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STUDIES ON RIPENING PROCEDURES FOR PERISHABLE COMMODITIES INTENDED FOR THE DOMESTIC MARKET IN SRI LANKA

By

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Thesis submitted to the University of Sri Jayawardenepura for the award of the degree of Master of Philosophy in Food Science and Technology on 10th May 2002
AFFECTIONATELY DEDICATED TO

My Husband Eshan

and

My Son Avantha
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List of Papers Presented and Publications

1. A scientific paper titled "The Effect of Selected Ripening Agents on Papaya" was presented at Post Harvest 2000 on the opening day at the 4th International Conference on Post Harvest Science held on 27th March 2000 in Jerusalem, Israel. This paper has been published in the Acta Horticulture June 2001. (Number 553, Volume 1)

2. Poster presentation on "The Effect of Selected Ripening Agents on Physico-chemical Properties of Banana" was carried out at the Annual Sessions SLAAS at Peradeniya on the 30th November 2000.

3. A scientific paper titled "Influence of Ethylene Gas on Mango (variety Karuthakolomban)" was presented at the Annual Sessions SLAAS Peradeniya on 01st December 2000.

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STUDIES ON RIPENING PROCEDURES FOR PERISHABLE COMMODITIES
INTENDED FOR THE DOMESTIC MARKET IN SRI LANKA

By Fenella M.E Jayawickreme

ABSTRACT

Post harvest losses in Sri Lanka are estimated to be approximately 40-60%. Mechanical injury during transportation has been identified as one of the major causes of these losses. Loss due to mechanical injury could be reduced if fruits are transported while they are firm in texture and therefore less vulnerable to rough handling during these operations. Ripening could then be induced after transportation and prior to distribution by the whole-saler. This study was conducted in order to regularize and introduce improved handling procedures in Sri Lanka and thereby reducing postharvest loss due to mechanical injury. At present growers pick fruits at various stages of maturity while traders ripen fruits by smoking and the use of Calcium carbide.

The commodities identified for this study are Banana, Papaya, Mango and Tomato. Ripening was observed to be hastened when banana, papaya and mango were exposed to ethylene gas, while tomatoes proved to be not sensitive to this treatment. As ethylene gas in cylinders is not available in Sri Lanka and the import of the gas would not be cost effective for use by traders, an alternate method was adopted where Ethrel (2-chloroethyl phosphonic acid) and NaOH were combined to release the required ethylene gas.

The studies revealed that a dosage of 100ppm - 150ppm of ethylene gas or 0.8 mL ethrel and 0.4 g NaOH would ripen bananas of ‘Embul’ variety, in a volume of 288 L in 48 hours. The study also revealed that Embul bananas required only 18 hours of exposure time to ethylene. However, papaya (variety ‘Rathna’) and mango (variety ‘Karuthakolomban’) were exposed to ethylene for 24 hours to induce the ripening process. Both papaya and mango would be ready for consumption after four to five days after exposing to ethylene gas. To induce the ripening process in papayas (on a volume of
288L), the fruits should be exposed to 200ppm to 300ppm ethylene gas or 1.65 mL ethrel and 0.8g NaOH. Studies revealed that, to ripen mangoes on the same volume, an ethylene gas concentration of 250 ppm or 1.65 mL ethrel and 0.8g NaOH would be suitable.

A comparison study of ripening agents (ethylene gas, ethrel and calcium carbide), proved ethrel as the most suitable ripening agent to ripen bananas, papayas and mangoes. Temperature studies on these commodities indicated that the high ambient temperatures, (28±2°C) prevailing in Sri Lanka are suitable to ripen papaya and mango using ripening agents. No adverse effects on bananas of Embul (Sour) variety were observed at this temperature. However bananas ripened at 22°C were observed to be better in cosmetic appearance and quality.

With the tested domestic varieties of tomatoes, a temperature of 22±2°C induced better development of red colour, while higher ambient temperatures in Sri Lanka retarded the process, due to the conversion of lycopene to β-carotene at high temperatures. A red light (650-700nm) treatment at ambient temperature (28±2°C) on tomatoes harvested at colour turning stage resulted in development of more redness in them. The light treatment induces the formation of lycopene via the activated phytochrome. A storage study on tomato indicated that, mature green tomatoes were more suitable for long-term storage (approximately one month) while breaker stage tomato could be stored up to 2 weeks at 12°C.
Chapter 1

INTRODUCTION

Studies on Ripening Procedures for Perishable Commodities Intended for the Domestic Market in Sri Lanka.

The magnitude of postharvest losses of perishable commodities is estimated to be 40% - 60%, although Sri Lanka is abundant with a wide variety of fruits. These losses are mainly due to diseases, improper maturity, mechanical injury and over-ripening of fruits (Wilson Wijeratnam, personal com, Chandrarathna, 2000) depending on the physico-chemical nature of the commodity.

Fresh fruits are living tissues, which are subjected to continuous changes after harvest. They are highly subjected to desiccation (wilting and shriveling) and are also susceptible to attack by pathogens (bacteria and fungi) resulting in pathological breakdown due to high water content in freshly harvested fruit.

Losses due to mechanical injury are eminent, when ripe fruits are transported from the field to selling points. This can be reduced if fruits can be harvested at mature green stage, and transported in proper packaging while the fruits are firm in texture. The ripening procedure could then be carried out at the distribution point and the retailers could obtain ripe fruits from the whole saler.

Smoking and use of calcium carbide (CaC$_2$) include the conventional methods of ripening in Sri Lanka. Discolouration of fruits, bruises, microbial infections and poor appearance in smoked ripe fruit lower consumer acceptance (Sarananda, 1990). Traders in Sri Lanka are presently exploiting the advantage of being able to ripen fruits via acetylene gas liberated by CaC$_2$. Acetylene gas does not bring out the desired quality in ripening, for it only induces surface colour development, resulting in an insipid taste of the fruit (Medlicot et al., 1990; Krishnamurthy and Rao, 1981). Further, the improper use of CaC$_2$
by traders may result with accumulation of toxic impurities in the consumer, and may be hazardous to humans.

Therefore, the ripening system practised currently by local fruit handlers is not satisfactory and unpredictable in its performance. Hence, there has been a growing concern among the consumers about the safety of ripe fruits available in the market. This is especially true among the consumers in the urban areas where quality are their primary concerns. In this regard, a proper ripening system has to be established, especially for commercial operation and to complement good handling practices. Thus, research on ripening is an important component that should be carried out and which has to be given emphasis by researchers.

Ethylene gas is liberated by climacteric fruits during ripening and is referred to as the ‘natural ripening hormone’ (Abels, 1972). Induced ripening with ethylene brings about uniform ripening in all the fruits treated and ripening time could be reduced considerably (Wills et al., 2001). Flavour and texture of ethylene treated fruits are similar to that of naturally ripened fruits (Jayawickreme et al., 2000).

Therefore, ethylene gas has been given priority in the current research on ripening. Various aspects related to the use of exogenous ethylene for commercial application have been evaluated in detail. These include the influence of fruit maturity, ripening temperature, concentration of ethylene gas, duration of exposure to exogenous ethylene and initial condition of the fruits prior to ripening.

In developed countries ripening is conducted in commercial operations, by exposing them to ethylene gas in temperature and humidity controlled ripening rooms. The required ethylene is obtained via ethylene cylinders and ethylene generators. However, this method is not practical to be followed in Sri Lanka due to the high cost of ethylene gas in cylinder form. As an alternative, ethylene-releasing chemicals could be used instead, as it is simpler and cost effective. A widely available plant hormone in Sri Lanka, 2-chloroethylphosphonic acid (commercially, known as ‘Ethrel’) could be reacted with an
alkali such as NaOH to obtain the required ethylene which would induce the fruits to ripen (Kumar and Purohit, 1998).

Controlled ripening is a necessity required by supermarkets, as fruits of particular ripening stage have to be on the market shelves, until consumers remove them. This requirement too can be achieved, when fruits are induced to ripen by ethylene gas. Hence, this study was carried out to improve on current adhoc procedures adopted to ripen fruits for domestic markets in Sri Lanka.

The four commodities selected for the trials are papaya, banana, mango and tomato. Banana is the most popular and widely available fruit in Sri Lanka (Dept of Agriculture, 1995) while, Papaya and Mango (although seasonal) are much sought by consumers as dessert fruits. Tomato is widely used in salads in the Sri Lankan diet and has a high demand for commercial processing such as ketchup and puree manufacture.
Chapter 2  
Literature Survey

2.1. Ripening of Fruits:

2.1.1. Introduction:

Fleshy fruits undergo a natural stage of development known as ‘ripening’. During this phase whether the fruit is attached to the tree or harvested, it undergoes many physico-chemical changes that determine the quality of the fruit. Ripening is a spectacular event in the life of a fruit. It transforms a physiologically mature, but inedible plant organ into a visually attractive olfactory and taste sensation. Ripening marks the completion of development of a fruit and the commencement of senescence (Wills et al., 1998).

2.1.1.1. Changes that may occur during the ripening fleshy fruits:

Ripening is the result of a complex of changes; many of them probably occurring independently to each other. Some of them are, colour changes, changes in the respiration rate, changes in rate of ethylene production, changes in the tissue permeability, cellular compartmentation, softening changes in the composition of pectic substances, changes in the carbohydrate composition, organic acids and changes, protein changes, production of flavour volatiles, development of wax on the skin, seed maturation and abscission (Pratt, 1975).

2.1.1.2. Senescence:

Ripening is followed by ‘senescence’. It is the final stage in development of a plant organ, during which a series of essentially irreversible events leads to cellular breakdown and death (Wills et al., 1998).
2.1.2. Respiration:

A major metabolic process taking place in harvested produce or in any living plant product is ‘respiration’. It is the overall process by which stored organic materials (i.e. carbohydrates, proteins and fats) are broken into simple end products, with a release of energy. In the process O\(_2\) is used up and CO\(_2\) is produced by the commodity (Wills et al., 1998).

Respiration rate of the commodity is an excellent indicator of metabolic activity of the tissue and thus, is a useful guide to the potential storage life of the produce. Respiration rate, per percentage weight is highest for the immature fruits and steadily declines with age (Wills et al., 1998).

2.1.2.1. Climacteric class of fruits:

A significant group of fruits (i.e. tomato, mango, banana, apples and papaya etc.) show a variation from the described respiratory pattern, in that; they undergo a pronounced increase in respiration coinciding with ripening. Such an increase in respiration is known as a ‘respiratory climacteric’ and this group of fruits is known as the ‘climacteric class’ of fruits (Wills et al., 1998).

2.1.2.2. Non-climacteric fruits:

Fruits that do not exhibit a respiratory climacteric are known as the ‘non-climacteric class’ of fruit (i.e. pineapple, strawberry, grapes citrus fruits etc) (Wills et al., 1998).

2.1.2.3. Respiratory climacteric:

The principal difference between climacteric fruits and the non-climacteric fruits is the presence of a ‘respiratory peak’. It is the main characteristic of the climacteric fruits. The commencement of the respiratory peak coincides approximately with the attainment of
maximum fruit size. It is during the climacteric that all the other characteristic changes of ripening occur (Wills et al., 1998). Normally the fruit enters a ripe edible stage at or, shortly after the peak. The climacteric is regarded as a signal, for the beginning of the ‘end’ in the life of the fruit, at the cellular level (Biale and Young, 1981). After the climacteric, the respiration slows down, as the fruit ripens and develops good eating quality (F.A.O training manual, 1989).

A close examination of the respiratory course of a climacteric fruit at a suitable temperature shows a declining trend to the lowest value termed as the ‘pre climacteric minimum’ followed by a more, or less sharp rise, depending on species to the ‘climacteric peak’ and a subsequent ‘post climacteric’ decline in rate of respiration (Biale and Young, 1981).

2.1.2.4. Phases of the climacteric:

![Figure I. Growth, respiration and ethylene production patterns of climacteric and non-climacteric plant organs (Wills et al, 1998) ](image-url)
The mature fruits, of the ‘climacteric group’ pass through three successive phases.

1) **Pre climacteric phase** - is of a relatively low metabolic activity, regarded as the ‘green life’. Duration of this stage depends on the variety and on the physiological stage of the fruit at which it was harvested, temperature, relative humidity and atmospheric composition.

2) **Climacteric phase** – The ripening phase itself.

3) **Senescent phase** – The phase during which the metabolism slows down, fruit quality deteriorates and pathogens are liable to develop.

The respiratory climacteric as well as the complete ripening process may proceed while the fruit is either attached or detached from the plant (Wills *et al*, 1998).

**2.1.2.5. Energy for Ripening and the Respiratory Climacteric:**

Today the ‘respiratory climacteric’ is to be seen quite generally in the context of the raised energy needs for ripening (Kumar and Purohit, 1998). One of the first phenomena at the beginning of the climacteric in apples is the disappearance of free fructose from the cytoplasm. This is attributable to the phosphorylation. A simultaneous change in tonoplast permeability is thought to permit further fructose to reach the cytoplasm from the vacuole. The stream of fructose is viewed, as the cause of the increased respiration.

The rate of the respiration is controlled by the concentration of phosphate receptors; mainly ADP. The rate of respiration is low if the ATP/ADP ratio is very great. The climacteric rise in respiration would be interpreted as the result from raised energy requirement at the beginning. With this, the splitting of ATP occurs and the resulting elevation of the ADP level accelerates the respiration (Kumar and Purohit, 1998).
2.1.3. Activity of Ethylene:

'Ethylene' is considered as a natural agent and a natural hormone and is physiologically active in trace amounts. It also plays a major role in abscission of plant organs. It is one of the simplest organic compounds that have an effect on a physiological process of plants.

\[
\text{H} - \text{H} \\
\text{H-C = C-H} \quad \text{The Ethylene Molecule}
\]

Ethylene is an unsaturated hydrocarbon and is a major product of the petroleum industry. The gas acts as a plant hormone. Ethylene is a natural product of plant metabolism and is produced by all tissues of higher plants.

Generally \( \text{C}_2\text{H}_4 \) production rates increase with maturity at harvest, physical injuries, disease incidences, increase of temperature up to 30°C and water stress. Exposure to ethylene accelerates the senescence of fruits (Kader, 1992).

2.1.3.1. Ethylene Production of Climacteric Fruits:

Ethylene is produced in all the cells particularly in the higher plants. A concentration of 0.01 ppm can be found in any tissue. The mechanism necessary for the production of ethylene is available in the fruits from the beginning (Abels, 1972). It is formed in the fruits, thus does not have to be transported from other parts of the plant. However, climacteric set fruits produce much larger amount of ethylene during ripening than non-climacteric fruits (Wills et al., 1998).
2.1.3.2. Exogenous Ethylene Effects:

The use of applied ethylene, with mature, but pre-climacteric fruits triggers the formation and increase of ethylene in such fruits. It was shown that a treatment with ethylene brings about a shift in time when the on-set of the rise in respiration occurs, without altering its shape. Applied ethylene shortens the time required to reach the climacteric and stimulates the early production of the endogenous ethylene. Exogenous ethylene is effective if applied, only during the pre-climacteric stage prior to the natural burst of ethylene production by fruits (Friend and Rhodes, 1981). In a climacteric fruit, if a concentration of this gas is applied over a period, to cause a respiratory rise, no return to the pre-climacteric stage would occur upon removal of the gas. Burg and Burg (1965) showed that ripening can also be delayed by removing C_2H_4 from tissues of fruits in pre-climacteric stage.

For climacteric fruits, the magnitude of the climacteric is relatively independent of the concentration of the applied ethylene and causes a single increase in respiration (Wills, 1998). This gas is best used in concentrations of 100 to 1000 ppm concentrations, in order to speed the rate of ripening. This results in the final concentration of ethylene in fruits, as 0.1 ppm or higher (Lee 1983).

2.1.3.3 Ethylene Biosynthesis:

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2.1.3.3 Ethylene Biosynthesis:

For climacteric fruits, the magnitude of the climacteric is relative...
The unraveling of biochemical pathway of ethylene biosynthesis in plants found by Yang (1991) as shown in Figure II. has been one of the most interesting biochemical stories of recent years (Reid, 1992). This finding has been greatly beneficial in improving the efficiency of agricultural systems, by being able to regulate ethylene responses.

Before ethylene can exert its effects, it has to be biosynthesized by the plant or supplied from an external source. As in the case of other hormones; ethylene is thought to bind to a receptor, forming an activated complex; which in turn initiates the chain of reactions leading to a wide variety of physiological responses.

2.1.3.4. Pathway of Ethylene Biosynthesis:

Adams and Yang (1979) elucidated the following sequence of ethylene biosynthesis as shown in Figure III, for ripening of apples, and this pathway has since shown to be in operation, in all other tested plant tissues (Yang, 1991). Lieberman and Ried (1992) was the first to report that methionine could be the starting material for ethylene production. The conversion of SAM (S-adenosyl methionine) to ACC (1-aminocyclo-propane-1-carboxylic acid) by enzyme ACC Synthase is thought to be the rate limiting step (i.e. key step) in the biosynthesis of ethylene (Wills et al., 1998).

It has been observed that, very little ethylene was produced in pre-climacteric avocado, where the ACC content was very low. As ripening began, there was a parallel increase followed by a fall, in both the ACC content and the ethylene production rate, indicating a close relationship between the two. The increase in ACC content was due to the development of ACC synthase activity as demonstrated in tomato tissue by Kende and Boller (1980).

The enzyme that converts ACC to ethylene, which is the 'Ethylene Forming Enzyme' (EFE) is also limited in pre-climacteric fruit tissue, but its activity usually start to increase before, the development of ACC synthase (Yang, 1987). Addition of ACC to pre-climacteric (unripe) fruit, generally results in only a small increase in ethylene
evolution, showing that, EFE (or known as ACC oxidase) is required to convert ACC to ethylene. This is a labile enzyme that is sensitive to oxygen (Wills et al., 1998).

Figure III. Pathway of Ethylene Biosynthesis (Redrawn from Yang, 1987)
Burg and Thimann (1959, 1961) too observed that apple tissue stopped producing ethylene, when it was kept in nitrogen, but showed an accelerated rate of ethylene production when it was returned to air. EFE is inhibited by anaerobiosis, temperature, above 35°C and cobalt ions (Wills et al., 1998).

It has been determined that, C-1 of the methionine gives rise to CO₂ while C-3 and C-4 give rise to ethylene. The methyl carbon, the sulfur and the C-2 of the molecule remain in the tissue and are metabolized widely (Lee, 1983).

Peiser et al (1984) have shown that during the oxidation of ACC to ethylene, which is derived from C-2 and 3 of ACC, the carboxyl group of ACC is liberated as CO₂, where as C-1 yields HCN. It is believed that the cyanide does not get accumulated, because it is effectively rapped by the activity of β-cynolamine synthase ubiquitous in ethylene production tissues. HCN thus formed, is rapidly metabolized to β cyanoalanine and then to aspargine.

\[
\text{ACC} + \frac{1}{2} \text{O}_2 \rightarrow \text{C}_2\text{H}_4 + \text{HCN} + \text{H}_2\text{O} + \text{CO}_2
\]

2.1.3.5. Methods of Ethylene Formations in Fruits:

Ethylene is produced in plants naturally via many methods.

a) Ethylene Induced Ethylene Production:

Ethylene itself has an effect on its own synthesis. It promotes, the last step in the biochemical pathway; the conversion of ACC of ethylene, apparently by inducing the synthesis of ethylene forming enzyme (EFE). This is the basis for the massive increase or 'autocatalysis' of ethylene production that occurs with fruit ripening. The 'preclimacteric' fruit is devoid of both ACC synthase and EFE. With the onset of ripening the activity, the ACC synthase, ACC level as well as EFE activity increase. Hence, both ethylene and ACC rapidly increase and then decrease depending on the ripening stage (Kumar and Purohit, 1998). It is also reported by the same authors that
C₂H₄ biosynthesis is controlled by the formation of polyamines from S-adenosyl methionine (SAM), a precursor of ACC and C₂H₄. On withdrawal of the C₂H₄ precursor, the products of the reaction polyamines inhibit C₂H₄ production. Conversely, inhibits polyamine production.

b) Stress and Ethylene Production:
Plants when subjected to stress produce ethylene. Such stresses may be disease, radiation, mechanical wounding and chemicals.

- Disease:
In infected plant organs, the rate of respiration is increased with that of ethylene production. This may be referred to as a ‘pseudo climacteric rise’—sudden increase in respiration before death.

c) Mechanical:
Wounding of plant organs generally results in a temporary, localized burst of respiration and cell division, formation of ethylene gas, and rapid turnover of certain cellular constituents and sometimes results in accumulation of certain secondary metabolites or products that appear to have protective function. In flesh organs, the wound cells commence synthesis of messengers RNA and proteins. Although the impact of wound physiology on plant food commodities is not fully understood (Fennema, 1985). However, recent work shows that ACC is also a useful precursor of C₂H₄ in wounded plant tissues and that C₂H₄ formation is based on the rapid enhancement of the activity of ACC synthase, a key enzyme of C₂H₄ biosynthesis (Kende and Boller, 1980).
2.1.3.6. The Two Systems for Regulation of Ethylene Biosynthesis:

McMurchie et al (1972) introduced the concept of two systems for ethylene production.

**System 1**: Ethylene production system that is in operation up to the initiation of ripening. This perhaps is initiated or controlled by an unknown factor that is probably involved in the regulation of senescence.

**System 2**: Ethylene production system induced for the process of fruit ripening. (autocatalytic ethylene production system)

The induction of system 2 ethylene is also called ‘autocatalytic’ ethylene production, because its production is stimulated by ethylene itself, triggering further production. Thus, system 1 triggers system 2, which is responsible, during ripening of climacteric fruits for the production of the large amounts of ethylene that are necessary for the full integration of ripening (Wang, 1988; Wills et al., 1998).

In climacteric fruits ethylene treatment accelerates the system 2 ethylene production, the accompanying rise in respiration and the onset of ripening, without appreciably altering the climacteric pattern or the magnitude of respiration. However, in non-climacteric fruits, the respiratory activity is stimulated as a function of ethylene concentration, but there is no increase in ethylene production, nor any distinct ripening changes associated with this rise (Wang, 1988).

2.1.3.7. Mode of Ethylene Sensitivity of Cells to Ethylene:

Probably all plants produce ethylene. Although, all cells are exposed to ethylene at some stage they are not equally affected; and many cells that respond to ethylene do so only at certain stages of development. The affected cells at that particular time, possess a particular molecular component (a receptor), that recognizes and responds to ethylene. Ethylene is thought to bind to these receptors, enabling a primary reaction that initiates
other reactions. No direct evidence is available about the nature of ethylene binding. However, indirect evidence suggests that ethylene binds reversibly to a metal containing receptor site which exists in a variety of plant species. Whether some or all of them are requisite for the action of C₂H₄ cannot be stated with certainty at present (Kumar and Purohit, 1998). Osborne et al (1985) suggested that, there are three general types of ethylene target cells, which have three distinct growth responses to ethylene and other hormones.

2.1.3.8. Ethylene binding:

Current research is investigating the way in which ethylene induces such a range of effects. As shown in Figure 4, the most favoured model is that, ethylene binds to a protein receptor called a binding site, thus stimulating a release of a so-called second message instructing the DNA to RNA molecules (messenger RNA) specific to the effects of ethylene. These molecules are translated into proteins by polyribosomes and proteins so formed are enzymes that cause the actual ethylene responses (Reid, 1992). This action is also shown by a modification of the endoplasmic reticulum. It indicates a change in protein synthesis or transportation of protein (Prasad, 1999). Dilworth (1986) found that ethylene influences the expression of genes (i.e. DNA to mRNA), at the transitional level and the post translated level (i.e. mRNA to protein) (Kumar and Purohit, 1998).

In the preclimacteric fruit, the responsiveness to ethylene for ripening varies with different species (i.e. according to the commodity), with different maturity stages of the same species (i.e. many fruits become more sensitive to ethylene as the fruit matures), whether they are attached to the tree or not (i.e. Avocado fruits do not ripen while attached to the tree). The variations reflect the differences in the sensitivity of different fruits to ethylene. An increase in the binding affinity to the receptors or an increase of receptors in these fruit organs during development could account for the increase responsiveness to ethylene (Yang, 1991).
2.1.3.9. Ethylene Binding Site:

Primary action site of ethylene may be ribosomes. The first evidence about the sites was found by Shimokawa and Kasi (1968). They found in their research that ethylene $^{14}\text{C}$ was fixed into high molecular immobile molecules in the leaves of Morning Glory plants. It was shown that ethylene has a high affinity for ribosome RNA and some affinity for ribosomal protein (Shimokawa and Kasai, 1968). They consider that the incorporation of ethylene into high molecules may induce a conformational change. In support of this, Freytag (1977) too published their research data. Ribosomes in ethylene treated cotton and sugar beet radicles were larger than ribosomes in control and nitrogen treated cells. The ribosomes in ethylene treated plants were swollen and less dense. The swollen ribosomes observed in electron micrographs of ethylene treated materials underwent conformational changes as was indicated by significant differences in sedimentation patterns.

Figure IV - Mechanism of Ethylene Action (Ried, 1992)
2.1.3.10. Quantity of Ethylene Receptors in Cells:

A calculation of the amount of ethylene receptors in plant tissue by Abels (1973) revealed, 10mg per metric ton or approximately 500 attachment sites per cell, assuming the receptor has a molecular weight of 100,000. Sisler (1979) estimated 4,000 binding sites per cell.

2.1.4. Influence of Other Compounds on the Receptors:

From kinetic studies on the responses of plant tissue to added ethylene, it has been proposed that the affinity of the receptor for ethylene is increased by the presence of O₂ and decreased by CO₂ (Wills et al., 1998).

CO₂ prevents or delays many ethylene responses when ethylene concentrations are below 1ppm. The mechanism of action is not known, but CO₂ has been suggested to be the competitive inhibitor of ethylene action, presumably by competing with ethylene for a binding site (Burg and Burg, 1967).

2.1.4.1. Molecular Requirement of Ethylene Analogues on the Binding Sites:

Certain chemical analogues of ethylene causes similar reactions that of ethylene, although far less biologically active. Propylene causes similar reactions, but 100 times the amount is needed compared with ethylene, while the need for acetylene is 3000 times greater than ethylene. Vinyl chloride, carbon monoxide, and 1-butene also bring out similar reactions that of ethylene although the activity is lower than ethylene (Kumar and Purohit, 1998) Burg and Burg (1965) discovered that this was due to the chemical structure of the above mentioned compounds resembling ethylene in certain ways. The molecular requirement to mimic ethylene should be that these compounds should be unsaturated compounds having an unsaturated bond adjacent to the terminal carbon atom. The activity of the compound is inversely proportional to the size of the molecule. CO₂ having a close
structural analogue to ethylene therefore, is a competitive inhibitor of ethylene action; and the effects are opposite to that of ethylene (Kumar and Purohit, 1998).

2.1.5. Ethylene Releasing Compounds:

Ethylene as a gas, that can only be stored more or less in closed systems, and the inconvenience limits the usefulness of this hormone. Liquid or solid ethylene releasing compounds would prove to be easier to handle by workers, although a closed system is necessary during the treatment period. Although many chemicals are available that release ethylene in aqueous solutions, the best known compound is ‘Ethrel’ (2-chloroethylphosphonic acid).

2.1.5.1. Ethylene Evolution from 2-Chloroethylphosphonic Acid:

Ethrel (2-chloroethylphosphonic acid) is a naturally occurring growth regulator which triggers the ripening process (Production technology home page). Stability of 2-chloroethylphosphonic acid breaks down, in the presence of a base, to form ethylene, with an apparent release of chloride and phosphonate. According to Warner and Leopold (1968) no optimum $p^H$ for ethylene evolution has been observed, but rather an increasing evolution with increasing $p^H$ was detected. However, the minimum $p^H$ at which ethylene evolution observed was $p^H 5$. In buffered solutions, ethylene evolution proceeds linearly with time for the first 7 hours (Warner and Leopold, 1968).

\[
\begin{align*}
\text{Cl} - \text{CH}_2 - \text{CH}_2 - \text{P} - \text{OH} + 2\text{NaOH} & \quad \text{H} - \text{C} = \text{C} - \text{H} + \text{NaCl} + \text{NaHPO}_3 + 2\ \text{OH}^- \\
\text{OH} & \\
\end{align*}
\]

(Warner and Leopold, 1968)
2.1.6. Hormonal Regulation of Fruit Ripening:

Five categories of plant hormones are known today which regulates fruit ripening. (i.e. Auxins, Cytokinings, Gibberellins, Abscisic Acid and Ethylene.) (Kumar and Purohit, 1998).

a) Auxins : Auxins must be broken down to make ripening possible. The peroxidases, primarily IAA oxidase, degrade the endogenous auxins and thus control fruit ripening. It is only when the auxins have largely disappeared; the tissue becomes sensitive to ethylene. In many climacteric and non-climacteric fruits ripening is accompanied by a rise in auxin degrading enzymes.

b) Cytokinings : Protein degradation is prevented by cytokinings rather than it is stimulated.

c) Gibberellins : It was found that gibberellins inhibit the degradation of chlorophyll and delay accumulation of carotenoids. In bananas, a treatment with gibberellins inhibits yellowing, while all other maturation processes are not affected.

d) Abscisic Acid( ABA) : Before the first visible phenomena of ripening, there is in many fruits an accumulation of abscisic acid. (ABA). A series of findings, underlines the importance of this ‘phytohormone’ a regulator of fruit ripening. In harvested apples, the ABA content increases tenfold within five days. At the beginning of the ripening process, higher ABA concentrations are found in the inner part of the fruit flesh of green tomatoes than in the outer part. Tomatoes ripen in a centrifugal direction. With progressive ripening, the relationship is reversed. ABA concentration falls again in the inner parts, which are already ripe. The Ripening of tomatoes is thus associated with an ABA wave, across the sectional area. Hence, there is a correlation between ABA and ethylene production in ripening fruits. However, it is not clear, whether ABA induces ethylene synthesis under natural conditions (Kumar and Purohit, 1998).
2.1.7. **Enzyme Regulation and its Effects on Fruit Ripening**

In recent years highly intensive research has been carried out on the changes in enzymal activities and the enzymal pattern during fruit ripening (Kumar and Purohit, 1998). It is obviously essential for the initial stages of the maturation processes that, there is a coordinated synthesis of specific enzymes with a simultaneous degradation of proteins which are not required. It has been shown that enzymes can undergo qualitative changes during the process of ripening. The progressive increase in softness together with a change in colour of the skin or flesh, and a production of a wide spectrum of aroma compounds, are some of the most easily recognizable changes that accompany ripening in climacteric fruit (Hobson, 1981).

2.1.7.1. **Changes in the Cell Walls During Growth and Ripening**

The bulk of fruit tissue is composed of parenchymal cells which expand considerably during growth, so that at maturity their walls are thin and their shape results in the formation of intercellular spaces. Near ripeness the pericarp cells become very large and cell separation much more complete, but within the cell the plasma lemma and the tonoplast remain intact both physically and physiologically (Friend and Rhodes, 1981). In unripe avocados, the middle lamella is quite obvious and fibrils are packed tightly in an orderly array on both sides of the middle lamella (Pesis, 1978). However, in post climacteric fruits no middle lamella was observed and many of the fibrils were missing (Hobson, 1981).

2.1.7.2. **Changes in Permeability**

It has been found that tissue slices from ripening fruits release increased amounts of dissolved substances into the medium (Kumar and Purohit, 1998). This is attributed to the raised permeability, and is quite generally an early sign of incipient senescence. Permeability in fruit tissue begins long before the start of the climacteric and is not
causally linked with it. By ethylene treatment, the respiratory climacteric can be induced without a simultaneous change in tissue permeability (Kumar and Purohit, 1998).

2.1.7.3. Starch, Sugar and Acid Transformations:

Carbohydrates contribute the major amount of energy needed for respiration. During the climacteric, polysaccharides such as starch change into sugars and carbon dioxide from respiration into acids (Kumar and Purohit, 1998).

a) Sugars: The sugars of apples, pears etc. consist mainly of fructose. Lower amounts of two enzymes involved in the synthesis of sucrose in potatoes, are sucrose synthetase and sucrose phosphate.

b) Acids: Prior to the ripe stage, CO₂ is synthesized into acids. When ripeness is reached the CO₂ converts into acids, although in lesser quantities. However, citrus fruits are usually ripened on the trees and the mature stage contains no starch. Therefore, the sugars present are probably derived from pectins and hemicelluloses and also from the fruit acids, since the amount of acid in oranges and grapefruits decreases in quantity during the ripening process. Post-harvest apples decrease in titratable acid as ripening progresses. The acid predominantly found in mature apple is malic acid. However, in earlier stages L-quinic acid is found (Lee, 1983). Organic acids are in a constant state of flux in post-harvest plant tissues and tend to diminish during senescence. Much of the loss is undoubtedly attributable to their oxidation in respiratory metabolism as suggested by an increase in respiratory quotient (Fennema, 1985). Therefore, usually organic acids decline during ripening, as they are respired or converted into sugars. Acids can be considered as a reserve source of energy to the fruit, and would therefore be expected to decline during the greater metabolic activity that occurs with ripening (Wills et al., 1998).

Apart from their general importance to flavour, texture and colour, certain organic acids appear to modify the action of plant hormones and thereby are implicated in control of ontogenic changes (Fennema, 1985).
2.1.7.4. RNase and RNA Metabolism:

In many fruits the maturation process is accompanied by an increased RNA synthesis. In apples which have been picked, the RNA content at the beginning of the climacteric, increase about 50%. This raised RNA synthesis is restricted to a relatively short period at the beginning of the climacteric and goes down again at the height of the climacteric. Fruits which show a rise in RNA concentration at the beginning of the ripening process also exhibit an elevation of the protein content. Results of studies using labeled precursors make it probable that this extra content of protein is attributable to new synthesis. This new synthesis is also necessary for the ripening of many fruits (Kumar and Purohit, 1998).

2.1.7.5 Chlorophyll Degradation:

Changes in the chloroplast structure during degreening of citrus fruits treated with ethylene were examined by Shimokawa and Kasi (1968). The number of chloroplasts decreased with ethylene treatment and tree ripening. Reduction in the chloroplast size was a characteristic feature of ethylene treated fruits. They lost grana and lamellar systems. In the chloroplasts of ethylene treated fruits, the double layered structures were degraded and membrane layers became separated from each other (Freytag, 1977).

2.1.7.6 Biogenesis and Degradation of Aromatic Compounds:

The characteristic flavour of fruits is determined by a complex spectrum of organic compounds. Aroma of fruits is generally caused by esters, aldehydes, ketones etc. In certain tissues, flavour precursors are enzymically converted to flavour compounds, when the cells are disrupted by mechanical injury (Kumar and Purohit, 1998).
2.1.8. Conventional Methods of Ripening:

In biblical times, as written in the book of Amos 7: 4, the farmers scarified the skin of young sycamore figs to produce rapid ripening of the fruit. This response is now known to be due to the increased ethylene production by the wounded fruit (Reid, 1992). Since then different methods are being used in the world over to ripen fruits. In India fruits are covered by dry straw or paper cutting or held in wooden boxes for ripening purposes. In this practice, heat is conserved and the ethylene produced by contaminating fungi is sufficient to stimulate the ripening (CFTRI, – 1990)

2.1.8.1. Smoking:

In Sri Lanka, bananas are generally ripened by the traditional practice of smoking for 24 to 36 hours, and subsequently storing at room temperature. Smoking appears to accelerate ripening process in green and unripe bananas due to presence of hydrocarbons in smoke. Burnt scars, microbial infections and poor appearance of smoked ripe fruit lower consumer attraction (Sarananda, 1990). In addition to the hydrocarbons in the smoke, heat is thought to induce ripening.

2.1.8.2. Use of Leaves to Induce Ripening:

Leaves of Billing fruit, (Averrhoa bilimbi), Glirisidia (Gliricidia maculata) and kappetiya (Crotolaria retusa) are used to ripen fruit; by sealing fruits with the leaves or adding them to smoke. It is assumed that these leaves contain hydrocarbons that ripen fruits.

2.1.8.3. Calcium Carbide (CaC₂):

CaC₂ is being used commercially today in Sri Lanka to ripen fruits. The advantage of being able to use CaC₂ is being exploited by profit minded traders. This adhoc use of CaC₂ is thought to cause a great health hazard to the consumers as it contains many impurities.
2.1.8.3.1. Toxicity of CaC\textsubscript{2}:

CaC\textsubscript{2} is imported to Sri Lanka from countries such as, South Africa, China and Korea. It is contaminated by impurities although used by traders to ripen fruit. These impurities may produce additional hazards. The impurities such as calcium phosphate or calcium arsenate may, when moistened give off phosphine and or arsine, both of which are extremely toxic (Encyclopaedia of Occupational health).

However more toxicity comes from the powder that remains from CaC\textsubscript{2} after C\textsubscript{2}H\textsubscript{2} gas is liberated. These impurities are fat soluble. If these residuals come in contact with the waxy layer in fruit, the impurities may get dissolved and penetrate the dermal layers of the fruit and get lodged in the fruit. Although, the concentration of these impurities may be very low, it may have an accumulative effect on the health of consumers, as fruit are consumed daily (Sarananda, 1996).

2.1.8.3.2. Advantages and Disadvantages of Ripening with CaC\textsubscript{2}:

**Advantages:** During the past decade traders have got used to the CaC\textsubscript{2} method of ripening fruit, and it is now being commercially used. This is to overcome the problem of non-uniformity and delayed ripening of fruits (i.e. mango, papaya etc) in order to catch the early market for higher returns. For reasons mentioned above traders do not avoid artificial ripening of fruits with CaC\textsubscript{2}. However, impurities in the carbide can be avoided, if traders would wrap up the required amount of carbide with news paper and place it among the fruits.

**Disadvantages:** However, consumers are of the view that when fruit are ripened with CaC\textsubscript{2}, they loose their real quality and people fail to appreciate the real flavours and aromas of the fruit, as the carbide ripened fruit are insipid in flavours. Due to the exothermic nature
of the CaC$_2$/H$_2$O reaction, a large amount of heat is generated. This heat would have a cooked effect on the fruit and reduce the quality.


2.1.8.3.3. Legality of Using CaC$_2$ for Ripening in Sri Lanka:

As the CaC$_2$ used for ripening fruits it only induces surface colour development, and use of it is hazardous; it has been banned by CCFS (Central Committee for Food Safety) in India.

The gazette of the Democratic Socialist Republic of Sri Lanka published on the 14th of October 1993, under clause 26 says that ‘No person shall sell, use, offer or expose for sale or have in his possession for the purpose of sale or for use as an ingredient in the preparation of any food intended for sale, any fruit which has been artificially ripened by the use of acetylene gas commonly known as carbide gas’.

2.1.9. Visible Radiations and Photosynthetic Pigments:

2.1.9.1. Light Energy:

The ‘radiation’ is the propagation of electromagnetic energy through space. Quantum mechanics established that light has properties both of wave and particles. When it interacts with matter, light can be thought of as discrete packets of energy or quanta that are called photon (Kumar and Purohit, 1998).
2.1.9.2. Action and Absorption spectra:

The visible radiation produced by the sun is a form of energy. These are various forms of sunlight (wave lengths). In order for light energy to be used full in any biological process, it must first be absorbed and converted to a form of chemical energy useful to the cell. But a given molecule will not absorb light of just any length of energy level. Rather, light is absorbed only when the photon is of just the right energy level to move an electron from one energy level to another more energetic level (Kumar and Purohit, 1998).

2.1.9.3. Phytochrome:

Phytochrome (Greek-phytos, plant, and chroma, a colour) is the pigment that receives the photoperiodic signal and plays a key role in many processes. It contains phycobiliproteins as pigments. These pigments are proteins with a tetra-pyrrole structure of the phytochrome chromophore, and are photoconvertible. Its structure and proportions change with the wave length of incident radiation. It exists in a form with maximum absorption in the red at 660nm ($P_r$), as well as in a form with its absorption peak in the far red at 730nm ($P_{fr}$). Irradiation with light of the wavelength of its absorption maximum
results in a conversion, via one or more intermediates in to the other form. The mechanism of this process is suggested to be a proton transfer. Phytochrome is believed to take part in the generation of changes of membrane potentials in conjugation with two plant hormones. The pigment displays various other regulatory functions such as enzyme synthesis (Kumar and Purohit, 1998; Prasad, 1999).

2.1.9.4. Absorption Patterns of Phytochrome:

Phytochrome exists in two forms. One ($P_r$) predominantly absorbing red light at 660 nm and the other ($P_{fr}$) predominantly absorbing for red light at 730 nm. The $P_r$ was converted to $P_{fr}$ on absorption of red light, while $P_{fr}$ was converted back to $P_r$ on absorption of far-red light. In many plants $P_{fr}$ is converted to $P_r$ during long period of darkness. $P_{fr}$ may be destroyed, as well as being converted to $P_r$. Both $P_r$ and $P_{fr}$ also absorb violet and blue light, but low irradiance levels of these wave lengths are much less effective than red and far-red light for the physiological studies (Kumar and Purohit, 1998).

2.1.9.5. Phytochrome Induced Pigment Formation:

Synthesis of both carotenoids and anthocyanins in ripening fruit is controlled by the phytochrome system. In both cases, the phytochrome does not act directly on the pigment formation, but probably influences in the first instance of phyto-hormones which
(i.e. ABA – Abscisic acid), in turn regulates the pigment synthesis (Kumar and Purohit, 1998).

2.1.9.6. Phyto-hormones act as a regulate of fruit ripening:

In ripening tomatoes, relationship was also discerned between the phytochrome system and the endogenous ABA concentration. The proportion of lycopene constitutes a measure of the degree of ripeness. When the fruits are illuminated with red light the ABA content first rises, reaches a maximum after 5 days and then falls. Lycopene synthesis parallels the rise in ABA.

ABA, thus appears to be a trigger of lycopene synthesis. The change in the ABA in tomatoes must be attributed to a phytochrome effect. From the presently available data it is concluded that Pₘ (the morphologically active form of phytochrome) allows the ABA concentration to rise, resulting in induction of the enzyme of carotenoid synthesis. Illumination with red also accelerates ethylene formation (Kumar and Purohit, 1998).

2.1.10. Pigments in Fruits:

![Structures of β Carotene and Lycopene](Kumar and Purohit, 1998)

Figure VI. Structures of β Carotene and Lycopene (Kumar and Purohit, 1998)
The colour of fruits is very important from the point of view of ultimate quality of the product. The chief pigments which impart the colour in fruits are carotenoids, chlorophylls, anthoxanthins and anthocyanins. The green colour masks the yellow and the red colour of the carotenes except in very young leaves in which the chlorophyll content is less.

The carotenes \((\text{C}_{40} \text{H}_{56})\) exist as \(\alpha\), \(\beta\) and \(\gamma\) carotens and lycopenes. Some of the carotenes in nature are important as precursors of vitamins. Carotenes contain two \(\beta\) ionine rings, whereas the others poses only one \(\beta\) ionine ring and therefore, have less activity. The red colour in tomato is due to the pigment lycopene. Lycopene is also present in pink fleshed Guava, Papaya, Grape fruit and Orange (Rangana, 1986).
2.2. Banana:

2.2.1. Introduction:

Bananas are the 4th most important (in order of preference by consumers and produced) fruit, after Apples, Citrus fruits and Grapes. It is considered as the most popular fruit in Sri Lanka. This fruit is widely available throughout the country (Dept. of Agriculture, 1995). ‘Kolikuttu’, ‘Anamalu’, ‘Ambun’ and ‘Sugar bananas’ are the most common varieties cultivated in Sri Lanka. However, ‘Embul’ or ‘Honderawala’ (*Musa acuminata*), is the main variety grown in Sri Lanka (CISIR Post Harvest booklet 3). Most cultivars of the edible bananas and plantains are derived from *acuminata* (A) and *balbisians* (B), genomes of *Musa acuminata* and *Musa balbisians* (Simmonds and Shephered, 1995). The ‘Embul’ type banana grown in Sri Lanka belongs to AAB group (Devarajah, 1990).

Bananas are transported to the whole sale markets in Sri Lanka (*i.e.* Manning market-Colombo, Dambulla and Kappettipola) from growing areas such as Embilipitiya, Dambulla and Mahaweli areas. The bananas are ripened mainly by exposure to smoke, after arrival at the whole sale markets. The shelf lives of the smoked ripened bananas are short due to over-ripening, mechanical injury and other problems that may occur due to the heat in smoke. Mechanical injury of bananas after ripening is estimated to be approximately 30% (Chandrarathna, 2000).

2.2.2. Fruit Development:

The initiation of the fruit bud in the plant starts the life of a banana fruit. The banana fruits are arranged in combs or hands on the single inflorescence, which is collectively known as a fruit bunch. Each hand has a crown to which 20 fruits or fingers are attached. Due to increasing weight of the developing fruits, the peduncle of the inflorescence bends down. Bananas are elongated, somewhat angular and carry a short pedicel. The final shape and the size of the fruits are typical of the variety.
2.2.3. Harvest Maturity:

Generally, the definition of maturity (which is based on the ability of the fruit to ripen) varies individually. Peacock and Blacke (1970) defined maturity in physiological terms as the ‘stage of biochemical development, that a fruit has reached when climacteric rise begins’. An alternate definition is which a grower may consider appropriate, is the stage of growth that enables maximum yield, but allows the fruit to reach the market in a green condition (Turner, 1997). Many strategies are used in practice to estimate harvest maturity of banana such as:

2.2.3.1. Caliper grade:

Measuring the caliper grade of the fruit is widely used by commercial companies, to decide whether the bunch is ready for harvest or not (Stover, 1972). The appropriate caliper grade needs to be determined for each cultivar, location and market.

2.2.3.2. Angularity:

A common and long used criterion is that of ‘fullness’. This is a visual estimation of the angularity of this fruit. Thus for distant markets, fruit may be harvested when three quarters full. For closer market ‘full fruit’ is acceptable. Over full fruit may have split peels or some ripe fruits in the bunch (Thompson and Burden, 1995).

2.2.3.3. Pulp: Peel ratio:

The measurement of the ratio of the fresh weights of the pulp and peel is a very useful technique for estimating the stage of fruit growth in experiments. The pulp: peel ratio (Pp) increases as the fruit grows because pulp growth increases exponentially, but the growth rate of the peel begins to decline, especially towards commercial maturity. When Pp reaches 0.5 the fruit is able to ripen. Fruits can be harvested when Pp is between 1.2 and 1.6 (Simmonds, 1966). For ‘Gros Michel’ banana pulp: peel is 1:17 when the fruit is
three quarters full and 1.3 when it is round full (Deullin and Monnet, 1956). However this method cannot be practiced, as it is destructive.

2.2.3.4. Bunch Emergence – Harvest Interval:

The time taken for a bunch to pass from emergence at the top of the pseudo-stem (bunching, shooting), until harvest is the ‘emergence – harvest interval’. (This is referred to as Eh) Emergence can be defined, as the day on which the first completed hand of fruit is visible. Duration of Eh is particular, and varies with the locality; cultivar and market but they can provide a very helpful indication of the harvest maturity. Placing bunch covers with uniquely coloured tags of different colours, on bunches emerging in a particular week, allows bunches that have reached the required Eh to be easily detected.

Montoya et al (1984) evaluated this approach in Equador for eliminating fruit that would ripen on transit. They established relationships between bunch age and green life. These relationships were sometimes quite strong but varied from one harvest date to another. Nutritional factors contributed to the variation in green life amongst fruit of the same age (Turner, 1997).

2.2.3.5. Maturity Indices for Embul Banana:

Wilson et al (1993) determined maturitiy indices for Sri Lankan variety of Embul bananas, as the traditional method used in Sri Lanka to assess maturity and time of harvest via the criterion of loss of angularity of fruits, led to heavy post harvest losses. They determined the age of the bunch, by a method of tagging, which commenced with the emergence of the second hand. The bunch was considered to be one week old at that stage.

Results from their study showed that the physiological maturity of Embul bananas occur between 9 and 11 weeks stages of maturity. Fruits for air freight and export markets may be harvested at 12 weeks, while 13 weeks maturity is acceptable for most domestic markets. While fruit weight increased considerably between weeks 10 and 11, fruit
curvature, pulp to peel ratio, diameter and carbohydrate content (as % glucose) showed considerable increase between weeks 8 and 11.

2.2.4. Ethylene Production and Respiration Pattern of Banana:

Banana exhibits a climacteric pattern of respiration, characterized by an initially low rate of CO\textsubscript{2} production or O\textsubscript{2} uptake (pre-climacteric), the sudden upsurge (climacteric rise), a leveling off (climacteric peak) and finally a decline (post climacteric). The same pattern applies for ethylene production (Marriot, 1980).

A few hours before the respiratory climacteric begins, there is an increase in ethylene evolution from 0.05 mL kg\textsuperscript{-1} h\textsuperscript{-1} in pre-climacteric fruit to a peak about 3mL kg\textsuperscript{-1} h\textsuperscript{-1} (McMurchie et al., 1972). This peak in ethylene evolution occurs when the respiration rate is increasing rapidly. As the fruit ages in the pre-climacteric phase, lower concentrations of exogenous ethylene will stimulate ripening. This is interpreted either as increasing sensitivity of the fruit tissue to ethylene or, the dissipation of an inhibitor or an accumulation of endogenous ethylene (Seymor, 1993).

The characteristic ethylene response of the whole banana fruit is a feature of pulp and not the peel. The peel responds to exogenous ethylene like a non climacteric tissue (i.e. respiration of the peel increase when ethylene is present, but cease when ethylene is withdrawn). The degreening of the peel (chlorophyll degradation) is associated with the presence of ethylene (Dominguez and Vendrell, 1994).

2.2.5. Colour Changes:

Changes of skin colour of banana are used as a rough guide to identify the stage of ripeness. Differences in respiratory behavior can also be observed during colour development, since some banana cultivars exhibit climacteric peeks at different colour stages (Lizada et al., 1983).
Banana peel yellowing is primarily due to chlorophyll breakdown (ascribed to chlorophyllase action) and the unmasking of the carotenoid pigments. Consequent to chlorophyll loss, the carotenoid pigments are unmasked. There is practically no net synthesis of carotenoids during ripening.

The chlorophyll levels of green bananas may vary with maturity, but not the carotenoid levels (Seymore et al., 1987). This indicates that the full potential of carotenoid synthesis in the peel is achieved well before the green mature stage. The rate of chlorophyll degradation in the banana follows an optimum response with temperature. At 22°C the rate is maximal. Very little chlorophyll breakdown occurs below 15°C and above 40°C. There was some indication that it was related to thylakoid ultra structure. In plantains the response is quite different as they do not remain green at high temperatures (Seymore et al., 1987). Thus, the failure of the peel to degreen at high and low temperatures may be affected by the diffusion of ethylene from the pulp or the sensitivity of the peel to its action. The situation might be quite different in plantains where perhaps, the peel as well as the pulp has both systems of ethylene biosynthesis.

2.2.6. Textural Changes:

The banana fruit softens progressively during ripening. The relative firmness of the fruit is greatly determined by physical and chemical attributes such as peel thickness and starch content. Softening during fruit ripening has been attributed to the solubilization of pectic substances in the cell wall and middle lamella. Increased levels of water soluble pectins are observed with advancing of ripening. Softening of banana fruit may be due to the breakdown of starch and other non pectic polysaccharides in the pulp. Starch which imparts cellular rigidity is broken down to sugars during ripening (Lizada et al., 1990).
2.2.7. Flavour:

Changes in phenolics, carbohydrates and acid during ripening contribute to the development of the flavour of bananas. For Cavendish bananas these parameters were observed to be high for those ripened at 13-27°C resulting in a better eating quality (Turner, 1997).

Volatile compounds derived from Leucine and Valine, increase in concentration as ripening progresses. Fatty acids are also precursors of flavour in bananas. According to McCarthy et al. (1963) the banana flavour is due to amyl esters and the fruitiness is attributable to butyl esters. Volatiles are produced, late in the respiratory climacteric over a period of four days. Different volatiles are produced at different stages of ripening, and the temperature changes the profile of volatiles produced (Mattei, 1973; McCarthy et al., 1963). The phenolics, (i.e. tannins) undergo polymerization forming insoluble compounds. This results in loss or decrease of astringency in the ripe fruit (Lizada et al., 1990). Phenolics are responsible for the oxidative browning reaction when the pulp of fruit (especially immature) is cut. The enzyme polyphenoloxidase is responsible for this reaction (Palmer, 1971).

2.2.8. Moisture Loss:

The change in the Pp (Pulp: peel ratio) during ripening is largely due to the changes in the water status in the fruit. The ratio increases with ripening in cultivars with thinner peel (Acedo and Bautista, 1993). Consequently the water content decreases in the peel, but not in the pulp during ripening (Suyanti and Dasuki, 1988).

2.2.9. Changes in Acidity:

Malic acid is the major organic acid in bananas. This along with citric acid increases with ripening (Ali Azizan, 1988). During ripening, the titratable acids increase consequently causing a drop in pH. Ripening, doubles and in some cases trebles, fruit acidity in certain
cultivars containing A and B genomes. Despite the increase in acids with ripening, the increase in sugar is greater and the sugar: acid ratio which is an important component of flavour, increases from 40 in unripe fruit to 100 – 180 in ripe fruit depending on the cultivar (Marriot, 1980).

2.2.10. Changes in Carbohydrate Content:

When bananas or plantains are harvested almost all the carbohydrates are in the form of starch. During subsequent ripening the total carbohydrate content is progressively reduced (to provide fuel source for respiration) and starch is broken down into reducing and non-reducing sugars (Barnell, 1940). During early part of ripening sucrose is the predominant sugar, but in the later stages glucose and fructose predominate. The proportion of the different sugars is related to the stage in the respiratory climacteric of the fruit. They also show that starch is broken down to sucrose by action of sucrose phosphate synthetase and non-reducing sugars from sucrose by acid hydrolysis. In bananas the breakdown of starch is usually completed during ripening, but in plantains this breakdown is not complete when ripe (George and Marriot, 1983).
2.3. Papaya

2.3.1. Introduction:

The *Carica papaya* is rapidly becoming an important fruit internationally both as a fresh and processed fruit (Sankat and Maharaj, 1997). It is an important fruit in the ASEAN countries. Besides providing food to the people, the economic value of the crop has potential to be exploited as an income generator. This can be accomplished by exporting and a strategic marketing, especially to countries where the fruit is in demand (Rohani and Yon, 1994). Papaya is second only to banana on consumption, average being approximately 200g per individual per annum (Dept of Agriculture, 1999).

Papaw plant is a short lived, quick growing, soft wooded tree, 2-10m in height. Usually unbranched and dioecious with latex vessels spread throughout (Seymar, 1993). There is a wide diversity of biological types of cultivated papaya, some are dioecious (with male and female flowers on separate plants) some monoecious (with male and female flowers on the same plant) other hermaphrodites (with male and female parts on the same flower (de Arriola et al., 1980; Wills, 1990).

2.3.2. Cultivars in Sri Lanka:

No true type of cultivars is found in Sri Lanka. Recently a new cultivar ‘Rathna’ was recommended by the Horticultural Crop Research and Development Institute. Following are some of the characteristics of ‘Rathna’:

- The fruits have a good flavour and an attractive red colour.
- The fruit peel has an attractive appearance without blemishes.
- The disagreeable smell normally associated with papaw is absent.
- The shape of the fruit is uniform.
- Can be sold in the local market as fresh fruits and processed products.
- Suitable for export.
Since seeds of this variety produced by selfing the fruit quality will remain uniform, and the percentage male plants will be few/absent.

The latex content is less.

The average fruit weight is about 670g.

2.3.3. Marketing Sequence and Post Harvest Losses in Sri Lanka:

In Sri Lanka, bulk of papayas (mixed varieties) is transported to the whole sale markets in Colombo and Dambulla from distant plantations such as Marawila, Embilipitiya and Mahaweli areas. Usually they are packed in wooden crates without proper cushioning material; hence mechanical injury is inevitable during transportation. Many traders treat the unripe fruits with calcium carbide, while during transportation or at the whole saler, and the consumers are unaware of any treatments. Due to the above reasons post harvest losses are found to be high. Observations recorded with respect to losses at collection centers and the wholesale market is presented in Table I.

Table I: Losses at collection centers and the wholesale market

<table>
<thead>
<tr>
<th>Cause of Loss</th>
<th>Mean % Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collection Point *</td>
</tr>
<tr>
<td>Mechanical damages</td>
<td>0</td>
</tr>
<tr>
<td>Disease</td>
<td>0.01 ± 0.00</td>
</tr>
<tr>
<td>Dehydration</td>
<td>0</td>
</tr>
<tr>
<td>Immature fruit</td>
<td>3.103 ± 2.3</td>
</tr>
</tbody>
</table>

Means of percentages on post harvest losses at key stages of marketing sequence. Data collected during the period of 1984 – 1986 (Wilson Wijeratnam, 1986)

* Data was collected from 3 collection points at Marawila.

** Data was collected from four whole sale agents at Manning market, Pettah.
Organized plantations of papaya are rare in Sri Lanka. Few private farms situated at places, such as Kekirawa, Eluvankulama and Giriandurukotte and in the Mahaweli areas have grown local and imported papaya varieties and cater only to the supermarkets. Post harvest losses for these papayas are low as the papayas are transported in plastic crates and the fruits covered with poly-ethylene netting. Some of the cultivators/ traders catering the supermarkets harvest papayas at an earlier stage and expose them to ethylene before the papayas are placed on the supermarket shelves.

2.3.4. Harvest Maturity:

One major problem facing papaya fruit marketing is the identification of optimum harvest maturity to ensure adequate fruit ripening to good eating quality (Proctor and Caygill, 1985). Papayas will not ripen to an acceptable condition if harvested before internal yellowing has been initiated (Birth et al., 1984). The response of the fruit to post harvest environment is affected by the stage of ripeness at detachment. Papaya ripening proceeds to completion if the fruit is left on the plant (Akamine and Goo, 1979).

Softness to touch is used as a ripening index. The change in latex colour (white to watery) is also an index of maturity, but evaluation based on change in peel colour is usually used to practice to judge maturity (Sankat and Maharaj, 1997). Usually papayas are harvested after the mesocarp has developed colour and the peel shows a trace of yellow. Hawaii specifics that papaya fruits should show at least 6% surface colouration at the blossom end region and a minimum of total soluble solids 11.5% in them (Akamine and Goo, 1971).

2.3.5. Ripening Pattern of Papaya:

Papaya is a climacteric fruit (Wardlow 1963; Akamine, 1966). Mature green fruits exhibit a typical respiratory curve with an extended pre-climacteric minimum period. Fruits harvested at the colour turning stage have already passed the pre-climacteric minimum (Paull and Chen, 1983). The respiratory climacteric appears to peak at a relatively
advanced stage of ripeness. In cavite special papayas harvested at the colour break stage, the climacteric peak was observed when the fruits were 50-75% yellow (Angels, 1984). On the other hand, kaphoo papayas harvested at the same stage exhibited the peak when the peel was 25% < 50% yellow (Robles and Lizada, unpublished). Fruits, ripening on the plant also exhibit a climacteric pattern of respiration as indicated by the pattern of internal concentrations of CO₂ (Akamine and Goo, 1979).

During ripening CO₂ accumulate in the cavity, which ranges between 3 and 6% in “solo” papaya (Paull and Chen, 1989; Lazan et al., 1990), and 5.5 to 15.5% in cavite special. The depletion in internal O₂ level also occurs later when the fruit is about 50% yellow (Selamat, 1993). The pattern of respiration in a ripening fruit varies depending on maturity at harvest and holding temperature (Lam, 1989; Akamine and Goo, 1979).

2.3.6. Ethylene Production:

Ethylene evolution during ripening of papaya fruit shows the same pattern as that of CO₂ production. Like the respiratory peak, the ethylene peak also occurs when the fruit is at an advanced stage of ripeness (Halimi et al., 1990). In fruit of Backcross “solo” papaya harvested at the green stage the internal ethylene reaches it’s maximum concentration when the fruit is about 25% yellow coinciding with steady state of internal carbon dioxide (Larzan et al., 1990; Selmat, 1993).

2.3.7. Colour Development and Pigments:

Peel colour changes from green to orange yellow, and flesh colour yellow to reddish from an off white colour. The carotenoids (pro vitamin A) content estimated as ß carotene showed 5 to 10 fold increase in yellow fleshed cultivars between the mature green stage and the full ripe stage (Selvaraj et al., 1982). In red flushed cultivars however, the colour is associated with a marked increase in lycopene content. The major difference between yellow and red fleshed papaya is the complete absence of lycopene in the yellow fleshed
types (Chan, 1983). The red fleshed fruit has 63.5% of carotenoids content as lycopene. Other carotenoids present were β carotene, δ carotene, cryptoxanthin, monoperoxide and cryptoxanthin. The total carotenoid content increased to a 14 fold from mature green stage to full ripe stage (Selvaraj et al., 1982b; DeAroila et al., 1975). The skin chlorophyll declined to, 1/16 of the ripe, compared to immature fruit (Birth et al., 1984). The chlorophyll a:b ratio was found to be 2.25 in immature fruits and about 1.70 at more mature stage. Immature fruit plastids contained loosely appressed thylakoids with few grana, where as more mature fruits (up to ¼ ripe stages) had well developed grana. When internal fruit ripening began, the exocarp remained relatively unchanged, indicating that external ripeness lagged considerably behind internal ripeness (Sankat and Maharaj, 1997).

2.3.8. Flavour Development:

The characteristic taste of a papaya fruit is contributed mainly by the type and level of volatile compounds present in the tissue. However, the concentrations of sugars, organic acid as well as phenolic compounds also give a significant contribution to the sensory component of the fruit (Mohd, 1994).

As many as 200 volatile components in papaya have been identified by Flath and Forrey (1977), MacLeod and Peiris (1983), and Flath et al (1990). The amount of each component varied in both with cultivar and locality (MacLeod and Peiris, 1983). Linalool has been found as the major volatile component. Fruits of ‘Solo’ had a high percentage of linalool (up to 94%). Only one papaya volatile, methyl benzoate, is described as having sweetish papaya qualities, on odour assessment (MacLeod and Peiris, 1983). The Hawaii variety had very little methyl butonate (0.06%) (Flath and Forrey, 1977) while Sri Lankan variety had 48.3% (MacLeod and Peiris, 1983). The sweaty odour quality of some papaya cultivars is probably due to the production of methyl butonate (MacLeod and Peiris, 1983). The relative proportions of different volatile component vary with the stage of ripeness; a nearly 400 fold increase of linalool and a 7 fold increase of benzyl
isothiocyanate production were found in the head space of “solo” during ripening (Flath et al., 1990).

2.3.9. Textural Changes:

Ripening of papaya is also characterized by a loss of tissue firmness, due to the modification of structure and chemical composition of cell wall carbohydrate of the fruit tissue (Huber, 1983). Since a very small amount of starch was detected in papaya (Selvaraja et al., 1982) the contribution of starch breakdown to fruit softening during ripening may be negligible (Mohd 1994). Softening is due to cell wall degrading enzymes during ripening. The polygalacturonase activity in papaya increases in the endocarp during fruit ripening (Chan et al., 1981; Paul and Chen, 1983), peaking when the fruit is 40-60% skin yellowing. The highest activity is found in the placenta, with activity decreasing outwardly to the mesocarp (Chan et al., 1981; Lazan et al., 1991).

2.3.10. Moisture Loss:

Loss of moisture through transpiration results in fruit shriveling, shrinking and decreasing in weight. ‘Eksotica’ papaya looses about 12% of the original weight if allowed to ripen at ambient (25°C) temperature at about 80% relative humidity (Lazan et al., 1990). The water content in the fruit, decrease due to transpiration, and accumulation of carbohydrate and other compounds (Lakshminarayana et al., 1970).

2.3.11. Carbohydrates:

The principal carbohydrate in papaya fruits are sucrose, glucose and fructose. In the early stages of fruit development glucose is the predominant sugar while at the pre-ripe and ripe stages, sucrose increases by two to five folds, reaching higher levels in the fruit than those of fructose and glucose (Chan et al., 1979; Selvaraj et al., 1982).

When the fruit seeds and pulp begins to change colour there is a dramatic change in the sugar content (Chen, 1964; Chan et al., 1979; Selvaraj et al., 1982a). Sucrose level
increases as a result of movement from leaves to fruit (Chan et al., 1979). Total sugar content of the fruit showed positive correlation with fruit weight. The invertase activity increases during ripening, causing a breakdown of sucrose to fructose and glucose (Pal and Selvaraj, 1987).

TSS may comprise mainly soluble sugars and organic acids. For ‘Eksotika’ papaya the TSS level increases during ripening (Lazan and Ali unpublished).

2.3.12. Acidity:

Citric acid is the major organic acid in ‘Eksotica’ papaya and the level decreases slightly during ripening, but the Malic acid level remains unchanged. The titratable acidity had been reported to increase slightly during ripening. Which is believed to be associated with an increase in free glacturonic acid (Paull, 1993; De Arriola et al., 1980) Citric acid, Malic acid and ketoglutaric acid is 85% of the total titratable acidity. Total volatile acids contribute 85% to the total titratable acidity (Selveraj et al., 1982). Cis-aconitic, oxalic and fumaric acids are present in relatively low amounts in Eksotika papaya (Lazan and Ali, unpublished).
2.4. Mango:

2.4.1 Introduction:

Mango is decidedly the most popular fruit among millions of people in the orient, particularly in India, where it is considered to be the choicest of all indigenous fruits. It occupies relatively the same position in tropics as the apple in temperate countries (Singh, 1968). It is one of the six major fruit crops in the world. The world production of mango is over 15 million tones per annum. Sri Lanka accounts for about 0.4% of the total world production and is the 20th largest producer (Warburton, 1993).

Mango (*Mangifera indica*) belongs to the Anacardiacea family. This genus has 62 spp, but only 15 spp yield edible fruits (Purseglove, 1979). ‘Karuthakolomban’, ‘Vellai colomban’, ‘Willard’ are some of the popular varieties of mango grown in Sri Lanka.

2.4.2.1. Harvest Maturity:

Various maturity indices for harvesting mangoes have been suggested for several varieties, but little effort has been made to determine indices that have a practical significance (Medlicott et al., 1988). Some of the characteristics suggested may not be reliable for all cultivars. Usually a combination of measurements is used together with experience in the specific cultivar and growing region to identify the maturity stage. Mangoes harvested at the fully mature and half mature stages ripen to good quality fruit while immature fruits do not ripen normally (Medlicott et al., 1990).

2.4.2.2. Harvesting of mangoes:

Wherever possible, mangoes should be harvested by hand from the ground, by snapping the mango from the stem. Fully mature fruit will detach easily, whereas half mature fruit will not. Optimum harvesting involves cutting the stem 1-2 cm away from the fruit. When harvesting by hand from the ground is not possible, harvesting implements should
be used (Web page 2). It’s revealed that method of harvesting had a significant effect on development of post harvest diseases. Lowest disease index and highest visual quality ratings were recorded for mangoes harvested with stalks attached, for test mangoes on a trial carried out by Amarakoon *et al.* (1999). This may be due to absence of latex exudates, which could damage the skin and thereby make entry points for pathogens. Therefore, harvesting with the stalk attached could be recommended for extending the post harvest life of mangoes (Amarakoon *et al.*, 1999).

### 2.4.2.3. Determination of Maturity:

Mango fruits are traded commercially for consumption as ripe fruits. They are harvested when mangoes are still green (before changing colour), and ripened after harvest. Hence maturity indices need to be developed for unripe mature fruit as follows.

* **Softness of the Cheeks:** When cheeks of the fruit are full and become softer the fruit is assumed to be mature (Mukharjee, 1959).

* **Peel Colour:** Fruit colour changes from dark to light green. Yellowing of the green fruit occurs as ripening begins (Burns and Prayag, 1921). Even though development of light green colour at latter stages of maturity was observed for ‘Karuthacolomban’, it was difficult to use it as an index, as the change in colour was not easily identifiable (Amarakoon *et al.*, 1999).

* **Flesh Colour:** When the fruit is immature, the flesh colour is pale green, but becomes white as fruit enlarges. The flesh of the mature fruit has a tint of cream colour breaking to yellow as it ripens. Slicing the pulp of a sample fruit before harvest, may incidentally serve as a guiding factor for harvest (Mitra and Baldwin, 1997).

* **Specific Gravity:** As mango fruit matures they accumulate dry matter and become denser. For mango variety ‘Nam Dorkmai’ up to 12 weeks, the volume of fruit was greater than weight (sg<1), but after 12 weeks the weight was greater than specific
gravity (sg.>1) (Kasantikul, 1983). Studies conducted for Sri Lankan mangoes by Amarakoon et al (1999), showed that applicability of the float / sink test to determine the maturity depended on the variety.

* Shape of fruit: Indonesian farmers determine the difference, between mature and immature fruit by the shape of the fruit. As the fruit matures, the fruit tends to have a rounder base (Kosiyachinda, 1984).

Mangoes with different harvest maturities vary in shape of shoulders;  
\[ i.e. \text{Immature fruit} \quad \text{Shoulders below pedicel insertion} \]  
\[ \text{Half mature fruit} \quad \text{Shoulders in line with stem} \]  
\[ \text{Fully mature fruit} \quad \text{Out grown shoulders} \]

Out grown shoulders of the mature fruit were prominent in 'Willard' than 'Karuthacolomba' and 'Vellai Colomban' (Amarakoon et al., 1999).

* Bloom on the Fruit: The appearance of a powdery material or a whitish waxy layer or bloom on the fruit surface may occur at a certain stage of development, close to maturity (Kosiyachind, 1984). Bloom is observed for 'Karuthakolomban' mature fruit.

* Computation (Time to Maturity): Age of the fruit is the simplest method of ascertaining maturity, although this method may not be commercially useful. Age of mango fruits can be calculated from induction of full bloom or fruit set. However, variations resulting from varietal differences, growing region, climatic conditions restrict the usefulness and wide application of these indices (Prinsely and Tucker, 1987). Usage of terms such as first bloom, full bloom and fruit set as reference points need some standardization. It is suggested that full bloom is probably the most easily standardized stage for most cultivars.

For local varieties, minimum duration of time taken for maturity of fruits varies between 85 - 95 days after fruit set, but appears to be dependant on the variety and the prevailing climatic conditions. Due to climatic changes, full bloom may not happen as expected
within a few days, but spread over a period of several weeks and set fruit at different
times. Fruits of ‘Willard’ become mature at 12 weeks, while cultivars ‘Karuthacolomban’
and ‘Velleicolomban’ take 13 weeks after flowering to become mature (Amarakoon et
al., 1999).

* Colour of Fruit Stem: In central Java, the term ‘nggenting’ applies to change of
colour of the fruit stem. The fruit is considered mature when the stem becomes yellow.
Fruits are considered ready for picking, when two thirds of the stem appears to be dry and
turning dark brown (Kosiyachinda, 1984).

2.4.2.4. Effect of Harvest Maturity on Disease Incidence and Visual Quality:

Visual quality may go down, when latex exudates damage the skin and thereby make
entry points for pathogens (Amarakoon et al., 1999). This may be due to the stress and
ethylene produced by burnt tissue, stimulates spore germination and appresoria formation
of pathogenic fungi causing a higher incidence of disease infection (Flaishman and
Kolattukudy, 1993).

2.4.3. Marketing Sequence and Losses in Sri Lanka:

Although, there are many mango producing areas in Sri Lanka, the organized mango
farms are few in number. In Sri Lanka it is a common practice to harvest mango in a
single picking which includes many maturity stages consisting immature and mature
fruits. The harvesters, who travel to these distant places in search of mango, go on
collecting them for few days until their vehicles are loaded to the capacity. The fruits are
then transported to the collection centers and distribution points as bulk transport; loaded
on to the vehicle itself, in wooden boxes or in large polypropylene fertilizer bags.
Therefore, during transportation, mechanical injury is evident, especially if the mangoes
are ripe. On arrival to their bases, the mangoes are artificially ripened using CaC2 and
delivered to distribution centers such as whole sale markets, factories and supermarkets.
‘Boragodawatta’ a village in Minuwangoda is regarded as the major mango collecting center in Sri Lanka. Over 50% of the mangoes harvested in Sri Lanka, are passed through the hands of collection agents at Boragodawatta (Wilson and Selvarajah, 1991). Overall mean percentages, attributed to major causes of loss, at key stages of marketing sequence observed are summarized in the Table II (Wilson and Selvarajah, 1991).

Table II. Postharvest losses in mango at key stages of marketing.

<table>
<thead>
<tr>
<th>Causes of Loss</th>
<th>% Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dehydration</td>
<td>9.3</td>
</tr>
<tr>
<td>Mechanical injury</td>
<td>7.5</td>
</tr>
<tr>
<td>Immature picking</td>
<td>6.4</td>
</tr>
<tr>
<td>Insect infestation</td>
<td>11.7</td>
</tr>
<tr>
<td>Other causes</td>
<td>1.3</td>
</tr>
<tr>
<td>Total</td>
<td>36.2</td>
</tr>
</tbody>
</table>

2.4.4. Ripening Pattern of Mango:

Mango is a climacteric fruit and undergoes increased (autocatalytic) ethylene production (Mattoo and Modi, 1969). Patterns of respiration and ripening behavior vary among varieties, the climatic conditions and the places where the fruit is grown (Krishnamurthy and Subramaniyam, 1970). The respiration decreases as the fruit mature, and again rises with ripening. The rapid increase in respiration commenced a week after harvest for immature ‘Golek’ whereas for mature fruit, three days after harvest (Pantastico et al., 1984).

2.4.5. Ethylene Production:

Ethylene production also decreases as the fruit matures, is undetectable for a period of time and then re-appears upon ripening (Akamine and Goo, 1973). The time to the
maximum rate of ethylene production occurred progressively at a longer time after
harvest as fruit approached full maturity. This is in contrast to the reduced time after
harvest, for more mature fruit to reach respiratory climacteric. The peak value of ethylene
was higher in immature fruit (Pantastico et al., 1984). Although Burg and Burg (1962)
stated that ethylene in fruit increases when or before carbon dioxide production rises in
ripening mangoes, Biale and Young (1981) included mangoes, among the fruits in which
ethylene rises after an increase in CO₂ production. Ethylene production by mango tissue,
as in many other climacteric fruit, is maximal at the onset of the climacteric phase of fruit
ripening (Burg and Burg, 1962; Mattoo and Modi, 1969).

2.4.6. Pigments and Colour Development:

2.4.6.1. Peel Pigmentation:

The peel colour of fruits changes on ripening from dark green to olive green; sometimes
reddish orange yellow or yellow hues appear from the base colour depending on the
cultivar. The colour depends on the relative amounts of individual pigments present in the
peel. Yellow and green colouration (i.e. carotenoids and chlorophylls) is imparted by the
lipid soluble plastid pigments, whereas the red colouration is due to the water soluble
anthocyanins present in the vacuoles. Anthocyanin content has been found to remain
constant or decrease slightly during ripening in association with the decreasing
chlorophyll and increasing carotenoid contents. Ultra structural analysis of peel
chloroplast to chromoplast transition showed almost complete breakdown of the
chloroplast lamellar system and the development of large osmiophillic globules
associated with colour changes (Prinsely and Tucker, 1987).

2.4.6.2. Pulp Pigmentation:

Mangoes are well known for their intense yellow to orange pulp colour imparted by a
high carotenoid content. The carotenoid level in the, ripe fruit varies among cultivars. In
ripe ‘Alphonso’ mangoes, presences of 16 carotenoids fractions have been identified. However, 50% of total carotenoids consist of β-carotenes (Jangalwala and Coma, 1963).

2.4.7. Flavour Development:

Flavour studies based on subjective evaluation and on quantitative amounts of flavour components present, have suggested that certain monoterpane hydrocarbons are important to mango flavour (MacLeod and Troconis, 1984). Monoterpane hydrocarbons represented nearly 49% (W/W) of the total volatiles in ‘Kensington’ mangoes. Analysis of volatile compounds of three varieties from Sri Lanka, identified terpenes as the main volatile (MacLeod and Troconis, 1984).

2.4.8. Textural Changes:

Ripening of mango is characterized by softening of the flesh due to solubility of cell wall pectin (Nasrijal, 1993). In mangoes, the ripening as characterized by changes in tissue softness is believed to be initiated in inner mesocarp tissue close to the seed, and progressing outward (Lazan and Ali, 1993). Physiological maturity in tree ripened mango fruit was reported to be associated with a drop in pectinesterase (PE) activity and the peel of mango was reported to have higher PE activity than the pulp (Ashraf et al., 1981).

2.4.9. Moisture Loss:

Moisture loss from mango fruit is through stomata, lenticels (regions in the epidermis, which are connected with intercellular spaces and continually open allowing gas exchange between cells and atmosphere) and other openings associated with the epidermal cells. The physical process involved in transpirations and the driving force is the vapour pressure deficit between the internal and external environment of the fruits. Since the vapour pressure of water is higher at increased temperature, moisture loss is higher for fruit held at higher temperatures in similar conditions of relative humidity and air movement. Excess transpiration during post harvest handling of mango fruits result in
shriveling and may cause poor development of colour, uneven ripening and sub-optimal sensory characteristics. Over-ripe fruits with more lenticels tend to wilt and shrivel more rapidly than young fruits with fewer lenticels (Pantastico et al., 1984).

2.4.10. Carbohydrate Sugars and Acids:

Taste is mainly a balance between sugars, acids, aroma, with sweeter fruits generally being more acceptable. The increase in sucrose content is mainly attributed to the breakdown of starch, so that starch is virtually absent at edible stage. It has been suggested that sweetness of ripe mango is largely contributed by sucrose (Lakshminarayana et al., 1970). At the commencement of ripening of mango, the majority of the sugars were reducing in nature, but ripe fruit contained non reducing sugars (in the form of sucrose 17%) than reducing sugars (3%). Non reducing sugars predominated during ripening of ‘Edward’ mangoes, and sucrose predominated in three or four Indian varieties studied (Prinsely and Tucker, 1987).

2.4.11. Organic Acids:

During ripening mangoes show a substantial loss of acidity as indicated by pH or titratable acidity (Medlicott and Thomson, 1985; Agnihorti et al., 1963). The predominant organic acid is citric acid, with lesser amounts of succinic and malic acid. They are the main accumulated free organic acids contributing to acidity. The initial decrease in acidity in ‘Alphonso’ mango was due to the loss of malic and other acids, while citric acid increased thereafter. In ‘Badami’ and ‘Keitt’ mangoes, the initial decrease in acidity was due to a high rate of loss, of citric acid (Shashirekha et al., 1976). Other organic acids identified include tartaric, oxalic, glycolic, succinic, pyruvic, oxaloacetic and alpha-ketoglutaric. Some of these are kreb - cycle intermediates and levels of alpha - ketoglutoric and pyruvic acids followed respiration rate.
2.5. Tomato:

2.5.1. Introduction:

The tomato is a member of the potato family Solanacea, belonging to the relatively small genus *Lycopersicon* (Pursglove, 1979). It is one of the most important vegetables in most regions of the world, ranking second in importance to potatoes in many countries.

2.5.2. Marketing Sequence and Losses in Sri Lanka:

Some of the tomato producing areas in Sri Lanka are Kandy, Matale, Bandarawella, Nuwara Eliya and Badulla. Most of the losses in tomato occur during transport. Ripe tomatoes are stacked in wooden boxes and transported to whole sale point such as Colombo (Manning market) and Dambulla, from where they are distributed to sales outlets. During transportation, a high percentage of losses occur due to mechanical injury, to which ripe tomatoes are highly susceptible. However, this problem is changing (although at a slow pace) with the opening of farm shops in Sri Lanka. Middle link is eliminated this way as tomatoes are brought from the field to the sales outlets, thereby hastening the sale without any loss of time.

Rupasinghe *et al* (1992) observed at the Manning Market (Whole sale market-Colombo) that losses were mainly due to long distance transportation and improper handling. Cumulative losses at the Manning whole sale market were observed to be approximately 40.54% (Chandraratna, 2000). Bruising is probably the major cause of post harvest losses in Sri Lanka. Losses due to transportation of ripe fruits can be reduced, if mature green fruits can be transported while they are firm in texture and ripening carried out at the distribution point. However, this is not practiced by farmers, as mature green fruits do not acquire the required colour in redness, if harvested before they become red and allowed to ripen at ambient temperature.
2.5.3. Pigments in Tomato:

The red colour in tomato is due to the pigment lycopene (C_{40}H_{56}). Tomatoes contain other carotenoid pigments besides lycopene. But in fully ripe fruit, the latter predominates. Unripe green and yellow has no lycopene but contains mainly chlorophyll and other carotenoid pigments (Rangana, 1986).

2.5.3.1. Importance of 阝-carotene and lycopene:

The redness in tomato is due to the pigment lycopene while the orangish red is due to a mix of lycopene and 阝-carotene in tomato. These components are very important in our diet as they are free radical scavengers (Di Masico et al., 1989). B-carotene is also a precursor of Vitamin A (Gross, 1991; Simpson, 1983).

2.5.4. Effect of Post Harvest Storage/ripening Temperature on Red Colour of Tomato:

When tomatoes are harvested at mature green stage and stored at 30°C or higher, the quality of tomatoes decrease, as the pigment formation is inhibited. This problem has been attributed to the inhibition of lycopene accumulation, the dominant red carotenoid pigment of tomato fruit (Laval Martin et al., 1975; Reymundo et al., 1967).

There are many carotenoids in tomato fruit besides lycopene, such as 阝-carotene (orange pigment), lutein (yellow pigment), phytoene and phytofluene which are colourless precursors of coloured carotneoids. It is observed that, high temperatures decreased lycopene and its precursors, especially phytoene. However, 阝-carotene content did not decrease in the fruit stored at 20°C and 35°C but tended to increase in the fruit stored at 30°C (Hamauzu et al, 1994; Hamauzu and Chacin, 1995).
2.5.5. Biosynthetic pathway of pigments.

Hamauzu et al (1998) incubated pericarp sections of tomato with $^{14}$C-mevalonic acid which is a labelled precursor of carotenoid, to trace the incorporation of this substrate into carotenoids in the whole fruit. Subsequently they isolated and determined the radioactivity of phytoene, lycopene and $\beta$-carotene (Hamauzu et al., 1998). From their results they proposed a relationship between lycopene and $\beta$-carotene in the biosynthetic pathway of carotenoids in tomato fruit is based on their specific radioactivities. They decreased in the order of phytoene $\rightarrow$ lycopene $\rightarrow$ $\beta$-carotene in all the tomato samples. They suggested that lycopene could be a precursor of $\beta$-carotene in normal red tomato fruit and also in the yellowish fruit, in which the red pigmentation is inhibited by temperature.

The accumulation of lycopene in tomato fruit stored at 20°C is favoured, because the conversion of lycopene to $\beta$-carotene is relatively slow at this temperature. At higher temperatures, (i.e. 30°C and 35°C) the conversion of phytoene to lycopene and lycopene to $\beta$-carotene was accelerated, leading to lower lycopene containing (yellowish) tomatoes. However, the amount of $\beta$-carotene in tomato fruit ripened at 35°C was not as large as that of phytoene or lycopene in the fruit ripened at 20°C. It is difficult to explain the phenomena only by the rapid turnover of $\beta$-carotene at the high temperatures (Hamauzu et al., 1998).

Possible hypothesis for metabolism of phytoene lycopene and $\beta$-carotene in tomato fruit ripened under 20°C, 30°C and 35°C for 10 days is shown in Figure VII. Width of arrows indicate the relative metabolic rate, and thickness of the enclosure represent the accumulation levels of each carotene. At 20°C biosynthesis and accumulation of phytoene and lycopene are fast, and those of $\beta$-carotene are slow. At 30°C biosynthesis and accumulation of lycopene and $\beta$-carotene are fast and phytoene accumulation is slow. At 35°C biosynthesis and accumulation of $\beta$-carotene are fast but accumulation
level is slower than 30°C; accumulation levels of phytoene and lycopene are slow. Probably, a rapid turnover of carotenes exists in fruit ripened at a higher temperature.

![Possible biosynthetic pathway of pigments](image)

**Fig VII.** Possible biosynthetic pathway of pigments (Hamauzu et al. 1998).

2.5.6. Moisture Content in Tomato:

The moisture content of immature green tomato increases from about 91% - 93% as the fruit develops (Hobson and Davies, 1971). Good quality ripe fruit have an average moisture content of 94 - 94.5% (Hobson & Davies, 1971; Purseglove, 1979).

2.5.7. Organic Acids:

The acids of tomato fruit have been the subjected to considerable investigation. Not only are they important as major taste components, but total acidity plays an important part in to satisfactory processing of tomato products (Lambeth et al., 1964). It is generally
agreed that the predominant acid of ripe tomato fruit is citric, with malic acid being the
next most abundant. During the ripening of the whole fruit from mature green to red,
acidity increases initially to a maximum value coinciding approximately, but not always
precisely with the first appearance of yellow pigment, followed by a progressive decrease
in acidity (Winsor et al., 1962a) Various reports have agreed that the titratable acidity of
the outer fruit walls is relatively low, compared with that of the locular contents
(Anderson, 1957; Winsor et al., 1962b; Sakiyama, 1966a).

The acidity of the locular contents decreases from the green yellow stage onwards, but
consistent trends in the acidity of the fruit walls after green yellow stage are difficult to
establish (Winsor et al., 1962b).

The relationship between potassium and acidity in tomato fruit is very close. Highly
significant positive correlations have been reported between potassium content and the
total, titratable and combined acidities. The juices of the tomato constitute a weak
acid/strong base buffer system in which the anions are mainly citrate and malate and the
cations are mainly potassium (Davies, 1964, Sakiyama, 1966b).

2.5.8. Carbohydrates:

Sugars have an important effect on the taste of ripe fruit, since sugars constitute 15-45% of
the fresh weight, equivalent to some 65% of the total soluble solids (Winsor, 1966). The soluble carbohydrate of the fruits of commercial varieties of tomato are almost
entirely reducing sugars (Winsor et al., 1962a; Lambeth et al., 1964). The sugar content
increases progressively throughout maturation and ripening (Winsor et al., 1962a;
Lambeth et al., 1964) with a particularly pronounced rise occurring with the appearance
of yellow pigmentation (Winsor et al., 1962a, b).

Other changes in sugar content, reflecting differences in the intensity and duration of
light are typified by seasonal trends (Hobson and Davies, 1971). A post harvest decline in
the sugar content of ripe fruit during storage at room temperature has been observed (Winsor et al., 1962a).

2.5.9. Volatile Components:

The significance of the four basic tastes sweet, sour, bitter and salt in tomato flavour has been discussed in general terms by Winsor (1966).

The presence of minute traces of volatile components makes a marked contribution to the typical aroma of a freshly picked tomato and consequently to its flavour. Much of the aroma appears to be associated with the calyx; however, it is unfortunately lost before the fruit reaches the consumer via the markets. Dalal et al (1965, 1966) found that the total volatile reducing substances increased continuously as tomatoes matured and ripened.

2.5.10. Phenolic Compounds:

The tomatoes possess little or no astringency although phenolic compounds present may take part in flower development. There is an increase in their concentration from the mature green stage until mid ripeness (Davies et al., 1967).
Losses in perishable commodities commence at harvest and continue to accumulate, as the product passes through various stages of the marketing sequence. If the high levels of the post harvest losses in Sri Lanka are to be minimized, several improvements would have to be made in the marketing sequence from the time of harvest until they reach the consumer.

For climacteric fruits grown under organized systems, the product is harvested at a commercially acceptable stage of maturity prior to the onset and initiation of ripening. At this pre-climacteric stage of development, the fruits are firm and able to withstand considerable handling operations during the course of marketing and distribution process; thereby reducing losses due to mechanical injury during transport. However, prior to placement on retail shelves, and in order to facilitate successful marketing, fruits need to acquire characteristics such as colour and flavour desired by the consumer. This could be achieved by inducing the fruits to ripen with ethylene gas.

Manipulation of ripening is also advantageous to domestic commercial operations in Sri Lanka. In commercial fruit production and marketing, induced ripening facilitates and controls the rate of ripening; thus enabling transport and distribution to be carefully planned. Food processing factories too require uniformly ripe fruits in large quantities on a set date for mechanical processing. This can be achieved when the fruits are induced to ripen by exposing them to ethylene, to suit their requirement.

However at present, the ethylene ripening method is not in use in Sri Lanka and the traditional ripening methods adopted are unsatisfactory. No systemic studies for developing ripening procedures for commercial use have been conducted previously in Sri Lanka.
It is the scope of this study to develop such procedures that may be of use to domestic markets in Sri Lanka and help reduce losses while maintaining quality.

In order to develop the technology for the ripening process, it is essential to study the characteristic-ripening pattern of each commodity under the project. Hence, some of the objectives considered important for the study were the maturity stage the fruits should be harvested, the most suitable ethylene concentration to initiate ripening in each commodity, the optimum ripening temperature and the duration of the ripening time for each commodity.

For commodities that are not sensitive to ethylene, alternate ripening methods have to be developed. The ripening methods to be used in Sri Lanka should also not be too expensive and complicated.

In this thesis the objectives of the study have been fulfilled, by introducing safe efficient cost effective ripening methods to several fruit handling establishments in Sri Lanka.
CHAPTER 4
MATERIALS AND METHODS

EXPERIMENTS WITH BANANA:

4.1 Influence of Ethylene Gas on Ripening of Banana:
Different dosages of laboratory prepared ethylene gas (i.e. 50 ppm to 400 ppm) were tested on banana to determine the optimum concentration of ethylene for ripening. The treatments were carried out at ambient temperature (29±2) °C.

4.1.1. Plant Material:
Plant materials for the experiment were obtained from a field at Minuwangoda. Banana bunches with full and rounded fruits light green in colour and 12 weeks of maturity (Wilson Wijeratnam et al., 1993), were selected for the trial. The harvested bunches were de-handed, de-sapped at the field and labeled, before being transported to the laboratory, in crates well packed with shredded paper and rubber foam.

The bananas harvested were re-sorted at the laboratory, to eliminate fruits containing bruises or pathogen attacks. The first and the last hands from each bunch were eliminated to avoid maturity differences. The chosen hands were randomized using random number procedure (Gomez and Gomez, 1984) before being allocated into treatments.

4.1.2. Experimental Design:
Experimental design used was a completely randomized design. Each treatment consisted of three replicates with four banana hands in each replicate. The ripening chambers were also placed in a randomized design using random numbers (Gomez and Gomez, 1984) to accommodate location effects.

4.1.3. The Ripening Treatment:
Wide mouthed 93 L glass cubicles with lids, Vaselin, and medical syringes were used in the trial. The randomized bananas were placed inside the 93L glass cubicles to carry out
the respective ripening treatments. The lids of the cubicles were sealed with vaselin after placement of the fruits. Laboratory prepared ethylene gas concentrations ranging from 50ppm to 400ppm were used in this trial. The calculated quantity of ethylene gas was measured into a medical syringe before injecting into the rubber tubes connected to the glass cubicles. Fruits not treated were considered as the control.

* Preparation of Ethylene Gas and the calculation:
Sulphuric acid 98% (G.P.R), Ethyl alcohol, pumic stones and NaOH were used in the trial. Ethylene gas was prepared according to method described by Browning and Joseph (1978) by heating ethyl alcohol and sulphuric acid together with pumic stones in a round bottom flask. The gas was washed twice using 10% NaOH before being collected in sealed flasks. It was stored in the same flask until used in the trial. The required volume of ethylene was calculated using the following formula.

\[ N_1V_1 = N_2V_2 \]

\( N_1 \) = Required concentration

\( V_1 \) = Headspace of the ripening container

\( N_2 \) = Concentration of ethylene in the preparation.  
  (assumed as 10^6 ppm.)

\( V_2 \) = Volume of ethylene taken into the syringe from laboratory preparation

The headspace was calculated by deducting the volume of fruits from the volume of the container to be used. The volume of the fruits was calculated by immersing them in water. The displaced volume of water was assumed to be equal to the volume of the fruit. The gas was checked for the percentage of ethylene in the preparation using gas chromatography and any differences from the expected concentration was corrected by calculation, before measuring into the syringe.

Fruits thus exposed to the ethylene gas for 24 hrs were permitted free ventilation by taking off the lids. The fruits were then left to ripen in the same container in which they were treated.
4.1.4. Recording of Observations:
Observations were recorded when 75% of all fruits used in the trials were assessed as being ripe. Fruits were subjected to physico-chemical (4.1.4a to 4.1.4g) and a sensory evaluation (4.1.4h) as follows. Equal portions taken from five fruits, of each replicate were used for the chemical analysis.

4.1.4.a. Pulp Extraction Methods:
A 10g sample of pulp was homogenized using a Jaipan liquidizer with 40ml of distilled water in the Liquidizer. The homogenate was filtered through double layers of muslin cloth (Sarananda, 1996).

4.1.4.b. Total Soluble Solids (TSS):
A hand held refractometer ‘Erma’ type (0-25% range) was used to record the TSS. Extractions were prepared as described in section 4.1.8.a and few drops of it were used on the refractometer at (24°C±2°C). The refractometer reading was multiplied by the dilution factor to calculate the actual total soluble solids content in banana (Sarananda, 1996).

\[
\text{Dilution factor} = \frac{\text{Weight of sample} + \text{Volume of water added}}{\text{Weight of sample}}
\]

\[
\text{TSS} = \text{Refractometer reading} \times \text{Dilution Factor}
\]

4.1.4.c. Titratable Acidity:
20mL of distilled water was added to 10mL of the filtrate prepared as described in section 4.1.4a and titrated against 0.1N NaOH in the presence of 1% phenolphthalein as an indicator. The end point was taken as a sudden slight change in pink colour. The acidity was expressed as grams of malic acid per 100g of fresh weight (Sarananda, 1996).
Calculation: -

\[
\% \text{ Total acid} = \text{Titre} \times \text{Dilution factor} \times \text{Equivalent weight of acid}
\]

Predominant acid was considered as malic acid. Equivalent weight in acid for malic acid is 0.006706g (Pearsons, 1986).

4.1.4.d. Ascorbic Acid:
10g samples of banana pulp as described in section 4.1.4 were homogenized with 10% acetic acid in a, Jaipan liquidizer for 2 minutes. The homogenate was filtered into a 100ml volumetric flask through double layers of muslin, and made up to volume with acetic acid. A sample of 10ml of the filtrate was taken and titrated against standardized ascorbic dye (2, 6 dichlorophenol – indophenol). The dye was standardized and dye factor calculated before the titrations were carried out. The end point was taken when a sudden slight change in pink colour, which persisted for 15 seconds (Rangana, 1986).

Calculation:

\[
\text{mg of ascorbic acid per 100g F.W} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Volume of extract} \times \text{Wt of sample taken for estimation}}
\]

4.1.4.e. pH:
An Orion digital pH meter model 410 A was used to determine the pH of pulp extracts obtained as described in section 4.1.4a.

4.1.4.f. Weight Loss:
Electronic balance – Sartorious BP 6100 (with four decimal points) was used to record observations. The weights of the fruits in the treatment in section 4.1.4 were recorded before and after they were subjected to the ripening treatment. The difference in weights was expressed as the percentage weight loss (% weight loss).
4.1.4.g. Fruit Firmness:
A Labsco Food Firmness Tester (Model d – 6336 Friedberry/H Germany) with probes of 3mm was used to test firmness of fruits. The degree of ripeness in the treated banana was assessed via measuring the compression strength of the fruit, due to the close relation between the two. The tensile strength of the skin of fruits and their resistance to pressure or puncture was measured by lowering the probe on to the fruit.

4.1.4.h. Organoleptic Evaluation:
Consumer acceptability of the banana treated as described in section 4.1.3 was assessed for sensory and organoleptic quality using a questionnaire which consisted a ten-point hedonic scale (appendix). Each member of the trained panel was presented with a portion of the fruit and the questionnaire ranging from ‘poor’ to ‘excellent’. A panel comprising a minimum of seven members was requested to assess the quality.

4.1.5. Statistical Analysis:
Data obtained from above experiments were subjected to statistical analysis as follows. Results of the physicochemical analysis were analyzed using ANOVA (Analysis of Variance) and mean separation using Duncan’s Multiple Range Test (DMRT) at confidence interval of 95%. Results of the organoleptic evaluation were analyzed using Friedman’s two-way non-parametric analysis (SAS, 1989–1996).

4.2. Influence of 2-Chloroethyl Phosphonic acid (ethrel) on Ripening Attributes of Banana:
The above mentioned chemicals were mixed to obtain the required ethylene gas. Different volumes of the chemicals were tested in this trial to determine the most suitable concentration to ripen banana. The treatments were carried out at ambient temperature (29°C±2°C).
4.2.1 Plant Material:
Banana of variety Embul of 12-week maturity were obtained from Nittambuwa and transported as described in section 4.1.1.

4.2.2. Experimental Design:
Banana transported to the laboratory were re-sorted and randomized as described in section 4.1.1. Each treatment consisted of 30Kg of bananas placed inside each 288L ripening chamber.

4.2.3. The Ethrel (2chloroethyl Phosphonic acid) and NaOH Treatment:
Ethrel 48% (2 Chloroethyl Phosphonic acid (Cl-C2H4-PO (OH)2 Commercial) ) was combined with appropriate amounts of sodium hydroxide (NaOH- Commercial grade) to obtain the ethylene gas to treat the fruits. The concentration levels of each chemical to be used in the ripening chambers were determined after conducting preliminary trials.

These scaled up type ripening treatment was carried out in 288L ripening chamber. Each treatment had one cabinet containing 30 Kg Embul banana hands at green mature stage. Two types of treatments were tested in this experiment. All three levels of ethrel as mentioned below were tested in (method 1) and 0.8 mL level in (method 2). Fruits not treated were considered as the control.

Combinations tested were:

1) 0.80 ml Ethrel + 0.375 g NaOH
2) 1.65 ml Ethrel + 0.75 g NaOH
3) 3.30 ml Ethrel + 1.50 g NaOH
4) Control – Not treated
4.2.3. Method 1 (Closed Chamber Treatment):
A beaker containing small amount of water and the required amount of ethrel (Cl-C₂H₄-P₀ (OH)₂) was placed among the fruits inside the ripening container. NaOH was added into the beaker prior to the closure (sealing) of the lids.

Method 2 (Trickle Treatment):
A side armed sealed 500mL flask containing ethrel (Cl-C₂H₄-P₀ (OH)₂) and NaOH was placed outside the ripening chamber and connected to the chamber through a rubber tube and a vent in the chamber. Another vent was left open in the ripening chamber for exchange of gases. The chemicals were replenished after 12 hours.

Fruits thus exposed to ethrel and NaOH for 24 hrs were permitted free ventilation thereafter by removing the lids.

4.2.4. Recording of Observations:
Recording of observations, physico-chemical and the sensory evaluations after the ripening period were assessed as described in 4.1.4. (i.e. 4.1.4a to 4.1.4h).

4.2.4.a. Peel Colour Measurements:
Numerical colour values of treated banana were measured using the Chromameter (Minolta-200). The chromameter was calibrated each time before being used, on the white plate. LCH colour space was recorded.

4.2.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.
4.3. Comparative Effects of Selected Ripening Agents on physico-chemical and organoleptic Characteristics of banana:

This study was carried out to compare fruits ripened with laboratory prepared ethylene gas, ethylene gas obtained by reacting ethrel with NaOH, and acetylene gas liberated by CaC₂. Untreated fruits were regarded as the control. The trial was carried out at ambient temperature (29°C±2°C). The most suitable dosage of the respective ripening agents, determined from previous trials conducted, was used to ripen the fruits in this experiment.

4.3.1. Plant Material:
Banana of variety Embul (12 week maturity) were obtained from Minuwangoda. They were harvested and transported to the laboratory as described in section 4.1.1.

4.3.2. Experimental Design:
The experimental design was a CRD with four banana hands in each replicate as described in section 4.1.2.

4.3.3. The ripening agents for the experiment:
The following ripening agents were used for the comparison.
Trial 1 - Ethylene gas liberated from ethrel and NaOH - (0.80 ml ethrel and 0.375g NaOH)
Trial 2 - Acetylene gas liberated from CaC₂ (1g / 1 Kg fruit)
Trial 3 - Control (Bananas not treated)

The fruits were exposed to ethylene gas via ethrel and NaOH in 93L glass cubicles as described in section 4.2.3.method 1. The appropriate amount of CaC₂ was wrapped in newspaper like a parcel and was placed among the fruits before the closure of the lids. Fruits thus exposed to the ripening agents for 24 hrs were permitted free ventilation thereafter.
4.3.4. Recording of Observations:
Recording of observations, physico-chemical and the sensory evaluations after the ripening period were assessed as described in 4.1.4. (i.e. 4.1.4a to 4.1.4h)

4.3.5. Statistical Analysis:
Data on physico-chemical parameters obtained from the trials were statistically analyzed as described in section 4.1.5.

4.4. Influence of Temperature on Ripening of Banana:
Most suitable concentration of ethrel and NaOH on banana, determined from a previous trial (4.2.), was combined with several temperatures to find the optimum ripening temperature for ripening of banana, in order to prepare a ripening guide that would be useful to local traders and exporters.

4.4.1. Plant Material:
Bananas of variety Embul at 12 weeks of maturity were obtained from Minuwangoda. They were harvested and transported to the laboratory as described in section 4.1.1.

4.4.2. Experimental Design:
Banana transported to the laboratory were re-sorted as described in section 4.1.1. The experimental design was, CRD with four hands per replicate as described in section 4.1.2.

4.4.3. The Ripening Treatment:
The ripening treatment was carried out in 93L glass cubicles, with 0.80 mL level of ethrel (as described in 4.2.3. Method 1) calculated proportionately on a volume of 93L. The bananas were treated with ethrel and NaOH as described in (4.2.3 Method 1), at temperatures ranging from $30^\circ \pm 2^\circ\text{C}$ (ambient), $24^\circ \pm 2^\circ\text{C}$, $20^\circ \pm 2^\circ\text{C}$ and $15^\circ \pm 2^\circ\text{C}$. A set of untreated bananas was left at ambient temperature without the ripening agent as a control. Fruits thus exposed to ethrel and NaOH for 24 hrs were permitted free ventilation thereafter.
4.4.4. Recording of Observations:
Physico-chemical analysis and recording of observations were carried out as described in 4.1.4. (i.e. 4.1.4a to 4.1.4g) when bananas in each temperature level were fully ripe.

4.4.4.a. The Ripening Stage:
The ripening stage at each temperature was assessed and recorded daily using a guide prepared by Lizada et al (1990).

4.4.4.b. The Ripening Guide:
A ripening guide (as shown in appendix 1) was prepared considering various stages of ripening with time at each temperature.

4.5 Minimum Threshold Time to Ripen Banana:
The usual practice world over is to expose bananas to ethylene for 24 hours (Friend and Rhodes, 1981). The objective of this investigation is to find the minimum treatment time to ripen banana. The fruits were exposed to ethylene for shorter time durations to determine the objective.

4.5.1. Plant Material:
Banana of variety Embul of 12 week maturity was obtained from Minuwangoda. They were harvested and transported to the laboratory as described in section 4.1.1.

4.5.2. Experimental Design:
Banana transported to the laboratory were re-sorted and randomized as described in section (4.1.1). The experimental design was a CRD with five banana hands in each replicate as described in section 4.1.2.
4.5.3. The Ripening Treatment:
The ripening treatment was carried out in 93L glass cubicles, with 0.80 ml level of ethrel (as described in 14.2.3 Method) calculated proportionately on a volume of 93L, while one set of bananas was exposed to double the mentioned dosage of chemicals and exposed for 12 hours. Other sets of bananas treated were exposed to the chemicals for periods of 12 hours, 18 hours, 24 hrs and free ventilation was permitted thereafter.

4.5.4. Recording of Observations:
As described in section 4.1.4 (i.e. 4.1.4a to 4.1.4h) and 4.2.4.a bananas in all the treatments were subjected to physico-chemical and sensory evaluations 48 hrs after the ethrel treatment.

4.5.5. Statistical Analysis:
Data obtained from the trials were subjected to statistical analysis as described in section 4.1.5.
EXPERIMENTS WITH PAPAYA:

4.6. Influence of Ethylene Gas on Ripening of Papaya:

Different dosages of laboratory prepared ethylene gas were tested on papaya to determine the optimum concentration of ethylene for ripening. The experiment was carried out at ambient temperature (29±2) °C.

4.6.1. Plant Material:
Plant material for the experiment was obtained from a field at Eluwankulam (Puttalam district). Mature green papayas of pure variety Rathna, light green in colour just prior to the colour break were used in this experiment. They were transported to the laboratory covered with polyvinyl netting and packed with shredded paper. The papayas harvested were re-sorted at the laboratory, to eliminate fruits containing bruises or pathogen attacks.

4.6.2. Experimental Design:
Fruits with similar maturity and size were chosen for the trial and randomized using the random number procedure (Gomez and Gomez, 1984) before being allocated into treatments. A completely randomized design was used for the experiment. Each treatment consisted of three replicates with five papayas consisting three female fruits and two hermaphrodite fruits per replicate. The ripening chambers were also placed in a randomized design using random numbers to accommodate location effects.

4.6.3. The Ripening Treatment:
The papayas were treated as described in section 4.1.3 with laboratory prepared ethylene gas levels of 100ppm, 200ppm, 300ppm 400ppm. Fruits, thus exposed to ethylene for 24 hrs were permitted free ventilation thereafter.
4.6.4. Recording of Observations:
Observations were carried out when the treated papayas were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h).

4.6.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.

4.7. Influence of 2-Chloroethyl Phosphonic (ethrel) acid on Ripening Attributes of Papaya (variety Rathna):

As described previously (in section 4.2) the above mentioned chemicals were reacted to obtain the required ethylene to treat the papaya. The treatments were carried out at ambient temperature (29°C±2°C).

4.7.1. Plant Material:
Papayas of Rathna variety for the experiment were obtained from Eluwnkulam. They were harvested and transported to the laboratory as described in 4.6.1.

4.7.2. Experimental Design:
Papayas transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD.

4.7.3. The Ethrel (2-chloroethyl Phosphonic acid) and NaOH Treatment:
The fruits were treated with ethrel and NaOH with all levels of chemicals as described in section 4.2.3 method 1 calculated proportionately on a 93L container. The fruits were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.
4.7.4. Recording of Observations:
Observations were carried out when the treated papayas were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h).

4.7.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.

4.8. Influence of 2Chloroethyl Phosphonic (ethrel) acid on Colour Development of Papaya (mixed varieties):

Commercial operations usually handled papayas of mixed varieties. This is a scaled up trial for mixed varieties. The fruits were ripened in this experiment, by exposing them to ethrel and NaOH. Fruits not treated were considered as the control.

4.8.1. Plant Material:
Plant material for the experiment was obtained from a field at Marawila. Mature green papayas of mixed varieties, with the first trace of yellow were harvested and transported to the laboratory as described in section 4.6.1.

4.8.2. Experimental Design and Ripening Treatment:
Papayas transported to the laboratory were re-sorted and randomized into three sections randomly. Papayas weighing 18 kg in total were placed inside each 93 L glass cubicle as shown below. The papayas were stacked on the wooden platform and exposed to ethrel and NaOH. Ripeness was assessed daily via peel colour indices, by evaluating fifteen fruits individually, from each treatment.
The fruits were treated with ethrel and NaOH with 1.65 mL and 3.3 mL dosage levels calculated proportionately on a 93L container. Beakers containing ethrel and water were placed under the wooden rack. A plastic pipe was placed into the mouth of the beaker as shown, before stacking the papayas on the wooden rack. Finally, NaOH pellets were dropped into the beaker through the pipe before sealing the lids with vaselin. The fruits were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.

4.8.3. Recording of Observations:
The ripening stage (via peel colour development) was evaluated daily according to colour indices of papaya prepared by Lam (1987). Fifteen fruits from each treatment were evaluated each time, to obtain a single data point.
4.9. Comparative Effects of Selected Ripening Agents on physico-chemical and organoleptic Characteristics of Papaya:

This experiment was carried out to compare papayas ripened with three ripening agents. (i.e laboratory prepared ethylene gas, the ethylene gas was obtained by reacting ethrel with NaOH and acetylene gas liberated by CaC₂). Untreated fruits were regarded as the control. The trial was carried out at ambient temperature (29°±2°C). The most suitable dosage of the respective ripening agents, determined from previous trials conducted, was used to ripen the fruits in this experiment.

4.9.1. Plant Material:
Papayas of Rathna variety for the experiment were obtained from Eluwnkulam. They were harvested and transported to the laboratory as described in section 4.6.1.

4.9.2. Experimental Design:
Papayas transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD.

4.9.3. Ripening Agents and the Treatments:
Treatment 1 - Laboratory prepared ethylene gas – 250ppm
Treatment 2 - Ethylene gas liberated from ethrel and NaOH - (1.65 mL ethrel level calculated proportionately on a 93L container)
Treatment 3 - Acetylene gas liberated from CaC₂ – 1g / 1 Kg fruit
Treatment 4 - Control (Fruits not treated)

The fruits were exposed to ripening agents in 93L glass cubicles. Ethrel and CaC₂ were exposed as described in (4.2.3.method 1) and (4.3.3.) while ethylene gas was exposed as described in section 4.1.3. The fruits were exposed to the ripening agents for 24 hrs and free ventilation permitted thereafter.
4.9.4. Recording of Observations:
Observations were carried out when the treated papayas were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4 (i.e. 4.1.4a to 4.1.4h) and 4.2.4.a.

4.9.5. Statistical Analysis:
Data on physico-chemical parameters and organoleptic evaluation obtained from the trials were statistically analyzed as described in section 4.1.5.

4.10. Influence of Temperature on Ripening of Papaya:
Papayas of Rathna variety were ripened at three temperatures, with the most suitable level of ethrel determined from trial 4.7.

4.10.1. Plant Material:
Papayas of Rathna variety for the experiment were obtained from Eluwnkulam. They were harvested and transported to the laboratory as described in section 4.6.1.

4.10.2. Experimental Design:
Papayas transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD and each temperature had three replicates.

4.10.3. The ripening Treatment:
The fruits were exposed to ethrel and NaOH in 93L glass cubicles. The papayas were treated with 1.65 mL ethrel level at temperatures 29° ±2°C (ambient), 22°±2°C and 18° ±2°C as described in section 4.2.3 method 1. The fruits were exposed to the ripening agents for 24 hrs and free ventilation permitted thereafter as described in section 4.1.3.
4.10.4. Recording of Observations:
When the treated papayas at each temperature were fully ripe, they were subjected to physico-chemical and sensory evaluations as described in section 4.1.4 (i.e. 4.1.4a to 4.1.4h) and 4.2.4.a.

4.10.5. Statistical Analysis:
Data on physico-chemical parameters obtained from the trials were statistically analyzed as described in section 4.1.5.
EXPERIMENTS WITH MANGO

4.11. Influence of Ethylene Gas on Ripening of Mango:

Different dosages of laboratory prepared ethylene gas were tested on mango (variety Karuthakolomban) to determine the optimum concentration of ethylene for ripening. The treatments were carried out at ambient temperature 29±2 °C.

4.11.1. Plant Material:
Mature green mangoes with raised shoulders (of variety Karuthakolomban) for the experiment were obtained from a single tree at Minuwangoda. They were harvested, de-sapped and transported to the laboratory in plastic crates packed with shredded paper.

4.11.2. Experimental Design:
Mangoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. A completely randomized design was adopted for the experiment. Each treatment consisted of three replicates consisting five fruits per replicate. The ripening containers were also placed in a randomized design using random numbers (Gomez and Gomez, 1984) to accommodate location effects.

4.11.3. The ripening Treatment:
The mangoes were exposed to laboratory prepared ethylene gas ranging from 50ppm to 400ppm in 4L plastic bottles. Ethylene gas was injected into the rubber tubing (fixed to the bottles) as described in section 4.1.3. The fruits were exposed to the ripening agents for 24 hrs and free ventilation permitted thereafter as described in section 4.1.3.

4.11.4. Recording of Observations:
Observations were carried out when the treated mangoes were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h).
4.11.5. Disease scores:
Disease scores (Anthracnose and, stem and rot) were recorded.

4.11.6. Statistical Analysis:
Data obtained from the above experiment were subjected to statistical analysis as described in section 4.1.5.

4.12. Influence of 2Chloroethyl Phosphonic acid (ethrel) on Ripening Attributes of Mango:
The above-mentioned chemicals were reacted to obtain the required ethylene as described in section 4.2, to treat the mango. The treatments were carried out at ambient temperature 29°±2°C.

4.12.1. Plant Material:
Mangoes (variety Karuthakolomban) for the experiment were obtained from single a tree at Minuwangoda and transported to the laboratory as described in section 4.11.1.

4.12.2. Experimental Design:
Mangoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD with six mangoes in each replicate.

4.12.3. The Ethrel (2 chloroethyl Phosphonic acid) and NaOH Treatment:
The fruits were treated with ethrel and NaOH (with all three levels of chemicals mentioned in section 4.2.3 calculated proportionately on a 93 L container and treated as described in section 4.2.3.method 1. The treatments were carried out in 93L glass cubicles. Untreated fruits were considered as the control. The mangoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.
4.12.4. Recording of Observations:
Observations were carried out when the treated mangoes were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h ) and 4.2.4.a.

4.12.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section (4.1.5).

4.13. Comparative Effects of Selected Ripening Agents on physico-chemical and organoleptic Characteristics of Mango:
This trial was carried out to compare mangoes ripened with laboratory prepared ethylene gas, ethylene gas obtained by reacting ethrel with NaOH, and acetylene gas liberated by CaC₂. The trial was carried out at ambient temperature 29°±2°C. The most suitable dosages of the respective ripening agents, determined from previous trials conducted, were used in this experiment.

4.13.1. Plant Material:
Mangoes (variety Karuthakolomban) for the experiment were obtained from a single tree at Minuwangoda and transported to the laboratory as described in section 4.11.1.

4.13.2. Experimental Design:
Mangoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD with six mangoes in each replicate as described in section 4.11.3.
4.13.3. The ripening agents and the Treatment:
The following treatments were carried out:
Treatment 1 - Ethylene gas (laboratory prepared) – 250ppm
Treatment 2 - Ethylene gas liberated from ethrel and NaOH - (1.65 mL ethrel level calculated proportionately on a 93 L container)
Treatment 3 - Acetylene gas liberated from CaC$_2$. 1g / 1 Kg mango
Treatment 4 - Untreated fruits were regarded as the control.

The fruits were exposed to ripening agents in 93L glass cubicles. Ethrel and CaC$_2$ were exposed as described in section 4.3.5, while ethylene gas was prepared and treated as described in section 4.1.3. The mangoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.

4.13.4. Recording of Observations:
Observations were carried out when the treated mangoes were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h) and 4.2.4.a.

4.13.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.

4.14. Influence of Temperature on Ripening of Mango:
Mangoes of Rata amba variety was used in the experiment. The fruits were ripened using two concentrations of laboratory prepared ethylene gas at two temperatures.

4.14.1. Plant Material:
Mangoes (variety Rata Amba) for the experiment were obtained from a single tree at Minuwangoda and transported to the laboratory as described in section 4.11.1.
4.14.2. Experimental Design:
Mangoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD as described in section 4.6.3. Each treatment had three replicates with five mangoes per replicate.

4.14.3. The ripening Treatment:
The experiment was carried out at two temperatures (i.e. $29^\circ\pm2^\circ$C and $22^\circ\pm2^\circ$C). At each temperature the mangoes were treated with two concentrations of ethylene (i.e. 100ppm and 250ppm) as described in section 4.1.3. The ripening treatment was carried out in 4L plastic bottles. The fruits were exposed to ethylene gas for 24 hrs and free ventilation permitted thereafter.

4.14.4. Recording of Observations:
Observations were carried out when the treated mangoes were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h)

4.14.5. Statistical Analysis:
Results of the physico-chemical analysis were analyzed using Multi Factor ANOVA and Duncan's Multiple Range Test (DMRT) at confidence level of 95%.

4.15. Study of Physico-chemical parameters of mango during development (7th to 14th week):
The objective of this activity is to study the physico-chemical changes during development of the fruit close to harvest, in order to identify the most suitable maturity for harvesting. Mangoes of Karuthakolomban variety of eight maturities (7th week to 14th week) were used in this study.

4.15.1. Plant Material:
Mangoes (variety Karuthakolomban) for the experiment were obtained from Dambulla.
4.15.2. Method:
Mango clusters carrying mango at fruit set stage were tagged with coloured plastic ribbons for eight consecutive weeks. A different colour was assigned to tag the trees each week. When the first set of tagged mango bunches were 14 weeks mature, all the tagged mangoes were harvested at once and analyzed.

4.15.3. Maturity Assessment:
The harvested mangoes of the eight maturities were subjected to physico-chemical analysis. In order to obtain a single data point, seven mangoes were analyzed.

4.15.3.a. Shapes of the fruits:
The shapes of the fruits were visually observed, and also copied on paper.

4.15.3.b. Fruit Firmness:
Fruit firmness of the harvested mangoes was measured as described in section 4.1.4.g.

4.15.3.c. Pulp Extraction Methods:
Pulp of the harvested mangoes was extracted as described in section 4.1.4.a.

4.15.3.d. Total Soluble Solids (TSS):
TSS of the harvested mangoes was measured described in section 4.1.4.b.

4.15.3.e. Titratable Acidity:
Titratable acidity of the treated mangoes was analyzed as described in section 4.6.4.c.

4.15.3.f. Ascorbic Acid:
Ascorbic Acid content of the harvested mangoes was analyzed as described in section 4.1.4.d.

4.15.3.g. pH:
pH of the harvested mangoes was measured as described in section 4.1.4.e.
4.16. Influence of the Maturity Stage on the Quality of Mango Exposed to Ethylene:

Mangoes harvested at three stages of maturity (close to harvest) were exposed to ethylene gas via ethrel and NaOH, to determine the most suitable maturity for induced ripening.

4.16.1. Plant Material:
Mangoes (variety Karuthakolomban) at three maturities (12 weeks, 13 weeks and 14 weeks) were harvested for the experiment from an orchard at Dambulla. The mango clusters were tagged at fruit stage with coloured ribbons to identify the maturity, as described in section 4.15.2. The harvested mangoes were transported to the laboratory as described in section 4.11.1.

4.16.2. Experimental Design:
Mangoes transported to the laboratory were re-sorted and randomized (each maturity separately) as described in section 4.6.2. The design was a CRD with six mangoes in each replicate as described in section 4.11.3.

4.16.3. The Ripening Treatment:
The fruits were treated with 1.65mL ethrel and NaOH as described in (section 4.2.3. method 1) calculated proportionately on a 93L container. An additional set mango of 12-week maturity was exposed to a higher dose of ethrel at 2mL level. The treatments were carried out in 93L glass cubicles. The mangoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.

4.16.4. Recording of Observations:
Observations were carried out when the treated mangoes were 75% ripe. They were subjected to physico-chemical and sensory evaluations as described in section 4.1.4. (i.e. 4.1.4a to 4.1.4h)

4.16.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.
EXPERIMENTS WITH TOMATO:

4.17. Influence of Ethylene Gas on Ripening of Tomato:

This trial was conducted to determine the effect of laboratory prepared ethylene gas on Tomato. Several dosages of the gas were tested on tomato to find the threshold concentration for ripening. The treatments were carried out at ambient temperature $29\pm2^\circ$C.

4.17.1. Plant Material:
Tomato variety T245 for the experiment was obtained from Kandy. They were harvested and transported to the laboratory in plastic crates packed with shredded paper.

4.17.2. Experimental Design:
Tomatoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. A completely randomized design was adopted for the experiment. Each treatment consisted of three replicates consisting fifteen fruits per replicate. The ripening containers were also placed in a randomized design using random numbers to accommodate location effects.

4.17.3. The ripening Treatment:
The tomatoes were exposed to laboratory prepared ethylene gas ranging from 50ppm to 500ppm in 4.5L plastic bottles. Ethylene gas was injected into the rubber tubing (fixed to the bottles) as described in section 4.1.3. The fruits were exposed to ethylene gas for 24 hrs and free ventilation was permitted thereafter.

4.17.4. Recording of Observations:
Observations were recorded when 75% of the treated tomatoes were assessed as being ripe. Equal portions taken from five fruits of each replicate were used for the chemical analysis and were subjected to physico-chemical analysis as follows.
4.17.4.a Pulp Extraction Method:
A sample of the pulp taken as described in 4.1.4. was homogenized in the Liquidizer (Jaipan liquidizer).

4.17.4.b. Titratable Acidity:
The homogenate was filtered through double layers of muslin. A sample of 5ml of the extracted juice (as described in section 4.17.4.a.) was taken into a 100mL volumetric flask and made up to volume using distilled water. A 10ml sample from the above solution was titrated against 0.1N NaOH using phenolphthaleine as an indicator. In the case, when red tomatoes were used further dilutions were carried out in order to identify the colour change clearly, at the end point (Ranganna, 1986).

Calculation: -

\[
\text{% Total acid} = \frac{\text{Titre} \times \text{Normality NaOH} \times \text{Volume made up} \times \text{Equivalent wt of acid} \times 100}{\text{Volume of sample taken for estimation} \times \text{Volume of sample taken} \times 1000}
\]

Predominant acid was considered as citric. Equivalent weight of acid 0.007005g (Pearsons, 1987).

4.17.4.c. Total Soluble Solids (TSS):
Tomato juice extracted as described in section 4.17.4.a and used on the refractometer to measure TSS as described in section 4.1.4.b.

4.17.4.d. Ascorbic Acid:
Ascorbic Acid content of the treated tomatoes was analyzed as described in section 4.1.4 d. with tomato juice extracted as described in 4.17.4.a.
4.17.4.e. pH:
The pH of the treated tomatoes was measured as described in section 4.1.4.e using pulp extracted as described in section 4.17.4.a.

4.17.4.f. Weight Loss:
Weight losses of the treated tomatoes were assessed as described in section 4.1.4.f.

4.17.4.g. Fruit Firmness:
Fruit firmness of the treated tomatoes was measured as described in section 4.1.4.g.

4.17.5. Statistical Analysis:
Data obtained from the above experiment were subjected to statistical analysis as described in section 4.1.5.

4.18. Influence of 2Chloroethyl Phosphonic (ethrel) acid on Ripening Attributes of Tomato:

As described in section 4.2 the mentioned chemicals were reacted to obtain the required ethylene to treat tomato. The treatments were carried out at ambient temperature (29°±2°C).

4.18.1. Plant Material:
Mature green tomatoes of variety T245 were harvested from a field in Kandy and transported to the laboratory as described in section 4.17.1.

4.18.2. Experimental Design:
Tomatoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD with fifteen tomatoes in each replicate as described in section 4.17.2.
4.18.3. The Ethrel (2 Chloroethyl Phosphonic acid) and NaOH Treatment:
The fruits were exposed to ethrel and NaOH (with all three levels of chemicals mentioned in section 4.2.3. and treated as described in section 4.2.3 method 1. In addition to the above mentioned dosages used, a set of tomatoes were exposed to 1.65mL level ethrel for 48 hours. In this treatment the chemicals were replenished after 24 hours. The treatments were carried out in 93 L glass cubicles with ethrel concentration calculated proportionately to suit the volume of the container. Untreated fruits were considered as the control. Other than the set of tomatoes exposed to ethylene for 48 hours, all remaining tomatoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter as described in section 4.1.3.

4.18.4. Recording of Observations:
Observations were recorded when 75% of the treated tomatoes were assessed as being ripe. They were subjected to physico- chemical analysis as described in section 4.17.4. and recording of the peel colour as described in 4.2.4.a.

4.18.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.

4.19. Comparative Effects of Selected Ripening Agents on physico-chemical and Organoleptic Characteristics of Tomato:
This trial was carried out to compare tomatoes ripened with laboratory prepared ethylene gas, ethylene gas obtained via ethrel with NaOH, and acetylene gas liberated by CaC\textsubscript{2}. Each ripening agent, in triple dosages was tested on tomato. Tomatoes not treated were considered as the control. The trial was carried out at ambient temperature (29°±2°C).
4.19.1. Plant Material:
Tomatoes of variety T245 at mature green stage were harvested from a field at Matale. They were transported to the laboratory as described in section 4.17.1. Tomatoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2.

4.19.2. Experimental Design:
The design was a CRD with fifteen tomatoes in each replicate as described in section 4.17.2.

4.19.3. The ripening agents and the Treatment:
Treatment 1 - Concentration of ethylene gas (laboratory prepared) - 100ppm, 200ppm, 300ppm
Treatment 2 - Ethylene gas liberated from ethrel and NaOH - 0.80 mL, 1.65 mL, 3.30 mL (ethrel level) calculated proportionately on a 93 L container.
Treatment 3 - Acetylene gas liberated from CaC2 - 0.5g / 1 Kg fruit, 1g / 1 Kg fruit, 1.5g / 1 Kg
Treatment 4 - Untreated fruits were regarded as the control.

The fruits were exposed to ripening agents in 93L glass cubicles. Ethrel and CaC2 were exposed as described in 4.3.5, while ethylene gas was prepared and treated as described in section 4.1.3. The tomatoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter.

4.19.4. Recording of Observations:
Observations were recorded when 75% of the tomatoes were assessed as being ripe. They were subjected to physico-chemical analysis as described in section 4.17.4.

4.19.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5.
4.20. Influence of Temperature on Ripening of Tomato:

Tomato of variety ‘Thilina’ was used in the experiment. The fruits were exposed to three levels of ethrel at three temperatures, to study the effect of temperature on ripening of tomato.

4.20.1. Plant Material:
Tomato (variety ‘Thilina’) for the experiment were obtained from a field at Banadawella and transported to the laboratory as described in section 4.17.1.

4.20.2. Experimental Design:
Tomatoes transported to the laboratory were re-sorted and randomized as described in section 4.6.2. The design was a CRD as described in section 4.17.2. Each treatment had three replicates with fifteen tomatoes per replicate.

4.20.3. The Ripening Treatment:
The fruits were treated with three levels of ethrel previously discussed in (4.2.3 method 1) calculated proportionately on a 93 L container, at temperatures 18°C±2°C, 22°C±2°C and at ambient temperature 27°C ±2°C. Untreated fruits placed at the three temperatures were considered as the controls. The tomatoes were exposed to the ripening agent in 93L glass cubicles. The tomatoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter and were allowed to ripen at the same temperatures they were treated.

4.20.4. Recording of Observations:
Observations were recorded when 75% of the treated tomatoes were assessed as being ripe. They were subjected to physico-chemical analysis as described in section 4.17.4. and recording of the peel colour as described in 4.2.4.a

4.20.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5
4.21. Development of Red Colour in Harvested Tomato at Ambient Temperature via Light Treatment:

The objective of this experiment was to study the possibility of increasing the redness of tomato by exposing them to visible light irradiations at ambient temperature. Tomatoes harvested at three maturities, were treated with two types of light and a combination of them. Tomatoes not exposed to light were regarded as the control.

4.21.1 Plant Material:
Tomato (variety ‘Thilina’) in three maturities (mature green, breaker and turning) for the experiment were obtained from field at Banadarawella and transported to the laboratory as described in section 4.17.1. Tomatoes transported to the laboratory were re-sorted and randomized (each maturity separately) as described in section 4.6.1.

4.21.2. Experimental Design:
The design was a CRD as described in section 4.17.2. Each treatment had three replicates with ten tomatoes per replicate.

4.21.3. The Light Treatment:
The tomatoes were placed blossom end upwards in 4L plastic bottles covered with black paper to provide a dark environment. The fruits were then exposed to light treatments for 5 minutes, for the first five days as follows.
Treatment 1- Red light alone
Treatment 2- A combination of red and blue lights
Treatment 3- Dark control (not treated)
Red light of a wave length 650 - 700 nm and blue light of wave length 400 - 450 nm was used in the experiment.

A 75W electric bulb covered with reflex paper (of the required wave lengths) provided the light source. (The wave lengths of the reflex papers were confirmed to be correct by
testing it on a spectrophotometer, before being used in the experiment.) The intensity of the lights which were at a distance of 12 inches was checked using a Lux meter.

The tomatoes exposed to light were stored in the dark; in the same container they were placed.

4.21.4. Recording of Observations:
Observations were recorded when 75% of the treated tomatoes were assessed as being ripe. They were subjected to physico-chemical analysis as described in section 4.17.4. and recording of the peel colour as described in 4.2.4.a

4.21.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5

4.22. Development of Red Colour in Harvested Tomato at Low Temperature via Light Treatment:

This trial was carried out to determine whether a combination of visible light treatment at low temperature would further reduce the hue angle by increasing the redness of tomato. The experiment was carried out at 22 ± 2°C, with irradiations of visible light on tomato variety ‘Thilina’.

4.22.1. Plant Material:
Tomato (variety ‘Thilina’) for the experiment were obtained from field at Banadara-wella and transported to the laboratory as described in section 4.17.1.

4.22.2. Experimental Design:
Tomatoes transported to the laboratory were re-sorted and randomized (each maturity separately) as described in section 4.6.2. The design was a CRD as described in section 4.17.2. Each treatment had three replicates with ten tomatoes per replicate.
4.22.3. The Light Treatment:
The light treatment was carried out using a 75 W electric bulb source as described in section 4.21.3. with the following treatments.
Treatment 1 -Red light alone
Treatment 2 -Blue light alone
Treatment 3 - A combination of red and blue lights
Treatment 4 - Dark control (not treated)

The intensity of the light was measured and stored after exposure as described in section 4.21.3.

4.22.4. Recording of Observations:
Observations on peel colour were recorded when 75% of the treated tomatoes were assessed as being ripe.

4.22.4.a. Peel Colour Measurements:
Changes in the peel colour were recorded daily using a chromameter as described in section 4.2.4 a.

4.22.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5

4.23. Effect of Temperature and Time on Quality of Tomato after Storage:
In this investigation, tomatoes harvested at three maturity stages were stored for 2 weeks and 4 weeks consecutively at 12.0°C, to study the physico-chemical and colour changes during storage.
4.23.1. Plant Material:
Tomato variety T-245 in three maturities (mature green, Breaker and Light red) for the experiment were obtained from a field in Kandy and transported to the laboratory as described in section 4.17.1.

4.23.2. Experimental Design:
Tomatoes transported to the laboratory were re-sorted and randomized (each maturity separately) as described in section 4.6.2. The design was a CRD as described in section 4.17.3. Each treatment had three replicates with fifteen tomatoes per replicate.

4.23.3. The Storage Treatment:
Each replicate of tomatoes were packed in perforated cardboard boxes and placed at 12±2° C for 2 weeks and 4 weeks consecutively. At the end of the mentioned periods, the specific replicates (i.e. test samples) assigned for the time periods were removed from storage for assessment.

4.23.4. Recording of Observations:
After completion of 2 weeks and 4 weeks respectively, they were subjected to quality assessment as described in section 4.17.4. and peel colour measurement as described in 4.2.4.a.

4.23.4.a. Edible Yield:
Edible yield is described as tomatoes devoid of disease or rot. Edible yield of each treatment was calculated as a percentage as follows.

\[
\text{Edible yield} = \frac{\text{Weight of good fruits}}{\text{Total weight of fruits before storage}} \times 100
\]

4.23.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5
4.24. Influence of Ethrel and Temperature on Ripening of Stored Tomato:

In this investigation the stored tomatoes (as described in experiment 4.23) were subsequently induced to ripen, to study the changes in physico-chemical and organoleptic properties. The tomatoes stored for 2 weeks and 4 weeks respectively, were exposed to ethrel and NaOH at the end of the mentioned storage periods. Two ripening temperatures were tested each time, to expose the tomatoes to the ripening agents. Those not exposed to ethrel were regarded as the control.

4.24.1. Plant Material:
Tomato variety T_{245} stored for 2 weeks and 4 weeks respectively at 12±2°C in experiment 4.23 was used as the plant material for this investigation. Only tomatoes of mature green and breaker stages were used in this trial. Tomatoes devoid of defects, blemishes or diseases, were selected for the experiment out of all the stored tomatoes.

4.24.2. Experimental Design:
The selected tomatoes were randomized (maturities separately) using the random number procedure. The design was a CRD as described in section 4.17.3. Each treatment had three replicates with six tomatoes per replicate.

4.24.3. The Ripening Treatment:
The fruits were treated with 3.3.mL level of ethrel calculated proportionately on a 4 L container, at temperatures 22°C±2°C and at (ambient temperature) 29±2°C. Untreated fruits placed at the two temperatures were considered as the controls for each temperature. The tomatoes were exposed to the ripening agent in 4L plastic bottles. Before the ripening treatment was carried out the tomatoes were conditioned by leaving in transitional temperatures for 24 hrs. The tomatoes were exposed to ethylene for 24 hrs and free ventilation permitted thereafter. They were allowed to ripen at the same temperature in which they were treated.
4.24.4. Recording of Observations:
When the treated tomatoes were 75% ripe, they were subjected to physico-chemical and sensory evaluations as described in section 4.17.4. and peel colour measurement as described in 4.2.4.a.

4.24.5. Statistical Analysis:
Data obtained from the trials were statistically analyzed as described in section 4.1.5
Chapter 5
RESULTS

Experiments With Banana:

5.1 Influence of Ethylene Gas on Ripening of Banana:
Observations were recorded after 48 hours, when 75% of all fruits used in the trial were assessed ripe. Total soluble solids content showed an upward trend until the ethylene level reached a concentration of 150ppm and evened off there after as seen from Figure 1.

![Fig 1 Effect of ethylene gas on TSS and TSS: acid ratio of banana](image)

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.

The higher T.S.S values for control fruits than the initial, shows that slight ripening has taken place, even though the control fruits were not exposed to ethylene. The highest T.S.S was observed in fruits that were treated with 150ppm ethylene, while the lowest was observed in bananas that were not treated (initial and control). Fluctuations in the Brix : Acid ratio were observed.
Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W – Fresh Weight)

Data relating to titratable acidity is presented in Figure 2. Bananas treated with 100ppm ethylene had the highest level of acidity, although it was significantly different (p>0.05) to the 150 ppm level (Fig 2). Untreated fruits had the lowest degree of acidity.

Firmness and Ascorbic acid levels were significantly different (p>0.05) in all fruits treated. Highest rating for overall acceptability at the sensory evaluation score was obtained for bananas ripened with 200ppm ethylene, while a highest rating for taste was obtained for bananas ripened with 150ppm level. Ratings for peel colour, flesh colour, and aroma were similar with respect for levels 100ppm and above.

5.2 Influence of 2-Chloroethyl Phosphonic Acid (Ethrel) on Ripening Attributes of Banana:
Observations were recorded after 48 hours, when 75% of all fruits used in the trial were assessed ripe. Observations on firmness (Figure3) and LCH colour (Lightness,
Chroma and Hue) values in Figure 4 indicate a significant difference (p<0.05) between the treated and the untreated bananas (i.e. initial and control), while there was significant difference(p>0.05) within the treated fruits. It could be observed that L and C values have increased while the hue angle (°h) has declined.

![Graph showing effect of Ethrel concentration on firmness and titratable acidity of banana](image)

**Fig. 3**: Effect of Ethrel concentration on firmness and titratable acidity of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W - Fresh Weight)

![Graph showing effect of Ethrel concentration on LCH colour values of banana](image)

**Fig. 4**: Effect of Ethrel concentration on LCH colour values of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.
Observations on titratable acidity, ascorbic acid level, TSS and TSS: Acidity Ratio indicate a slightly different pattern. For these parameters, while there was no significant difference within the treated, the initial and control values were significantly different to each other (p<0.05). These observations are presented in Figures 3, 5, 6 and 7 respectively.

Fig. 5: Effect of Ethrel concentration on ascorbic acid content of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W - Fresh Weight)

Fig. 6: Effect of Ethrel concentration on TSS of banana

Control fruits were not treated. (F.W - Fresh Weight) Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.
Fig. 7: Effect of Ethrel concentration on TSS: Acidity ratio of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.
Fig. 8: Effect of Ethrel concentration on organoleptic properties of banana

As shown in Figure 8, the highest ratings at the organoleptic evaluation for aroma and taste were obtained for trickle system bananas (4.3.2.2.) while the ratings obtained for the 0.8mL level was comparatively higher than other levels.

5.3. Comparative Effects of Ripening Agents on Physico-chemical and Organoleptic Characteristics of Banana:

Treated fruits were ripe in two days, while the untreated controls took 5 days to ripen. Peel firmness (Figure 9) was observed to be lowest in the CaC$_2$ treated bananas. However, there was no significant difference between the treatments. Significant differences (p>0.05) in acidity and T.S.S. (Figures 9 and 10) were observed between ethrel treated and the naturally ripened control bananas, while it was significantly lower in the carbide treated fruits.
Fig. 9: Effect of ripening agents on Firmness and titratable acidity of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.

Fig. 10: Effect of ripening agents on TSS of banana
Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.

Fig. 11: Effect of ripening agents on Ascorbic acid content of banana

Ascorbic acid content (Figure 11) was significantly (p<0.05) higher in the carbide treated fruits. Ethrel treated and the control fruits had lower, and similar ascorbic acid contents. Sensory evaluation scores recorded (Figure 12), for taste and overall acceptability, were higher in both the controls, and the Ethrel treated fruits.

Fig. 12: Effect of ripening agents on organoleptic properties of banana
These results indicate that fruits treated with the CaC₂ were poorer in quality than naturally ripened fruits and fruits ripened with ethrel.

5.4. Influence of Temperature on ripening of Banana:
Analysis was carried out when each set of bananas stored at the mentioned temperatures reached maturity stage six (full yellow). The prepared ripening guide is presented in the appendix. Observations from the physicochemical analysis are presented below.

As shown in Figure 13 highest TSS was obtained in the control fruits and fruits ripened at 24°C±2°C while the highest acidity level was observed at temperature 24°C±2°C (Figure 14).

![Fig. 13: Effect of ripening temperature on TSS of banana](image)
Initial values were recorded before the commencement of the trial.
Control fruits were not treated.

![Fig. 14: Effect of ripening temperature on acidity of banana.](image)
*Initial values were recorded before the commencement of the trial.
Control fruits were not treated. F.W – Fresh Weight.
As shown in Figure 15 lowest ascorbic acid content was observed in fruits ripened at 24°±2°C.

![Graph showing effect of ripening temperature on Ascorbic acid content of banana]

**Fig. 15 : Effect of ripening temperature on Ascorbic acid content of banana**

Initial values were recorded before the commencement of the trial.

Control fruits were not treated. F.W – Fresh Weight.

It was observed that bananas ripened at 24°±2°C this temperature were firmer (0.83 Kp) than those ripened at 30°±2°C (0.52 Kp), and had a better cosmetic appearance. Differences in weight losses did not vary much within the temperatures tested.

**5.5. Minimum Threshold time to Ripen Banana :**

It was observed that bananas exposed to ethrel treatment for 12hrs and 18 hrs had better colour development than those treated for 24 hrs. *(i.e. 48 hrs after the initiation of the treatment)* Observations on the development of colour are shown in Figure 16. Rapid colour development could be observed in bananas that were exposed to the Ethrel treatment for 12 hrs, 12hrsDd (Double dose) and 18hrs. At the time of analysis (44 hours after treatment) the mentioned three treatments had similar hue angles while the 24 hour treatment had a higher hue angle. *(i.e. the bananas were greener).*
(12 Dd - Treated for 12 hrs with double dose ethylene)

Fig. 16 : Effect of exposure time of ethrel on color development of banana
Each data point represents mean of 25 fingers. Initial values were recorded before the Commencement of the trial. Control fruits were not treated.

Fig. 17 : Effect of exposure time to ethrel on TSS of banana fruit tissue.
Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.
As shown in Figure 17 TSS was lowest in the 24 hr treatment within the treated fruits. However, there were significant differences (p>0.05) within the treated fruits. The initial and control bananas had significantly lower TSS values. Regarding the T.A, except for the bananas not treated, titratable acidity was significantly different (p>0.05) within all the treatments (Figure 18).
Fig. 18: Effect of exposure time of ethrel on titratable acidity of banana

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. F.W – Fresh Weight.

Fig. 19: Effect of exposure time of ethrel on weight loss, fruit firmness and ascorbic acid content of banana. F.W – Fresh Weight.

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.

It could be observed from (Figure 19) that, fruit firmness was significantly different (p>0.05) within the treated fruits. Weight loss was highest in the 12Dd (12hr Double dose) treatment while the lowest was observed for the 24 hour treatment and the control. It could be noted that 12 hour and the 18 hour treatments had similar weight loss percentages. Ascorbic acid content was highest in the initial fruits while the lowest was observed in the 12 hour treatment (Figure 19).
As shown in Figure 20, highest ratings at the organoleptic evaluation were obtained for fruits ripened with 18 hours exposure time of ethylene. Further, it could also be observed that ratings for taste and overall acceptability obtained for 18 hour treatment is comparatively high, than for all other treatments. However, 12 hour treatment had the next highest ratings, while the 12 hour Dd treatment had comparatively lower ratings than the 12 hour treatment. Lowest ratings were obtained for the 24 hour treatment, other than for the control fruits.

- **A** - Single Dose – 12 hour treatment
  (30 hours after opening)

- **B** - Double dose – 12 hour treatment
  (30 hours after opening)

- **C** - Control – not treated

- **D** - Single dose – 18 hour treatment
  (24 hours after treatment)

- **E** - Single dose – 24 hour treatment
  (18 hours after opening)

**Plate 2**: Bananas exposed to ethrel for different exposure periods
Trials with Papaya:

5.6. Influence of Ethylene Gas on Ripening of Papaya:

Seventy five percent of fruits from all treatments were observed to have ripened in four days. As shown in Figure 21 and 22, although fruits treated with 200ppm & 300ppm ethylene had the highest Total Soluble Solids (TSS) and the lowest acidity respectively, both parameters were significantly (p>0.05) different within the treatments including that of the control.

![Fig. 21: Effect of ethylene gas on TSS and Ascorbic aid levels of papaya](image)

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%.
Plate 3: Preparation of ethylene gas

Plate 4: Papayas being ripened in the 93 L Glass chambers
Fig. 22: Effect of ethylene gas on titratable acidity of papaya

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. F.W – Fresh Weight.

The firmness in the control fruits was significantly (p< 0.05) different to those treated. As seen from the Figure 21 there was no significant difference in Ascorbic acid levels between the control fruits and those that were the treated.

Fig. 23: Effect of ethylene gas on Brix : acid ratio of papaya
(Values represent mean of 15 samples.)
As shown in Figure 23, TSS: Acidity ratio was observed to be the highest for fruits exposed to 300ppm, while the next highest was observed in the 200ppm level.

![Graph showing Friedman Rank](image)

**Fig. 24**: Effect of ethylene gas on organoleptic properties of papaya

Highest scores for flesh colour and overall acceptability at the organoleptic evaluation were obtained for fruits ripened at 300ppm level, while 200ppm level had the highest scores for aroma and taste as shown in Figure 24. Lowest score out of the treated fruits were obtained for papayas ripened with 400ppm ethylene.

![Images of fruit](image)

**Female Fruits of Rathna**

**Hermaphrodite fruits of Rathna**

Plate 5
5.7. Influence of 2-Chloroethyl Phosphonic (ethrel) acid on Ripening Attributes of Papaya (variety Rathna):

Seventy five percent of fruits from all treatments were observed to have ripened in four days. Firmness values were lowest in the 3.30mL level treatment. There was significant (p>0.05) difference in firmness, between initial values recorded at the commencement of the trial and those recorded for untreated controls at the end of the trial. However, the fruits became softer with the increase of the concentration and firmness was significantly (p<0.05) different within the treatments (Figure 25).

Initial and control fruits were similar in TSS, while being significantly (p<0.05) different to the treated fruits. Acidity was significantly different (p>0.05) within all the treatments (Figure 26), while ascorbic acid level was highest in the 3.30mL level (Figure 25).

![Fig. 25: Effect of Ethrel concentration on TSS, Ascorbic acid and fruit firmness of Papaya](image_url)

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.
Fig. 26: Effect of Ethrel concentration on titratable acidity of Papaya.

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%.

*Initial values were recorded before the commencement of the trial.

Fig. 27: Effect of Ethrel concentration on TSS: Acidity ratio of Papaya

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5% *Initial values were recorded before the commencement of the trial.

TSS: Acid ratios (Figure 27) of the treated fruits were significantly different (p<0.05) to that of the control and the initial fruits.
Scores at the sensory evaluation suggest that, (Figure 28) papayas ripened with 1.65 mL and 3.30 mL Ethrel had better organoleptic characteristics than other treatments. The 3.30mL level had the highest peel and flesh colour development while the highest ratings for the taste and the overall acceptability were obtained for the papayas ripened with 1.65 mL Ethrel.

5.8. Influence of 2-Chloroethyl Phosphonic (ethrel) acid on Colour Development of Papaya (mixed varieties):
Results from the experiment are summarized in figure 29.
Rapid rate of ripening (evaluated by the peel colour as described by Lama 1987 as shown in appendix plate No.2) is observed in fruits treated with 1.65 mL and 3.30mL Ethrel. It could be seen, that after 72 hours the papayas treated with this concentration had reached the stage five, while the controls had not reached even stage two.

5.9. Comparative Effects of Selected Ripening Agents on physico-chemical and organoleptic Characteristics of Papaya:

Fruits treated with ripening agents were ready for consumption in four days while the untreated were observed to take seven days. As shown in figures 30, 31 and 32, significant differences (p>0.05) were observed in weight loss, fruit firmness, TSS, acidity and ascorbic acid levels within the respective treatments.

![Fig. 30: Effect of ripening agents on weight loss, firmness, and pH of Papaya.](image)

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%.*Initial values were recorded before the commencement of the trial.
Fig. 31: Effect of ripening agents on ascorbic acid content and TSS of Papaya.

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial.

Fig. 32: Effect of ripening agents on Titratable acidity of Papaya

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. F.W – Fresh Weight.

However, sensory evaluation scores for flesh colour, aroma, taste and overall acceptability were higher in ethrel treated fruits as shown in Figure 33. No difference in peel colour was observed with respect to ethrel and Calcium Carbide treatments.
However, uneven ripening resulting in blotchy green patches (i.e. green islands) were observed in the latter instance on fruits as they changed from unripe green to yellow ripe stage.

![Graph showing the effect of ripening agents on organoleptic characteristics of Papaya.](image)

**Fig. 33**: Effect of ripening agents on organoleptic characteristics of Papaya

A - Control

B - Ethylene (200 ppm)

C - Ethrel (1.65 mL level)

D - CaC₂ (1g / Kg papaya)

![Plate 4 showing papayas ripened with different ripening agents.](image)

**Plate 4**: Papayas ripened with different ripening agents.
5.10. Influence of Temperature on Ripening of Papaya:
Papayas placed at 29°C±2°C reached edible stage, on the 4th day after ripening was induced, while those at 22°C±2°C were edible on the 6th day. The fruits held at 18°C±2°C, were not edible, even after 14 days and had to be discarded due to a high level of deterioration in quality. The skin of these papayas, became soft and prone to fungal attacks, so that disease set in before they reached the edible stage. Results from the trial are summarized in Table 1.

Table 1. Influence of temperature on physico-chemical parameters of papaya.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Weight Loss%</th>
<th>Firmness Kp</th>
<th>TSS °Brix</th>
<th>TA g 100 FW</th>
<th>Ascorbic acid mg 100 FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>29°C ± 2°C</td>
<td>3.75 a</td>
<td>0.93 a</td>
<td>10.16 c</td>
<td>0.037 d</td>
<td>4.03 e</td>
</tr>
<tr>
<td>22°C ± 2°C</td>
<td>3.01 a</td>
<td>1.86 b</td>
<td>11.85 c</td>
<td>0.039 d</td>
<td>6.60 f</td>
</tr>
</tbody>
</table>

Values represent mean of 15 samples. Any two means having common letters within means are not significantly different at 5% level. Mean separation by DMRT. F.W – Fresh Weight.

It can be observed from the results, that there were significant differences (p>0.05) in, weight loss, titratable acidity, and TSS between the two temperatures tested. However, TSS was observed to be slightly higher at 22°C±2°C, while ascorbic acid level and firmness was observed to be significantly (p<0.05) higher at this temperature.
Fig. 34 Influence of temperature on lightness (L values) of papaya
Each value represents mean of 15 samples. Initial values were recorded before the commencement of the trial.

35 : Influence of temperature on chroma (C values ) of papaya
Each value represents mean of 15 samples. Initial values were recorded before the commencement of the trial.
Fig. 36: Influence of temperature on hue angle (°h) of papaya during ripening.

Each value represents mean of 15 samples

*Initial values were recorded before the commencement of the trial.

Fig. 37: Influence of temperature on hue angle (°h) of peel colour and flesh colour at edible stage of papaya

(Each value represents mean of 15 samples)
Peel colour development of papaya from initiation to edible stage, (i.e LCH values) is presented in Figures 34, 35 and 36 respectively. Peel and flesh colour of papaya at edible stage is shown in Figure 37. It is seen that lower hue angles were obtained for both peel and flesh colour of papayas ripened at 22°±2°C.

It can be observed from results of this experiment, that there are no major differences in physico-chemical parameters of papayas ripened at 29°±2°C and at 22° ±2°C except the differences in the flesh colour.
Experiments With Mango:

5.11. Influence of Ethylene Gas on Ripening of Mango:
Observations on ethylene treated fruits were recorded five days after treatment when 75% of the treated mangoes were ripe. The control fruits followed irregular ripening patterns. Significant differences (p<0.05) in firmness, weight loss, and TSS, acidity, and Ascorbic acid levels were observed between the treatments.

![Graph](image_url)

Fig. 38: Effect of ethylene gas on TSS of mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. Initial values were recorded before the commencement of the trial. Control fruits were not treated.

As shown in the Figure 38 an increasing trend in the degree of Total Soluble Solids can be observed with the increase in dosage of ethylene gas until the 300 ppm level, when a downward trend in the TSS occurred. The lowest TSS was observed in the control set of fruits, while 50 ppm and 400 ppm levels had similar degree of TSS.

The acidity level Figure 39 was observed to decrease up to 200 ppm level and then increase. It could be observed that highest acidity level was found in the fruits treated with 50 ppm and this level was almost similar in acidity to the fruits ripened with 400 ppm ethylene.
Fig. 39: Effect of ethylene gas on titratable acidity of mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W- Fresh weight).

Fig. 40: Effect of ethylene gas on TSS: acidity ratio of mango

Values represent mean of 15 samples. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.

Brix:acid ratios are used in commercial operations and also are indicators of taste development. Therefore the ratio between TSS and acidity is a good measure of the
taste. As shown in Figure 40, the highest Brix:acid Ratio was obtained for mangoes ripened at 200ppm level.

![Graph showing Brix:acid Ratio](image)

**Fig. 41**: Effect of ethylene gas on Ascorbic acid content and pH of mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%.*Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W: Fresh weight).

![Graph showing Ethylene Concentration](image)

**Fig. 42**: Effect of ethylene gas on organoleptic properties of mango

As shown in Figure 41 ascorbic levels were similar in all the treated fruits and showed significant differences (p>0.05) except at 50 ppm where the lowest level was observed. Control fruits had a significantly higher level than the treated fruits.
As seen in Figure 42 ratings at the organoleptic evaluation indicated that 250ppm ethylene treatment obtained the highest ratings for flesh colour and overall acceptability, while 200ppm level also was observed to have comparatively higher ratings. Firmness in Figure 43 was significantly different (p>0.05) between treatments above 100ppm level and no significant differences in weight loss were observed between the treated mango.

![Graph showing effect of ethylene on firmness and weight loss of mango](image)

Fig. 43: Effect of ethylene on firmness and weight loss of mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%.*Initial values were recorded before the commencement of the trial.

It was observed that anthracnose and stem endrot was of common occurrence in ripe fruits. There were significant differences (p>0.05) in disease scores between the treatments. However, the disease incidence was 6.66% in the controls and 11.66% in all the mangoes treated.

5.12 Influence of 2-Chloroethyl Phosphonic Acid (Ethrel) on Ripening Attributes of Mango:

Observations were recorded four days after the treatment in this trial, when 75% of all treated fruits were observed to be ripe. The untreated mangoes were not fully ripe even after seven days. As shown in Figure 44 there were significant differences (p<0.05)
between fruits treated before treatment and the untreated controls with respect to fruit firmness.

![Graph showing effect of Ethrel concentration on fruit firmness and ascorbic acid content in Mango.]

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W- Fresh weight).

As shown in the same figure Ascorbic acid levels were significantly (p< 0.05) lower in the treated fruits than the initial volume and the values obtained from the untreated control. It can be observed from Figure 45 that acidity was significantly (p<0.05) different between the treated and the untreated fruits. However, there was significant difference between the treated fruits (p>0.05).

The lowest TSS was found in the fruits at initial level, while the highest was obtained for fruits ripened with 1.65 mL Ethrel although significantly (p>0.05) different within the treated (Figure 46).
Fig. 45: Effect of Ethrel concentration on titratable acidity of Mango.

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W- Fresh weight).

Fig. 46: Effect of Ethrel Concentration on TSS of mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.
As shown in Figure 47 highest TSS: acid ratio was observed in fruits ripened with 1.65 mL Ethrel, while being significantly different (p>0.05) to that of 0.8 mL level. Further, it can also be observed that ratios 3.30mL level fruits were lower than that of the 0.8mL and 1.65mL levels.

Fig. 47 : Effect of Ethrel concentration on TSS: acid ratio of mango
Values represent mean of 15 samples. *Initial values were recorded before the commencement of the trial.

Fig. 48 : Effect of Ethrel concentration on colour development (hue angle) of Mango
Values represent mean of 15 samples. *Initial values were recorded before the commencement of the trial.
As shown in Figure 48 it could be observed that even 0.8 mL of ethrel is sufficient to induce the colour development in mango. Mangoes treated with 3.3 mL ethrel had a slower rate of colour development than that of the 0.8 mL level. However, at the edible stage, colour was almost similar in all the mangoes treated.

![Friedman Ranks](image)

**Fig. 49:** Effect of Ethrel concentration on organoleptic properties of Mango.

As shown in Figure 49 highest ranks for flesh colour, aroma, taste and overall acceptability (i.e. all organoleptic characteristics except the peel colour) were obtained for fruits ripened with 1.65 mL Ethrel. However, highest organoleptic scores for peel colour were obtained for mangoes ripened with 3.3 mL ethrel even though other organoleptic scores were less.

5.13. Comparative Effects of Ripening Agents on Physico-chemical and Organoleptic Characteristics of Mango:

Observations were recorded four days after the treatment in this trial, when 75% of all treated fruits were observed to be ripe. As shown in figures 50, 51 and 52, significant differences (p>0.05) were observed between the ripening agents, on fruit firmness, TSS, titratable acidity and ascorbic acid levels.
Fig. 50 : Effect of ripening agents on fruit firmness of Mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. *Initial values were recorded before the commencement of the trial. Control fruits were not treated.

Fig. 51 : Effect of ripening agents on titratable acidity of Mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%.*Initial values were recorded before the commencement of the trial. Control fruits were not treated. (F.W- Fresh weight).
Fig. 52: Effect of ripening agents on TSS of Mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. Initial values were recorded before the commencement of the trial. Control fruits were not treated.

Fig. 53: Effect of ripening agents on TSS: acidity ratio of Mango

Values represent mean of 15 samples. Any two means having common letters are not significantly different by DMRT 5%. Initial values were recorded before the commencement of the trial. Control fruits were not treated.

As shown in Figure 53, TSS: acidity ratio was similar in all treatments although a slight increase was observed in the ethrel treated fruits.
Fig. 54: Effect of ripening agents on colour development (hue angle) of Mango, before and after ripening treatments

It could be observed from Figure 54 that, the best peel colour development (lowest hue colour) was obtained in calcium carbide ripened fruits, while there was no difference in the flesh colour between the treatments. The peel colour of mango in the control fruits had hardly changed colour even after three days.

Fig. 55. Effect of ripening agents on organoleptic properties of Mango
The highest rating for the peel colour at the organoleptic evaluation was obtained for the calcium carbide ripened fruits while ethrel ripened fruits were rated high for the flesh colour (Figure 55). Aroma and taste were observed to be higher in ethylene and ethrel ripened fruits.

5.14. Influence of Temperature on Ripening of Mango:
Observations were recorded four days after the treatment in this trial, when 75% of all treated fruits were observed to be ripe. Results from the experiment are summarized in Table 2 and 3.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Firmness</th>
<th>TSS °Brix</th>
<th>Titratable acidity g g⁻¹₀₀ FW</th>
<th>Ascorbic acid mg g⁻¹₀₀ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>28° ±2°C</td>
<td>2.856 x</td>
<td>15.6 z</td>
<td>0.065 c</td>
<td>4.56 e</td>
</tr>
<tr>
<td>22° ±2°C</td>
<td>2.863 x</td>
<td>15.2 z</td>
<td>0.124 d</td>
<td>3.42 f</td>
</tr>
</tbody>
</table>

Values represent mean of 15 samples. Any two means having common letters are not significant at 5% level. Mean separation by DMRT. (F.W- Fresh weight).

<table>
<thead>
<tr>
<th>Ethylene Concentration</th>
<th>Firmness</th>
<th>TSS °Brix</th>
<th>Titratable acidity g g⁻¹₀₀ FW</th>
<th>Ascorbic acid mg g⁻¹₀₀ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.15 a</td>
<td>14.0 d</td>
<td>0.106 g</td>
<td>4.32 x</td>
</tr>
<tr>
<td>100ppm</td>
<td>2.83 b</td>
<td>15.2 e</td>
<td>0.096 h</td>
<td>3.82 y</td>
</tr>
<tr>
<td>250ppm</td>
<td>2.60 c</td>
<td>16.8 f</td>
<td>0.083 k</td>
<td>3.89 y</td>
</tr>
</tbody>
</table>

Values represent mean of 15 samples. Any two means having common letters are not significant at 5% level. Mean separation by DMRT. Control fruits were not treated. (F.W- Fresh weight).
No temperature effect was observed in mangoes for TSS and firmness, while it can be observed from Table (2) that ripening at ambient temperature ($28^\circ \pm 2^\circ$C) had significantly ($p< 0.05$) lowered the acid content in mango. Ascorbic acid was observed to be lower in mangoes ripened at $22^\circ \pm 2^\circ$C.

![Graph showing pH levels at different temperatures and ethylene concentrations](image)

Fig. 56 Combined effects of temperature and ethylene on pH of mango

It can be observed from table 3 that, that ethylene concentration had a significant effect in ripening of mango. It is seen that TSS, titratable acidity and fruit firmness were significantly different, in fruits that were in the control, 100ppm level and 250ppm level. However, the ascorbic acid content was similar within the treated fruits. Fig 56 indicates that, a higher pH was obtained by fruits ripened at $28\pm 2^\circ$C which indicates that the acidity is low in the ambient ripened fruits.

5.15 Study of Physico-chemical parameters of mango during development

(7th to 14th week):

Changes in TSS of mango from 7th week to 14th week after fruit set are presented in Figure (57). An increasing trend in TSS could be observed up to the 13th week (i.e. the highest TSS) followed by a decrease there after. The curve indicates two peaks of week 9 and week 12 respectively, with the latter being higher and a sharp increase in TSS observed between 12th and the 13th week.
Fig. 57: Changes in TSS and pH of during development of mango fruits over 7-14 weeks after fruit set.
(Values represent mean of 15 samples.)

The titratable acidity was observed to increase until the 9th week while a decrease was observed (Figure 58) from the 11th week up to 14th week. As shown in Figure 57 pH has an increasing trend. A sharp increase in pH could be observed between 11th week and 12th week while a sharp drop in titratable acidity is observed during the same period as shown in Figure 58.

Fig. 58: Changes in titratable acidity of mango during development 7-14 weeks after fruit set. (Values represent mean of 15 samples. (F.W- fresh weight).
Results of Ascorbic acid levels at respective stages of maturity are presented in Figure 59. Levels were observed to decrease steadily over the 14 weeks with the exception of a slight increase in week 13.

Fig. 59: Changes in Ascorbic acid content of mango during development Over 7-14 weeks after fruit set (Values represent mean of 15 samples)

Fig. 60: Changes in fruit firmness of mango during development over 7-14 weeks after fruit set. (Values represent mean of 15 samples)
As shown in Figures 59 and 60 decreasing trends in Ascorbic acid content and firmness are observed. However, it is noted that an increase of firmness is observed at 13 weeks. This could be attributed to some physiological change. That would be discussed later.

![Graph showing changes in TSS:acid ratio of mango during development over 7-14 weeks after fruit set.](image)

**Fig. 61:** Changes in TSS:acid ratio of mango during development over 7-14 weeks after fruit set. (Values represent mean of 15 samples)

Figure 61 shows a sharp continuous increase in TSS: acid ratio from 11th week to 14th week of development. Observations on the shape revealed that, as the mangoes became mature, the shoulders around the pedicel raised.

**5.16. Influence of the Maturity Stage on the Quality of Mango:**
Observations on the treated fruits were recorded four days after treatment when 75% of the treated fruits were assessed ripe. Changes in fruit firmness and pH are presented Figure 62.
Fig. 62 Effect of maturity stage on firmness of mango exposed to ethrel treatment.

Values represent mean of 15 samples. Any two means having common letters are not significant at 5% level. Mean separation by DMRT. T* indicates mangoes ripened with a higher dose of Ethrel. Control fruits were not treated.

A significant difference in firmness (p<0.05) was observed between fruits at different stages of maturity. As shown in Figure 62 however, all treated fruits irrespective of maturity stage had lower fruit firmness values with respect to the controls. pH values were similar between all the treatments of maturity.

Fig. 63 Effect of maturity stage on TSS of mango exposed to ethrel treatment.

Values represent mean of 15 samples. Any two means having common letters are not significant by DMRT 5%. T* indicates mangoes ripened with a higher dose of Ethrel. Control fruits were not treated.
As shown in Figure (63) it can be observed that all treatments were significantly different (p>0.05) in TSS. However, mango at 13 week stage of maturity had the highest TSS.

Figure 64 shows the influence of maturity stage on acidity of mango treated with ethrel as stated in 4.16. Mangoes treated at 12th and 13th week stage of maturity had the lowest titratable acidity values, which were significantly different (p>0.05). It was also observed that ascorbic acid levels were significantly different (p<0.05) between the treatments. Lowest value was observed from treated mangoes at 14th week stage of maturity, while the highest was obtained from control set of mangoes at 12th week stage of maturity.

Fig. 64 Effect of maturity stage on titratable acidity mango exposed to ethrel treatment.
Values represent mean of 15 samples. Any two means having common letters are not significant by DMRT 5%. T* indicates mangoes ripened with a higher dose of Ethrel. Control fruits were not treated. (F.W- Fresh weight).
Higher ratings for organoleptic characteristics were obtained for fruits that were ripened with ethrel (i.e. at all the maturity levels). However, it could be observed from Figure 65 that the highest ratings for taste and overall acceptability were obtained for fruits ripened at 13th week and 14th week stage of maturity.
Experiments With Tomato:

5.17. Influence of Ethylene Gas on Ripening of Tomato:
Results of the physico-chemical analysis are summarized in table 4.

Table 4: Effect of ethylene on physico-chemical parameters of tomato

<table>
<thead>
<tr>
<th>Treatment Ethylene ppm</th>
<th>T.S.S °Brix</th>
<th>Firmness Kp</th>
<th>Ascorbic acid mg g⁻¹ F.W</th>
<th>T.A g g⁻¹ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.27 a</td>
<td>3.90 b</td>
<td>05.78 w</td>
<td>0.300 y</td>
</tr>
<tr>
<td>50 ppm</td>
<td>3.33 a</td>
<td>3.92 b</td>
<td>14.53 x</td>
<td>0.340 y</td>
</tr>
<tr>
<td>100 ppm</td>
<td>3.70 a</td>
<td>3.87 b</td>
<td>14.95 x</td>
<td>0.333 y</td>
</tr>
<tr>
<td>150 ppm</td>
<td>3.40 a</td>
<td>3.91 b</td>
<td>13.67 x</td>
<td>0.357 y</td>
</tr>
<tr>
<td>200 ppm</td>
<td>3.80 a</td>
<td>3.93 b</td>
<td>14.90 x</td>
<td>0.348 y</td>
</tr>
<tr>
<td>250 ppm</td>
<td>3.60 a</td>
<td>3.98 b</td>
<td>12.77 x</td>
<td>0.300 y</td>
</tr>
<tr>
<td>300 ppm</td>
<td>3.60 a</td>
<td>3.96 b</td>
<td>14.90 x</td>
<td>0.330 y</td>
</tr>
<tr>
<td>350 ppm</td>
<td>3.90 a</td>
<td>3.96 b</td>
<td>12.87 x</td>
<td>0.341 y</td>
</tr>
<tr>
<td>400 ppm</td>
<td>3.20 a</td>
<td>3.94 b</td>
<td>12.65 x</td>
<td>0.359 y</td>
</tr>
<tr>
<td>450 ppm</td>
<td>3.90 a</td>
<td>4.00 b</td>
<td>14.22 x</td>
<td>0.326 y</td>
</tr>
<tr>
<td>500 ppm</td>
<td>3.30 a</td>
<td>3.99 b</td>
<td>13.80 x</td>
<td>0.317 y</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not significantly different at 5% level. Mean separation by DMRT. Values represent mean of 15 samples. Control fruits were not treated. (F.W – Fresh Weight)
The tomatoes were rather yellow in colour instead of the desired redness, when taken for analysis ten days after the ethylene treatment. Results from the physico-chemical analysis revealed that, there were no significant differences between the treated and the untreated fruits.

5.18. Influence of 2-Chloroethyl Phosphonic (ethrel) acid on Ripening Attributes of Tomato:

When the tomatoes were analyzed nine days after the ethrel treatment, the fruits were of yellowish red colour (i.e. not the acceptable red colour). As presented in Table 5 there was no significant difference in titratable acidity, TSS and firmness between the control and the treated fruits. However, ascorbic acid content was higher in tomatoes ripened with 3.3 mL ethrel.

Table 5 Effect of ethrel on physico-chemical parameters of tomato

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight loss %</th>
<th>Firmness Kp</th>
<th>TSS ° Brix</th>
<th>Ascorbic acid mg g⁻¹ FW</th>
<th>pH</th>
<th>Acidity g g⁻¹ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>-</td>
<td>0.85 e</td>
<td>4.00 y</td>
<td>04.76 a</td>
<td>4.64</td>
<td>0.98 p</td>
</tr>
<tr>
<td>Control</td>
<td>3.05 a</td>
<td>0.45 f</td>
<td>4.08 y</td>
<td>09.00 ab</td>
<td>4.30</td>
<td>0.91 p</td>
</tr>
<tr>
<td>0.8 mL</td>
<td>3.14 a</td>
<td>0.44 f</td>
<td>4.06 y</td>
<td>18.56 b</td>
<td>4.06</td>
<td>0.93 p</td>
</tr>
<tr>
<td>1.65 mL</td>
<td>3.05 a</td>
<td>0.45 f</td>
<td>4.06 y</td>
<td>18.90 b</td>
<td>4.00</td>
<td>0.89 p</td>
</tr>
<tr>
<td>3.3 mL</td>
<td>3.50 a</td>
<td>0.46 f</td>
<td>4.00 y</td>
<td>26.10 c</td>
<td>4.04</td>
<td>0.92 p</td>
</tr>
<tr>
<td>1.65 mL**</td>
<td>3.13 a</td>
<td>0.48 f</td>
<td>4.26 y</td>
<td>20.00 bc</td>
<td>4.07</td>
<td>0.69 q</td>
</tr>
</tbody>
</table>

(Double dose of ethrel exposed for 48 hours is indicated by **)  
Any two means having common letters within columns are not significantly different at 5% level.  
Mean separation by DMRT. Values represent mean of 15 samples. Control fruits were not treated.  
(F.W – Fresh Weight)
5.19 Comparative Effects of Selected Ripening Agents on physico-chemical and Organoleptic Characteristics of Tomato:

Observations were recorded when the tomatoes changed colour in 10 days after the treatment and 75% of all the fruits treated were assessed ripe. However, the desired redness was not obtained. Table 6 shows that there is no significant difference (p<0.05) in weight loss, fruit firmness, TSS, titratable acidity between the treated and untreated fruits. It is noted that these parameters have had no influence even when concentration of the ripening agent was increased. However, it was observed that ascorbic acid content had increased significantly (p<0.05) in Calcium Carbide and ethrel ripened fruits.

Sensory evaluation revealed that the organoleptic properties of tomato, such as peel colour, flesh colour, aroma, taste and overall acceptability had obtained a similar rank between all treatments.

Table 6: Effect of ripening agents on physico-chemical parameters of tomato

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Titratable Acidity g°FW</th>
<th>Ascorbic Acid mg g°FW</th>
<th>TSS °Brix</th>
<th>Firmness Kp</th>
<th>Weight Loss %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5g CaC2</td>
<td>0.960a</td>
<td>6.340c</td>
<td>4.20a</td>
<td>0.53a</td>
<td>1.76a</td>
</tr>
<tr>
<td>1.0g CaC2</td>
<td>0.789a</td>
<td>6.042c</td>
<td>3.93a</td>
<td>0.47a</td>
<td>1.70a</td>
</tr>
<tr>
<td>1.5g CaC2</td>
<td>0.960a</td>
<td>4.560b</td>
<td>4.07a</td>
<td>0.50a</td>
<td>1.81a</td>
</tr>
<tr>
<td>Ethrel 0.80 ml</td>
<td>0.832a</td>
<td>7.638c</td>
<td>4.20a</td>
<td>0.55a</td>
<td>1.67a</td>
</tr>
<tr>
<td>Ethrel 1.65 ml</td>
<td>0.768a</td>
<td>7.182c</td>
<td>4.30a</td>
<td>0.63a</td>
<td>1.55a</td>
</tr>
<tr>
<td>Ethrel 3.30 ml</td>
<td>0.810a</td>
<td>6.840c</td>
<td>4.10a</td>
<td>0.47a</td>
<td>1.86a</td>
</tr>
<tr>
<td>C₂H₄ 100ppm</td>
<td>0.896a</td>
<td>3.762ab</td>
<td>4.20a</td>
<td>0.40a</td>
<td>1.81a</td>
</tr>
<tr>
<td>C₂H₄ 200ppm</td>
<td>0.960a</td>
<td>4.218ab</td>
<td>4.20a</td>
<td>0.53a</td>
<td>1.73a</td>
</tr>
<tr>
<td>C₂H₄ 300ppm</td>
<td>0.789a</td>
<td>3.420ab</td>
<td>4.70a</td>
<td>0.57a</td>
<td>1.55a</td>
</tr>
<tr>
<td>Control</td>
<td>0.853a</td>
<td>2.622a</td>
<td>4.10a</td>
<td>0.60a</td>
<td>1.70a</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not significantly different at 5% level. Mean separation by DMRT. Values represent mean of 15 samples. Control fruits were not treated. (F.W - Fresh Weight)
5.20. Influence of Temperature on Ripening of Tomato:
Tomatoes treated and ripened at 22° ±2°C and had 27° ±2°C changed colour from green to red in eight days, other than the treated tomatoes ripened at 18° ±2°C. Hence additional six days were allowed for the latter to change colour fully (i.e. altogether 14 days).

Individual influences of temperature and ethrel concentration on TSS of tomato can be observed in Figure 66, and the combined effect in Figure 67. TSS values were significantly higher in tomatoes ripened at 27°±2°C and at 22°±2°C than the other temperature. Effect of ethrel alone had not contributed to change the TSS.

![Fig. 66](image)

**Fig. 66:** Individual effects of temperature and ethrel concentration on TSS of tomato.

(Any two means having common letters within means are not significantly different by DMRT 5%. Values represent mean of 15 samples. Control fruits were not treated.)

![Fig. 67](image)

**Fig. 67:** Combined effects of ethrel and temperature on TSS of tomato.
Fig. 68: Individual effects of ethrel and temperature on Titratable acidity of tomato.

(Any two means having common letters within means are not significantly different by DMRT 5%. Values represent mean of 15 samples. Control fruits were not treated.)

Figure 68 shows a significant effect of temperature on the acidity of tomato, while a significant difference contributed by ethrel cannot be observed. Acidity was observed to be lowest at 18°C±2°C. The combined effect of ethrel and temperature on ripening of tomato is shown in Figure 69.

Fig. 69: Combined effects of ethrel and temperature on Titratable acidity of tomato

Figure 68 shows a significant effect of temperature on the acidity of tomato, while a significant difference contributed by ethrel cannot be observed. Acidity was observed to be lowest at 18°C±2°C. The combined effect of ethrel and temperature on ripening of tomato is shown in Figure 69.
Individual effects of temperature and ethrel concentration on hue angle (red colour development) are shown in Figure 70, and the combined effect in Figure 71. It is seen that Ethrel has had no effect on the hue angle while the low temperatures have dramatically lowered the hue angle in tomato. It could be observed that the lowest hue angle was obtained from tomato ripened at 18° ±2°C for 14 days (°h = 40.21) while the highest (°h = 55.23) was from tomatoes ripened at 27° ±2°C. Hue angle of a tree ripened tomato with high red colour, measured for comparison had a value of 37°h.

Fig. 70 : Individual effects of ethrel and temperature on the hue angle (red colour) of Tomato
Any two means having common letters within means are significantly not different by DMRT 5%. Values represent mean of 15 samples.

Fig. 71 : Combined effect of ethrel and temperature on hue angle (red colour) of tomato.
Table 7: Influence of temperature (irrespective of ethrel concentration) on Physico-chemical parameters of tomato

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Weight Loss %</th>
<th>Firmness Kp</th>
<th>Ascorbic acid mg g⁻¹00 FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>18° ±2°C</td>
<td>1.96 a</td>
<td>0.43 c</td>
<td>18.28 e</td>
</tr>
<tr>
<td>22° ±2°C</td>
<td>3.33 b</td>
<td>0.32 d</td>
<td>22.60 f</td>
</tr>
<tr>
<td>27° ±2°C</td>
<td>3.40 b</td>
<td>0.31 d</td>
<td>23.20 f</td>
</tr>
</tbody>
</table>

Any two means having common letters within means are significantly not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Table 8: Influence of ethrel concentration (irrespective of temperature) on physico-chemical parameters of tomato

<table>
<thead>
<tr>
<th>Ethrel</th>
<th>Weight Loss %</th>
<th>Firmness Kp</th>
<th>Ascorbic acid mg g⁻¹00 FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 mL</td>
<td>3.06 p</td>
<td>0.37 r</td>
<td>21.15 s</td>
</tr>
<tr>
<td>1.65 mL</td>
<td>3.01 p</td>
<td>0.37 r</td>
<td>21.24 s</td>
</tr>
<tr>
<td>3.3 mL</td>
<td>3.04 p</td>
<td>0.37 r</td>
<td>22.21 s</td>
</tr>
<tr>
<td>Control</td>
<td>3.80 q</td>
<td>0.30 r</td>
<td>20.84 s</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Individual effects of temperature and ethrel on tomato are shown in Tables 7 and 8 respectively. It is seen that only the temperatures have had an effect on the physico-chemical parameters of tomato. Therefore, it could be observed that the temperature influences more ripening in tomato.
5.2.1 Development of Red Colour in Harvested Tomato via Light Treatment at Ambient Temperature:

Light treated tomatoes were red in colour and were analyzed after 10 days. The results of the physico-chemical analysis were subjected to Multifactor ANOVA and are presented in Tables 10 and 11.

Table 9: Effect of light quality, on physico-chemical parameters of tomato harvested at three maturity stages - Mature green, Breaker and turning (10 days after initial treatment)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight Loss %</th>
<th>Firmness Kp</th>
<th>TSS °Brix</th>
<th>Ascorbic Acid mg g⁻¹FW</th>
<th>TA g g⁻¹FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red light</td>
<td>2.63 a</td>
<td>0.38 a</td>
<td>4.9 ab</td>
<td>24.46 a</td>
<td>0.510 a</td>
</tr>
<tr>
<td>Red and Blue Light</td>
<td>2.87 a</td>
<td>0.40 ab</td>
<td>4.98 b</td>
<td>24.87 a</td>
<td>0.483 a</td>
</tr>
<tr>
<td>Control</td>
<td>2.64 a</td>
<td>0.42 b</td>
<td>4.86 a</td>
<td>24.67 a</td>
<td>0.487 a</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

No significant interactions (p<0.05) were observed between light quality and the stage of maturity. As it could be observed from Table 9, firmness was significantly lower (p<0.05) and total soluble solids content significantly higher (p<0.05) in the light treated tomatoes than the controls. However total acids, ascorbic acid content and the weight losses were not affected by the light treatment.
Table 10: Effect of maturity, on physico-chemical parameters of light treated tomatoes 10 days after initial treatment

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Weight Loss %</th>
<th>Firmness Kp</th>
<th>TSS °Brix</th>
<th>Ascorbic Acid mg g⁻¹FW</th>
<th>TA g g⁻¹FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature green</td>
<td>2.88 a</td>
<td>0.37 a</td>
<td>4.86 a</td>
<td>22.0 a</td>
<td>0.46 a</td>
</tr>
<tr>
<td>Breaker</td>
<td>2.59 a</td>
<td>0.38 a</td>
<td>4.99 b</td>
<td>25.3 b</td>
<td>0.47 a</td>
</tr>
<tr>
<td>Turning</td>
<td>2.70 a</td>
<td>0.46 b</td>
<td>4.89 a</td>
<td>25.5 b</td>
<td>0.49 a</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Total soluble solids content (Table 10) was significantly higher (p<0.05) in light treated breaker stage tomatoes. It could be observed from the same Table that, firmness was highest in tomatoes harvested at turning stage and treated with light while ascorbic acid content was lowest in light treated mature green tomatoes.

Effect of light quality on colour of tomato was measured by hue angle at each maturity level. Readings were subjected to a one way ANOVA with data presented in Figures 72, 73 and 75.
Fig. 72: Effect of light quality on hue angle of tomato harvested at mature green stage

Any two means having common letters within means are significantly not different by DMRT 5%. Values represent mean of 15 samples.

Figures 72 and 73 indicate that a combination of red and blue lights are most suited to enhancing red colour development in (lower the hue angle) tomato harvested at mature green stage and breaker stages respectively. However, red light alone was observed to be best out of all treatments to develop red colour and lower the hue angle of tomato harvested at turning stage (Figure 74).
Plate 7: Tomatoes being harvested at Bandarawela.

Plate 8: Light treatment on tomatoes
Fig. 73: Effect of light quality on hue angle of tomato harvested at breaker stage

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples.

Fig 74: Effect of light quality on hue angle of tomato harvested at turning stage

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples.
Development of colour of tomato at turning stage over a period of ten days, after the red light treatment, is presented in Figure 75.

![Diagram of tomato colour development](image)

Fig. 75 : Development of red colour of tomato at turning stage when subjected to light treatments (at ambient temperature)

5.22 Development of Red Colour in Harvested Tomato via Light Treatment at Low Temperature (22±2°C):

LCH values from the trial subjected to Multi Factor ANOVA are presented in table 11.

Table 11: Effect of maturity, on LCH colour values of light treated tomatoes (at 22±2°C) 10 days after initial treatment

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>C</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature Green</td>
<td>40.77 a</td>
<td>34.67 c</td>
<td>42.05 x</td>
</tr>
<tr>
<td>Breaker</td>
<td>39.86 b</td>
<td>33.25 d</td>
<td>41.82 y</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not different by DMRT 5%. Values represent mean of 15 samples.
Table 12: Effect of quality of light, on LCH colour values of light treated tomatoes (mature green, breaker and turning at 22±2°C) 10 days after initial treatment

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>C</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>39.7 a</td>
<td>33.83 d</td>
<td>40.80 p</td>
</tr>
<tr>
<td>Blue</td>
<td>39.64 a</td>
<td>33.34 e</td>
<td>41.15 q</td>
</tr>
<tr>
<td>Red and Blue</td>
<td>40.51 b</td>
<td>34.15 f</td>
<td>41.95 r</td>
</tr>
<tr>
<td>Control</td>
<td>41.43 c</td>
<td>34.52 g</td>
<td>43.85 s</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not different by DMRT 5%. Values represent mean of 15 samples.

The breaker stage tomatoes have a significantly lower hue angle than the mature green tomatoes (Table 11). Out of all light treatments, the tomatoes exposed to red light had the lowest hue angle (Table 12). Therefore it could be concluded that red light is better suited to be treated on tomatoes harvested at breaker stage.

5.23. Effect of Temperature and Duration on Storage of Tomato:
Changes in the colour development of tomato from green to red recorded over 4 weeks at 12°±2°C recorded via hue angle is shown in Figure 76.

![Figure 76](image)

Fig. 76: Changes in the hue angle of tomato during storage at 12°±2°C, for 4 weeks. (Each data point represents mean of 15 tomatoes).
The above figure shows that all three maturities of tomato chosen for the trial have continuously changed colour, as indicated by the decrease in the hue angle recorded in the Figure 76. It could be seen that the highest change in colour was observed from tomatoes stored at mature green stage (i.e. difference of 58°), while the lowest change has been from those harvested and stored at the light red stage of maturity. It could also be observed from Figure 76 that, mature green tomatoes stored at 12° ± 2° C, had turned to light red stage after 4 weeks of storage. Breaker stage tomatoes showed a rapid change in colour within the first 2 week period of storage and a slower change thereafter up to the 4th week. Colour of breaker stage tomatoes have come close to the colour of light red tomatoes after 2 weeks storage Change in colour of both these maturity stages from 2 weeks to 4 weeks have closely followed a similar pattern.

Changes in the edible yield and physico-chemical parameters of tomato harvested at the three stages mentioned above and stored for 4 weeks at 12°±2° C are presented in Figures 77 to 81. It is noted that as light red stage tomatoes completely changed colour to red by the 2nd week.

Figure 77 indicates that, mature green tomatoes have given a satisfactory edible yield at the end of 4 weeks, while edible yield of other maturities have decreased with time. Figure 77 also shows that tomatoes harvested at light red stage cannot be stored for more than 2 weeks. It could also be noted that, edible yields of other maturities (i.e. except mature green) have dropped considerably even with 2-week storage.
The firmness had considerably dropped in all three maturities in tomato as could be seen from Figure 78.

![Graph showing changes in firmness of tomato](image)

**Fig. 78:** Changes in firmness of tomato (harvested at three maturity stages) during storage for 4 weeks at 12°±2° C.

(Each data point represents mean of 15 tomatoes).

Changes in titratable acidity are shown in Figure 79. The acidity of tomatoes harvested and stored at mature green stage has increased considerably up to the 4<sup>th</sup> week in storage at 12±2°C, while for the breaker stage it had increased up to the second week and then shown a gradual decrease. It is noted that, for red stage tomato, acidity had decreased continuously with 2 weeks storage at 12°±2° C.
Fig. 80: Changes in the TSS of tomato (harvested at three maturity stages) during storage for 4 weeks at 12 ± 2° C.
(Each data point represents mean of 15 tomatoes).

As shown in the Figure 80 the TSS of tomato harvested and stored at mature green and breaker stages have decreased up to 2 weeks and then increased, while the TSS of light red stage tomatoes shows a gradual increase during 2 weeks storage at 12°± 2° C.

Fig. 81: Changes in the ascorbic acid content of tomato (harvested at three maturity stages) during storage for 4 weeks at 12 ± 2° C.
(Each data point represents mean of 15 tomatoes).

The ascorbic acid content of tomato at all three maturities increased with storage. (Figure 81). The most prominent increases were observed in the mature green and breaker stage tomato stored between the 2nd and the 4th week.

Physico- chemical attributes of stored tomato was analyzed at 4 weeks after storage at 12 ± 2° C and subjected to Multi Factor ANOVA is presented in tables 13 and 14.
Table 13: Effect of maturity in relation to physico-chemical attributes of tomato when stored at (12 ± 2°C) C for 4 weeks.

<table>
<thead>
<tr>
<th>Maturity Stage</th>
<th>Edible yield (%)</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic acid mg g⁻¹⁻⁰⁻⁰ FW</th>
<th>TA g⁻¹⁻⁰⁻⁰ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature Green</td>
<td>86.67</td>
<td>0.63 x</td>
<td>4.45 p</td>
<td>8.24 c</td>
<td>0.65 r</td>
</tr>
<tr>
<td>Breaker</td>
<td>62.33</td>
<td>0.46 y</td>
<td>4.63 p</td>
<td>9.23 c</td>
<td>0.72 s</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are significantly not different by DMRT 5%. Values represent mean of 15 samples. (F.W - Fresh Weight)

Results indicate that tomato harvested and stored at the mature green stage gave an edible yield of 86.67% compared to the breaker stage which has a lower percentage of 62.23% (Table 13). Mature green fruits were significantly (p<0.05) firmer than the breaker stage tomatoes. After 4 weeks storage at (12 ± 2°C) titratable acidity was higher in breaker stage tomatoes, than in the mature green fruits. There was significant difference (p>0.05) observed in TSS and Ascorbic acid content, during storage between the two maturities.

Table 14: Effect of storage time in relation to physico-chemical attributes of tomato stored at (12 ± 2°C) C for 4 weeks.

<table>
<thead>
<tr>
<th>Storage Time (weeks)</th>
<th>Edible yield (%)</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic Acid mg g⁻¹⁻⁰⁻⁰ FW</th>
<th>TA g⁻¹⁻⁰⁻⁰ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>0.18 x</td>
<td>4.68 p</td>
<td>3.54 z</td>
<td>0.56 w</td>
</tr>
<tr>
<td>2</td>
<td>79</td>
<td>0.44 y</td>
<td>3.93 q</td>
<td>5.57 v</td>
<td>0.72 s</td>
</tr>
<tr>
<td>4</td>
<td>44.5</td>
<td>0.40 y</td>
<td>4.25 r</td>
<td>16.86 t</td>
<td>0.77 s</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not different by DMRT 5%. Values represent mean of 15 samples. (F.W - Fresh Weight)
It could be observed from the above table that edible yield decreased with storage. The TSS decreased up to 2 weeks and then increased, while the ascorbic acid level and the titratable acidity had increased continuously with storage.

5.24. Influence of Ethrel and Temperature on Ripening of Stored Tomato:

Tomato at mature green and breaker stage were stored for 2 weeks at 12 ± 2°C and were then exposed to ethrel and NaOH at two temperatures 22 ± 2°C and 29 ± 2°C. Tomatoes that were not exposed at both temperatures were regarded as the control. Data subjected to multi factor ANOVA and mean separation by DMRT are presented in Tables 15 and 16.

Table 15: Effect of maturity in relation to physico-chemical properties of tomato stored for 2 weeks at 12 ± 2°C and exposed to ethrel at two temperatures (22± 2°C and 29± 2°C).

<table>
<thead>
<tr>
<th>Maturity Stage</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic Acid mg  g⁻¹ FW</th>
<th>TA g  g⁻¹ FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature Green</td>
<td>0.42 b</td>
<td>4.04 x</td>
<td>15.92 r</td>
<td>0.687w</td>
</tr>
<tr>
<td>Breaker</td>
<td>0.34 a</td>
<td>3.68 y</td>
<td>15.01 r</td>
<td>0.69 w</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not significantly different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

In Table 15, a significant difference on effect of maturity on firmness and TSS can be observed in tomatoes stored for 2 weeks and ripened with ethrel at two temperatures. Both firmness and TSS are significantly lower in breaker stage tomatoes than mature than in the greens. However, significant effect (p>0.05) of maturity on ascorbic acid and titratable acidity can be observed from the above table.
Table 16: Effect of ethrel treatment in relation to physico-chemical properties of tomato stored for 2 weeks at 12 ± 2°C and exposed to ethrel at two temperatures (22± 2°C and 29± 2°C)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic acid mg g⁻¹00FW</th>
<th>TA g⁻¹00FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethrel Treated</td>
<td>0.38 a</td>
<td>3.88 x</td>
<td>15.84 e</td>
<td>0.686 f</td>
</tr>
<tr>
<td>Control</td>
<td>0.38 a</td>
<td>3.93 x</td>
<td>15.10 e</td>
<td>0.679 f</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not significantly different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Significant effect of ethrel (p>0.05) on firmness, TSS, ascorbic acid content and titratable acidity of tomato stored and ripened under the above mentioned conditions was observed as indicated in Table 16.

Table 17: Effect of temperature on physico-chemical properties of tomato stored for 2 weeks at 12 ± 2°C and exposed to ethrel at two temperatures (22±2°C and 29±2°C)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic acid mg g⁻¹00FW</th>
<th>TA g⁻¹00FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 ± 2°C</td>
<td>0.38 a</td>
<td>3.87 b</td>
<td>14.63 c</td>
<td>0.689 e</td>
</tr>
<tr>
<td>29 ± 2°C</td>
<td>0.38 a</td>
<td>3.87 b</td>
<td>15.81 d</td>
<td>0.693 c</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Effect of temperature on induced ripening of stored tomato is shown in Table 17. There was a significant temperature effect (p>0.05) on firmness, TSS and titratable acidity, except the ascorbic acid content which was observed to be higher in tomatoes ripened at 29±2°C.
Changes in colour of tomatoes that were stored at 12 ± 2°C over a period of 4 weeks and then exposed to ethrel treatment at two temperatures to induce ripening were recorded via hue angle could be observed from Figure 82. It could be observed from this Figure that, the hue angle had decreased continuously throughout the process. However changes in hue angle after 4 weeks storage were not very prominent although a slight decrease in the hue angle of tomatoes ripened at 22± 2°C could be observed. No major differences within the ethrel treated tomatoes and the control were noted.

Figure 82: Changes in the hue angle of mature green tomato stored for 4 weeks at 12 ± 2°C and exposed to ethrel at two temperatures (22± 2°C and 29± 2°C)

Data from organoleptic characteristic observations of tomato (mature green and breaker) stored for 2 weeks at 12±2°C and then treated with ethrel at two temperatures (29±2°C and 22±2°C) were subjected to Friedman non parametric analysis is summarized in Table 18.
Table 18: Organoleptic properties of tomato stored for 2 weeks at 12 ±2°C are exposed to ethrel at two temperatures (22±2°C and 29±2°C)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Friedman Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peel Colour</td>
</tr>
<tr>
<td>MG/Stored/Con/22°C</td>
<td>4.1</td>
</tr>
<tr>
<td>MG/Stored/Eth/22°C</td>
<td>5.3</td>
</tr>
<tr>
<td>MG/Stored/Con/29°C</td>
<td>2.5</td>
</tr>
<tr>
<td>MG/Stored/Eth/29°C</td>
<td>3.5</td>
</tr>
<tr>
<td>Br/ Stored/Eth/22°C</td>
<td>5.3</td>
</tr>
<tr>
<td>Br/ Stored/Con/29°C</td>
<td>3.5</td>
</tr>
<tr>
<td>Br/ Stored/Eth/29°C</td>
<td>3.5</td>
</tr>
</tbody>
</table>

It can be observed from Table 18 that highest Friedman Ranks were obtained for tomatoes that were stored at the mature green stage and ripened with ethrel at 22±2°C, while mature green tomatoes ripened without ethrel at 22±2°C were preferred next by the panelists.

As breaker stage tomatoes were not available in quantity after 4 weeks storage (i.e. due to perish ability), only mature green tomatoes were exposed to ethrel and NaOH.

Physico-chemical properties of mature green tomato, stored for 4 weeks at 12±2°C followed by exposure to ethrel treatment at temperatures 22±2°C 29±2°C, are presented in Tables 19 to 20. Observations were subjected to multi factor ANOVA.
Table 19: Effect of ethrel treatment in relation to physico-chemical properties of mature green tomato stored for 4 weeks at 12±2°C and exposed to ethrel and NaOH at two temperatures (22±2°C and 29±2°C)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic acid mg g⁻¹00FW</th>
<th>TA g g⁻¹00FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethrel Treatment</td>
<td>0.24 a</td>
<td>3.98 b</td>
<td>14.2 c</td>
<td>0.74 d</td>
</tr>
<tr>
<td>Control</td>
<td>0.24 a</td>
<td>3.8 b</td>
<td>13.38 c</td>
<td>0.75 d</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are not different by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

Table 20: Effect of temperature in relation to physico-chemical properties of mature green tomato stored for 4 weeks at 12±2°C and exposed to ethrel and NaOH at two temperatures (22±2°C and 29±2°C)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Firmness Kp</th>
<th>TSS (Brix°)</th>
<th>Ascorbic acid mg g⁻¹00FW</th>
<th>TA g g⁻¹00FW</th>
</tr>
</thead>
<tbody>
<tr>
<td>22°C</td>
<td>0.26 a</td>
<td>4.05 c</td>
<td>14.15 d</td>
<td>0.75 e</td>
</tr>
<tr>
<td>29°C</td>
<td>0.23 b</td>
<td>3.73 c</td>
<td>13.46 d</td>
<td>0.75 e</td>
</tr>
</tbody>
</table>

Any two means having common letters within columns are by DMRT 5%. Values represent mean of 15 samples. (F.W – Fresh Weight)

The remaining tomato stored at breaker stage for 4 weeks at 12±2°C without any further treatment (i.e. direct from storage temperature) was compared with other treatments for organoleptic properties.

The following Table 21 shows the organoleptic characters of mature green tomato stored and ripened at above-mentioned conditions. Observations were subjected to Friedman non-parametric analysis.
Table 21: Organoleptic properties of mature green tomato stored for 4 weeks at 12±2°C and exposed to ethrel and NaOH at two temperatures (22±2°C and 29±2°C)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Friedman Ranks</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peel Colour</td>
<td>Flesh Colour</td>
<td>Aroma</td>
<td>Taste</td>
</tr>
<tr>
<td>MG/stored/Eth/22°C</td>
<td>2.66</td>
<td>3.66</td>
<td>3.25</td>
<td>3.16</td>
</tr>
<tr>
<td>MG/stored/Con/22°C</td>
<td>3.00</td>
<td>3.00</td>
<td>2.98</td>
<td>2.85</td>
</tr>
<tr>
<td>MG/stored/Eth/29°C</td>
<td>2.91</td>
<td>2.41</td>
<td>3.00</td>
<td>3.08</td>
</tr>
<tr>
<td>MG/stored/Con/29°C</td>
<td>3.83</td>
<td>3.83</td>
<td>3.50</td>
<td>3.58</td>
</tr>
<tr>
<td>Br/stored</td>
<td>2.58</td>
<td>2.25</td>
<td>2.83</td>
<td>2.91</td>
</tr>
</tbody>
</table>

It could be observed from the above table that there is not much variation between ratings within the treatments. However, breaker stage tomatoes stored for 4 weeks have obtained lower ratings.
Plate 9: Tomatoes (T245) before and after storage at 12±2°C for 2 weeks and 4 weeks
Chapter 6
DISCUSSION

Banana:

Results from experiments with ethylene (5.1) and ethrel (5.2.) have indicated similar trends for physico-chemical parameters tested. Bananas exposed to ethylene or ethrel, would be ready for consumption 48 hours after the treatment.

An upward trend in TSS was observed in both the ethylene and ethrel treated fruits during the ripening period. This trend could be attributed to the hydrolysis of starch during ripening, where TSS was observed to follow a similar pattern as the sugar (Lizada et al., 1990). It is reported in the literature, that the increased sugar content consequent to starch hydrolysis is the most striking chemical change during ripening of banana fruit. Starch, the major constituent of the pulp of unripe fruit, comprises about 15-25% in table dessert varieties, and when ripe they have distinctly lower (less than 5%) starch content. A significantly higher degree of TSS, at 50ppm level of ethylene in the ethylene trial, (Figure 1) indicated that ripening was initiated at this level.

It is seen from the results, that both ripening agents have influenced titratable acidity dramatically. From the data presented, it is noted that the treated fruits had a higher titratable acidity which increased with ripening. This is in agreement with similar findings reported previously, where despite a decrease in organic acids during ripening of many fruits; that banana was observed to be an exception, where the highest level was attained when fully ripe (Wills et al., 1998). Banana acidity is reported to double or treble in certain cultivars containing A and B genome types (Turner, 1997). Since Embul bananas belong to the A and B genomes (Devarajah, 1990), the observation from these present trials are consistent with the reporting of Turner. Further, it is reported that, Malic acid is the major organic acid in bananas. This, together with citric acid increases with ripening (Ali Azan, 1988).
The sugar: acid ratio is an important component of flavour, rising from 40 to 180 in ripe banana fruit depending on the cultivar (Marriot, 1980). Hence it should be noted that, despite the increase of acids with ripening, the increase of sugar has been greater. However while observations from the present trials show an increase in the ratios; figures are much lower than those reported by Marriot. In the ethylene gas trial (i.e. 150 ppm level of ethylene shown in Figure 1) the highest TSS: acidity ratio value was 28.94 for the ripe fruit, while for the control it was 19.06. This may be attributed to the characteristic high acidity level in ‘Embul’ (sour) banana as the name implies.

It is observed from present trials that, ascorbic acid level dropped during the ripening procedure. For Cavendish bananas, ascorbic acid level significantly drops at maturity stages 3 and 4 when fruit colour changes from green to yellow (Wills et al., 1984). Observations from present trials therefore appear to be consistent, with this report.

A decrease in firmness was observed in treated fruits. This is in agreement with corresponding studies reported in the literature. According to Kiyohide et al (1994) a decrease in fruit firmness as the fruit ripens was observed for Giant Cavendish bananas of Musa (AAA group); and the lowering was due to the sequential degradation process of pectic, hemicellullosic polysaccharids and starch, which imparts cellular rigidity which is broken down to sugars during ripening (Lizada et al., 1990).

Highest ratings at the organoleptic evaluation in the ethrel trial were obtained for bananas ripened with 0.8-mL ethrel via the Trickle method (Figure 8). Possibly, this may be due to the free ventilation in the ripening chamber without the accumulation of CO₂ and also the ready availability of O₂ during the treatment period (Possibly, more O₂ may have been responsible to enhance the characteristic banana flavour).

It could be noted that, higher concentrations of both ethylene and ethrel tested in the study have retarded rate of ripening in banana. These observations suggest that lower levels of ethylene (150ppm) or ethrel (0.8mL) appear to be more suitable for banana
ripening. According to Wills et al (2001) bananas are highly sensitive to ethylene; and can be induced to ripen even at very low concentrations. Further, low levels would be cost effective in commercial scale ripening. Peacock (1980) used ethylene concentration of 200 ppm continuously to ripen ‘Giant Cavendish’ bananas, although others have used concentrations ranging from 10 ppm to 1000 ppm (Liu, 1976).

Therefore, it could be recommended from this study that 150-200 ppm ethylene or 0.8 mL ethrel with 0.4 g Sodium hydroxide (for a volume of 288 L) is suitable to ripen bananas of ‘Embul’ variety. A method similar to Trickle system, where free ventilation would permit more oxygen in to the chamber and remove excess carbon dioxide, would dramatically enhance the banana flavours.

In order to maintain quality and minimize loss of bananas during transportation, the following could be suggested. For fruits to be sold by small domestic and retail outlets bananas could be harvested and transported at the mature green stage. (i.e. 11-12 week - Wilson Wijeratnam et al., 1993). In this instance, ripening could be conducted at ambient temperature, where ripening is quicker; so as to avoid incidence of disease such as anthracnose caused by pathogens such as Colletotricum musae. Shelf life in this case is no longer than 48 hours.

It could be observed from results of the banana trial 5.3., that Ascorbic acid content, TSS and titratable acidity were not significantly different between ethrel treated fruits and naturally ripened control fruits. The low TA and TSS levels observed in Calcium Carbide ripened bananas (Figures 9 and 10) indicates that this ripening agent was less effective and did not contribute favourably to enhance flavour. With ripening, acid content and sugar content increases in bananas of Embul variety as discussed in the previous paragraph. Thus, TSS and acid balance contributes immensely to the characteristic taste in ‘Embul’ banana and explains why carbide ripened bananas was judged to be of poor quality by the trained taste panelists.
However, fruit firmness in bananas was not significantly different with respect to all three treatments, although values recorded were slightly lower in the CaC\textsubscript{2} treated fruits. These observations suggested that, although CaC\textsubscript{2} ripened fruits were softer; they had not acquired the full ripening characteristics of the ‘Embul’ variety. Ratings at the organoleptic evaluation confirmed these observations. It could be further noted that, ethrel ripened fruits were judged as not being different in taste to that of the naturally ripened bananas.

Thus, observations from the ripening studies on banana suggested the suitability of ethrel as the most effective ripening agent. Results from the present trial indicated that, CaC\textsubscript{2} treatment does not induce all the desired ripening characteristics in bananas. Similar observations were recorded by Pal (1998) when ripening properties of mango were compared between ethrel (dip treatment) and CaC\textsubscript{2} treatments. Ethrel treated fruits had better ripening attributes while CaC\textsubscript{2} was less effective in attaining good ripening attributes with particular reference to sugar – acid blend, carotenoid development etc.

More observations regarding influence of CaC\textsubscript{2} have been reported by Medlicott (1990). According to him, mangoes ripened with CaC\textsubscript{2} had poor flavour, but good peel colour development. Although carbide advances fruit softening and peel colour development, other important ripening changes were found to continue at a natural rate. Thompson and Seymour (1982) reported that bananas exposed to acetylene gas ripened at a slower rate than ethylene gas treated fruits.

In this present trial, CaC\textsubscript{2} ripened bananas did not score high ranks at the organoleptic evaluation. These observations are in agreement with those in literature. Impairment of organoleptic qualities by CaC\textsubscript{2} treatment is reported in ‘Pairi’, ‘Alphonso’, ‘Banganapal’, ‘Totapuri’ and ‘Langra’ varieties of mangoes. Krishnamurthy and Rao (1981) and Nagaraj et al (1984) reported that aroma was less in the carbide treated mangoes as indicated by sensory evaluation. Though, the rate of carotenoid synthesis in the pulp of treated fruits were higher at initial stages, the total carotenoid content was lower, than in the control after the fruits were ripe. This is in accordance with the report of
Pattabhiraman et al (1968) where intensity of aroma and flavour in the mango fruit was observed to be proportional to the carotenoid content.

It is reported that, CaC₂ treatment had also resulted in more rotting in ripe fruits possibly due to uncontrolled liberation of acetylene and exothermic reaction of CaC₂ (Pal, 1998). The presence of arsenic and phosphorous in trace amounts was confirmed in five samples of CaC₂ tested during the course of this study (Methodology presented in the appendix 5). These impurities may pose a health hazard to consumers, should CaC₂ comes in contact with the fruits (personal communication: Sarananda).

Possibly, better ripening characteristics contributed by ethrel and NaOH treatment can be attributed to the slow releasing pattern of ethylene from these chemicals.

It could be observed from results of the trial 5.4, that higher acidity and TSS levels were observed from bananas ripened at 24°±2°C. As discussed earlier, higher acidity and TSS levels are a characteristic of quality ripening attributes for 'Embul' bananas. Observations on cosmetic appearance too suggested that this temperature was better suited for ripening of bananas of 'Embul' variety.

However, rapid ripening (in 48 hours) was observed in fruits ripened at ambient temperature (30°±2°C) without any adverse effects. At this temperature the shelf life of fruits at stage 6 in maturity was 24 hrs. However, at 24°±2°C the shelf life was extended by an additional 24 hrs. These observations are in agreement with those of Peacock (1980) that, shelf life of bananas was found to decrease exponentially with the increase in temperature. Further according to his observations, weight loss during ripening was found to be independent on temperature provided humidity was kept high (>95%), while firmness was affected by temperature. Lower ripening temperatures provided firmer fruit. Peacock's observations are in agreement with findings of the present trial regarding weight loss and firmness.
Ripening temperatures between 14.5°C to 21°C are recommended for bananas in Australia, where quality is observed to suffer at temperatures above 23°C. Pulp temperature is usually 1-2°C above room temperature, because of the heat produced during ripening. This heat has to be removed, in order to improve the quality of banana (Rippon and Trochoulias, 1977). Further, according to them, if Australian Cavendish type bananas are ripened above 23°C, the pulp would soften (‘boils’) whilst the peel is dull and usually grayish-yellow. Lower temperatures of 14°-15°C induced the pulp to ripen ahead of the skin. Under above conditions mentioned, the pulp tends to be of poor flavour and somewhat soft in texture, whilst the skin colour tend to be dull grayish-yellow.

However, it is observed that Malaysian banana varieties such as ‘Pisang Ratsali’ and ‘Pisang Mas’ etc ripen normally, at temperatures between 23° to 40°C (Teng and Yik, 1989). In ASEAN countries, it is the usual practice to ripen bananas at ambient temperature, where normal temperature range is between 20°C to 35° C (Lizada et al., 1990).

In Sri Lanka, Embul bananas are generally ripened at ambient temperature (26°- 32°C) and fruit quality is observed to be satisfactory. This implies that ‘Embul’ bananas like the ASEAN thin skin varieties are not sensitive to high temperatures unlike the ‘Cavendish’ type thick skinned varieties in temperate countries.

In commercial ripening, temperature control is important in order to obtain fruits of the best quality within a specific duration before distribution (Lizada et al., 1990). Shelf life and cosmetic appearance of fruits are important factors at sales outlets. Hence, for domestic supermarkets and hotels where low temperature facilities are available, fruits harvested and transported at the 11 to 12 weeks stage of maturity could be ripened at 24°±2°C in an air conditioned environment (Wilson Wijerathnam et al., 1993). Under these conditions shelf life could be extended a further 24 hours.

The banana-ripening guide developed in the study for Embul bananas (Appendix 1) showing the temperatures and ripening times necessary to produce fruit of any desired degree, would be beneficial to fruit handlers and exporters.
The results from the experiment 5.5, indicated that a treatment time of 12 hrs to 18 hrs was sufficient to ripen banana. Those exposed to 24 hours showed poor physico-chemical attributes and colour development compared with lower exposure times. After the initiation of ripening, oxygen is needed to effect satisfactory ripening changes. It is possibly, that the oxygen content in the 24-hr treatment time was not able to supply the necessary oxygen.

Whitehead and Bosse (1991) observed that it took 8 days and 10 days respectively for 24 hour and 6 hour ethylene treated fruits to reach a colour score of 7; while it took 18 days for non treated fruits to reach the same stage. They alluded that ethylene gas binds to the ethylene receptor sites in the tissue of the fruit pulp, and longer the exposure, the more the ethylene binds to the sites until saturation is achieved. After an exposure of 6 hours, the ethylene binding effect was reversible, while the 24 hour saturation became irreversible.

Liu (1976) explained three types of ethylene responses. In the first response he explained about the response of a banana fruit exposed to ethylene for a short period (below threshold level). In this, respiration rate was the same or slightly higher than the control, for a single day to few days. If respiration rate was slightly higher, it soon resumed to the levels of control. There were no significant increases in ethylene during the transitory respiration rise and subsequent recovery period. This banana ripened at a similar time and in a similar manner to the control fruit.

The second response a banana fruit was ripened by exposing it to a ‘minimum length of time’ required by use of 10ppm ethylene to initiate ripening. In this case, the respiration rate was slightly higher after the treatment, but there was a lag period of a single day before the sharp increase towards the climacteric peak occurred. The ethylene production rate was undetectably low during the lag period, but rose with a sharp rise in respiration.
The third was the typical response of a banana to ethylene treatment for a period longer than the minimum length of time required to initiate the respiratory climacteric and ripening. In this case, the respiration rate was significantly higher after the ethylene treatment, and it continued to rise without delay to reach the climacteric peak, usually within 2 to 3 days. The elevated rate of ethylene production was detectable a few hours after the ethylene treatment ended.

A shorter exposure time to ethylene gas, would be an advantage, especially to the traders and fruit handlers in small scale domestic retail outlets, where space is a factor for induced ripening purposes. The results from the present experiment suggest that, it is possible to reduce the usual practice of 24 hours of exposure time, to duration between 12 hours to 18 hours. Those in the fruit industry would then be able to carry out more ripening cycles in the space allocated to them
PAPAYA:

Papayas exposed to ethylene and ethrel have given similar results in physico-chemical parameters tested. It is evident from the results of both trials (5.6 and 5.7) that, papayas induced to ripen would be ready for consumption after four days.

Ripening agents were observed to affect a slight increase or a decrease in TA. Conflicting reports regarding TA and TSS in papaya are found in literature. Selvaraj et al (1982a) and Ghanta et al (1994) have reported of a decrease in TA with ripening, while de Arriola et al (1980) and Paull (1993) reported of an increase. According to Paull, the slight increase in TA observed during ripening is believed to be associated with an increase in free galacturonic acid.

Results of the present trials indicated that, TSS hardly changes with ripening. It is noted that, although a slight increase could be observed in the ethrel trial, no significant increase could be observed in the ethylene trial. Chen (1964) and de Arriola et al (1975) have reported a slight increase in TSS (1-2%) during ripening, while Chan et al (1979) have reported that TSS hardly changes after harvest, as papaya fruits have no starch reserves for production of soluble solids during ripening. Thus, it is reported that, papaya fruit, previously determined to be a climacteric fruit behaves similarly to the plum which is also a climacteric fruit Rees (1958), Chan et al (1979) that has little starch present during ontogeny. According to Selvaraja et al (1982b) since very small amount of starch had been detected in papaya at developing stages, the contribution of starch breakdown during ripening may be negligible.

Although papayas used in these trials were expected to be of pure variety ‘Rathna’, varying tastes, colours and sizes were observed in them possibly due to mixing with other varieties. Possibly, varying values for physico-chemical parameters observed in the present trials could be attributed to this factor.
The treated fruits were observed to have lower fruit firmness values than the untreated. This is in agreement with those in literature that ripening of papaya is characterized by changes in tissue softness that is believed to be initiated in the inner mesocarp tissues close to the seed and to progress outward (Selmat, 1993). The exogenous ethylene treatment mainly accelerates the ripening change in the mesocarp tissue near the seed cavity (An and Paull, 1990).

The present experiment reveals that, papaya ripened with 1.65mL and 3.3mL ethrel and ethylene at 200 to 300ppm levels indicated better ripening characteristics. Thus, concentrations mentioned above could be utilized in commercial ripening procedures.

The experiment carried out to determine the effect of ethrel on mixed varieties have also proved that above mentioned levels are suitable to induce ripening in papayas. It is seen from the results that the higher level of ethrel had induced better peel colour development in mixed varieties of papaya.

It is seen from the results of the experiment 5.8, that no significant differences were observed in fruit firmness, TSS, titratable acidity and ascorbic acid level between the ripening agents. However, a significant difference was observed with respect to the organoleptic evaluation of the ripened fruit, where the highest scores were observed when ethrel was used as the ripening agent. Possibly, it may be due to the slow ethylene-releasing pattern from ethrel and NaOH.

Disadvantages of using calcium carbide have been discussed in the earlier paragraph under the same title for banana.

Results from the experiment 5.9, suggested that no major differences in physico-chemical parameters were observed in papaya with respect to temperature. However, it could be noted that papayas ripened at 22°C±2°C had better flesh colour development (red) than those ripened at the higher temperature (i.e. ambient 29±2°C). Similar observations were recorded by Feng An Paull (1990) for Sunset papayas which had red flesh colour. Red
flesh colour of papaya is due to lycopene development (Chan, 1983) which is possibly inhibited by high temperature, similarly to tomato (Hamauzu et al., 1998).

According to Feng An Paul I (1990) the optimum temperature to ripen papaya (Sunset) is 22.5°C while for Sunrise solo it is 20°C (Broughton et al., 1977). However Akamine (1966) found that Solo papayas did not ripen normally when stored at 22.8°C when compared with those stored at 25°C which ripened satisfactorily. Nazeeb (1976) reported that chilling at 15°C damaged the ‘Taiping’ and ‘Bentong’ varieties of papaya. Akamine (1966) has reported chilling injury at higher temperatures (i.e. 22.8°C) for ‘Solo’ papaya. Perishability of fruits at 18°C in this present trial could be attributed to chilling injury.

It is seen from the results that, papayas with better red colour development could be obtained if ripened at a temperature close to 22°C, which could be obtained by air conditioning the environment. This temperature could be recommended for ripening of fruits for super markets and tourist hotels, and fruit processing plants. The ambient temperature 29± 2°C is suitable to ripen the normal mixed varieties of papaya for small domestic retail outlets. Quick ripening reduces loss due to latent pathogen infections.
Mango;

The mangoes (variety Karuthkolomba) treated with ethylene and ethrel have given similar trends in physico-chemical parameters tested. Results from both trials (5.11 and 5.12) indicated that, mangoes become edible four to five days after exposure to the ripening agents. It could be noted that similar results are obtained irrespective of how ethylene gas is obtained by the fruits.

It seen from the Figures 38, 40, 46 and 47, that with the progress of ripening in mangoes, TSS levels and TSS: acidity ratio levels increased while the titratable acidity (Figures 39 and 45) decreased. However, with higher concentrations of ethylene (>300ppm) or ethrel (3.3mL) used, it is seen that the above-mentioned parameters have moved in the opposite direction.

These observations are in conformity with those reported in the literature. Yonea et al (1990) reported that post harvest ripening of mango fruit is characterized by softening of the flesh, decrease in acidity and an increase in sugars, while cultivar differences were not observed to be dramatic for these parameters.

The predominant acid in mango is citric, followed by varying amounts of malic and other acids contributing to the acidity. However, citric acid concentrations are shown to decrease as low as 0.1 to 0.5% during ripening while other acids remained constant. (Medlicott and Thompson, 1985, Fang, 1965, Yonea et al., 1990).

As for TSS, most data have shown that sucrose, which is the predominant sugar, increases several folds during ripening. The increase in sugar content is attributed to breakdown of starch, which is virtually absent at the edible stage (Kumar et al., 1994).

It is reported in the literature, that organic acids make an important contribution to the quality of fruits, as it is related to the balance between sugar and acid content (Prinsely and Tucker, 1987). Thus the ratio between TSS and acidity is a good measure of taste.
Results from these trials revealed that the highest TSS: acidity ratios were obtained for fruits treated with 200 ppm ethylene and 1.65 ml ethrel (Figures 40 and 47).

Highest scores at the organoleptic evaluation were also obtained for above-mentioned ripening treatments (Figures 42 and 49). Similar observations were made for popular ‘Haden’ mango in Hawaii. ‘Haden’ had a high TSS: titratable acidity ratio as compared to other varieties and explains why ‘Haden’ is highly popular (Yonea et al., 1990).

As seen from Figures 43 and 44, there were no differences in firmness within the treatments at ripe stage. Roe and Brummer (1981) reported that peak ripeness is associated with a fairly narrow range of firmness and that there is a good correlation between loss of firmness and increase in polygalacturonose and cellulase activity in ‘Keitt’ mango.

A retarding effect of ripening could be observed from the ethylene trial (Figures 38, 39, 40) and the ethrel trial (Figures 44, 45, 46, and 47) with the increase of the concentration of the ripening agent. Similar observations have been reported by Chundawat et al (1973). They observed that when ‘Dashehari’ mangoes were treated with a higher dosage of ethrel (i.e. 750 ppm as a dip treatment) ripening performance was observed to be poorer than that of the 500 ppm level. Fruits treated with the higher concentration 750ppm ethrel were greener (instead of the bright yellow of the 500 ppm treated fruits), with a poor sheen and a semi hard texture. They also observed that, TSS and the TSS: acidity ratio was lower than that of the 500 ppm treated fruits and that the 500 ppm treated fruits attained higher scores at the organoleptic evaluation.

Pal (1998) had also found similar observations for ‘Dashehari’ mangoes. A higher dose of ethrel (i.e. 600ppm) treatment gave more electrolyte leakage from the pulp resulting in poor textural properties, than lower concentrations during ripening.

In the ethylene treatment trial, it was observed that ripe fruits were infected with anthracnose and stem end rot. However, disease scores taken were not significant within
the treatments and indicate that ethylene concentrations do not have any affect on the disease incidence. It is reported in the literature that diseases have the ability to remain latent in green and immature fruit and develop rot during storage and marketing (Moshe et al., 1993).

Observations from this trial indicated that the degree of ripening depended on the ethylene concentration used. To ripen mango, ethylene concentrations ranging from 200ppm to 250ppm or ethrel at 1.65 levels could be recommended.

Results from the experiment 5.13 indicated that no significant differences were observed in fruit firmness, TSS, titratable acidity and ascorbic acid level (Figures 50 to 53) between the ripening agents. However as seen from Figure 55, better scores were obtained at the organoleptic evaluation for ethrel-ripened fruits. As discussed previously, a similar observation was made in the papaya comparison trial. Findings of other researchers regarding poor ripening qualities by CaC₂ were also discussed previously under the comparison trials. Therefore it could be concluded that CaC₂ does not contribute very much to obtain fruits with better ripening attributes. Mangoes of better quality could be obtained when fruits are exposed to ethylene via ethrel and NaOH, possibly due to slow ethylene releasing pattern of the mentioned chemicals.

Results from the experiment 5.14 do not indicate any major differences on the individual effect of temperature as seen from (Table 2). However, it could be noted from (Table 3) that the effect of ethrel concentration had been greater than the effect of temperature on ripening of mango. Fruits ripened at 28°±2°C had a significantly lower content of acid, which would thereby increase the sugar acid ratio of mango ripened at this temperature. A higher sugar acid balance would enhance the flavour characteristics as discussed earlier. Therefore, ambient temperature (28°±2°C) may be better suited to ripen mangoes.

As seen from results of the experiment 5.14 an upward trend in TSS (although a slight decreases at 13 weeks) could be observed at the final stage of maturity close to harvest
(Figure 57). Kasantikul (1983) has recorded similar observations for Nam Dorkmai mangoes. For this variety of mangoes, the upward trend in TSS was broken at the final stage at 14 weeks. Possibly this drop in TSS could be attributed to respiration rate overtaking the accumulation of sugars.

An increase in titratable acidity (Figure 58) up to 11 weeks could be observed in mango of karthakolomban variety. It is noted that, the acidity reached the maximum value at the 11th week and then decreased continuously. Similar observations have been reported by Kasantikul (1983) for acidity in Nam Dorkmai mangoes, where titratable acidity reached a maximum value at about the 9th week and then declined till harvest.

Although, a drop in TSS at 13 weeks was observed for Karthakolomban variety, TSS: acidity ratio (Figure 61) has shown a definite upward trend after the 11th week. This implies that the decline in titratable acidity has overtaken the drop of TSS.

Declining trends in ascorbic content and fruit firmness were observed as the fruits matured (Figures 59 and 60). Observations on raising of the shoulders are in agreement with those of Amarakoon et al (1999) who have recorded similar observations.

When mango of maturities 12, 13 and 14 weeks were treated with ethylene as seen from the results of experiment 5.16, the treated fruits showed lower values in firmness, acidity and ascorbic acid content than the controls as seen from the results of experiment 5.15. It could be observed that, treated fruits of 13 week maturity had the lowest firmness (Figure 62) while it had a declining pattern in the order of 12 weeks, 13 weeks and 14 weeks both among the treated and the control fruits.

Ascorbic acid content also followed a similar pattern in the declining order of 12 weeks, 13 weeks and 14 weeks, while they were significantly different among the treatments. As for TSS (Figure 63), although it was observed to be higher in the treated fruits, there
was no significant difference within the treatments. Acidity was significantly lower in the treated fruits.

Higher ratings were obtained for treated fruits at the organoleptic evaluation. 13 week and 14 week treated fruits had higher ratings for taste and overall acceptability. Therefore, it is recommended that mangoes of ‘Karuthakolomban’ variety is harvested at 13 to 14 weeks after fruit set in- order to optimize the quality of mangoes.
TOMATO:

It could be seen from Table 5 (Experiment 5.17) that all physico-chemical parameters, except the ascorbic acid content was unchanged even for tomatoes exposed to the ripening agents for a longer duration (i.e. 48 hours). This is contradictory to what is recommended in the web page 4, that tomatoes may be exposed to ethylene gas of a concentration of 100ppm - 150ppm for 24 hours to 48 hours.

However, the observations regarding the ascorbic acid from this trial is in agreement with those of Luis et al (1977) who have reported that fruits accumulate ascorbic acid during ripening on or off the plant although the increase was 16% to 27% greater for those fruits left on the plant.

Some findings and reports in the literature are contradictory to the present findings. According to Winsor et al (1962a, 1962b), total solids and total sugars increase progressively during ripening from mature green to red stage, for tomatoes left for ripening on the vine. It is also reported that, titratable acidity increased from green to green-yellow stage, but no consistent changes were established after the yellow stage. Several researchers including Stevens (1972) had confirmed the above findings that the acidity reaches the maximum at breaker stage, and then decreases with further ripening for tomatoes ripened on the vine. However, in the present trial tomatoes were harvested at mature green stage and induced to ripen by exposing them to ripening agents. As the tomatoes were ripened off the vine, the same pattern as that of the vine ripened tomatoes cannot be fully expected.

Although the procedures are available in the web pages (web page 1 and web page 2) to induce ripening with exogenous ethylene, Wills et al (2001) report of its low sensitiveness to exogenous ethylene. McGlassen et al (1975 and 1978) also confirms above observations by reporting that, ‘tomato appears to be an exception in its sensitivity to ethylene, although a climacteric fruit’. It is reported that McGlassen et al (1975) examined the role of propylene in respiration and ethylene production of
tomato fruits of RIN- a non ripening mutant. Propylene stimulated the respiration in
the immature fruits of RIN, but there was no change in the endogenous ethylene
production. It was concluded that the onset of ripening in normal tomato fruit is not
controlled by endogenous ethylene, and increased ethylene production is probably an
integral part of the ripening process. They further report that, tomato is unique in its
exceptionally high resistance to ethylene. Although ethylene reduces the pre-
climacteric life of tomato, it is not instrumental, not even at high concentrations in
inducing the autocatalytic production (McGlassen et al., 1975; McGlassen et al.,
1978).

Hoboson (1989) reported that, in order to achieve the maximum flavor and colour
development, tomato fruit should be left to ripen fully on the plant. According to Falik
(1999) fruits harvested at mature green stage end up with inferior flavour at ripening.
Similar observations have also been reported by Kader et al (1977) that, fruits picked
at earlier stages of ripeness and ripened to table ripeness at 20°C had flavour
characteristics that were significantly different, from those picked at table ripe stage
from the plant. Tomatoes picked at earlier stage of ripeness and ripened at 20°C have
been evaluated by panelist as being less sweet, more sour, less ‘tomato like’ and
having more ‘off flavour’ than those picked at table ripe stage. Shah et al (1969)
reported that the concentration of short-chain (C2-C6) volatile compounds were higher
in artificially ripened fruits, whereas long-chain (C9-C12) carbonyls and the terpene
esters were predominant in field ripened fruits.

Sugars and acids are key components in the overall flavour intensity of tomatoes.
Generally, overall flavour had the highest correlation with TSS, titratable acidity and
pH (Stevens et al., 1979). Picking tomatoes before they are table ripe has an impact in
their sugar and acid content at the table ripe stage and is clearly implicated as one of
the reasons for variation in flavour quality relative to fruits harvested at table ripe
stage (Kader et al., 1977). Fruits left on the vine to ripen have higher sugar content
and are sweeter than fruits picked at earlier stage of ripeness (Betancourt et al., 1977).
Therefore, the observations from both the present trials, and several reportings from literature discussed in the above paragraphs suggest, that picking tomatoes at an earlier stage of ripeness and exposing to ripening agents do not result in quality tomatoes acceptable to consumers. Thus, the application of ripening agents cannot be recommended for tomatoes.

No significant differences were observed in firmness, TSS titratable acidity and organoleptic characters between the ripening agents as seen from the results of the experiment 5.19. These observations also suggest that, ripening agents have not influenced better ripening characteristics of tomato. Bondad and Pantistico (1971) reported that, CaC2 at all concentrations used, had little or no effect on tomato ripening, except the increase in the ascorbic acid content. Therefore, this behavior may be possibly attributed to tomato’s low sensitivity towards ethylene or to it’s analogues as discussed in the previous experiment (Wills et al., 2001; McGlassen et al., 1975 and McGlassen et al., 1978).

Results from the experiment 5.20, suggested that the ripening agent ethrel had limited ability to influence the physico-chemical parameters and red colour development of tomato. However, the expected ripening differences were clearly visible by the effect of temperature. It is noted that red colour development (hue angle) closest to the tree ripened tomato (°h = 37°) was obtained by tomatoes treated at 18°±2°C and stored for 14 days at the same temperature (°h = 40.21°), while the hue angle of the ambient ripened tomato was observed to be comparatively high (i.e. ° h= 55.23°) (hue angle is inversely related to the development of red colour- Appendix 6)

Hue angle is a good assessment of lycopene, the pigment responsible for the redness of tomato (D’Souza et al., 1992). Therefore, the lycopene content was higher in tomatoes ripened at lower temperatures than at ambient temperatures. Similar observations have been reported by Artes et al (1998) who observed that fruits kept at 20°C became increasingly red while the hue angles decreased.
Observations of the present trial are in agreement with those of Hamauzu et al. (1998) who have reported that high temperatures decrease lycopene and its precursors, especially phytoene. Further, the high temperatures inhibit the accumulation of lycopene in tomato fruit, due to the conversion of lycopene to ß-carotene, which is stimulated instead of the lycopene accumulation.

One of the most important attributes in the sale of fresh tomato is surface colour due to lycopene. This pigment is considered as an important food component and a free radical scavenger (Di Mascio et al., 1989). Therefore it becomes necessary to develop the redness by increasing the lycopene content in tomato storing them at 22°C±2°C. However, non development of redness at high temperatures becomes a problem (i.e. more yellow and less red and would be softer), only when tomatoes are allowed to ripen off the vine above 25°C (Suslow and Cantwell, 1999). Therefore, it is evident from the present trial that a temperature range of 18°C to 22°C is suitable to ripen tomato in order to increase the redness. However, at lower temperature 18°C ripening may seem too slow for commercial purposes. According to Suslow and Cantwell (1999) the optimum ripening temperature to ensure sensory and nutritive quality of tomato is 20°C. In the temperate countries however, the ambient temperatures are low and non development of red colour has not been reported.

As Sri Lanka comes under a tropical climate with high ambient temperatures (30°C±2°C), the ripening temperature for tomato has to be brought down in order to induce the development of redness. Tomatoes grown at colder climates in Sri Lanka are harvested before they become red and transported to warmer climates before they are ripe. Usually the ripening takes place at the warmer climates and therefore do not achieve the required redness. However, if tomatoes are ripened under low temperature the desired redness of the tomatoes could be obtained. This requirement of temperature (22°C±2°C) could be achieved in an air conditioned environment.
addition to the enhancement of redness, the lowered temperatures would ensure the sensory and nutritive quality of tomato.

As seen from results of experiment 5.21, the lowest hue value (i.e. the highest red colour) from all the treatments (h= 49.5°) was obtained from tomatoes harvested at turning stage and treated with red light alone. As reported by D’Souza et al (1992) hue values give a good indication of the redness and the lycopene content in tomato. Therefore in order to obtain a good red colour in tomatoes, they have to be harvested at turning stage and treated with red light alone. The results of this trial are in agreement with those of Lee et al (1997) who have reported that the greatest effect of colour development of tomato were from those harvested at breaker and turning stages compared to the pink and light red stages. Lee et al (1997) reports further, that the maturity stage of tomatoes at the time of light treatment affected the colour development very much.

Results from this trial also indicated that for other maturities however, a combination of red and blue lights proved to be the most suitable. Similar observations have been reported by Lee et al (1996) who found that the red light alone or with a combination of blue light, irradiated for 3-5 minutes were effective in accelerating redness in tomato. Observations reported by Khudari and Aboleda (1971) also support the findings from this trial. They reported that synthesis of the red pigment lycopene was enhanced by red light.

Jen (1974 a, b) reports that red light was most effective in accelerating biodegradation of chlorophyll, while blue light was most effective in enhancing biosynthesis of carotenoid, which in ripening tomatoes is mediated by phytochrome. According to Jen et al (1997) however, the phytochrome content decreased with ripening to about one third of the amount in mature white fruit of the yellow lutescent tomato. The decline in phytochrome content was sharpest near the climacteric peak of the respiratory pattern, when ethylene production was increasing sharply. According to Jen and Thomas (1977), it was possible that the fruits entered a phase of senescence during ripening.
and phytochrome was no longer needed in the various physiological processes. Jen and Watada (1977a) have reported that the phytochrome is activated by red light. Possibly the light treatments have some effect in activating and rejuvenating the diminishing phytochrome content in tomato to enhance the ripening attributes.

Using normal red tomatoes at the mature green stage of maturation Rabinowitch and Rudich (1972) showed that a bio-regulator, CPTA (2-4 chlorophenylthio-triethyl amine hydrochloride) stimulated the accumulation of lycopene at high temperature (32° C), when the fruits were supposed to have ceased lycopene biosynthesis. Jen and Thomas (1977) have further reported that even yellow lutescent tomatoes devoid of lycopene can be induced to produce the red pigment lycopene, when treated with bio-regulators such as CPTA. A combination of red light and CPTA however, stimulated the lycopene accumulation to a very high degree (i.e. 225µg/g) of lycopene in mature white lutescent tomato compared to tomatoes treated with CPTA and kept in dark (i.e. 65µg/g). In previous studies, visible light was shown to enhance carotenoid biosynthesis in normal red and two strains of lutescent tomato (Jen, 1974a).

Raymundo et al (1970, 1976) believed that there were two physically separated biosynthetic pathways for carotenogenisis in tomatoes; one chloroplastic and the other chromotoplastic. Pigmentation changes are from chloroplasts to chromatoplasts which are the major sites of carotenoid biosynthesis (Gross, 1991). The yellow lutescent tomatoes used may have had only one of the two biosynthetic pathways, possibly the chloroplastic one. According to them the effectors, whether it is a bio-regulator or the red light which activated phytochrome, was able to activate the other pathway.

In this experiment, the tomatoes were stored in the dark devoid of any light. The treated ones were taken out of dark only for five minutes to be exposed to the light, while the controls were always kept in the dark. According to Lee et al (1997) phytochrome is stabilized in darkness and when exposed to red light, phytochrome (P_r) is instantaneously converted to P_h, thus immediately affecting the stimulation of red colour development. Jen and Watada (1977b) also report that red light irradiation
induced the conversion of P to P$_{fr}$ presumably the physiologically active form of phytochrome. Kumar and Purohit (1998) have also explained extensively about the dark reversion of phytochrome from P$_{fr}$ to P$_r$.

Jen and Watada (1977a) have reported that red light accelerates other aspects of tomato ripening as well, in addition to the biosynthesis of carotenoids. They have also observed that, the climacteric rise and ethylene production were advanced by about 3 days in tomatoes treated with red light.

Apparently phytochrome is closely related to several phenomena associated with ripening and according to one of the theories the reaction mechanism of phytochrome is to change the membrane permeability of cells (Jen and Watada, 1977a). Borthwick (1972) also reported that the primary action of P$_{fr}$ on various physiological phenomena is probably through changes of membrane permeability of cell and cell organelles. Biale (1975) postulated that the cell membrane permeability might conceivably account for the wide variety of both anabolic and catabolic processes associated with ripening. It's also believed that phytochrome takes part in the generation of changes in membrane potentials in conjunction with two plant hormones. The pigment also displays various other functions such as enzyme synthesis Kumar and Purohit (1998). However according to Pratt (1994), it is uncertain whether phytochrome functions by modulating membrane properties or by directly influencing gene transcription.

It is also noted from the results of this trial, that light treated tomatoes had significantly lower values for fruit firmness. Similar observations were reported by Lee et al (1997) for tomatoes treated with red light, having lower firmness values than other treatments. Differences in firmness values for light treated tomatoes appeared to be due to cell wall changes which resulted in fruit softening. However, according to Jen (1970) and Shewfelt (1970) light treatments affected the degree of ripening, but had no destructive influence on fruit tissue; although these theories may have changed by now.
As shown in the results of this trial, light treatment has significantly increased the TSS content in tomato. As from Table 9, a combination of both red and blue lights are more suitable in increasing the TSS, while red alone had somewhat proved to increase the TSS significantly at ambient temperature. Increase in TSS may be attributed to an effect of the increased ethylene concentration in tomato due to the light treatment, as discussed earlier.

However, increase in the redness, at ambient temperature may seem to be the greatest advantage in treating the tomatoes with light. Sri Lanka being a tropical country the ambient temperature is approximately 28° ± 2°C or higher, in many parts of the country. Even though some of the tomato growing areas are confined to areas that have lower temperatures, the harvested tomatoes from these areas have to be transported to the warmer areas for distribution, and mechanical damage during transportation is inevitable if red ripe tomatoes are transported. However, if tomatoes are not harvested at the red ripe stage, the colour (which is one of the most important factors of consumer acceptance according to Rushing and Huber (1983) would not develop, due to the problem of ‘non development of redness in tomato at high temperatures’ (Hamauzu et al., 1998).

Even though, storage at low temperature develops red colour as discussed earlier, low temperature facilities are necessary to carry out the procedure. Most of the farmers and traders in Sri Lanka are not in a position to accommodate low temperature facilities. However, they could easily afford to carry out light treatment (i.e. it needs only a red coloured electric bulb of the required wave length) and this procedure would definitely benefit them. Post harvest losses due to mechanical injury may also be reduced as the farmers could harvest the tomatoes at turning stage, transport while they are firmer in texture, and then expose to light to induce colour development prior to distribution.

It could be concluded that tomato at turning stage is better suited for light treatment. Treating tomatoes at turning stage of maturity with red light alone would enhance the red colour. Sensory quality of tomatoes would not suffer to a great extent as tomatoes
are harvested at a latter stage, *i.e.* a more mature stage) where most of the physico-chemical properties have been already established.

Results from the experiment 5.22, revealed that hue angle, could further be lowered, if treated with light at a low temperature. Breaker stage tomatoes are better suited to be irradiated with red light. Even though, the low temperature facilities are not available to most of the farmers and traders some of the sales establishments such as supermarkets are in a position to carry out a combination of the low temperature and the (*i.e.* 22±2°C) light treatment to enhance the red colour development.

Better results (*i.e.* high redness) could be expected if tomatoes at turning stage were available for the present experiment and if they were treated with red light at low temperature. Continuation of this trial further by treating turning stage tomatoes at low temperature would definitely enable to obtain tomatoes similar in colour to those ripened on the vine.

Results from the experiment 5.23, indicated that mature green tomatoes changed colour very rapidly within the first 2 weeks of storage at 12±2°C. Further, it could be observed that slow ripening had occurred in mature green tomatoes during the storages period. It is noted that at the end of 4 week period, mature green tomatoes had turned light pink.

Evaluation results on the edible yield indicated poor recovery of light red stage tomatoes at the end of 2 weeks. However it is seen that breaker stage tomatoes could be stored for 2 weeks with a recovery of 72%, while mature green tomatoes have given a satisfactory percentage of tomato even after 4 weeks of storage. These observations are in agreement with those available in the web (web page 2) which reports that pink stage tomato can be stored between from 7 to 14 days at 10°C, while the mature greens could be stored for 21 to 28 days at 15.5°C. According to Fuchs *et al* (1995) cherry tomato fruit had acceptable market quality after 21 days of storage.
and transportation between 12°C to 17°C. A period of 28 days was observed to be too long and the tomatoes resulted in off flavours and more decay.

It is seen in the results, that tomatoes of all maturities have become softer throughout the storage period. This is in agreement with those of Nyalala and Wainwright (1998) who observed a decrease in fruit firmness during storage.

It is reported that, Heinz and Craft (1954) did not observe any significant change in tomato acidity during chilling or after ripening of the chilled fruit. However, other researchers have reported an increase in acidity of tomatoes which were chilled before ripening. It could be observed from the results of this present experiment that acidity of stored tomato had varying patterns.

According to Stevens (1972) acidity peaks, when tomatoes are at the breaker stage and then decreases. These reportings tally with the results of this present experiment. A continuous increasing trend of acidity could be observed in the mature greens, while a drop is observed in the breaker stage, after 2 weeks storage. As the light red stage tomatoes have already passed the breaker stage, the acid content is probably at a decreasing trend. Buescher (1975) who stored tomatoes for 21 days at 2°C reports, that malic acid declines during chilling, while citric acid increases. Furthermore, the accumulation of citric acid during chilling substantiates the concept that normal metabolism in chill sensitive tissues exposed to low temperature is disrupted by the mitochondrial function or structure (Jaweed et al., 1969; Lyons et al., 1969 and Rayson et al., 1971). There is also evidence that, tomato fruit detached at the mature green stage produce more acid during storage Sakiyama (1970), while other reports indicate that acids are metabolized after fruit is detached from the plant (Davies and Maw, 1972).

Buescher (1974) and, Heinze and Craft (1954) report that TSS fluctuates without definite trends during chilling and that TSS was lower in chilled fruit than in the non-chilled fruit. TSS in the present trial shows a fluctuating pattern, and it could be noted
that the TSS decreased within the first 2 weeks of storage and then increased, in tomatoes stored at mature green and breaker stages. However, as discussed earlier a similar pattern in the opposite direction is seen, for organic acids although the changes observed were only for mature greens and breaker stage tomatoes. No fluctuating patterns were shown for the light pink stage, in both parameters. Therefore, it is possible that both parameters (i.e. TSS and the acid content) are inter-related.

As reported by Hulbert and Bhowink (1987) the decrease in the TSS content during the first two weeks of storage could be attributed to the use of accumulated sugars for respiration. According to Nyalala and Wainwright (1998) starch is broken down to simple sugars which increases the TSS during storage, while dissolution of the pectin materials too contributes to the increase. However, in this instant, the respiration may have out-rated the increase of the sugars which resulted in the decrease of TSS, possibly when the available sugars needed for the respiration were diminishing. As reported by (Lee 1983) the fruit acids may have been converted into sugars to replenish the substrate for the respiration. This is in agreement with the report of Davies and Maw (1972) who reported that, acids are metabolized after tomato fruit is detached from the plant. Further, fluctuating patterns were observed only in tomatoes of mature green and breaker stages where respiration rate is high, and physico-chemical changes are prominent. Negative fluctuations in TSS and titratable acidity were observed in tomatoes at light red stage, possibly due to the low respiratory rates.

Goodenbough and Thomas (1980 and 1981) observed different fluctuating patterns of monosaccharide between the cultivars and attributed them to the varietal differences. The storage of tomatoes at low temperature involves the activation of an enzyme of the phenylproponoid metabolic pathway (Rhodes and Wooltortan, 1977) and this enzyme may be responsible for the changes during low temperature storage of tomato.

As for the ascorbic acid content, the result from this present trial indicates increases in all the maturities; and it is in agreement with those in the literature as discussed earlier.
Findings from this trial indicate that mature green tomatoes are suitable for long term storage. Tomatoes harvested at this stage of maturity could be stored for 4 weeks. However, breaker stage tomatoes could be stored up to 2 weeks while tomatoes harvested at light red stage could be stored only for few days. A temperature of 12°C could be used for storing of tomato. Falik (1999) too has recommended this temperature for prolonged storage of tomatoes.

Even though, harvesting at mature green stage should be avoided due to the quality differences compared to the vine ripe fruit, during a time of glut it would be essential for the farmer to prolong the harvest in-order to avoid low prices. In USA during the past few years, sales of mature green tomatoes have increased. In part, this increase occurred because of higher shipping, harvesting and handling losses for vine-ripened fruit and also the narrowing in price difference between mature green and vine-ripened tomatoes (web page 4). As, it is not always feasible or practical to harvest tomatoes close to tree ripe stage, alternatives must be accepted to withstand constraints of the current marketing system. However, the stored tomatoes may be utilized for processing of tomato products, by addition of flavours and seasonings to make up for the lost organoleptic properties.

The results from the experiment 5.24 indicated that, there were no significant differences between the treated and the untreated fruits ripened at two temperatures, although the hue angles were slightly lower in the low temperature ripened tomatoes.

The tomatoes were already ripened to some extent when they were exposed to ethrel. According to the web page 4, tomatoes beyond breaker stage will not benefit from the application of ethylene, since the ripening process has been already initiated by tomato’s own ethylene. Further, the low sensitivity of tomato to exogenous ethylene was discussed earlier. Therefore, exposing stored tomatoes to ripening agents would not result in any advantages.
Chapter 7
CONCLUSION

- Findings from this study revealed that mature green fruits could be conveniently transported for distribution with minimum physical injury, and that the ripening time at ambient temperature (28±2°C) could be dramatically reduced while maintaining the quality, when mature green bananas, papayas and mangoes are exposed to ethylene gas. A combination of ethrel and NaOH provided a safe, convenient and easily available commercial source of ethylene gas compared to ethylene gas in a cylinder.

  An exposure time of 18 hours was sufficient to induce ripening attributes in ‘Embul’ banana.

- Tomatoes were not found to respond to exposures of ethylene gas. This behaviour could be attributed to the low sensitivity of tomato to exogenous ethylene as reported in the literature by some researchers.

- Comparison studies of the ripening agents (i.e. ethylene, ethrel and calcium carbide) on banana, papaya, mango and tomato, indicated that ethrel as the most suitable ripening agent and that the good ripening attributes induced by this ripening agent resulted in fruits with superior quality.

When the bananas were exposed to the ripening agents, no differences in physico-chemical parameters were observed between ethrel-ripened bananas and the naturally ripened fruits. While better peel colour development was induced in the calcium carbide ripened bananas, differences in physico-chemical parameters and organoleptic characteristics were observed between the calcium carbide ripened bananas and the naturally ripened fruits. The calcium chloride ripened bananas were of inferior quality.
However, no differences in physico-chemical parameters were observed between all three ripening agents in papaya and mango, although higher sensory panel scores were obtained for organoleptic properties in both commodities.

- Physico-chemical analysis carried out after the ripening procedure indicated a significant increase in TSS in banana and mango. The total acidity, decreased in mango significantly with ripening, while an increase was observed in 'Embul' (sour) banana, as its name implies. However, only slight changes in TSS and acidity were observed in papaya, while no significant changes were observed in tomato for the same parameters.

Ascorbic acid content decreased in mango and banana while increases were observed for papaya and tomato.

- Studies on temperature revealed that better red colour development was observed when tomatoes were ripened at low temperature (approximately 22°C) while higher temperatures retarded formation of the red pigment lycopene in tomato.

- The problem of non-development of red colour in tomato at ambient temperature (29±2°C) could be overcome, when tomatoes at turning stage are treated with red light. Trials indicated that further development of red colour could be enhanced, if this treatment is carried out at low temperature.

- Storage studies in tomatoes revealed that, fruits harvested at mature green stage were better suited for long-term storage (i.e. approximately 4 weeks), while tomatoes harvested at breaker stage could be stored up to 2 weeks.

The tomatoes changed colour to red during storage. Exposing stored tomatoes to ethylene gas (via ethrel) did not result in any further colour enhancements.
Recommendations

**Ripening of Banana**:

Banana of Embul variety at mature green stage would be ready for consumption 48 hrs after exposure to ethylene.

**Harvest maturity for induced ripening**:

Bananas of 12 week maturity (after emergence of first hand) are suitable for the ripening treatment.

**Laboratory dosages for ethylene treatment**:

- 100 - 150 ppm ethylene
- 0.8 mL ethrel and 0.4 g NaOH per volume of 288 L
  (Approximately 30 Kg bananas could be ripened under above conditions)

**Dosages of Ethylene for Commercial Ripening**:

- 10 mL of Ethrel combined with 5g NaOH dissolved in approximately 50 mL of water would ripen approximately 3000 Kg of bananas commercially.

(For laboratory trials, few bananas of identical maturity are selected as a replicate. However, for commercial ripening, selection of the identical maturity is not practical. Therefore, as bananas at several ripening stages might be included in the batch of bananas of mixed maturities to be ripened, low dosages of ethrel than the laboratory dosage could be used. Heat and ethylene gas liberated from the bulk of bananas of mixed maturities induces the fruit ripening).

**The Suitable Treatment Time for Induced Ripening of Banana**:

- A minimum of 12 to 18 hours of exposure time to ethylene gas would induce the bananas to ripen.

**The Suitable Temperature for Ripening of Banana**:

- Ripening at approximately 22° C would give a better cosmetic appearance and longer shelf life. However, ripening at the ambient temperature (29±2°C) does not give rise to any adverse effects.

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Ripening of Papaya:

Papayas harvested at green mature stage (light green) would be ready for consumption four days after exposure to ethylene gas.

Harvest maturity suitable for ripening:
Papayas light green in colour or/with a speck of yellow in the fruit, are suitable for inducing ripening with ethylene.

Laboratory dosages for ethylene treatment of Papaya:
- 200ppm to 300ppm ethylene gas
- 1.65 mL ethrel and 0.8g NaOH on a volume of 288L

Dosages of Ethylene for Commercial Ripening:
- Approximately 50mL of Ethrel combined with 25g of NaOH and approximately 100mL water would ripen 2000 Kg of papaya.

(The for laboratory trials, few papayas of identical maturity are selected as a replicate. However, for commercial ripening, selection of the identical maturity is not practical. Therefore, as papayas at several ripening stages might be included in the batch of papayas of mixed maturities to be ripened, low dosages of ethrel than the laboratory dosage could be used. Heat and ethylene gas liberated from the bulk of papayas of mixed maturities induces the fruit ripening).

The Suitable Temperature for Ripening of Papaya:
- Ambient temperature (29±2°C) is suitable to ripen papaya. However, a lower temperature of approximately 22°C would give a better flesh colour in papaya variety Rathna (red fleshed varieties).

The Suitable Treatment Time for Induced Ripening of Papaya:
- The papayas would have to be exposed to ethylene gas for 24 hours.
**Ripening of Mango:**

The mangoes harvested at mature green stage would be ready for consumption 4 to 5 days after exposure to ethylene.

**The Suitable Maturity for Induced Ripening of Mango:**
- Mangoes harvested at 13 to 14 weeks after fruit set and having raised shoulders, could be induced to ethylene for ripening.

**Laboratory dosages for ethylene treatment of Mango:**
- 250 ppm ethylene gas
- 1.65 mL ethrel and 0.8g NaOH on a volume of 288L

**Dosages of Ethylene for Commercial Ripening of Mango:**
- Approximately 50mL of Ethrel combined with 25g of NaOH in 100mL water would ripen 2000 Kg of Mangoes.

(For laboratory trials, few mangoes of identical maturity are selected as a replicate. However, for commercial ripening, selection of the identical maturity is not practical. Therefore, mangoes at several ripening stages might be included in the batch of mangoes of mixed maturities to be ripened. Therefore, low dosages of ethrel than the laboratory dosage could be used. Heat and ethylene gas liberated from the bulk of mangoes of mixed maturities induces the fruit ripening).

**The Suitable Treatment Time for Induced Ripening of Mango:**
- The mangoes were exposed to ethylene gas for 24 hours.

**The Suitable Temperature for Ripening of Mango:**
- The ambient temperature (30±2°C) is suitable to ripen mango.
Ripening of Tomato:

- Tomatoes harvested at turning stage could be treated with red light, at low temperature (22 ± 2°C) to obtain tomatoes with better colour development.

Storage of tomato:

- Mature green tomatoes are the most suitable for long-term storage. *(i.e for 4 weeks at 12± 2°C)*. Breaker stage tomatoes could be stored up to 2 weeks at the same temperature while tomatoes harvested at light red stage could be stored only for few days.
Recommendations for Further Study

- Development of red colour in harvested tomato via light treatment (both at ambient and low temperatures) should be continued.

- Retarding the ripening rate of tomato by exposing them to far-red light.

- Effect of ooze sap and spurt sap on shelf life of mango.

- Effect of harvest time (ie morning / evening) and sap extrusion of mango, on shelf life of mango.

- Minimum threshold time (exposure time to ethylene) to ripen papaya and mango.
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Web Pages

Web page 1
http://google.yahoo.com/bin/query?p=produce+facts+california+davis&hc=0&hs=0

Web page 2
http://www2.ncsu.edu/iae/programs/...licat/postharv/tomatoes/tomat.html

Web page 3
http://google.yahoo.com/bin/query?p=produce+facts+california+davis&hc=0&hs=0

Web page 4
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Web Page 5
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<tr>
<td>ACC</td>
<td>1-Aminocyclo-propane-1-carboxylic acid</td>
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<tr>
<td>ADP</td>
<td>Adenosine Di Phosphate</td>
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Appendix 1 - Guide for Banana (Embul) Ripening at different temperatures

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<tr>
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<tr>
<td>20°C±2°C</td>
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<tr>
<td>Day 1 2 3 4 5 6 7</td>
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</tr>
<tr>
<td>15°C±2°C</td>
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<tr>
<td>Day 1 2 3 4 5 6 7 8 9 10</td>
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<td>Control -30°C±2°C</td>
<td>Uneven Ripening</td>
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<tr>
<td>Day 1 2 3 4 5 6 7</td>
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Maturity stages of banana

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<tr>
<td>1</td>
<td>Green</td>
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<tr>
<td>2</td>
<td>Trace of yellow</td>
</tr>
<tr>
<td>3</td>
<td>More Green</td>
</tr>
<tr>
<td>4</td>
<td>More yellow</td>
</tr>
<tr>
<td>5</td>
<td>Green tip</td>
</tr>
<tr>
<td>6</td>
<td>All yellow</td>
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</table>

(Colour index developed by catalytic generators Inc, USA)
Appendix 2

Organoleptic Evaluation for ......................

Name : 
Sample : 
Date : 
Time : 

Quality grade          Score
Excellent             9-10
Good                  6-8
Fair                  4-5
Poor                  1-3

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<th>Sample No</th>
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<th>3</th>
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<tr>
<td>- Flesh colour</td>
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<td>2. Flavour</td>
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<td>3. Taste</td>
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<td>4. Texture</td>
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<td>5. Over-all acceptability</td>
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<tr>
<td>6. Aroma (intensity)</td>
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</tbody>
</table>

Comments : 

...........................................

Signature.

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Appendix 3

Maturity indices of Papayas (Rathna)

Stage 1  Full green
Stage 2  Green with trace of yellow
Stage 3  More green with yellow
Stage 4  More yellow than green
Stage 5  Yellow with trace of green
Stage 6  Fully yellow

(Lam 1987)
Appendix 4

Maturity indices of Tomato T245

Stage 1  Mature green
Stage 2  Breaker
Stage 3  Turning
Stage 4  Pink
Stage 5  Light red
Stage 6  Red

(Ripening guide – Catalytic generators)
Appendix 5

Procedure for analysis of Arsenic content in Calcium Carbide

Five samples of CaC₂ were obtained from five randomly selected hardware stores in Colombo. Analysis was carried out via atomic absorption procedures.

The CaC₂ samples obtained were powdered. A sample of 5g was weighed and moistened with a little distilled water and then dissolved in approximately in 5-10 mL of concentrated acid (HCl or HNO₃). The solution was volumized upto 100mL using distilled water. A sample of this solution was used to measure the absorbance.

(A.O.A.C 1980)
Appendix 6

**LCH Colour Space**

LCH colour space uses the same diagram as Lab colour space; but use cylindrical coordinates instead of rectangular coordinates.

In this colour space:

- **L** - *Light* - Same as the 'L' of lab colour space
- **C** - *Chroma* - The value of chroma (C) is 0 at the center and increases according to the distance from the centre.
- **H** - *Hue* - Hue angle (°h) is defined as starting at the +a axis and is expressed in degrees

*i.e.* 0° would be + a (red)
90° would be + b (yellow)
180° would be − a (green)
270° would be − b (blue)

'Precise Colour Communication' - Minollta Co. Ltd, Japan