to 2.51 per cent and the Red Banana plants, 2.28 to 2.36 per cent.

In the floral phase, the Robusta plants exhibited a N content of 2.39 to 2.40 per cent. The Palayankodan plants had a N content of 2.78 to 2.91 per cent and the Red Banana plants, 2.01 to 2.20 per cent.

At completion of the differentiation process, the N content in Robusta plants was 1.99 to 2.01 per cent. The



Palayankodan and the Red Banana plants showed a nitrogen content of 1.61 to 1.69 per cent and 1.93 to 2.10 per cent, respectively at this stage.

#### 4.8. Carbohydrate (CHO) content in the leaves

In the vegetative phase, the Robusta plants had a CHO content of 14.91 to 15.21 per cent, the Palayankodan plants 15.9 to 16.1 per cent and the Red Banana plants 16.56 to 17.20 per cent (Table 9).

Table 9. Mean total CHO (%) content in the leaves of the three cultivars at different stages

Stages	Robusta	Palayankodan	Red Banana
Vegetative	14.91-15.12	15.90-16.10	16.56-17.20
Transition	13.85-14.21	15.08-16.01	16.10-16.21
Floral	18.10-18.61	17.81-18.01	17.91-18.61
Completion	17.10-17.91	15.91-16.22	18.09-18.22

In the transition phase, the Robusta plants had a CHO content of 13.85 to 14.21 per cent, the Palayankodan plants 15.08 to 16.01 per cent and the Red Banana plants 16.10 to 16.21 per cent.



In the floral phase, the Robusta plants had a CHO content of 18.10 to 18.61 per cent, the Palayankodan plants 17.81 to 18.01 per cent and the Red Banana plants 17.91 to 18.61 per cent.

At the completion phase, the Robusta plants had a CHO content of 17.10 to 17.91 per cent, the Palayankodan plants 15.91 to 16.22 per cent and the Red Banana plants 18.09 to 18.22 per cent.

#### 4.9. C:N ratio in the leaf

In the vegetative phase, C:N ratio in the Robusta plants ranged from 6.04 to 7.45. The Palayankodan and the Red Banana plants showed a C:N ratio of 7.6 to 8.23 and 5.35 to 5.63, respectively (Table 10).

Table 10. CHO/N ratio in the leaves of the three cultivars at different stages

Stages	Robusta	Palayankodan	Red Banana
Vegetative	6.04-7.45	7.60-8.23	5.35-5.63
Transition	5.66-5.72	6.37-7.14	6.86-7.06
Floral	7.51-7.75	6.18-6.40	8.45-8.91
Completion	8.59-8.91	9.59-9.88	8.67-9.44

In the transition phase, the Robusta plants exhibited a C:N ratio of 5.66 to 5.72. The Palayankodan plants had a C:N ratio of 6.37 to 7.14 and the Red Banana plants, 6.86 to 7.06.

During the floral phase C:N ratio in the Robusta plants ranged between 7.57 and 7.75. The Palayankodan and the Red Banana plants showed a C:N ratio of 6.18 to 6.40 and 8.45 to 8.91, respectively.

The Robusta plants had a C:N ratio of 8.59 to 8.91 at completion of the flower bud differentiation. The Palayankodan and the Red Banana plants recorded C:N ratios of 9.50 to 9.88 and 8.61 to 9.44, respectively at this stage.

# DISCUSSION

## 5. DISCUSSION

Flower bud differentiation is an important event in the life of a flowering plant. Information on the site and time of differentiation and on the critical stages of the differentiation process will provide valuable tips for scheduling the cultural practices for successful crop production. However, as Barker and Steward (1962a) pointed out, "the botanical literature lacks a satisfactory study of the growing point of banana . . . .", particularly with respect to the cultivars of importance to India. The present investigations were, therefore, undertaken with a view to examine the growing point in both the vegetative and flowering phase, in three commercially important cultivars of the State.

The inflorescence of the banana plant develops from the terminal vegetative meristem that is located within 30 cm of the ground and within the pseudostem (a cylinder of sheathing leaf bases). The plant is perennial and the flower buds form without regard to the seasons and without any external symptom. Because of these, an intensive study of the morphology and physiology of banana at the time of floral induction present difficulties.

The stem or trunk of the plant, commonly called as the pseudostem, is not a true stem; but a collection of tightly wrapped leaf sheaths with their bases connected at the corm, covering the growing point at the base near the ground level. The true stem is a corm, most of which remains buried underground at the early stages. The stem remains at the same level and elongates only when differentiation of flower buds starts.

The two most distinguishing features of the growing point of banana at the vegetative phase are the absence of axillary buds in the leaf axils and the extremely congested internodes, which indicate very powerful apical dominance. Instead of axillary buds, lateral buds are produced far away from the inner leaf sheath, at unusual positions. They are situated not in the axils of the leaves but opposite to these in the stem, a little above between two free leaf margins of the sheath. Skutch (1937) suggested a possibility that, banana rhizome being a sympodium, the apparently lateral bud is in reality a terminal bud of arrested development which has been pushed to one side by the development of the true lateral bud. Barker and Steward (1962) presumed this abnormality to be an auxin (probably IAA)-mediated phenomenon exerted by the vegetative shoot tip.

On dissection, for removal of the leaf bases, an outgrowth, representing the lateral bud was located on the true stem opposite the axil and just above the two overlapping margins of the mature leaf bases. Outwardly, the growing apex was seen to be a conical structure covered by a number of leaf primordia. Each immediate older leaf was seen fitted upon the younger, as an inverted funnel formed by the encircling leaf bases, projecting a filiform appendage at the tip, enclosed by the next primordium. Fahn et al. (1963) described in detail the structure of the vegetative bud of the banana plant. They observed five cytohistological zones, a tunica (composed of two layers of cells), a zone of central mother cells, a transitional cambium-like zone, a rib meristem and a flank meristem.

### 5.1. Early vegetative phase

In the early vegetative phase, the apical meristem appears as a flat, dome-like structure situated at the centre of the corm, at a lower level than the surrounding primordial leaf bases (Plates 2, 3(a) and 3(b)). These leaf primordia initiated from the flank meristem by means of anticlinal and periclinal divisions (Plate 3(a)). A block of tissue, composed of very small and compact cells, was

observed in the tunica layer, which was deeply stained due to its active protoplasm. The tunica, then bulged out due to the expansion of cells and a protuberance was formed which separated from the periphery of the apex (Plate 3(c)). This primordium enlarged quickly and encircled the axis before the next younger leaf primordium would initiate (Plate 1(a)). After the separation of the leaf primordium, the size of the dome got reduced (Plate 1(a)). Quickly enlarging to its maximum size by cell division, the meristem became ready for initiating the next primordial leaf spirally. The production of leaf initials was observed to be the most important growth activity in the vegetative stage. The corpus remained mostly inactive at this stage.

### 5.2. Late vegetative phase

The stages seen in this phase are actually preparatory to the transition stage. The tunica which is single layered in the early vegetative phase became three or four-layered at this phase (Plates 4(a), 4(b) and 4(c)). These plates show the characteristics of vegetative apex at this phase. It consists of a central dome with tunica layer and below this, the unspecialized cells which only divide infrequently and whose main function seems to be to add to the bulk of



the apex, as the bulk increased slowly with the age of the plant.

The vegetative bud of a cultivar continued to have the same shape and size throughout the vegetative stage with the same number of primordial leaves. This is because the vegetative bud is meant for the production of primordial leaves and continues to fulfil the function until the transition stage. There is a repetition of the same activity throughout the vegetative stage, while in the reproductive buds, there is a progressive increase of the growing activity for laying down the different floral parts. Therefore, the reproductive buds became more plump and bigger, as they grew. The presence of the precursory appendage at the tip, is characteristic of the primordial leaves and not of the bracts. Therefore, presence of this appendage is an indication of the bud being vegetative.

The developmental processes of the growing point have been represented by photomicrographs covering various phases. No difference in the structure or pattern of development of the apical bud was manifest among the cultivars. But the pattern of change in shape and size could be identified as a distinct feature of the stages of development. As the growth

of the plant progressed, the growing point had a flattened dome located in a depressed zone in the centre of the corm in the young plant. The shape and size changed into a conical structure when the vegetative phase was over.

In the vegetative stage, the apical meristem was visualized as a flat dome-like structure. Barker and Steward (1962a) reported that as in other angiosperms, the shoot apex of banana takes the form of a central dome of meristematic cells. The leaves grow peripherally around the apex, forming the enclosing sheath around the axis. The latest leaf grows very rapidly around the shoot apex and eventually encircles it before the next younger primordium is initiated. Therefore, portions of the same leaf always appear on the two sides of a median longitudinal section of the apex (In the plates 1(a), 1(b) and 2). In the reproductive stage, the growing point had a raised central axis with flower primordia at the axis of the bracts (Plates 9(a), (b), (d) and (e)). From the histological studies, no difference in the structure or the mode of development could be observed in the different cultivars. Chakrabarty (1977) also has reported that the mode of development was similar in the cultivars, Robusta and Poovan.

### 5.3. Transition stage

The transition from vegetative to reproductive phase showed a marked change in the shape of the growing point. The transition was first indicated by the rapid elongation of the apical dome (Plates 5(a) to (d)). While the vegetative bud was observed to be broadly conical, the reproductive bud was acutely conical. Several workers have observed the change in shape of the bud from a broad flattened dome to a pointed cone as the transition occurred from vegetative to floral phase (Fahn et al., 1963; Pillai & Shanmughavelu, 1975). Mohan Ram et al. (1962) described the change as from the original broad central apical dome of meristem to an elevated and strongly tapered one. According to them, the first visible change indicative of the transition is the elongation of the apex, to give it a conical shape. With an increase in the age of the reproductive bud, there was a distinct increase in size. Chakrabarty (1977) also found that in banana, the previously flattened dome started elongation and became conical in shape at the transition stage. The rapid elongation of the dome is due to the meristematic activity, and the broad dome later on assumed a conical shape and started initiation of the bracts. The transition stage

is marked by the initiation of bract primordia (Plate 5(a) (b) and (c)). The bracts arose like leaf primordia in the sub-epidermal layers of the flank meristem, spirally in the conical apex. At the time of differentiation of the bract, the flank region of the conical apex become more meristematic and the bracts were separated spirally from the flank meristem at higher level of the apex (Plate 6(a) (b) and (c)). Mohan Ram et al. (1962) observed that the bract primordium arose as a small mound (as seen in Plates 5(a) (b) (c) (d) and (e)) and exhibited both periclinal and anticlinal divisions of the sub-epidermal layer. The epidermis kept pace with this increase in volume, by anticlinal division. According to Barker & Steward (1962b), the bracts appeared in rapid succession with active growing region in every axil. These bracts later elongated and became boat shaped (Plates 7(a) and 7(b)). These boat shaped bracts were observed by (Barker and Steward, 1962b; Chakrabarty, 1977). Mohan Ram et al. (1962) opined that it is due to the greater growth on the abaxial side that the bracts became boat shaped and converged towards the apex. They observed that there will be many more bracts than there will be leaves on the vegetative axis.

#### 5.4. Development of hand primordia

The growing regions seen in the axils of the bracts (Plates 8(a) and 8(b)) are the primordia from which the hands developed. The time interval between the formation of bract primordia and hand primordia is negligible. A distinct interval of time cannot be specified. At this stage, the tunica or mantle seems to be at least three-cell layers deep. The mother cell zone of the corpus consist of deeply staining cells which contrast with the less dense and more vacuolated zone in the vegetative apex (Barker & Steward, 1962b). In some of the sections (Plate 8(a), bract primordia and bracts can be seen whereas in other sections (Plate 7(a), bract primordia only can be seen. Chakrabarty (1977) found that the production of bract and hand primordia occurred simultaneously.

The hand primordium developed in acropetal succession after the formation of bracts. In the older stage of development, two rows of flower primordia can be seen. Mohan Ram et al. (1962) observed that the members of the inner (adaxial) row tend to grow faster than the outer (abaxial) ones. The primordia of the abaxial row will be at a slightly lower level.

### 5.5. Development of floral primordia

During the next stage, floral primordium can be seen to arise in acropetal succession (Plate 9(d) and 9(e)).

A typical banana flower has a zygomorphic perianth of two whorls, each of which consists of three tepals which are fused in such a way as to form, two distinct segments - an adaxial free tepal and a large compound tepal which consists of two minor tepals (lobes) of the inner and three of the outer whorl. The basic pattern of the androecium is 3+3; but in the Musaceae, one of the inner three stamens is often absent. The gynoecium is tricarpeillary and the ovary inferior, trilocular with axile placentae. The three styles are fused and bear a six-lobed stigma (Simmonds, 1966).

Such detailed sequence of formation of the floral parts could not be detected in the photomicrographs. Flower primordia which develop in acropetal succession can be seen in Plates 9(a), (b), (c), (d) and (e). Perianth lobes formed can be clearly identified (Plate 9(f) and 9(h)). Mohan Ram et al. (1962) found the floral parts to develop in the sequence - perianth, stamens, carpels. The functionally female flower can be seen with the club shaped structure in Plate 9(f). According to Mohan Ram et al. (1962), the mode

of origin of the primordia of the floral organs is the same in the male and female flowers. In the functionally female flowers, the stamens do not form anthers and filaments; but they remain as reduced club shaped structures.

These developmental phases shown through the microphotographs in the different cultivars were basically the same. In the evolution of cultivated bananas, hybridization and polyploidy played dominant roles. These two phenomena, have probably not altered the basic developmental pattern of the inflorescence. It can also be conceived that the pattern which existed in the parental diploids continue to exist in the present day cultivars.

The whole development processes of the growing apex from vegetative shoot to inflorescence, traced out by the anatomical studies clearly indicate the redistribution of growth in the different zones at the various stages of development. In the vegetative phase, the flank meristem is the sole centre of growth activity where the leaf initials are produced and leaf production is the chief activity of the growing point. Leaf initials are produced by quick cell division and cell enlargement. At this stage, the central

mother cells, particularly the rib meristem, seem to be less active. This may be one of the reasons why the growing point remained a flat, domelike structure in the vegetative phase.

With march of time, at the transition stage, the growing apex shows elongation by virtue of its metabolic activity with a concomitant increase in protoplasmic activity, in both tunica and corpus. These may be due to some causal stimulus for active cell division, particularly transverse cell division in the rib meristem, which increase, the height of the apical meristem.

Both the height and the girth of the apex increases, indicating higher metabolic activity of the apex for laying down more cells. Production of leaf primordium ceases at this stage and bract primordium begins to be initiated on the wider apex in a quick succession.

The distinguishing feature between the vegetative and the reproductive apex is the production of the bract primordium with a thinner base, distinguished from the leaf primordium with broader base. The reproductive apex is distinguished by the initiation of hand primordium at the axils of



the bracts which also may be controlled by some regulatory stimulus (stimuli).

In offering a suitable hypothesis, Mohan Ram et al. (1962) took the amount of histological changes which occur at the growing point during the change from a vegetative, to a floral phase. They suggested that a two-factor stimulus, along the lines of Chailakhyan (1961), may be involved. Anthesin would be required to convert the growing point to a floral state and gibberellin-like substance to cause stem elongation and internodal growth in the other-wise short shoot of the rosette-like vegetative plant. Barker and Dickson (1961) explains that a translocated factor is involved in flowering. Pillai (1975) and Chakrabarty (1977) studied the histological and biochemical changes occurring at the time of transition from vegetative to floral phases in some cultivars of banana. They stated that the nature of the control of flowering in banana is complex and more studies are needed to supplement the available information.

In banana, age is probably a dominant factor for flowering, as flowering cannot be induced by changing the daylength or by vernalization (Turner, 1970). This can be particularly emphasised in the present study.

### 5.6. Plant morphology Vs flower bud differentiation

At the transition phase, the tallest were the Red Banana plants (296.45 cm) when compared to Palayankodan (248.85 cm) and Robusta (188.75 cm) plants. This may be due to the fact that Red Banana is a long duration variety, Palayankodan and Robusta being medium and short duration varieties.

The increase in height from transition to floral phase was maximum in the case of Robusta (29.65 cm), followed by Palayankodan (19.90 cm) and Red Banana (18.55 cm). From the floral to the completion phase, the increase was the maximum in Red Banana (30 cm), followed by Robusta (24.45 cm) and the least in Palayankodan (7.35 cm).

As in the case of height, the girth was also the maximum in Red Banana at the transition stage (80.18 cm), followed by Palayankodan (59.57 cm) and the least in Robusta (50.83 cm). The increase in girth from transition to floral phase was maximum in Robusta (9.57 cm), followed by Palayankodan (8.43 cm) and Red Banana (5.82 cm). Robusta, being a short duration cultivar, the maximum increase in the height and girth is seen in between the transition and floral phases.

From floral to the completion phase, the increase in girth was the maximum in Red Banana (4 cm), followed by Palayan-kodan (0.5 cm) and the least in Robusta (0.31 cm).

The rapid increase in pseudostem height and girth during the vegetative and early phase of reproductive phase is ascribed to the supply of reserve materials by the plants to the growing point. Turner (1972) recorded high NAR in the early vegetative phase, though the total leaf area in the early vegetative phase was less. He attributed this to the supply of dry matter from the initial planting material.

Reduction in the rate of increase of pseudostem height after transition and during the early reproductive phase may be attributed to the slow rate of leaf emergence. Reduced rate of leaf emergence was reported by Champion (1961).

Regarding the leaf area, the leaf area was the maximum at the transition phase in Red Banana plants. The cultivar, inspite of being a long duration one, is more robust in all the morphological characters than the other two. At the completion phase also, the leaf area was maximum in Red Banana plants.

Leaf production at the growing point ceases with its

conversion to floral apex. The stimulus which produces the effect cannot be initiated by environmental factors such as light or temperature. No external morphological characters demonstrate the occurrence of floral initiation. The leaves remaining within the pseudostem continue to emerge; but at a slightly reduced rate, according to Champion (1961).

Turner (1970) explains that the growing point commences as a lateral bud opposite the leaf axil, on the parent corm. It first becomes macroscopically evident about ten leaf bases away from the apical meristem. Barker and Steward (1962a) give no indication as to the number of leaves within the pseudostem of the plants they examined.

In this work, it was found that the number of functional leaves in the three developmental phases for the three cultivars were in the range 9 to 11. Summerville (1944) found 11 leaves within the pseudostem, during vegetative as well as the floral phases.

#### 5.7. Content of nitrogen, carbohydrates and the C/N ratio

The content of nitrogen during the vegetative phase in the three cultivars showed variation. The maximum amount

of N (3.1%) was found in Red Banana. The amount of N was the least (2.06%) in the Palayankodan plants. The Robusta plants showed a N content (2.25%) in between Red Banana and Palayankodan plants. Even though the highest value of N during the vegetative phase was for Red Banana plants, this showed the least value (2.32%) in the transition phase. During the floral phase, the maximum N content (2.86%) was found in Palayankodan followed by Robusta (2.42%) and Red Banana (2.17%). In the completion phase, the trend seen was same as in the vegetative phase, the maximum value (2.06%) being for Red Banana, followed by Robusta (1.98%) and Palayankodan (1.76%).

Nitrogen content was higher in the vegetative, transition and floral stages than in the completion stage in the three cultivars. The Red Banana plants showed a decrease in N content from vegetative to the completion phase. In the Palayankodan plants, there was a gradual increase from vegetative to floral phase and a sharp decrease during the completion phase. In the Robusta plants there was an increase in N content from vegetative to transition phase. From transition to floral phase, there was a decrease in N content.

Chakrabarty (1977) has shown that the nitrogen content in the leaves showed a gradual decrease from vegetative to

reproductive stage. In the present investigations, a similar trend was seen in the case of Red Banana. Here also, even though there were differences in the N content in the vegetative, transition and floral phases, the nitrogen content was the lowest in the completion phase in the cultivars. This decrease of N during the completion phase may be explained as resulting from the dilution effect with associated increase in the bulk of the plant. Turner (1970) have also recorded a decrease of leaf nitrogen with the increase in the age of banana plant.

Eventhough Red Bananà plants showed gradual decrease in N content from the vegetative to the completion phase, Robusta and Palayankodan did not show such a trend. In Palayankodan plants, there was an increase from vegetative to floral phase. In Robusta, there was an increase in N content from vegetative to transition phase and a decrease from transition to floral phase.

The relationship between N status and flower bud initiation, thus, poses a rather confusing situation in banana. Many investigators could not find a definite relation between the flower bud initiation and nitrogen content with respect to mango (Singh, L.B., 1960; Singh, R.N., 1960; Sen et al.,

1963). However, nitrogen showed a positive correlation with flower bud differentiation in pepper (Rajan, 1985). Nitrogen content was also reported to be high at flower bud differentiation/flowering in apple (Archbold, 1928), sweet orange (Milella, 1968) and mango (Chacko, 1968). In grapes, higher levels of nitrogen decreased differentiation causing barrenness (Baldwin, 1966; Bindra and Chohan, 1974). A high dose of nitrogen before transition period may perhaps be helpful in this regard and this aspect requires further investigation.

In the vegetative and transition phase, the maximum CHO content was in Red Banana, followed by Palayankodan and Robusta. In the floral phase, Robusta and Red Banana plants showed the same CHO content. In the Palayankodan plants, the CHO content was slightly less. During the completion phase, the Palayankodan plants showed lowest CHO content, followed by Robusta and Red Banana.

With regard to CHO content, vegetative and transition stages alone were compared. In the three cultivars, CHO content was more in the vegetative phase than in the transition phase. Grainger (1964) studied the growth cycles of seventeen plant species in different situations in relation to the transition from vegetative to reproductive stage and concluded

that in none of the situations did any plant initiated flowers until a sufficiently high percentage of total carbohydrate accumulated in shoot, bringing about 'ripeness for flowering'. In the present studies, the floral and completion phases showed a higher CHO content than the transition phase.

Further detailed studies are required to obtain a clear picture in this regard.

Among the different phases of growth, the later phases had high C/N ratio while at the early phases, it was low. In the case of pepper, Rajan (1985) has observed a possible role of C/N ratio for induction of flowering. Similar beneficial effects have been reported in mango (Singh, 1960) and coconut (Bai and Ramadasan, 1982).

However, the present studies could not indicate any definite role for the C/N ratio in the induction of flowering in banana.

The present investigations have clearly brought out, with respect to three banana cultivars, of importance to the State, the anatomical changes occurring in the shoot apex between the vegetative phase and the completion of the flower



bud initiation. The occurrence of the different stages could be logged only approximately, because of the age differences even in the apparently uniform suckers. Further studies with tissue-cultured plants would help generate more accurate data with regard to the time of occurrence of the different stages. Detailed investigations are also required to examine the role of carbohydrates (qualitative and quantitative), nitrogen and the Carbon Nitrogen ratio on flower bud initiation in banana.

As per the Package of Practices Recommendations of the Kerala Agricultural University, manuring of banana is recommended to be done during the second and fourth month after planting. The present findings indicate that the time of application of fertilizers need to be modified. The split-application of fertilizers may have to be continued at least upto the transition stage. Accordingly, fertilizer application and earthing up may have to be done upto seven to eight months in Robusta, eight to nine months in Palayankodan and eleven to twelve months in Red Banana.

# SUMMARY

## 6. SUMMARY

6.1 Studies were undertaken at the College of Agriculture, Vellayani during 1987-88 to determine the site, time and histological aspects of flower bud differentiation in three banana cultivars, Robusta, Palayankodan and Red Banana.

6.2 The stages in the growth of the banana meristem were identified as the early vegetative phase, the late vegetative phase, the transition phase, development of the hand primordia and development of the flower primordia.

6.3 Basic differences were not observed in respect of the histological features of differentiation among the three cultivars, Robusta, Palayankodan and Red Banana.

6.4 With regard to duration of the different phases, there was marked difference among the cultivars. In Robusta, the vegetative phase terminated and transition occurred between 228 and 278 days. In the case of Palayankodan and Red Banana, the transition occurred between 250 and 311 days and between 334 and 365 days, respectively.

6.5 Formation of the bract primordia, hand primordia and flower primordia in Robusta occurred between 254 and 305 days. These were observed between 315 and 323 days in Palayankodan and between 365 and 374 days in Red Banana.

6.6 For completing the process of flower bud differentiation, Robusta took 285 to 312 days, Palayankodan 340 to 345 days and Red Banana, 380 to 382 days.

6.7 In the vegetative stage, the apical meristem was visualized as a flat dome-like structure and the leaves observed to grow peripherally around the apex, forming enclosing sheath around the axis.

6.8 The change over of the shape of the meristem from the flattened dome to conical, and initiation of the bracts indicated the transition from vegetative to floral phase. The apex at this stage indicated high meristematic activity.

6.9 After the transition, the conical apex became more meristematic and the bracts separated spirally from the flank meristem. The bracts later elongated and became boat shaped. From the axils of the bracts, hand primordia developed. During the next stage, floral primordia were seen to arise in acropetal succession.

6.10 At the transition stage, the Red Banana plants were the tallest, followed by Palayankodan and Robusta plants. The increase in height from transition to floral phase was maximum in the case of Robusta plants, followed by Palayankodan and Red Banana plants.

6.11 The girth was the maximum in the Red Banana plants at the transition stage, followed by Palayankodan and the least in Robusta plants.

6.12 The leaf area was the maximum at the transition phase in Red Banana plants.

6.13 The number of functional leaves between the vegetative phase and completion of flower bud differentiation ranged from 9 to 11 in the three cultivars.

6.14 The present studies could not indicate any definite role of N, CHO or C/N ratio in the induction of flowering in banana.

6.15 The occurrence of the different stages could be logged only approximately, because of the age differences in the apparently uniform suckers. Further studies with tissue-cultured plants have been suggested to generate accurate data with regard to the time of occurrence of the different stages.

6.16 The studies have indicated the need to reschedule the manurial and fertilizer practices in banana, taking into account the time required (from planting) for transition from vegetative to floral bud.

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# FLOWER BUD DIFFERENTIATION IN BANANA

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# APPENDICES

APPENDIX I

Weather data (monthly average) for the period from June, 1987  
to April, 1988

Month	Temperature		Relative humidity (%)	Total rainfall (mm)	Sunshine hours
	Maxi- mum (°C)	mini- mum (°C)			
June 87	31.01	23.61	74.42	223.1	6.08
July 87	31.20	24.35	76.09	20.4	9.43
August 87	30.40	24.00	81.15	273.4	6.27
September 87	31.25	24.10	78.97	286.0	7.52
October 87	30.62	26.97	82.85	296.9	6.11
November 87	30.09	23.67	81.49	183.0	7.06
December 87	30.86	23.23	80.29	233.7	7.27
January 88	31.54	20.96	65.00	4.4	10.12
February 88	32.29	21.80	66.00	6.6	10.41
March 88	33.23	25.16	71.00	55.3	10.16
April 88	32.83	24.79	72.00	82.3	8.62

# FLOWER BUD DIFFERENTIATION IN BANANA

By  
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**ABSTRACT OF THE THESIS**  
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## ABSTRACT

Studies were undertaken at the College of Agriculture, Vellayani during 1987-88 in Robusta, Palayankodan and Red Banana cultivars to determine the site, time and histological aspects of flower bud differentiation.

The time of differentiation varied in the three varieties. The transition from vegetative to reproductive stage occurred in Robusta between 228 and 278 days, in Palayankodan between 250 and 311 days and in Red Banana between 334 and 365 days.

The apical meristem visualized as a flat dome-like structure in the vegetative phase changed into a conical structure during the transition. After this, the conical apex became more meristematic and the bracts separated spirally from the flank meristem. In the axils of the boat shaped bracts, hand primordia developed. Later on, floral primordia were seen to develop in acropetal succession.

Basic differences were not observed in respect of the histological features of differentiation among the three cultivars.

With respect to morphological characters, there was rapid increase in the height and girth of the pseudostem during the vegetative and early stage of reproductive phase. The leaf area was the maximum in Red Banana plants at the transition phase. The number of functional leaves in the three developmental phases ranged from 9 to 11 in the three cultivars.

The present studies could not indicate any definite role for CHO, N or C/N ratio on the induction of flowering in banana.

Further studies with tissue-cultured plants have been suggested to generate accurate data on the time of occurrence of the developmental stages.