
UNIVERSITI PUTRA MALAYSIA

# POSTHARVEST STUDIES ON CARAMBOLA ( AVERRHOA CARAMBOLA L . ) FRUIT

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FP 1983 2

# POSTHARVEST STUDIES ON CARAMBOLA (*Averrhoa carambola* L.) FRUIT

by

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A thesis
submitted in partial fulfilment
of the requirements for the degree of
Master of Agricultural Science in the Dept. of Agronomy and Horticulture
in the Faculty of Agriculture
Universiti Pertanian Malaysia

October 1983

ACKNOWLEDGEMENTS

Sincere appreciation is expressed to my supervisor, Dr. Wan Chee-Keong for his guidance, understanding, interest and encouragement throughout all phases of this research.

Appreciation is also expressed to:

Encik Abdul Munir Jaafar for analyzing the data;

Encik Musa Baba for providing the author with facilities in the MARDI orchard;

John Ng K.H., Anthonysamy A., and Norhayati M. for their assistance; and

Dato' Mohamad Tamin Yeop, Dr. Ahmad Zaharudin Idrus and Encik Mohd. Hashim Hassan for allowing the author to undertake this study.

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by

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## ABSTRACT

The carambola (Averrhoa carambola L.) is determined to be a non-climacteric type fruit. The characteristic upsurge of carbon dioxide exhibited by climacteric fruits was not evident in carambola fruits of different ages. Green mature fruit did not respond to 700 ul/l of $C_2H_4$ and 1000 ul/l of ethrel treatment.

Unripe fruits (less than 25 % yellow colour) were susceptible to chilling injury after storing for 5 weeks at 5 $^{o}$C, but ripe fruits (more than 25 % yellow colour) were not affected. Ripe fruits have a storage life of approximately 9 to 12 weeks in 1.5 percent perforated (holes of 5 mm diameter) polyethylene bags. Storage life decreased with increasing storage temperatures from 5 $^{o}$C to ambient temperatures (24$^{o}$ to 35 $^{o}$C). The storage life was 5 weeks at 10$^{o}$ and 15 $^{o}$C; 1 to 3 weeks at 20$^{o}$ and ambient temperatures. Unripe fruits in sealed polyethylene bags at 20 $^{o}$C can be stored for 2 to 3 weeks. They could be stored for another one week when the bags were opened and the fruits exposed to normal air. The fruits would ripen and turn completely yellow in colour.

# INTRODUCTION

The carambola (Averrhoa carambola L.) is a relatively small tree, and produces fruits all the year round. The fruit is ovoid in shape, about 14 cm in length, with five prominent longitudinal ribs. The skin is thin, smooth, glossy and is from yellow to pale orange in colour when ripe. The flesh is juicy and fairly crisp in texture with no fibre.

The carambola fruit is a popular dessert fruit in Malaysia and has great potential for export to other overseas markets. The fruit is harvested ripe and must be sold in the market within a few days as it has a short shelf life. Little is known about the postharvest storage behaviour of the fruit to extend its shelf life. Grierson and Vines (1965) found that fruits held at $0^{o}$ and 4 $^{o}$C retained their original appearance to a remarkable degree. However, they did not know whether the fruits would have ripened to a normal colour on removal from storage.

There appears to be some confusion as to the climacteric nature of the fruit. Vines and Grierson (1966) in their studies showed that carambola is a climacteric type fruit. On the contrary, Oslund and Davenport (1981) reported that it is a non-climacteric fruit. These conflicting reports could be due to the interpretation of the term 'climacteric' (Rhodes, 1970) and the method(s) used to test it (McGlasson, 1970; Pratt and Reid, 1974; Pratt and Mendoza, 1980 b).

The main objective of this study was to determine the storage behaviour of the carambola fruit using various methods and temperature regimes. This, perhaps, would lead to a better postharvest handling of the fruit and extend its shelf life. Additionally, the question of whether it is a climacteric or non-climacteric type fruit was investigated using fruits of different maturity by the

sealed system (Broughton et al. 1977), the continuous system (Claypool and Keefer, 1942), and their response to ethylene and ethrel treatments (McGlasson and Pratt, 1964; Burg and Burg, 1962; McGlasson, 1970; Reid and Pratt, 1970; Pratt and Mendoza, 1980 b).

PART I. STORAGE STUDIES Low temperaure has been used to store fruits such as bananas (Broughton et al. 1978), guava (Broughton and Wong, 1979), papayas (Broughton et al. 1977), rambutans (Mendoza et al. 1972) and carambola (Grierson and Vines, 1965). Broughton et al. (1977; 1978) recommended 20 $^{o}$C for storing bananas, guavas and papayas, while Mendoza et al. (1972) recommended 10 $^{o}$C for storing rambutans. On the other hand, Grierson and Vines (1965) found that 5 $^{o}$C could easily prolong the storage life of carambola for 4 weeks, but they did not know whether at this temperature the fruit would suffer from chilling injury or not.

An important chemical composition of a fruit that determines it sweetness at maturity is the amount of sugar present. Chan and Heu (1975) identified the major sugars in carambola as fructose, glucose and sucrose. Pratt et al. (1977) found that in the musk melon there was no further increase in sugar after harvest because the muskmelon did not store starch. Fruits that store starch at the unripe stage such as mangoes (Subramanyam et al. 1975) and bananas (Von Loesecke, 1949) showed that the starch content would decrease whilst the sugar content would increase during ripening.

Polyethylene bags have been used successfully to store banana (Scott et al. 1971) and avocado (Chaplin and Hawson, 1981) fruits at ambient temperatures. When cold storage and polyethylene bags were used in combination they acted synergistically (Scott et al. 1970) to prolong the storage life of the fruits. The polybags act as a method of modified atmosphere storage (Australian United Fresh Fruit and Vegetable Association, 1980).

The storage behaviour of papayas (Broughton et al. 1977) and bananas (Broughton et al. 1978) in carbon dioxide and ethylene-removed, and low and high relative humidities were investigated by Broughton et al. (1977; 1978). They found that the storage life was extended in the carbon dioxide and ethylene-removed, and low relative humidity environment. The objective of this study was to determine the storage behaviour of carambola fruits stored in various temperature regimes, and the physical and chemical changes that they undergo during storage. In addition the effects of storing fruits in which carbon dioxide and ethylene have been removed and low and high relative humidities were studied.

PART II. CLIMACTERIC STUDIES The carambola (Averrhoa carambola L.) was reported to be a climacteric type of fruit by Vines and Grierson (1966). They showed that the fruit exhibited an upsurge in respiration rate and the peaks were distinct when the fruits were stored at 15$^{o}$ and 20 $^{o}$C. On the contrary, Oslund and Davenport (1981) reported that the carambola is a non-climacteric type fruit. They showed that the fruit did not exhibit an upsurge in the respiration rate and also it did not respond to ethylene treatment as in the climacteric type fruits.

Biale (1960 a) stated that to show a fruit is climacteric it was sufficient to demonstrate that it exhibited an upsurge in respiratory pattern. However, to show it is non-climacteric it was necessary to demonstrate that it does not exhibit an upsurge in respiratory pattern under numerous conditions such as various ages of fruits and the correct temperature used in the determinations. Biale (1960 b) and McGlasson (1970) showed that climacteric fruits would respond to ethylene treatments, that is, the fruit would show autocatalytic production of ethylene. Pratt and Mendoza (1980 b) showed the star-apple (Chrysophyllum cainito) to be non-climacteric

by its failure to respond to ethylene and ethrel treatments. They used these methods because the measurement of the respiration rate in this fruit was not satisfactory. The present study was undertaken to determine the climacteric nature of the carambola fruit.

# REVIEW OF LITERATURE

## TERMS USED IN POSTHARVEST PHYSIOLOGY STUDIES

Climacteric. The term "climacteric" was first used by Kidd and West (1925; 1930) to describe the respiratory pattern in the ripening of apple fruits. It was found that ripening was associated with a dramatic change in the respiratory rate of the fruit. Initially there was a slow decline in oxygen uptake and carbon dioxide evolution after harvest. This phase of low respiratory activity is known as the pre-climacteric minimum. Then the respiration rate rises and reaches the climacteric maximum which is often referred to as the climacteric peak. The respiration then falls, terminating in senescence, physiological breakdown and/or microbial invasion.

Rhodes (1970) defined the climacteric as a period in the ontogeny of certain fruits during which a series of biochemical changes is initiated by the autocatalytic production of ethylene, marking the change from growth to senescence and involving an increase in respiration and leading to ripening. Examples of climacteric fruits are apples, avocados, bananas, mangoes, melons, papayas, passion fruits, and pears.

The respiratory pattern of non-climacteric fruits, in contrast to the climacteric types, remains rather constant without the characteristic upsurge in carbon dioxide evolution during the ripening process (Biale, 1960 a and b). Examples of non-climacteric fruits are cherry, citrus, cucumber, fig, grape, grape fruit, lemons, oranges, pineapples and strawberry.

Ripening. Fruit ripening should be regarded as a collective term covering many changes which are not necessarily causally related to each other, but which occur more or less in parallel

and in a time relation to the climacteric (Pratt and Goeschl, 1969). It is a special case of organ senescence; the fruit is more complex in its senescence than other plant organs, and all of these changes which occur do not represent deterioration. The physiology of harvested fruits is chiefly the physiology of ripening and senescence. Some fruits after picking exhibit changes which are characteristics of ripening. These are changes in colour, firmness, odour, flavour and composition, until the fruit becomes of eating ripeness. Also, there are other fruits which die without ripening (Ulrich, 1958). Sacher (1973) defined senescence in fruits as the final phase in the ontogeny of the organ in which a series of normally irreversible events are initiated leading to cellular breakdown and death of the organ.

Ripening can be accelerated or retarded by temperature and various gaseous components. Ethylene gas, a plant hormone endogenously produced by plants (Pratt and Goeschl, 1969; Yang and Pratt, 1978), has been demonstrated to trigger and accelerate ripening of fruits (de Wilde, 1971). Ethylene, in the concentration range of 0.1 to 1000 ul/l in air, is only effective in promoting the ripening of the climacteric type of fruits when applied during the pre-climacteric phase (Biale and Young, 1971).

Chilling injury. Chilling injury is a physiological disorder shown by plant organs after having been exposed to low temperature, above freezing, for a certain duration of time. The primary effect of chilling injury is the induction of a phase change in the membrane lipids and consequently changes in the conformation of enzymes associated with the membranes (Raison, 1974). The secondary events which are mainly irreversible and lead to visual symptoms of chilling injury are imbalances in metabolism, accumulation of

fermentative products, deterioration of cellular compartmentation and degeneration of the tissue.

Although chilling injury has been recognised for many years, its severity is difficult to define quantitatively. It can be estimated qualitatively in terms of visual observations (Lyons, 1973). Exposure to chilling temperature must be relatively long before cells of most sensitive plants are injured. The injuries observed often require days or weeks of chilling temperature . In general, the severity of injury of sensitive plant tissues increases as temperature is lowered or as exposure to chilling temperature is extended.

## POSTHARVEST HANDLING OF TROPICAL FRUITS

Storage of tropical fruits. The storage of fruits is to minimize loss in quality and to extend storage life after harvest. This primarily involves retardation of the physiological and biochemical changes associated with senescence (Hansen, 1966). The length of storage of commercial fruits is a function of composition, resistance to attack by fungal and bacterial organisms, and external conditions such as temperature, and gases in the environment (Biale, 1975).

Pantastico et al. (1975) recommended a storage temperature of 24 $^{o}$C for the preservation of most tropical fruits. Some of the ranges of temperatures that they recommended were 13$^{o}$ to 16 $^{o}$C for bananas (Musa sapientum L.), 11$^{o}$ to 14 $^{o}$C for jackfruit (Arthocarpus heterophyllus Lam.) and langsat (Lansium domesticum Jack.), 10 $^{o}$C for rambutan (Nephelium lappaceum L.), 8$^{o}$ to 10 $^{o}$C for papaya (Carica papaya L.) and 5$^{o}$ to 10 $^{o}$C for mango (Mangifera indica L.). In a series of studies on storing fruits from 5$^{o}$ to

30 °C, a temperature of 20 °C was found to be the optimum for papayas (Broughton et al. 1977)), bananas (Broughton et al. 1978; Broughton and Wu, 1979), and guava (Broughton and Wong, 1979). Broughton and his co-workers did not differentiate between ripening and storage studies. What they did was to determine the storage temperature at which ripening of the fruits would occur. They followed the respiration rate of the unripe fruits at different temperatures and concluded that the optimum storage temperature was the lower limit of temperature in which the climacteric fruits showed the climacteric peak. This optimum temperature was in fact the temperature at which ripening of the fruit occurred. The optimum storage temperature of the ripe fruit would, therefore, be lower than what they have reported. Brecht et al. (1982) recommended that when long term storage of cling peaches is necessary, green fruits should probably be ripened before rather than after storage. This was because when fruits were ripened immediately after harvest, decay was not a significant problem whereas there was a much greater amount of decay observed in fruits ripened after storage.

Extensive storage studies have been conducted for bananas (Scott et al. 1970; Ben-Yehoshua, 1966; Scott, 1975; Broughton et al. 1978, and Broughton and Wu, 1979), mangoes (Hatton and Reeder, 1966; Thompson, 1971; Mann and Singh, 1976 and Roe and Bruemmer, 1981), and pineapples (Collins, 1960; Dull, 1971). This may be due to the fact that these fruits are also available in the sub-tropical countries and are grown commercially in plantations. To a lesser extend, some storage studies have been conducted on the lesser known fruits such as langsat (Srivastava and Mathur, 1965; and Pantastico et al. 1969), rambutan (Mendoza et al. 1972), star-apple (Pratt and Mendoza, 1980 b) and custard apple (Broughton

and Tan, 1979). Only a few notes on the storage behaviour of carambola fruits are available (Grierson and Vines, 1965; Vines and Grierson, 1966; and Oslund and Davenport, 1981).

The most important problem that arises during storage is the appearance of diseases in the fruit. This will in most instances determine the length of the storage life of the fruits. In fruits, diseases are mainly caused by fungi, bacteria (Eckert et al. 1975) and yeast. Lewis and Johar (1954) reported a type of yeast which caused white fruit rot at the ridges of carambola. Diseases of banana fruits are due to fungal rots (Long, 1970 a and b; Griffee and Burden, 1974). The common diseases are rots on fruit stalk end, anthracnose, and crown rot. Guavas are commonly attacked by anthracnose. Anthracnose is also the most serious and destructive disease of mangoes (Spalding and Reeder, 1972; Jacobs et al. 1973).

Another problem is caused by too low a temperature used in storage. This results in chilling injury. Ripe banana fruits are reportedly less sensitive than green bananas (United Fruit Sales Corp, 1962). The green colour of the skin of the harvested durian fruits turned brown and then to black when stored at 12 $^{o}$C (Lam and Lye, unpublished data, 1982). Fruit kept at 5 $^{o}$C failed to ripen when transferred to ambient temperatures (24$^{o}$ to 35 $^{o}$C). Mendoza et al. (1972) have shown that the skin of rambutans darken when stored at 7 $^{o}$C.

Methods of storage. Low temperature above the chilling injury range has long been used as a method of storing fruits. Low temperature reduces the activities of enzymes and hence the rates of metabolism and respiration (Biale, 1960 b), thereby prolonging the storage life of fruits. It further retards the growth of any fungi, yeast or bacteria, present on the fruits. Humidity management comes hand in hand with temperature management in storage

(Australian United Fresh Fruit and Vegetable Association, 1980).

Controlled atmosphere (CA) storage is a method whereby the gas compositions are regulated to a constant volume. In common usage CA refers to increased carbon dioxide, decreased oxygen, and high nitrogen levels as compared with normal atmosphere. It is used commercially for storing apples and pears (Smock and Blanpied, 1972; Tugwell, 1977). Not all varieties respond equally well to CA storage. Smock and Blanpied (1972) recommended that 'McIntosh' apples be stored in 3 $^{o}$C or below with 2 to 3 % $CO_2$ for one month after which the concentration should be raised to 5 %. 'Cortland' apples respond very well to CA and is stored at 0 $^{o}$C. Differences in fruit quality between regular cold storage and those in CA storage normally do not appear until after about 90 days of storage in these two cultivars. The metabolic processes of fruits are so complicated that Claypool and Allen (1947) recognised neither high $CO_2$ nor low $O_2$ is a completely satisfactory method of changing the whole chain of reactions involved in respiration. This is evident by the development of off flavours, failure to soften properly, or even a complete breakdown of tissues before normal ripening processes are completed.

Smock (1967) showed that 'Lacatan' and 'Dwarf Cavendish' bananas were effectively stored for 3 weeks at 6 to 8 % $CO_2$ and 2 % $O_2$ at 15$^{o}$ to 16 $^{o}$C. Parson et al. (1964) suggested that 1 % $O_2$ may be the lower limit of safety at 15 $^{o}$C. Gane (1936) indicated that 10 % $CO_2$ (10 % $O_2$ and 80 % $N_2$) as the upper limit for 'Gros Michel' bananas at 15 $^{o}$C. Under these conditions the fruits can be stored for 17 to 20 days before they were removed to normal atmosphere for ripening.

Hatton and Reeder (1966) and Pantastico et al. (1970) showed that a 5 % level of $O_2$ and $CO_2$ respectively at 13$^{o}$ to 15 $^{o}$C

prolonged the storage life of mangoes for 20 days. Hatton and Reeder (1969) were able to store papayas in 1 % $O_2$ and 5 % $CO_2$ at 5 $^{o}$C for 3 weeks. At a higher concentration of 10 % $CO_2$ in air, Akamine (1959) showed that papayas remained good but decayed very rapidly upon removal to normal atmosphere.

Modified atmosphere (MA) storage, such as packaging in polyethylene bags also requires a decrease in $O_2$ and an increase in $CO_2$ or $N_2$. Generally, the produce itself generates the final gas concentration by consuming $O_2$ within the bag and giving off $CO_2$ (Australian United Fresh Fruit and Vegetable Association, 1980). The film has some permeability to both $O_2$ and $CO_2$. Scott and Gandanegara (1974) demonstrated that banana fruits stored in sealed permeable bags over a range of 13$^{o}$ to 30 $^{o}$C successfully prolonged their storage life from 10 to 50 days. Their storage life was extended considerably when an ethylene adsorbent was placed in the bag. The fruits stored at 13 $^{o}$C ripened satisfactorily when removed to 20 $^{o}$C at any time interval before the 50 days storage period. The bag is a dynamic system in which respiration and gas permeation are occurring simultaneously. There is an uptake of $O_2$ and evolution of $CO_2$, ethylene ($C_2H_4$), and water, and other volatiles. At the same time, there is restricted permeation of the gases through the packaging film. Low concentrations of $O_2$ has been reported to delay fruit ripening (Biale, 1960 a and b). The effect appears to be due to an inhibition of $C_2H_4$ production as opposed to a lack of respiratory energy for ripening or a lack of $O_2$ to permit $C_2H_4$ action (Hesselman and Freebairn, 1969).

Skin coating with waxes is also a method for storing fruits. Ben-Yehoshua (1966) found that skin coating imparted the following advantages to bananas: (i) extension of storage life, (ii) reduction in weight loss; (iii) improvement in appearance, and

(iv) reduction in the incidence of decay. Shillingford (1978) also found that wrapping banana fruits with or without wax-coating, reduced the occurrence of decay in storage.

Hypobaric storage is subjecting the storage product to an environment of low pressure which normally is below the atmospheric pressure. This method was developed by Burg and Burg (1966). It increases the diffusion of $C_2H_4$ from the tissues of the fruit, consequently extending its storage life (Burg and Burg, 1966; and Wu and Salunke, 1972). Apelbaum et al. (1977) showed that pre-climacteric banana fruits of 'Dwarf Cavendish' when stored in 14 $^{o}$C at 250 Torr changed colour after 60 days, and at 150 or 80 Torr retained the green colour and firmness for up to 120 days. In all cases, when they were transferred to atmospheric pressure and 20 $^{o}$C, the fruits yellowed and softened within a few days. Their results indicated that there is no necessity to reduce the pressure below 150 Torr for prolonged storage of up to 120 days. Bangerth (1973) compared the $C_2H_4$ emanations, respiration and fruit firmness of 'Golden Delicious' apples for a duration of 180 days kept at 100 Torr and 3 $^{o}$C to fruits stored at normal pressure (about 760 Torr) and aerated with air at 4.5 l/hr. They found that $C_2H_4$ emanations of fruits during hypobaric storage did not surpass 2 ul/kg/h whereas the control exceeded 70 ul/kg/h after 6 weeks in storage. This result was consistent with that of Burg and Burg (1966). Furthermore, the respiration rates of fruits in hypobaric storage were lower than the control, but firmness was vice-versa.

Physical and biochemical changes. Firmness readings of fruits is a good indicator for maturity. When a fruit ripens it will be more soft. This is due to a series of biochemical reactions occurring in the fruit (Biale, 1960 b). Haller (1941) described

a number of pressure testers such as the fruit pressure tester for apples and peaches, and the Idaho pressure tester for stone fruits (except peaches) and strawberries. Abbott et al. (1976) compared the use of the manual pressure testers, Effe-gi and Magness-Taylor, with the Instron Universal Testing Machine. Firmness measurement is usually done with punctures on the fruit with or without the skin. The reading at the point when the fruit punctures will give an indication of the degree of firmness of the fruit. A higher reading will denote a more firm fruit.

Other tests on the texture of fruit consisted of the compressive failure patterns done by compressing at a known given height on a sample (Peleg et al. 1976). Also, the texture profile analysis can be done by compressing twice a cylinder of equal diameter at a known given height on a sample which simulate two 'bites' (Bourne, 1968; Breene et al. 1972) in an Instron Universal Testing Machine.

Vines and Grierson (1966) have determined quantitatively seven organic acids in carambola fruits. Oxalic and tartaric acids were the major acids in green mature carambola fruits. As the fruit reached the yellow mature stage the tartaric acid decreased, while oxalic, and $\alpha$-ketoglutaric acid content increased. They also found that the major amino-acids in the green mature carambola fruits were serine, glutamic acid and alanine. All amino acid concentrations decreased about 50 % (15.0 to 7.5 micromoles per gram fresh weight) suggesting that amino-acids were utilized as the respiratory substrates.

# MATERIALS AND METHODS

## PART I. STORAGE STUDIES

Plant material. Carambola (Averrhoa carambola L.) of clone 'B 10[1]' were obtained from the MARDI orchard in Serdang. The fruit is green in colour when unripe, and yellow when ripe. It has a good flavour, is juicy and sweet, and a fine texture. It is a large fruit and weighs about 200 g.

Methods of measuring respiration rate ($CO_2$), ethylene ($C_2H_4$) emanation, and oxygen ($O_2$). The dynamic (Claypool and Keefer, 1942) and static systems were used for physiological studies. Respiration rate in the dynamic or continuous aeration system was measured by passing a known volume of air of approximately 1 litre/hour/100 g of fruit through a low pressure manometer flowboard into a glass bottle of approximately 3.65 litres in volume. The inlet flow rate into the bottle was controlled by

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[1]The common name for this clone is Ching Sing Keow which was named after the owner from Sri Kembangan, Selangor, Malaysia. It was registered with the Department of Agriculture, Peninsular Malaysia in 1968.

All experiments were conducted at the Postharvest Laboratory and with facilities at the Division of Food Technology, Malaysian Agricultural Research and Development Institute (MARDI), Serdang, Selangor, Malaysia.

the manometer height and the size of the capillaries. The outlet air from the bottle was equilibrated with a dilute mixture of sodium bicarbonate and bromthymol blue (Claypool and Keefer, 1942). The percent transmission of the sample solution was measured in a spectrophotometer (Spectronic 20) at 617 nm (Pratt and Mendoza, 1980 a). The percent $CO_2$ present in the solution was then obtained from a prepared standard curve. The percent $CO_2$ was subsequently converted to mg $CO_2$ $kg^{-1}hr^{-1}$ to indicate the respiratory rate as shown in Appendix 1.

In the static system such as a sealed bag or sealed bottle the $CO_2$ and $O_2$ content were determined by withdrawing 1 ml gas samples and analyzed using a Varian 1420 gas chromatograph fitted with a thermal conductivity detector. The quantity of $CO_2$ was measured using a 150 cm x 3 mm stainless steel column of 80 to 100 mesh Porapak R with helium as the carrier gas adjusted to a flow rate of 30 ml/min. Oxygen was similarly measured using a 150 cm x 3 mm column of 45 to 60 mesh Molecular Sieve 5A. The flow rate of the carrier gas, helium, was adjusted to 25 ml/min. The column temperature for both $CO_2$ and $O_2$ measurement was set at 35 $^{o}C$. The percent $CO_2$ and $O_2$ were calculated as shown in Appendices 2 and 3 respectively.

The ethylene ($C_2H_4$) emanation in the dynamic and static systems was determined by gas chromatography. Gas samples of 1 ml was injected into a Varian 1440 gas chromatograph equipped with a flame ionisation detector and a stainless steel column (180 cm x 3 mm) packed with 100 to 120 mesh Porapak T operated at 100 $^{o}C$. The $N_2$ carrier gas flow rate was adjusted to approximately 30 ml/min. The amount of $C_2H_4$ emanation was calculated as in Appendix 4.