

Chapter 2

Review of Literature

1. Effect of mango rootstocks on scions.

1.1 Effect on growth, yield and fruit quality of scions.

Swamy *et al.* (1972) described results of a rootstock trial involving six polyembryonic mango rootstocks for 'Baneshan' and four for 'Neelum'. 'Neelum' grew larger on polyembryonic rootstock than on monoembryonic rootstock. 'Goa' and 'Olour' rootstocks produced the largest trees followed by 'Salem' and 'Pahutan'. 'Baneshan' trees were larger on 'Pahutan' and 'Olour' rootstocks. Based on growth and fruit yield from 1942 to 1965, 'Pahutan' and 'Goa' rootstocks were recommended for 'Neelum' and 'Olour' rootstock was recommended for 'Baneshan'.

Oppenheimer (1960) reported the highest yield for 'Haden' mango occurred on polyembryonic 'Sabre' rootstock (per unit area basis) among three different rootstocks. George and Nair (1969) reported the results of a rootstock trial using polyembryonic 'Chandrakaran' and 'Bappakai' and monoembryonic 'Puliyani' rootstocks for scion 'Bennet', 'Alphonso' and 'Baneshan'. Polyembryonic rootstock 'Chandrakaran' and 'Bappakai' grew more vigorously and produced higher yields during the first 6 years compared to monoembryonic 'Puliyani' rootstock. In South India, polyembryonic 'Olour' and 'Bappakai' and monoembryonic rootstocks were evaluated using 'Neelum' as a scion (Gowder and Irulappan, 1970). 'Bappakai' was recommended as a rootstock in terms of fruit yield and uniform growth of 'Neelum'.

Performance of 'Dashehari' on 24 rootstocks (10 polyembryonic and 14 monoembryonic) was reported by Rajan and Pandey (1991a,b). Rootstock strongly affected tree vigour with tree height ranging from 4.0-6.0 m after 14 years of growth. 'ST-9' and 'Latra' rootstock stimulated the most vigorous growth. 'Ambalvi', 'Pahutan', 'Olour', 'Nakkare', 'Mylepelian', 'Rumani', 'Willard', 'Mundappa' and 'Moovandan' caused dwarfing. Stem swelling was recorded with 'Mahmuda Vikarabad' rootstock; however, the scion girth varied with rootstocks. 'Rumani' and 'Ambalvi' rootstocks caused less scion girth (0.75-0.8 m) than the vigorous 'ST-9' and 'Latra' rootstocks (0.79-0.84 m). Crown spread was also greater with vigorous rootstocks than with

dwarfing rootstocks . The canopy of 'Dashehari' trees on 'ST-9' and 'Latra' rootstock was 2.15 and 2.25 x greater than on 'Rumani'. Fruit yield varied from 8 to 25 kg per tree. Dwarfing rootstock imparted higher fruit yield per unit canopy volume without much change in fruit quality. In an earlier study, polyembryonic rootstocks 'Ambalvi', 'Mylepelian', 'Olour' and 'Vellaikolamban' were compared with 'Dashehari' seedling rootstock with 'Dashehari' scion (Jauhari *et al.*, 1972; Singh and Singh, 1976). The 'Dashehari' seedling rootstock was most vigorous and produced higher yields, whereas 'Vellaikolamban' stock was the least effective. 'Vellaikolamban' impeded dwarfing to 'Alphonso' with low yields/tree (Anonymous, 1994), and has been recommended as a rootstock for high density 'Alphonso' orchards, based upon higher yield per cubic meter of canopy. 'Neelum' fruit quality on 'Bappakai' rootstock was better compared to 'Neelum' grown on 'Olour' and monoembryonic seedlings (Gowder and Irulappan, 1970). Larger 'Neelum' fruits having higher total soluble solids developed on 'Pahutan' rootstock than on 'Goa', 'Olour' and 'Salem' rootstock (Swamy *et al.*, 1972). 'Madu' and 'Gurih' rootstock delayed fruiting in Indonesia compared to 'Gurung', 'Kopjor', 'Budadaja', 'Nanas' and 'Saigon' (Kusumo *et al.*, 1971)

Malcolm *et al.* (1996) have described results of selection of rootstock influences yield, yield efficiency, fruit size and fruit external appearance of mango. For example, in one experiment in the Northern Territory, marketable tree yield of 'Kensington' fruit accumulated over four successive seasons was almost twice as much on one rootstock as on another. In another experiment, 'Tommy Atkins' yield 43% more in one season on 'Turpentine' (syn 'Common') rootstock than on 'Sabre'. Such results contradict the common perception in Australia that rootstocks do not influence yield, and provide a case for more research focussed on this aspect of mango cultivation. Although effects on yield and tree size have been shown in other countries and also found that rootstock influences fruit appearance and maturity times.

Avilan *et al.* (1996) reported that the influence of the polyembryonic mango rootstocks 'Rosa', 'Comphor', 'Ceniap', 'Peru' and monoembryonic rootstocks 'Divine', 'Tetenene Manzana' and 'Currucai' on fruit size and shape of 'Haden', 'Tommy Atkins', 'Edward' and 'Springfels' cultivars. These rootstocks were selected by their medium to small growth habit. Results indicated that the rootstocks modified the fruit dimension, weight and shape, and these changes varied according to the scion/rootstock combination used. In general, the cultivars

Edward and Springfels increased their fruit weight and size significantly. 'Haden' and 'Tommy Atkins' increased fruit weight and size also, but the fruit shape was modified, as compared to the fruits from the CENIAP old collection (> 35 years) that were considered true to type.

1.2 Effect on nutrient uptake of scions.

Rootstock and scion have reciprocal influences on nutrient uptake affecting the leaf nutrient content. Differences in nutrient content were demonstrated by Thakur *et al.* (1989) with 'Dashehari' grafted onto ten polyembryonic and 14 monoembryonic rootstocks. Leaf samples from the middle of non-fruiting terminals analysed for ten mineral elements exhibited the highest levels with 'Rumani' (nitrogen), 'Ambalavi' (iron) and 'Dashehari' (zinc and copper) rootstock. In another trial (Reddy *et al.*, 1989), 'Alphonso' was grafted onto eight rootstocks including openly pollinated 'Alphonso', and leaf nitrogen, phosphorus, potassium, calcium, magnesium and sulphur content differed significantly among the rootstock. 'Alphonso'. On 'Vellaileulumban' had the lowest levels of nitrogen, potassium and calcium but the highest magnesium level. 'Alphoso' on 'Olour' rootstock had the highest leaf nutrient content.

1.3 Effect on tolerance of scions.

Polyembryonic rootstock '13-1' has been demonstrated to tolerate calcareous soil containing 20% CaCO₃ and saline irrigation water containing over 600 ppm chloride (Stoler, 1976; Kadman *et al.*, 1978). Gazit and Kadman (1980) were able to grow 'Maya' mango on '13-1' rootstock on calcareous soils with up to 20% lime and 250 ppm chloride. In addition, 'Ann' and 'Gomera' polyembryonic rootstocks also showed salt-tolerance (Galan Sauco, 1993).

1.4 Effect of everbearing mango rootstocks on off-season flowering of scions.

Kulkarni (1986, 1988b and 1991) reported that the floral stimulus is also graft transmissible. Early flowering of seedling stems was stimulated by grafting them onto mature trees or by grafting the mature stems onto juvenile plants. Similar results were obtained by approach-grafting seedling plants to mature tree. Some mango cultivars selected in the tropics can flower at higher temperatures than others and are not restricted to winter flowering. Transfer of the floral stimulus from tropical selections to those requiring lower temperatures for induction has been accomplished using reciprocal grafts between these cultivars. Cultivars which would never flower in warm temperature condition were made to flower in the off-season using these techniques. Three conditions were made essential for summer flowering to occur in the low-

temperature-requiring cultivars (receptors) when grafted to the summer flowering type (donors): (i) the summer-flowering donor cultivar stocks or scion were in flowering cycle; (ii) buds on the receptors scion or stock of grafted plants had initiated shoot growth during this cycle; and (iii) receptor stocks or scion had been completely defoliated for transfer and/or expression of the floral stimulus. The presence of any leaves on receptor plants resulted in vegetative growth.

Manochai (1994) attempted to induction of off-season flowering of conventional mango cultivar (flowering once a year : cv. Man Khom, Nong Sang, Khiew Sawoey, Tong Dum, Nam Dok Mai and Fahlan) by through grafting of such a scion on branch of multiflowering mango cultivar (Choke Anan). Grafting should be made at one month before flowering time of rootstock plant. Scion grafted on flowering branches of rootstock showed a good flowering performance. But, the main problem observed was low fruit set, except only Fah Lan had high fruit set.

2. Environment influence on growth and reproductive development.

2.1 Temperature

Mangoes, along with most other subtropical and tropical fruit trees, show a vegetative bias (Wolstenholme, 1990), which becomes stronger with increasing temperature providing nutrients and water are non-limiting. Whiley *et al.* (1989), in controlled environment studies with potted trees, have defined the mean temperature for zero shoot growth in mango as 15 °C. Their data showed that as temperature increased the number of vegetative flushes over a 20 weeks period rose from 1.02 at 17 °C to 3.21 at 27.5 °C (mean). However, of greater interest was the variation in the number of flushes among cultivars at any given temperature. For example, with 'Irwin' (mono-) and 'Kensington' (poly-) at 27.5 °C (mean), it took approximately 25 days from bud-break to full expansion of the youngest leaf on the new shoot. However, the number of growth flushes during the experimental term, ranged from 2.0 ('Irwin') to 4.7 ('Kensington') without any significant difference in the accumulated dry matter of the total new shoot growth. A closer examination of these differences shows 'Irwin' to have approximately 45 days of quiescence at the end of each flush while 'Kensington' had a rest period of 5 days before beginning a new flush. These differences are reflected in the starch concentrations in woody trunk tissue, 'Irwin' had 13% compared to 3.6% in 'Kensington' at the end of the 20 weeks. Furthermore, it is likely that these differences in growth responses to temperature between these two cultivars are

responsible for the better yield performance of 'Irwin' in tropical Australia (Scholefield *et al.*, 1984).

Comparing three poly-embryonic cultivars, 'Carabao', 'Kensington' and 'Nam Dok Mai' growing under controlled condition at 27.5 °C (mean), the number of growth flushes over the 20 weeks period were 3.3, 4.7 and 2.3, respectively. This gives a rest period of 17 ('Carabao'), 5 ('Kensington') and 36 ('Nam Dok Mai') day at the end of each flush before new shoot growth occurs. It is of interest that flowering of 'Carabao' and 'Nam Dok Mai' under tropical conditions is more reliable than that achieved with 'Kensington' (Whiley, 1993) which is likely attributable to an extended period of quiescence between successive vegetative flushes when growing under field conditions (Chadha and Pal, 1986).

Shu and Sheen (1987) observed that axillary buds on 'Haden' held at day/night temperatures of 19/13 °C and 25/19 °C for two or more weeks had 87 and 60% floral development, respectively. Trees held at 31/25 °C were vegetative when shoots from axillary buds grew (Davenport *et al.*, 1993). In a separate study, cvs. Alphonso, Florigon, Glenn, Haden, Irwin, Kensington, Nam Dok Mai, and Sensation flowered after being held at 15/10 °C for up to 20 weeks; only 'Florigon' flowered when held at 20/15 °C (Whiley *et al.*, 1989). 'Tommy Atkins' trees flowered within 10 weeks when held at day/night temperatures of 18/10 °C, whereas trees held at 30/25 °C produced vegetative growth but did not flower (Davenport *et al.*, 1993). Similarly, when containerized 'Sensaton' trees were exposed to day/night temperatures of 15/10 °C for 20 weeks, 100% flowering occurred (Chaikiattiyos *et al.*, 1994). In that study, 'Sensation' trees were kept well watered in sunlit controlled-temperature cabinets at temperatures of 15/10, 20/15, 25/20, and 30/25 °C, but there were no flowering in trees which were held at 20/15 °C or higher. At 20/15 °C all buds remained dormant, while at 25/20 and 30/25 °C vegetative growth was promoted. Pongsomboon (1991) exposed container-grown 'Nam Dok Mai' trees grafted on 'Kensington' seedling rootstock, to day/night air temperatures of 30/20 and 15/10 °C, while the roots were held at either 12.5 or 25 °C. Pre-conditioning of these trees at 30/20 °C was performed to force a growth flush prior to exposing trees to their respective experimental temperatures. No flowering occurred in trees held at 30/20 °C at either soil temperature. However, at 15/10 °C air and 12.5 °C soil temperatures, all trees had flowered after 16 weeks but only 40% of trees

flowered when soil temperatures were held at 25 °C. Panicle growth was almost 400% greater in those trees held at 12.5 °C soil compared with trees held at 25 °C soil.

It is difficult to estimate the required period of low temperature for floral induction because in most studies treatments were imposed until visual expression of flowering occurred. Shu and Sheen (1987) demonstrated an increase from 18 to 100% flowering in axillary buds of 'Haden' when the trees were transferred to 31/25 °C following 1-3 weeks at 19/13 °C. Unfortunately we cannot conclude that 3 weeks of low temperature are sufficient to induce floral morphogenesis as axillary buds may have received some pre-conditioning during the period that led to the development of the terminal panicle.

The minimum leaf age and time of exposure to a low temperature regime (18 °C day/10 °C night) required by stems to initiate inflorescens was examined by Nunez-Elises and Davenport (1995). Leaves became competent to respond to cool temperatures when they reached 7 weeks of age. Apical buds of stem in which the distal whorl of leaves were clipped initiated inflorescence morphogenesis after only 3 weeks of exposure to a 18 °C day/10 °C night temperature regime. This was at least 2 weeks earlier than that displayed by non-clipped shoots. In contrast, Whiley *et al.* (1991) found that at least 17 weeks were required for initiation of reproductive shoots on non-clipped stems of trees continuously maintained at temperatures of 15 °C day/10 °C night. In similar experiments with different cultivars placed in controlled environment chambers without previous clipping of distal leaves to stimulate initiation, inflorescence differentiation was observed after 5 weeks of treatment at 15 °C day/10 °C night temperature (Chaikiattiyos *et al.*, 1994). Although inductive conditions were present in each of these studies, initiation of shoot growth was delayed by the presence of distal leaves. The earlier initiation of inflorescence development observed in tip-defoliated shoots compared to intact ones demonstrates that although the floral stimulus may be present, the buds are not induced until initiation occurs. Moreover, it demonstrates the importance of artificially stimulating initiation of stems by tip defoliation or pruning so that the inductive response can be observed. The delays in shoot initiation note in these studies occurred because the experimental protocols depended on the plants' internal initiation cycle to initiate shoots. This proposed cycle slows down when exposed to lower temperatures (Whiley *et al.*, 1991).

Production of reproductive shoots requires initiation of growth during exposure to cool, inductive temperatures. For example, resting buds of plants which had been exposed to cool temperatures (18 °C day/10 °C night) for more than 3 weeks and then transferred to a warm temperature regime (30 °C day/25 °C night) before initiation occurred, typically produced vegetative growth (Nunez-Elisea *et al.*, 1996).

The reduction in flowering when roots were grown at 25 °C, despite shoots being held at temperatures conducive to flowering (15/10 °C), was also reported for litchi grown under similar conditions (Menzel *et al.*, 1989). This effect on flowering suggests that 'root signals' may be implicated in floral induction of mangoes. Skene and Kerridge (1967) and Atkin *et al.* (1973) have shown that soil temperature affects the root export of cytokinins and gibberellins in grapes and maize, respectively. Export of these growth substances was greatest at higher root temperatures. In mango, flowering is suppressed by foliar application of gibberellins despite tree being grown under inductive conditions (Kachrue *et al.*, 1971; Nunez-Elisea and Davenport, 1991). Therefore, it is likely that endogenous gibberellins or other growth substances may be implicated in reduced flowering of mango when soil temperatures are high. This aspect needs further investigation as the focus in the literature has largely been with signals generated in the shoots (Chocko, 1991).

2.2 Water relations

Water stress is used successfully as a floral inductant in some evergreen tropical crops (e.g. coffee and lemons) and it is widely accepted that it is effective with mangoes growing under tropical conditions (Tatt, 1976; Singh, 1977; Chacko, 1986). Pongsomboon *et al.* (1992) have provided data on critical responses to water stress.

In pot studies with mangoes, Pongsomboon *et al.* (1992) found that trees had the ability to maintain high plant water status for a prolonged period (\approx 30 days) after withholding water. This is not surprising as they have a latex system which has been shown to impart drought resistance in other species (Kallarackal *et al.*, 1986; Devakumar *et al.*, 1988). In their study, as the leaf water potential (ψ_l) approached -2.0 MPa its decline accelerated over the following 20 days, reaching a critical value of -3.45 MPa beyond which permanent damage was sustained. Despite this indication of drought tolerance, their value of ψ_l at zero turgor (-1.75 MPa) was low when compared with -2.06 MPa in custard apple and -3.80 MPa in macadamia (Stephenson *et al.*,

1989). They also found that the critical value at which permanent leaf damage occurred was at 77% relative water content (RWC). This is quite high when compared with 50% RWC in macadamia (Stephenson *et al.*, 1989) and the even much lower value of 32 and 27% RWC for pigeon peas and C₄ grasses, respectively (Flower and Ludlow, 1986; Sinclair and Ludlow, 1985). These data indicate that the mechanism of drought tolerance in mango is based on maintenance of turgor in the leaves rather than a resistance by the tissues to damages.

The containerized trees of 'Nam Dok Mai' of flowering size were placed in sunlit rooms at day/night temperatures of 30/20°C (tropical temperatures) for 16 weeks and ψ_1 maintained at -1.5 MPa (pre-dawn) (Pongsomboon, 1991). When stress was released, none of these trees flowered and new growth from terminal buds was vegetative. In a similar study, containerized trees of 'Sensation' were grown in sunlit rooms at day/night temperatures of either 15/10°C or 30/25°C for 4 weeks and the relative water content (RWC) of leaves monitored (Chaikiattiyos *et al.*, 1994). At 15/10°C trees were watered daily (RWC \geq 97%) but at 30/25°C water was withheld to impose a deficit in the trees (RWC \approx 93%). Flowering occurred in the trees held at low temperatures, whereas vegetative shoots grew out of terminal buds of the high temperature/water stress treatment 1-2 weeks following rewatering (Chaikiattiyos *et al.*, 1994).

The influence of water stress on floral induction has also been quantified for field-grown 'Nam Dok Mai' trees through the dry season near Bangkok where the mean max/min temperature during the 6 weeks study was 28/17 °C (Pongsomboon, 1991). Different water deficits were maintained in trees and pre-dawn ψ_1 was monitored with a pressure chamber on a weekly basis. After 5 weeks of water stress, trees were irrigated and the percentage of terminals that flowered was recorded. The percentage of terminals that flowered increased with mean water deficit with more than 90% of terminals flowering when ψ_1 was \leq -0.75 MPa (Pongsomboon, 1991). The discrepancy between the results from containerized and field grown trees may be due to higher VPD in the field compared to the greenhouse. Minimum temperatures in the field were also lower than in the controlled environment studies and together with water stress may have had a synergistic effect on floral induction.

Recent experiment with container-grown mango trees, examining the role of water stress in floral induction, failed to produce inflorescences after 8 weeks of water deficit as determined by soil moisture content (Wolstenholme and Hofmeyr, 1985). In another study conducted under

glasshouse conditions (27 °C day/22 °C night; RH ≥ 90%), container-grown, monoembryonic cultivars were water-stressed through deficit irrigation for 14 days, resulting in an average leaf xylem water potential of -3.9 MPa (Davenport, 1992; Nunez-Elisea and Davenport, 1992a, 1994b). Following resumption of irrigation, all trees grew vegetatively without flowering. Similarly, only vegetative growth was obtained after container-grown trees were deprived of irrigation for 36 days during summer, although leaf xylem water potential of -3.78 MPa were attained (Nunez-Elisea and Davenport, 1994b). Water stress imposed on plants during the cool autumn months (night temperatures below 15 °C) did not increase the proportion of apical buds forming inflorescences in stressed over non-stressed plants, but it expedited shoot initiation after rewatering (Nunez-Elisea and Davenport, 1994b). These results indicated that cool temperatures provided the inductive condition, whereas relief of water stress accelerated initiation of shoots during exposure to cool, inductive temperatures. Flowering was delayed in separate study using container-grown trees when monoembryonic mangoes were water-stressed at temperatures of 18° C day/15 °C night (Chaikiattiyos *et al.*, 1994). In the same experiment, water-stressed trees held at temperatures of 29 °C day/25 °C night did not flower but grew vegetatively.

Others have observed increased flowering (85%) compared to irrigated controls (56%) of field-grown mango trees following 12 weeks of water deficit (Bally, 1999). The latter study took place at a higher latitude and was certainly influenced by cool temperatures. No temperature information is available in the former study, and information on the timing of vegetative flushes, especially in the irrigated control trees, during the course of the experiments in both studies is lacking. The mechanism of mango floral induction in tropical climates remains intriguing since it can occur in the presence of minimum daily temperatures greater than 20 °C, which are considered conducive to the expression of vegetative growth. Drought prevents vegetative flushing, thereby increasing the proportion of mature to immature leaves in the canopy. Mature leaves produce the floral stimulus (Nunez-Elisea and Davenport, 1992), whereas immature mango leaves are rich sources of floral inhibitors (Chen, 1987). Thus in tropical climates, water stress may promote flowering by increasing the total amount of floral stimulus produced by the canopy.

In tropical climates, the lower concentration of floral stimulus in each leaf is probably only partially compensated for by the increased proportion of mature leaves in the canopy. Under conditions of drought stress, dehydrated apical meristems may become more sensitive to low

levels of floral stimulus. Thus, increased sensitivity to floral stimulus in addition to increased mature leaf area may compensate for the lack of chilling temperatures for floral induction in the tropics (Schaffer *et al.*, 1994).

2.3 Photoperiod

Flowering in most woody perennials does not appear to be under photoperiodic control (Kozlowski *et al.*, 1991). Mango cultivation is concentrated between 27°N and 27°S latitudes, where the shortest annual photoperiods exceed 11 hours. Cultivars growing in the upper-latitude tropics and subtropics flower during the winter months when photoperiods are the shortest; however, trees growing in the low-latitude tropics are known to flower at any time of the year, and flowering on spring-grown shoots in subtropical latitudes is known to occur during summer. Studies with field- and container-grown plants failed to demonstrate a correlation between short 8-h photoperiods and flowering (Schaffer *et al.*, 1994). More recently, Nunez-Elisea and Davenport (1995) studied the effect of photoperiod and temperature on mango flowering. They exposed marcotted, container-grown mango trees to 11-, 12-, 13- and 24- h photoperiods at 18 °C day/10 °C night, or to 11- or 13- h photoperiods at 30 °C day/ 25 °C night provided by controlled environment chambers. Photoperiod had no effect on the vegetative or reproductive fate of buds, and the promotive effect of cool temperatures on flowering was independent of photoperiod. Photoperiods of 11-, 12- or 13-h, when combined with 18 °C day/10 °C night temperatures, caused floral initiation in nearly all trees within 40 days of imposing the treatments. The 24-h photoperiod, which included 12-h thermoperiods of 18 °C and 10 °C, caused flowering of nearly all trees within 35 days of imposing the treatments. Photoperiods of 11- or 13-h at 30 °C day/25 °C night resulted in vegetative growth exclusively. With warm temperatures, vegetative shoots were produced within 17 days of commencing treatments. These results indicate that floral induction is caused by cool temperatures and not by short photoperiods and that flowering is inhibited by warm temperatures, not by a long photoperiod.

3. Hormonal influence on flowering.

3.1 Cytokinins.

Chen (1987) measured the cytokinins content of xylem sap derived from roots during various stages of leaf differentiation, in mature green leaves (bud rest), during early flowering, and in full bloom using high-performance liquid chromatography (HPLC) separation coupled with soybean

cotyledonary callus bioassay (Miller, 1963; Chen, 1983). The lowest levels of putative trans-zeatin and its riboside were translocated from roots during the vegetative growth and resting stages, whereas the highest levels were measured during the early flowering and full bloom stages. In contrast, Paulas and Shanmugavelu (1989) observed no significant difference in cytokinin levels of the fourth and fifth leaves during resting bud and flowering stages.

Kurian *et al.*, (1992) reported a substantial reduction in several cytokinins in mango leaves in the limp red leaf stage from trees treated with paclobutrazol. Concurrent with this response was suppression of bud initiation and reduced internode lengths for 2 years. In addition to repression of canopy growth through inhibition of gibberellin synthesis (Griggs *et al.*, 1991; Rademacher, 1991), this class of compounds also causes reduction in feeder root development and formation of thick, blunt roots in numerous species (Bausher and Yelenosky, 1986, 1987; Burrows *et al.*, 1992; Vu and Yelenosky, 1992; Wang and Lin, 1992), which possibly results in reduced cytokinins translocation to buds.

The role of cytokinins in flowering is still unresolved. The few available reports draw conflicting conclusions, primarily due to sampling of different organs at non-comparable times or conditions. The elevated cytokinin levels found prior to and during flowering and the flowering response to applied BA led to the conclusion that cytokinins are involved in flowering of mango (Chen, 1987), however, such a response can also be explained if cytokinins are involved in stimulation of bud break, not necessarily flowering *per se*.

One of the most documented roles for cytokinins in higher plants, especially evident in tissue culture systems, is initiation of bud-break (Salisbury and Ross, 1992; Davies, 1995). The primary cytokinins found in higher plant are trans-zeatin, dihydrozeatin, isopentenyl adenine and their ribosides. They are translocated from roots and accumulate in resting stems (Hendry, 1982a,b). Their rate of accumulation may be related to periodic root flushes which tend to alternate with shoot flushes (Krishnamurthi *et al.*, 1960; Bevington and Castle, 1986; Cull, 1991; Williamson and Coston, 1989).

Chen (1991) reported that Lychee (*Litchi chinensis*) has been analyzed for cytokinins in buds before and after flower bud differentiation, using reverse phase high performance liquid chromatography in combination with *Amaranthus* bioassay and gas chromatography-mass spectrometry-selected ion monitoring. Four cytokinin, zeatin, zeatin riboside, N⁶-(δ^6 -isopentenyl)

adenine, and N⁶-(δ^6 -isopentenyl)adenine riboside, were detected in buds. There was an increase of cytokinins activity in the buds during flower bud differentiation. In dormant buds, the endogenous cytokinins content was low, and the buds did not respond to exogenous cytokinins application. Application of kinetin promotes flower bud differentiation significantly after bud dormancy. These results are interpreted as an indication that the increase in endogenous cytokinins levels during flower bud differentiation may be correlative rather than the cause of flower bud initiation.

Chen *et al.* (1997) reported the presence of endogenous cytokinins were detected in the terminal buds of longan (*Euphoria longana* Lam.) after purification by ion exchange and Sephadex LH-20 chromatography, and bioassay, enzymic degradation, high-performance liquid chromatography, gas chromatography-mass spectrometry. Permethylated derivatives of two highly active cytokinin glucoside compounds from dormant buds were: 6-(4-O- β -D glucosyl-3-methyl-but-2-enylamino)purine(zeatin-O-glucoside) and 9- β -D-ribofuranosyl-6-(4-hydroxy-3-methyl-but-2-enylamino)purine(zeatin-O-glucoside). Simultaneously, four active cytokinins from buds at the stages of leaf flush and flower bud initiation were identified as 6-(4-hydroxy-3-methyl-but-*trans*-2-enylamino)purine(zeatin), zeatin-9- β -D-ribofuranosylpurine(zeatin riboside), 6-(3-methyl-2-butenyl) aminopurine (isopentenyladenosine, 2iPA) and N-(3-methyl-2-butenyl) adenine (isopentenyladenine, 2iP). The total cytokinins levels were low at leaf flush, with the zeatin and zeatin riboside in the buds about 70% of the total. In the transition of terminal bud from leaf flush to dormancy, the principal cytokinins were zeatin-O-glucoside and zeatin riboside-O-glucoside. However, significant decreases in the levels zeatin-O-glucoside and zeatin riboside-O-glucoside and increase in those of zeatin, zeatin riboside, 2iPA and 2iP were observed at flower bud initiation. It is suggested that in longan, the cytokinins that are translocated to the shoots are accumulated in the buds at the dormant stage, and that later there is a considerable increase in free cytokinins during flower bud initiation, leading to the promotion of flower bud development.

3.2 Gibberellins

The reports of endogenous gibberellins in mango tissues. Especially in buds, are difficult to interpret with respect to a regulatory role in bud break or flowering. Problems include sampling of tissues other than apical buds, i.e. whole shoots (Tongumpai *et al.*, 1991b), leaves (Paulus and Shanmugavelu, 1989; Sivagami *et al.*, 1989) and xylem sap (Chen, 1987) or at times when

developing shoots may contribute to the overall result (Chen, 1987). Pal and Ram (1987) tentatively identified the presence of gibberellins A₁, A₃, A₄, A₅, A₆, A₇ and A₉ based on co-chromatographic comparison of authentic external standards. Chen (1987) identified gibberellins A_{1/3}, A_{4/7}, A₅, A₁₇, A₂₀ and A₂₉ in xylem sap. More recent studies have identified gibberellins A₁, epi-A₁, A₃, A₁₉, A₂₀ and an unidentified putative gibberellins in buds and leaves of different ages (Nunez-Elisea and Davenport, 1998). Gibberellins A₃ and A₁₉ were most abundant in leaves of shoots in the limp red leaf stage of development. All of the detected gibberellins are members of the early 13-hydroxylation pathway of gibberellins synthesis (Takahashi, 1986; Pearce *et al.*, 1994). The latter two studies employed extensive partitioning and/or chromatographic purification followed by identification using gas chromatography-mass spectrometer (GCMS). Use of bioassay for gibberellins determinations make quantitation difficult due to the presence of interfering or non-resolved compounds. Use of internal standards to monitor losses during extraction and purification is essential for quantitative assessments. Notwithstanding these limitations, the estimated levels of gibberellins in apical buds measured monthly for 6 months prior to the flowering season were reported to be higher in the vegetative 'off' year than in the flowering 'on' year of an alternate-bearing cultivar (Pal and Ram, 1978). Chen (1987) reported the highest levels of gibberellins in mango xylem sap during leaf differentiation and lower concentrations during rest panicle emergence and full flowering. Tongumpai *et al.* (1991b) observed increasing levels of gibberellins in whole shoot over the 16 weeks prior to vegetative shoot emergence and decreasing level over the same period prior to panicle development. Nunez-Elisea and Davenport (1998) were unable to detect significant difference in endogenous GA₃ levels of buds from the limp red leaf to mature green stages. They reported that GA₃ delayed inflorescence initiation but did not cause vegetative morphogenesis when bud differentiation occurred in cool temperatures. In contrast to delaying inflorescence initiation in cool temperatures, GA₃ did not delay vegetative growth during warm temperature. Thus, could be concluded that GA₃ prevents initiation of reproductive shoots of mango rather than inhibiting floral induction.

Pongsomboon *et al.* (1997) observed in the mango trees cv. 'Nam Dok Mai' found the GA₃-like substances were comparatively high (1.5-1.7 µg equivalent/g fresh wt.) at the beginning of

the dormant period, but declined by about 50% in late November. They then increased somewhat and remained relatively stable during the second week of December before dropping to 0.6 μg equivalent/g fresh wt. in mid December. Finally, levels increased slightly in late December through to inflorescence emergence.

4. Photoassimilate influence on flowering

Flowering has been thought to be regulated by sugar to nitrogen ratios with high levels being conducive to flowering. The role of starch reserves, soluble carbohydrates and/or nitrogen content in mango flowering has been investigated. Sucrose levels reaching the apical bud is central to modern theories of floral induction (Sachs, 1977; Bernier *et al.*, 1981, 1993). It has been suggested that sugars play a regulatory role in floral induction, based on circumstantial evidence in mango (Rameshwar, 1989) and other species (Ramina *et al.*, 1979; Bernier *et al.*, 1981). The theory of photoassimilate diversion to the apical bud, presented by Sachs *et al.* (1979) is the basis for the carbohydrate-regulated flowering model. Both stored starch and soluble carbohydrates are utilized during panicle development (Ravishankar and Rao, 1982). Several investigations have examined correlation of starch reserves and C/N ratios with flowering. Pongsomboon *et al.* (1997) observed in the mango trees cv. 'Nam Dok Mai' found that the total nonstructural carbohydrate (TNC) contents in terminal shoots were quite low (ca. 70-98 mg glucose equivalent/g dry wt.) at the beginning of the dormant period. Thereafter levels increased to 110-120 mg glucose equivalent/g dry wt. Although there was some fluctuation. Finally levels declined at ca. 70 mg glucose equivalent/g dry wt. prior to inflorescence emergence. Nartvaranan *et al.* (1998) observed in the mango trees cv. 'Nam Dok Mai' that TNC and reducing sugar (RS) content of mango inflorescence tissue gradually decreased as the inflorescence developed from 5 days after bud-break to full bloom (25 days after bud-break). A similar trend in changes of TNC was found in leaf and bark tissues collected during the same period. However, the TNC content of the shoot and RS content of the shoot, leaf and bark remained constant during the period of inflorescences development.

Kanlayanarat *et al.* (1982) studied the seasonal changes in TNC and total nitrogen (TN) contents in leaves and terminal shoots of mango cv. 'Nam Dok Mai'. TNC in leaves and terminal shoots were found increased at two peaks, first in June, before the flush of new shoots and second in January, before flowering. The TN contents in leaves and terminal shoots were high during

the period from June to December, then decreased rapidly. In early January, TNC were increased with the decreased in TN, this phenomena was at the same period of flower initiation. Observations of starch accumulation during extended periods of canopy rest prior to flowering provide supportive evidence, but there seems to be little consensus regarding the role of carbohydrates and nitrogen in flowering. It is generally felt that a direct role for stored carbohydrates in mango floral induction has not been conclusively demonstrated.

5. CO₂ assimilation and stomatal behavior

Schaffer and Gaye (1989) present data on the response of net CO₂ assimilation or net photosynthetic rate, *A* to light using pot-grown 'Turpentine' mango trees. Their data show that the light saturation point for trees used in their research was $\approx 350 \mu\text{mol quanta m}^{-2} \text{s}^{-1}$. In the study of Whiley (1993) the maximum *A* measured was $7.2 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ which is similar to the rate reported by Pongsomboon (1991) of $7.8 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ measured in pot-grown 'Kensington' mango trees and by Phattaralerphong (1997) of 9.4 and $8.8 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ measured in pot-grown 'Nam Dok Mai' and 'Khiew Sawoey' mango trees at the leaf age of 45 days, respectively.

Being a tropical species one could assume that the optimum temperature for photosynthesis would be in the vicinity of 30 °C (Whiley, 1993). Pongsomboon (1991) measured *A* of mature leaves of pot-grown 'Kensington' growing under two different temperature regimes. The maximum *A* measured at 30/20°C (day/night) was $7.8 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ while at 15/10 °C it fell to $3.1 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$. Unpublished results of Smillie and Hetherington (Whiley, 1993) show that mango is sensitive to photo-inhibition during winter in subtropical areas so it is not unexpected that *A* is reduced by 60% at the lower temperature. In more recent results collected in subtropical Australia (Whiley, 1993), maximum *A* has been measured in field-grown 'Kensington' trees at $13.5 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ in March (mean monthly max/min = 27.4/18.2 °C). This rate subsequently declined to $8.2 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ in June (mean monthly max/min = 21.3/7.8 °C). While other seasonal effects may be in part responsible for this drop, there is little doubt that temperature would also be effecting the photosynthetic efficiency of trees during winter at subtropical latitudes. The maximum rate of $13.5 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ is considerably higher than reported for pot grown trees by Schaffer and Gaye (1989) , Pongsomboon (1991) and Phattaralerphong (1997).

Factors affecting stomatal aperture dependent on a number of environmental factors, including light, carbon dioxide concentration, humidity and temperature (Schulze and Hall, 1982), and internal factors such as tissue water status and the level of such plant growth regulators as ABA and cytokinins. Collatz *et al.* (1991) state that the primary factor causing a midday decrease in stomatal conductance (g_s) is a decrease in net photosynthesis, related to rise in leaf temperature above the optimum for photosynthesis but this must be a special case. The temperature rise is said to be caused by low boundary layer conductance.

Stomatal closure in response to high vapour pressure deficits (VPD) has been reported for many fruit crops (Jones *et al.*, 1985). The mechanism protects leaves against desiccation when the surrounding air is dry. The response of g_s in mango to VPD has been reported by Pongsomboon (1991) who was able to show that g_s fell with increasing VPD. This is not a surprising result considering that mango is adapted for drought tolerance. Because of the importance of stomata in controlling water loss and CO_2 uptake, there has been much interest in the measurement of stomatal aperture or the conductance of stomata. Some investigators have expressed the stomatal opening in terms of conductance, others as resistance which is the reciprocal of conductance, resulting in hyperbolic curves by use Porometers.

The stomatal aperture can be observed visually on epidermal strips fixed in alcohol or by applying collodion or silicone rubber to leaves, stripping it off, and examining the impressions under a microscope. Direct visual observations can be made with special cameras and imaging equipment. Rapid estimates of stomatal aperture can be made from the rate of infiltration of liquids of various viscosities (Kramer and Boyer, 1995). There were some reports that used visual observation method to studied stomatal behavior : Majumder *et al.* (1969) have ready attempted to classify mango rootstocks in different vigor groups on the basis of number of stomatal per unit leaf area (stomatal density) recorded from plastic film replicas of leaf surfaces. Beakbane and Majumder (1975) reported that the effect of a number of apple rootstock varieties on the vigor of scion varieties budded on them was found to be related to the number of stomatal per unit leaf area of rootstock leaf (stomatal density). Stomatal counts made from plastic film replicas of leaf surfaces may provide a rapid means of assessing the probable growth potential of apple seedlings. Pathak *et al.* (1977) studied to used the stomatal distribution as an index for predicting vigor plum rootstocks. Data were presented on the stomatal density/unit leaf area for 9 plum rootstocks.

Stomatal numbers varied between 18.98 with Myrobalan A (classified as very vigorous) and 6.62 with Damas C (dwarfing). Banger and Prasad (1992) collected leaf samples from 13-year-old ber (*Ziziphus mauritiana*) plants on 4 different rootstocks (*Z. rotundifolia*, *Z. mauritiana*, *Z. nummularia* [*Z. nummularia*] and *Z. spinichristii* [*Z. spina-christi*]) in 1989. Stomatal density and size were measured. Plant height, spread, stem girth and leaf area were recorded for each rootstock. Stomatal density was strongly and positively correlated with the growth parameters. Highest stomatal density (61,753 stomata/cm²) was found on *Z. mauritiana* rootstock, which was very vigorous. Lowest stomatal density (8,099 stomata/cm²) was found on *Z. nummularia*, which was a dwarfing rootstock. Stomatal size was also greater in the more vigorous rootstocks. Guirguis *et al.* (1995) studied the leaf stomata and stem lenticels as a means of identification of some stone fruit stocks. A study was conducted during the 1990 and 1991 season on the leaves and stem of several stone fruits. The highest stomatal density occurred in peach cv. Nemaguard (193/mm²) and the lowest in peach cv. Florida 9/3 (87/mm²) and sweet almond (88.6/mm²). Peach cv. Okinawa and bitter almond had the longest stomata, and Okinawa and Nemaguard had the widest. Local apricot had the highest number of lenticels (8.67/ cm²) and sweet almond (1.33/ cm²) had the lowest.

6. Impacts of climatic variability.

In normal conditions, ocean surface temperatures across the tropical Pacific contribute significantly to the observed patterns of tropical rainfall and tropical thunderstorm activity. The heaviest rainfall is typically observed across Indonesia and the western tropical Pacific, and the least rainfall is normally found across the eastern equatorial Pacific. The mean patterns of sea surface temperature and equatorial rainfall are accompanied by low level Easterly winds (East-to-West flow) and upper level Westerly winds across the tropical Pacific. Over the Western tropical Pacific and Indonesia this wind pattern is associated with low air pressure and ascending motion, while over the Eastern Pacific it is accompanied by high pressure and descending motion. Collectively, these conditions reflect the equatorial Walker Circulation, which is a primary large-scale circulation feature across the Pacific. The subsurface ocean structure is characterized by a deep layer of warm water in the Western tropical Pacific, and by a comparatively shallow layer of warm water in the eastern Pacific. This warm water is separated from the cold, deep ocean waters by the oceanic thermocline, which is normally deepest in the west and slopes upward toward the surface farther east. The resulting east-west variations in mean upper-ocean temperatures result in

east-west variations in sea level height, which is higher in the west than in the east, shown in Figure 2.1(a), (b) middle (cpc.NCEP/NOAA, 1999a).

In El Niño condition, El Niño episodes feature large-scale changes in the atmospheric winds across the tropical Pacific, including reduced Easterly (East-to-West) winds across the eastern Pacific in the lower atmosphere, and reduced Westerly (West-to-East) winds over the eastern tropical Pacific in the upper atmosphere near the tropopause. These conditions reflect a reduced strength of the equatorial Walker Circulation, which in strong El Niño episodes can be completely absent. During the developing phase of the El Niño, the subsurface ocean structure is characterized by an abnormally deep layer of warm water and an increased depth of the thermocline across the eastern tropical Pacific. Thus, the slope of the thermocline is reduced across the basin. In very strong El Niño episodes, the thermocline can actually become flat across the entire tropical Pacific for periods of several months. Accompanying these conditions, the sea level height is higher than normal over the eastern Pacific, resulting in a decreased slope of the ocean surface height across the basin. There is also considerable evolution in the subsurface temperature and thermocline structure during El Niño, shown in Figure 2.1 (a), (b) lower (cpc. NCEP/NOAA, 1999b).

In La Niña conditions, La Niña episodes also feature large-scale changes in the atmospheric winds across the tropical Pacific, including increased Easterly (East-to-West) winds across the eastern Pacific in the lower atmosphere, and increased Westerly (West-to-East) winds over the eastern tropical Pacific in the upper atmosphere. These conditions reflect an enhanced strength of the equatorial Walker Circulation. During the developing phase of La Niña, the subsurface ocean structure is characterized by an abnormally shallow layer of warm water across the eastern tropical Pacific, in association with a reduced depth of the oceanic thermocline. Thus, the slope of the thermocline is increased across the basin. In very strong La Niña episodes, the thermocline can actually come very close to the ocean surface for extended period. This cooling represents a decreased depth of the oceanic mixed layer, and accompanies the appearance of nutrient-rich waters very close to the ocean surface. Thus, its existence is quite beneficial to marine life throughout the region. Accompanying these conditions, the sea level height is lower than normal over the eastern Pacific, resulting in an increased slope of the ocean surface across the basin.

There is also considerable evolution in the subsurface temperature and thermocline structure during La Niña episodes, shown in Figure 2.1 (a), (b) (cpc NCEP/NOAA, 1999c).

The ENSO (El Niño / Southern Oscillation) cycle refers to the coherent, large-scale fluctuation of ocean temperatures, rainfall, atmospheric circulation, vertical motion and air pressure across the tropical Pacific. Thus, it represents a coupled ocean-atmosphere phenomenon centered in and over the tropical Pacific. The scale of these fluctuations is quite vast, with the changes in sea-surface temperatures oftentimes spanning a distance of more than one-quarter the circumference of the globe, and the changes in tropical rainfall and winds spanning a distance of more than one-half the circumference of the earth.

During a strong El Niño episodes, ocean temperatures can locally average 2°C - 5°C (4°F - 9°F) above normal between the date line and the west coast of South America, sometimes resulting in nearly uniform surface temperatures across the entire equatorial Pacific. During a strong La Niña episode ocean temperatures locally average 1°C - 4°C (2°F - 7°F) below normal between the date line and the west coast of South America, resulting in large East-West variations in ocean temperatures across the equatorial Pacific (cpc. NCEP/NOAA, 1999d).

During El Niño , heavy rainfall and thunderstorm activity develops across the eastern equatorial Pacific in regions where the abnormally warm ocean temperatures reach approximately 28°C (82°F) or greater. Farther west, rainfall tends to be suppressed across Indonesia, the Phillipines and northern Australia. Another typical El Niño feature is a northeastward shift of the South Pacific Convergence Zone (SPCZ) from its mean position between Australia and New Guinea toward the anomalously warm equatorial waters. An equatorward (southward) shift of the Intertropical Convergence Zone (ITCZ) is also evident over the eastern tropical Pacific during El Niño episodes. Whereas during La Niña , rainfall and thunderstorm activity diminishes over the central equatorial Pacific, and becomes confined to Indonesia and the western Pacific. The area experiencing a reduction in rainfall generally coincides quite well with the area of abnormally cold ocean surface temperatures (cpc. NCEP/ NOAA, 1999e).

El Niño and La Niña events tend to alternate about every three to seven years (Hensen and Trenberth, 1998). However, the system oscillates between warm (El Niño) to neutral or cold (La Niña) conditions with an on average every 3-4 years (U.S. Department of commerce/NOAA, 1999).

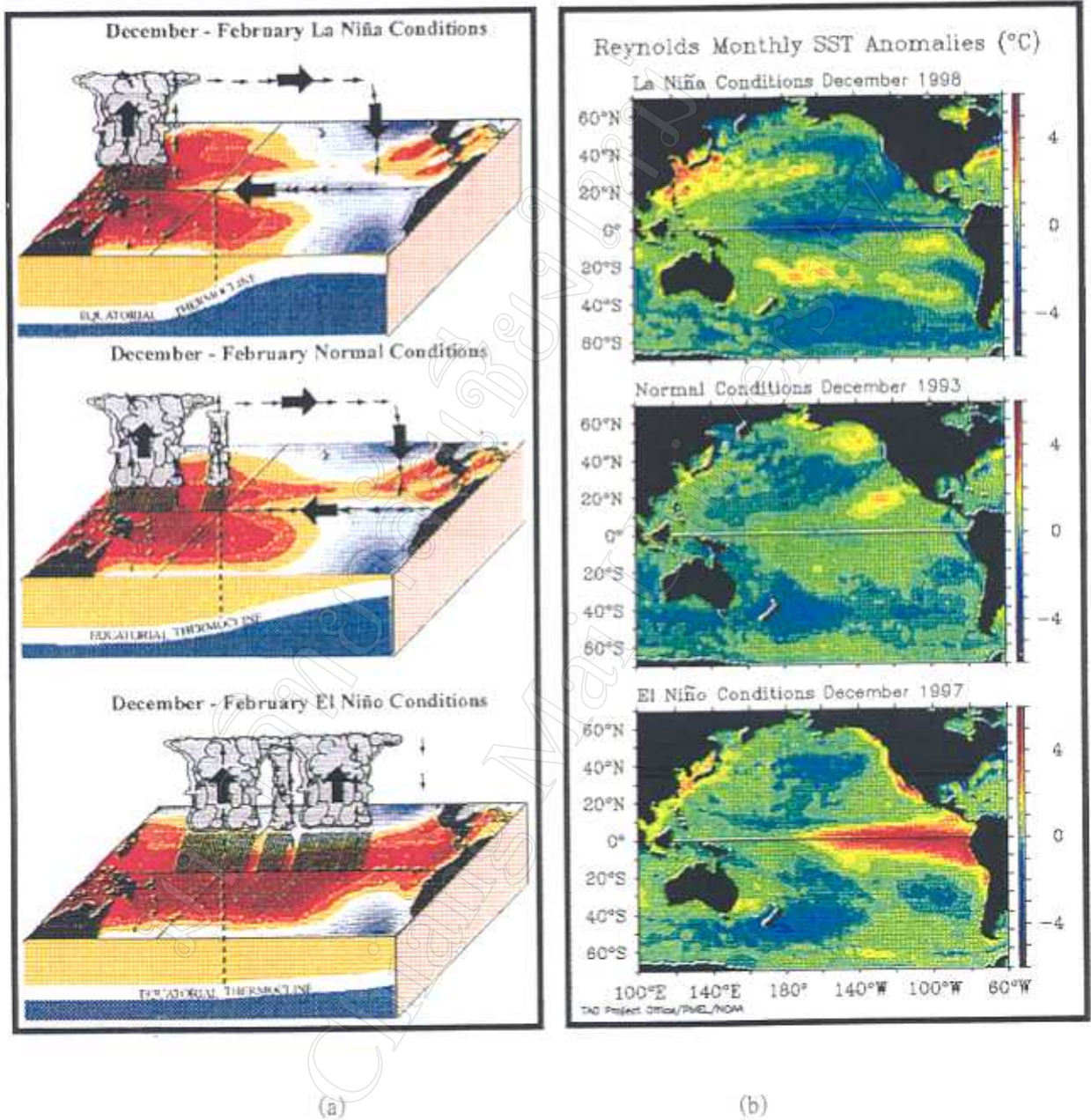


Figure 2.1 (a) Equatorial thermocline during the occurrence of (upper) La Niña conditions (middle) Normal conditions (lower) El Niño conditions (CPC, NCEP/NOAA, 1999). (b) Sea surface temperature anomaly of the Pacific Ocean surface during the occurrence of (upper) La Niña conditions (middle) Normal conditions (lower) El Niño conditions (U.S. Department of Commerce/NOAA/PMEL/TAO, 1999).

For the strength of events; as judged by the pressure anomaly; indicated that the 1997-98 El Niño which occurred in May 1997 was the strongest El Niño (Hensen and Trenberth, 1998) and the 1998-1999 La Niña was moderate to strong La Niña (U.S. Department of commerce/NOAA, 1999). El Niño conditions typically last approximately 12-18 months; while La Niña conditions typically last approximately 9-12 months but may persist for as long as two years. Since 1975, La Niñas have been only half as frequent as EL Niños. El Niños were present 31% of the time and La Niñas 23% of the time from 1950 to 1997, leaving about 46% of period in a neutral state (U.S. Department of commerce/NOAA, 1999). For the 73-year period examined, this definition results in 22 El Niño years, 29 neutral years, and 22 La Niña years (Pielke and Landsea, 1999). Using a state-of-the art General Circulation Model (GCM) in 1992, NCAR was the first to demonstrate the evolution of ENSO-like behavior in hypothetical atmosphere containing twice the carbon dioxide of the present (a state likely to be reached by the year 2060). The model indicate that the rainfall anomalies connected to El Niño and La Niña may become stronger in a global-warming scenario (Henson and Trenberth, 1998). The image of the Pacific Ocean was produced using sea-surface height measurement taken by the U.S.-French TOPEX/ Poseidon satellite; reports on August 20, 1998 showed that the effects of El Niña could remain in the climate system for a long time and could still impact weather condition around the world; while reports on October 21, 1998 demonstrated that the image showed sea surface heights were indicator of the changing amount of heat stored in the ocean. This image showed the area of low sea level that this cold pool will evolve into a long-lasting La Niña situation. The coexistence of these two contrasting (El Niño and La Niña) conditions indicated that the ocean and the climate system remain in transition (jpl nasa, 1999).

El Niño abnormal effects on the main components of climate : sunshine, temperature, atmospheric pressure, wind, humidity, precipitation, cloud formation, and ocean currents that changed weather patterns across the equatorial Pacific and in turn around the globe (Suplee, 2000). Especially the impact on temperature and rainfall, that were lacking of rainfall from the region of heavy rainfall (humid regions) and shifted heavy rain fall in the drought regions (arid regions). Indonesia and surrounding regions suffered months of drought. Forest fires burned furiously in Sumatra, Borneo, and Malaysia, forcing drivers to use their headlights at noon. The haze traveled thousands of miles to the West into the ordinary sparkling air of the Maldives

Islands, limiting visibility to half a mile (0.8 kilometer) at times (Suplee, 2000). These occurred from creating a cloud of smoke that blanketed an area more than half the size of the continental United States. The cloud sent air pollution levels soaring not only in Indonesia but in Malaysia, Brunei, Singapore, the Philippines and Thailand (cnn, 2000). These fires damaged the area above 300,000 acres, more than 5,000 people sicked from the smoke (WWF, 1998). For Thailand, every times of the strong El Niño, in the northern and north-eastern regions had rather more arid than the normal years (Pleaksawan, 1992). In the year 1998 there were very few precipitation in the northern region of Thailand; because low atmospheric pressure blew across the southern China for a long time and south western tropical monsoon blew weakly over the northern region of Thailand. There were no Tropical monsoon across the northern Thailand except the one of them named 'Penny' blew across during August 9-11, 1998. Australia and New Zealand already had seen an erratic cycle of rain and drought in 1997, especially some three fourths of New South Wales already was facing a drought (cnn, 2000). India had already faced severe drought too. According to historical records, 600,000 people died in just one region of India from the epic droughts of the 1789-1793 El Niño. In Africa the altered wind, heat and moisture patterns of El Niño portend drought-generally in the rest and extreme south (National geographic, 2000a).

Because El Niño moves the rains that would normally soak the western Pacific toward the Americas; the heavy rain fall than normal years along the west coast of South America, flooding in Peru and Sub-tropical zone of North and South America (from the southern Brazil to the central Argentina (Watana *et al.*, 1998), floods in Poland, cyclones in Madagascar, mudslides in the United states, and the heat waves in Mongolia. The giant El Niño of 1997-98 had deranged weather patterns around the world, killed an estimated 2,100 people, and caused at least 33 billion (U.S) dollars in property damage, that exceeded even that of the El Niño of 1982-83, which killed 2,000 people worldwide and caused about 13 billion dollars in damage(Suplee, 2000).

During a La Niña event, an abnormal cooling in the eastern Pacific produces conditions more or less the opposite of those created by El Niño. With so much water flowering toward Asia, the Pacific's mighty heat engine remains firmly anchored in the west, causing heavier monsoon rains in India, higher than average precipitation in Australia, and wetter than normal conditions as far west as southern Africa. The huge air masses and cloud banks associated with the hot zone also change the path of the jet streams, which move high altitude air from west to east across the

ocean. The subtropical jet stream that blows across Mexico and the Gulf during El Niño events weakens during La Niña; consequently, far less rain falls in the Gulf and southeastern states. Drought is common in the desert Southwest. Hurricanes in tropical Atlantic encounter no westerly wind resistance and therefore are twice as likely to strike the U.S. The 1998 La Niñas hurricane season was the deadliest in the past two centuries (National geographic, 2000b). Bove *et al.* (1998) analyzed all continental U.S. land falling hurricanes and intense hurricanes of this century by the concurrent phase of El Niño ; and found that the probability of at least two hurricanes striking the U.S. is 28% during El Niño years compared with 48% during neutral year and 66% during La Niña years. Likewise the probabilities for at least one intense hurricane striking are 23%, 58% and 63% for El Niño, neutral and La Niña years, respectively (Pielke *et al.* 1999). The mean annual number of U.S. hurricanes during El Niño years is 1.04, 1.61 during neutral years, and 2.23 during La Niña years (Bove *et al.*, 1998). The average damage per storm in El Niño years is \$ 800 million vs. \$ 1,600 million in La Niña years (Pielke *et al.*, 1999).

The 1997-98 El Niño marked the first time in human history that climate scientists were able to predict abnormal flooding and droughts months in advance, allowing time for threatened populations to prepare. The U.S. National Oceanic and Atmospheric Administration (NOAA) first announced a possible El Niño as early as April 1997; Australia and Japan followed a month later. By summer detailed predictions were available for many regions. In northern Peru warnings allowed many farmers and fishermen to make the best of El Niño's effects. Grass grew on land that is usually barren, and farmers raised cattle. Rice and beans could be planted in area normally too dry to support them; fishermen were able to plan for shrimp harvests in coastal waters, generally too cold for the shellfish. The potential uses of advance information are almost limitless, pointing out how governments and industries around the world can make planning for El Niño and La Niña pay off. For example, Kenyan coffee growers find their product in greater demand when droughts affect coffee harvests in Brazil and Indonesia. Palm oil production in the Philippines typically declines during El Niño, as does the squid catch off the California coast. Countries that anticipate these developments can fill the gaps and prosper.

At the very least, preparation can save lives. Even in poverty-ridden Peru constructing storm drains and stockpiling emergency supplies saved hundreds of lives during 1997 and 1998. Forewarnings brought timely international aid to such places as Papua New Guinea, where

highland populations were threatened with starvation after frost and drought combined to destroy subsistence crops. Many affected area could prepare for floods and fires, population migration, and the spread of disease (National geographic, 2000a).

The Tropical Atmosphere Ocean (TAO) array of buoys was developed in order to better describe, understand, and predict El Niño and La Niña events. The array is part of a multinational research program sponsored by the government of France, Japan, Taiwan, and The United States. The array consists of nearly 70 buoys, moored with steel cable, spanning the equatorial Pacific between the Galapagos Islands and New Guinea (U.S. Department of Commerce/NOAA/PMEL/TOA, 1999). Completed in 1994, the TAO buoys are now the world's premier early-warning system for change in the tropical ocean. They monitor water temperature from the surface down to 1,600 feet (500 meters), as well as winds, air temperature, and relative humidity.

The data collected by the buoys are transmitted to polar-orbiting satellites and then to NOAA's Pacific Marine Environmental Laboratory in Seattle. Supplemented with temperature measurements taken by research ships, the ocean and lower atmosphere. Meanwhile the TOPEX/Poseidon satellite, a U.S.-French mission begun in 1992, orbits Earth at a height of 830 miles (1,300 kilometers), measuring sea-surface elevation and relaying information about ocean circulation, including the enormous rhythmic sloshings called Kelvin and Rossby waves that travel back and forth across the entire Pacific. Climate scientists now have information of unprecedented range and accuracy, which has enabled them to confirm and expand their theories about what occurs both during normal weather patterns and during sea changes that herald the periodic and inevitable arrivals of El Niño and La Niña (National geographic,2000a).

The NCEP coupled model forecast and the latest LDEO forecast indicate that cold episode conditions will weaken during the next 3 months (counted from May 10, 2000), followed by near-normal condition during August-October and by slightly warmer-than-normal conditions later in the year. The NCEP statistical model forecast shows a similar evolution through October, but indicates near-normal conditions remaining through April 2001. Other available coupled model and statistical predictions indicate the continuation of cold episode (La Niña) conditions through the end of 2000. Thus, it is like that La Niña conditions will gradually weaken over the next 6 months and that near-normal or slightly cooler than normal conditions will be present in the tropical Pacific at the end of the year 2000 (Climate Prediction center/NCEP, 2000).

Aridness over Thailand in 1997-98 El Niño years were caused by lower sea surface temperature and higher atmospheric pressure caused south-western tropical monsoon blew weakly that made lesser rainfall and lower humidity, but temperature raised. While in winter, high atmospheric pressure from Siberia with cold-dry wind blew to the low atmospheric pressure over Indonesia and Australia. But, Northern Thailand had lower temperature, higher atmospheric pressure, caused the cold wind blew weakly. So that winter temperature were higher than normal year (less cold than normal). These affected the lower flowering of fruits such as longan, litchi and mango in normal season at the northern Thailand, especially at Chiang Mai; or continued scattering off-season flowering in some trees or some shoots on the trees.

Impact of 1998-2000 La Niña conditions for Thailand on South-western tropical monsoon that in normal years blew from Southern Indian Ocean during May to August, in the same time, the Southern hemisphere were in winter had low temperature and high atmospheric pressure. Thus, the wind blew to Asia, especially, Southeast Asia (Indonesia and Thailand) which had high temperature and low atmospheric pressure. But in La Niña year, sea surface temperature around Indonesia and the Thai Gulf were hot than normal years, air temperature above sea surface were higher, while atmospheric pressure were lower so that the south-western tropical monsoon from the southern hemisphere blew stronger that occurred more precipitation and storms in Thailand than normal years (nic. Fb4/ NOAA, 1999). In winter of the normal years cold-dry wind from Siberia which colder and higher atmospheric pressure blew to the Pacific and Southern Indian ocean. In the same time, the southern hemisphere were in Summer which lower atmospheric pressure. But in the La Niña year, sea surface temperature around Thai Gulf and Indonesia were higher temperature and lower atmospheric pressure; cold-dry wind from Siberia blew stronger and had higher wind velocity so that temperature in the winter of Thailand were lower than normal.