

**PHYSICAL , CHEMICAL AND PHYSIOLOGICAL RESPONSES OF
PINEAPPLE TO GLAZING AFTER HARVEST .**

BY

PAPA KOW BARTELS

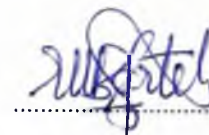
The logo of the University of Ghana is a shield-shaped emblem. The top section is blue with three golden wheat stalks. The bottom section is also blue with a golden scrollwork design. A golden banner at the base contains the university's motto in Latin.

**A THESIS SUBMITTED TO THE DEPARTMENT OF NUTRITION AND FOOD
SCIENCE, UNIVESITY OF GHANA , LEGON , IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE AWARD OF AN M.PHIL DEGREE IN FOOD
SCIENCE**

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DECLARATION

I Papa Kow Bartels, declare hereby that the work embodied in this thesis is original and has never been submitted in part or in whole for the award of any certificate, diploma or a degree in this or any other university.



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.....
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DEDICATION

1. To the glory of God
2. To my wonderful family , Abena , Moed , Abeku and to Eden for making it through thick and thin. "For it is not him that willeth nor him that runneth but the lord that showeth mercy".



ABSTRACT

The post harvest management of pineapple quality is a problem that many Ghanaian pineapple exporters are grappling with. Importers pay premium only on top quality fruits that satisfy market and consumer expectation. An effective Quality Management Approach (QMA) which takes into consideration market demands and consumer expectation would be the key to making Ghanaian exports competitive on the world pineapple trade.

In this study, glazing or surface coating of pineapple was employed as a QMA tool, and the physical, chemical and physiological responses of the fruit were monitored under ambient and refrigerated storage.

The results of a comparative study of four levels of coating viz: 0, 5, 7.5 and 10% concentration showed that the physical and chemical quality attributes of pineapple could be enhanced by surface coating with the wettable emulsion "stay fresh 7055" and refrigerated storage at 8°C. 7.5% polymeric coated fruit gave the overall best quality attributes evaluated. However, 5% coating was preferred for further study because of economy and also because it was frequently observed that there was no significant difference in the treatment means of the 5% and 7.5% coated fruit. Refrigeration (8°C) minimised physical and chemical quality deterioration. However, fruit quality deteriorated when redrawn into physiological temperature (18°C and above). Physical and chemical quality deteriorated with increasing storage interval. Incorporating fungicide (thiobendazole) in the polymeric coating mixture had no significant effect on the quality indices studied.

Mass Shrinkage Characteristics (SHC), Shell Colour Break (SCB) and Crown Withering Index (CWI) could be predicted using mathematical models. Mean SHC, SCB and CWI were significantly higher for fruits harvested at 160 days after floral induction (FI) than fruits harvested at 140 days FI. SHC and SCB were significantly higher for fruits evaluated at night (6pm - 6am) than for fruits evaluated during the day (6am - 6pm). 5% polymeric coating significantly arrested SHC, SCB and CWI under both low temperature (8°C) and ambient (28°C) storage. Application of fungicide at 0.01% was significant in

reducing shrinkage under ambient storage. Shrinkage Characteristic, Shell Colour Break and Crown Withering Index increased with increasing storage interval, but the effect was twice as much for ambient than for low temperature storage.

The pineapple fruit exhibited a non-climacteric respiration. CO₂ production and O₂ utilisation increased with increasing holding time. The effect was more pronounced in non-coated than for coated fruit. Respiration Quotient (RQ) was 1.25 for coated and 1.92 for non-coated fruits. Nitrogen content in the storage atmosphere decreased with increasing holding time.

Post Low Temperature Storage (LTS) behaviour of pineapple significantly affected the vitamin C content of whole fruit. 5% coating was effective in enhancing mean vitamin C retention by 27% over non-coated fruit 5 days after LTS. Sugar content, pH and pulp temperature increased while firmness retention deteriorated from the apical to the basal section of the fruit. Coated fruits were firmer, had higher pulp temperature and lower pH value. Internal browning was over 150% times more intense for non-coated fruits than for coated fruits. Internal browning and firmness retention could be predicted by linear mathematical models.

Peroxidase activity determination in pineapple was optimised using the Central Composite Rotatable Design. Activity was highest at the basal section and showed a decreasing effect through the mid to the apical section. Maximum response to peroxidase activity was observed at pH range 5.5 - 6.0, using 0.5% 3,3'-dimethoxybenzidine and 0.15-0.25% hydrogen peroxide. 5% polymeric coating was effective in delaying the onset of internal browning 5 days after LTS (8°C) and showed low peroxidase activity at 23°C. Non-coated fruit showed severe internal browning two days post LTS at 23°C ambient and had a higher peroxidase activity. Elevating conditioning temperature from 23°C to 30°C and 45°C respectively resulted in isozyme formation, an increase in peroxidase activity of polymeric coated fruit and a decreased activity in non-coated fruit.



Finally, it can be concluded from the results of this study that glazing or surface coating holds great promise for the Ghanaian pineapple exporter in minimising the many physical, chemical and physiological disorders associated with the export trade.

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1.0**INTRODUCTION****1.1****Background Information**

Traditionally, the mainstay of Ghana's foreign exchange earnings has been cocoa which accounts for over 60% of the total export revenue. In recent years, world cocoa prices have been falling and cocoa importing countries have placed less premium on the use of cocoa butter and other derivatives in the cosmetic, food and beverage industry. The government of Ghana recognising the danger in the over reliance of cocoa as the major source of foreign exchange earning instigated an Economic Recovery Programme (ERP) in 1983. A major thrust in the ERP was the establishment of a clear policy to resuscitate export trade through diversification into non-traditional exports. This policy was strengthened with the birth of a three year Non - Traditional Export Plan (NTEP 1988 - 1990) with agricultural commodities especially horticultural export playing a pivotal role.

The aftermath of these policy initiatives led to a rapid expansion in pineapple production and the establishment of pineapple production estates with modern production techniques geared towards the export market.

1.2**Pineapple Production In Ghana**

Information on the origin and cultivation of pineapple in Ghana is sketchy. However, commercial pineapple cultivation in Ghana has been recorded as far back as 1934-35 where production was concentrated in the western region (Plan Consult, 1993). It was



intercropped with food crops and allowed to ratoon over several generations. The fruits were mainly sold for local consumption (Plan Consult, 1993).

Currently, two varieties belonging to the Cayenne and Penambuco groups are popularly cultivated in Ghana, although the Queen and Red Spanish can be found in some germplasm collections. The Smooth Cayenne is cultivated for export while the Penambuco is cultivated for local consumption.

Pineapple production for export is concentrated around Nsawam, Aburi, Samsam and Kasoa in the coastal savannah zone where it is cropped in pure stands. It is estimated that Ghana produces between 40 - 65,000 MT annually (AMEX, 1995).

1.3 Pineapple As A Non -Traditional Export Crop -

The Quality Factor

The supply of premium quality pineapple to Europe is dominated by Ghana (GEPC, 1994; COLEACP, 1993; Dixie, 1993). Of the approximately 15,000 tonnes of pineapple supplied annually Ghana controls approximately 60% of the supply market (GEPC, 1994).

Growth in export volumes of pineapple has been remarkable. From an export level of 4907MT in 1988 it more than doubled to 10674MT by 1991, grossing US \$4.4 million by 1992 (GEPC, 1994).

These achievements have been made against the background that until recently pineapple export was relatively unknown (Plan Consult, 1993). Ofori (1995) has reported that within the frame work of a Medium Term Agricultural Development Strategy (MTADS), the government of Ghana has launched the Agricultural Diversification Programme. Pineapple has been identified as a priority crop under this programme.

With the institutionalisation of the above programmes coupled with the rapid expansion in the local fruit juice manufacturing industry, a firm basis has been set for pineapple export to play an important role in Ghana's export revenue.

1.4 Constraints To The Pineapple Export Industry

Despite the earnest growth in pineapple export and the expanding local consumption, no work has been carried out to determine the shelf-life of the fruit under existing conditions and how it may be improved (GEPC, 1994).

Until recently, approximately 90% of pineapple export was by air freighting. The fares were relatively cheap and with small export volumes, pineapples were quickly transported to their destinations. However, with increasing volumes of export coupled with increasing freight charges, persistent delays have been encountered (Lamptey, 1994). These delays result in deterioration in quality (Dixie, 1995; Soler 1992). Dixie (1993) and Dixie (1995) has described as "worryingly high" dehydration or shrinkage of pineapple exported from Ghana; he reported weight loss of between 10-14%. As importers pay net weight on arrival, this loss has a significant impact on export revenue.

Air freighting which remains predominant as the means of pineapple export is served by a limited physical infrastructure. At present the common practise at Kotoka International Airport is to hold fruits in the open at the back of trucks or in a small cargo shed before they are loaded into the aircraft.

An emergency alternative to the high air freight charge, the persistent delays and the inability to freight the total volume of export at a go, is the use of sea freight. Sea freighting

has the capacity to hold large volumes of export. However, one drawback to sea freighting is the duration of transportation that has serious implications on the shelf life and quality of exported pineapples (Pantastico, 1975; Py *et al.*, 1987).

1.5 Technical Solutions

The problem confronting the fresh fruit pineapple industry in Ghana is not how to store the fruit in order to obtain a consumer acceptable ripe fruit but rather how best to manage the fruit for minimum detractions in fruit quality before and after harvest. This calls for a Quality Management Approach (QMA) that is consumer demand driven and has an inherent evaluation scheme right from production through post production to the consumer table. Evidently, much work is being done on production to the neglect of post harvest management although the post harvest operation is central to the table quality of the fruit (Ofori, 1995; World Bank, 1993).

The QMA adopted in maintaining fruit quality are varied and vary from country to country and institution to institution. However they are either adopted singly or in various combinations.

- QMA consists of adopting good crop husbandry practises which ensures that healthy planting material and proper varietal selections are made and cultivated in the right edafic medium with minimum pathological and physiological consequence.
- Refrigeration may also be employed to reduce field and respiratory heat which promote senescence and deterioration.
- modified or controlled atmosphere and surface coatings have been used extensively to extend the shelf-life and minimise quality changes in fruits and vegetables.

- Irradiation has also been used as an approach to delay senescence and deterioration in many fruits.

A review of the application of QMA has been detailed in chapter 2 under section 2.5. In this study however, a combination of good agronomic practises, refrigerated storage and the use of surface coatings were employed as a quality management approach to minimising quality detractions in post-harvest pineapple.

1.6 Aim And Objectives

1.6.1 Aim

The overall aim of this study is to evaluate the effect of post-harvest treatments on the shelf- life and quality of pineapple with the view of recommending suitable post-harvest management practices that would minimise quantitative and qualitative losses and maximise economic returns on pineapple export.

1.6.2 Specific Objectives

The specific objectives of this study are as follows :-

1. To evaluate the effect of glazing or fruit coating on selected physical and chemical quality indices of post harvest pineapple.
2. To study the effect of glazing with a polymeric coating substance on the post harvest physiology of pineapple.
3. To determine the shelf-life and shrinkage characteristics of pineapple.

4. To evaluate the post-storage behaviour of pineapple after low temperature storage.
5. To study the contribution of peroxidase activity to deteriorative changes in pineapple.
6. To analyse the above evaluations in order to develop suitable models for predicting pineapple quality under specified conditions for export.



2.0

LITERATURE REVIEW

2.1

The Pineapple Plant

2.1.1

Origin And Dispersion

On November 3, 1493, a convoy of ships led by Christopher Columbus on his second voyage, reached the Lesser Antilles and landed on a small island that he named Marie Galante. According to the chronicles of Pedro Martyr De Angleria (1530), near Marie Galante was also another island which he called Guadeloupe. It was here in a tiny Indian village, that they first saw the pineapple plant and its fruit.

Michael De Cuneo, a lone voyager confirmed the discovery in a letter dated October 28, 1494, and it reads thus "There were some plants like artichoke plants, but four times as tall, which gave a fruit in the shape of a pine cone, twice as big, which is excellent, and can be cut with a knife like a turnip, and it seems to be wholesome" (Morrison, 1963).

Py *et al.* (1987) have reported several documentary evidence that points to the fact that Pineapple (*Ananas comosus* (L) Merrill) is a crop native to tropical Americas. However one species though is thought to have originated from the West African country of Guinea (Py *et al.*, 1987).

The dispersion of pineapple from tropical Americas to other parts of the world occurred immediately after the discovery of America (Morrison, 1963). It is thought that the exploits and conquest of the Spanish and Portuguese brought the fruit to Africa and Asia. Salunkhe and Desai (1984) have reported that pineapples have been cultivated in India and Malaysia since 1548.

2.1.2

Botany And Cultivars

2.1.2.1

Botany

Pineapple is a xerophytic, succulent, herbaceous perennial, monocotyledonous plant with leaves arranged in a dense rosette pattern. Its leaves are trough-shaped and are arranged spirally around the stem with a 5/13 phyllotaxy (Ekern, 1965).

As a result of environmental stimuli or the application of growth regulators the plant produces a spike-like inflorescence which is a collection of fruitlets (Batholomew and Criley, 1983). Fertilisation is by cross pollination (Salunkhe and Desai, 1984) although De Wald *et al.* (1992) have reported self-compatibility in commercially cultivated pineapples.

The pineapple fruit is a compound of several parthenocarpic fruitlets fusing together with the bracts and central axis of inflorescence (Salunkhe and Desai, 1984). The fruit terminates in a vegetative shoot commonly referred to as the crown. (Bartholomew and Malezieux, 1994).

The fruit flesh can either be opaque or translucent at maturation, with the primary difference being the absence or presence of liquid in the intercellular spaces (Py *et al.*, 1987).

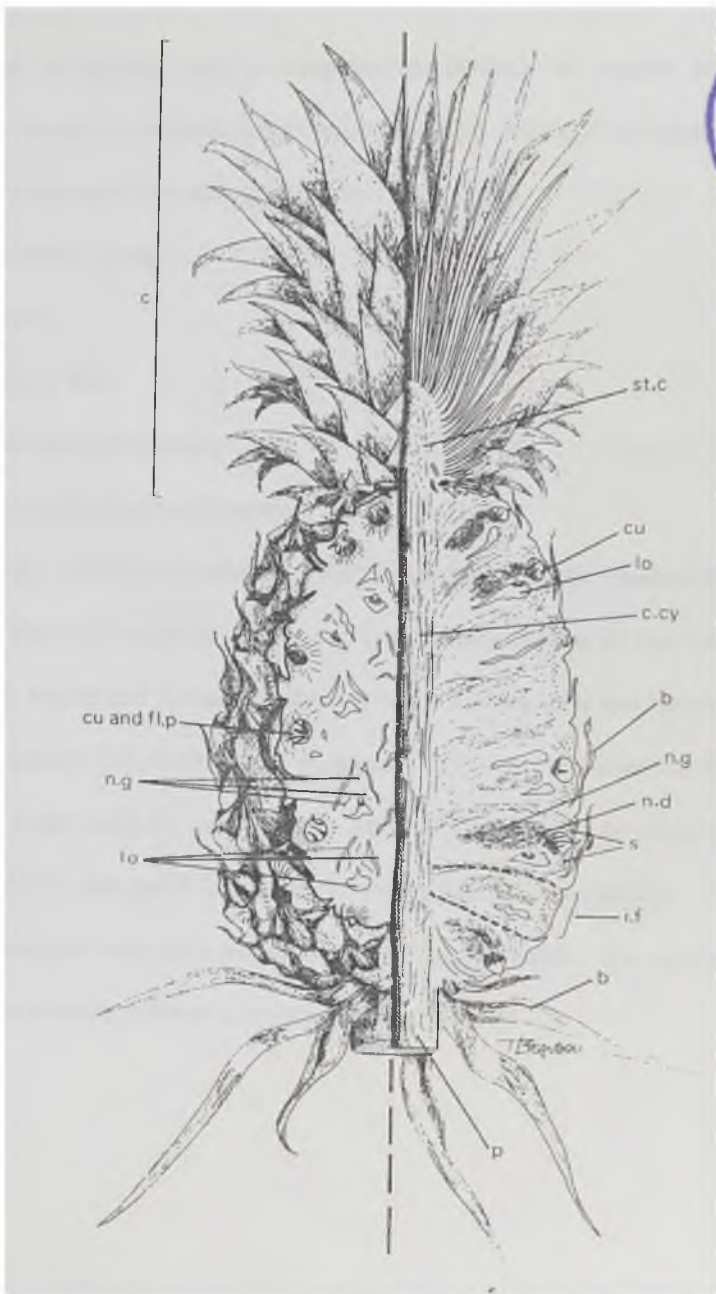
Opaque fruits have a specific gravity less than one while the specific gravity of translucent fruit is one or greater (Py *et al.*, 1987).

Pineapple is best suited for mild tropical climates with temperature ranging between 16 - 32°C with minimal shading and mild sunshine (Knight, 1980)

Fig. 2.1 Botanical Parts of the Pineapple Fruit

c	=	Crown
st.c	=	Stem of Crown
cu	=	cupule
lo .	=	locule
c.cy	=	Central Cylinder
b	=	bract
cu and fl.p	=	cuplile and floral parts
n.g	=	nectary gland
n.d	=	nectary duct
s	=	sepals
i.f	=	individual fruitlet
p	=	peduncle

source : Py *et al.*, (1987)



2.1.2.2

Cultivars

The terminology used to categorise the diversity of material of pineapple that is cultivated appears to be inadequate (Samuels, 1980). However the pineapple of commerce appears to come from five main groups viz.

1. Smooth Cayenne
2. Queen
3. Spanish Red
4. Penambuco (Abacaxi)
5. Mordilonus-Perola-Maipure

Knight (1980) and Samson (1980) have described the characteristics of pineapple cultivars. The most commonly grown and predominant cultivar all over the world is smooth cayenne. It has several favourable characteristics such as spineless leaves, high production, high fruit quality and resistance to gummosis. No other cultivar has fruit of such good cylindrical shape ideal for canning. The Spanish Red cultivars have spiny leaves and have great variability only good for the fresh market and fair for canning. The Penambuco or Abacaxi group has long spiny leaves and a very long fruit stalk. It is not suitable for canning or for export as fresh fruit and is mostly consumed locally.

2.1.3**Production And Utilisation****2.1.3.1****Production**

Pineapple is produced over a wide range of latitudes from approximately 30°N in the northern hemisphere to 33° 58'S in the southern hemisphere (Bartholomew and Kadzimin, 1977). Cultivation systems used throughout the world vary from gathering fruits from wild plants under tree cover as in some areas of Brazil, to the intensive systems used in Hawaii. In the Phillipines and Thailand pineapple is cultivated as a monoculture on thousands of hectares (Bartholomew and Malezieux, 1994). As a result, yields vary greatly from region to region and can range from 30 to more than 100 MT ha⁻¹. In Ghana (AMEX, 1995) have estimated yield figures to be in the range 40 - 65 MT ha⁻¹.

Table 2.1: Pineapple Production ('1000MT) By Some Major Pineapple Producing Countries As Compared To Ghana

COUNTRY	1979-81	1992	1993	1994
World	9585	11125	11546	11832
Africa	1678	2003	1967	1911
Thialand	2857	2180	2589	2686
Phillipines	861	1135	1254	1190
Brazil	392	826	818	999
China	299	668	777	860
Nigeria	600	800	800	800
Mexico	530	264	281	280
Kenya	177	270	270	270
La Cote D'Ivoire	295	201	270	270
Venezula	85	83	133	137
South Africa	217	187	143	79
Ghana	6	12	18	12

Source: F.A.O (1995) Production Yearbook 1995, Vol.48



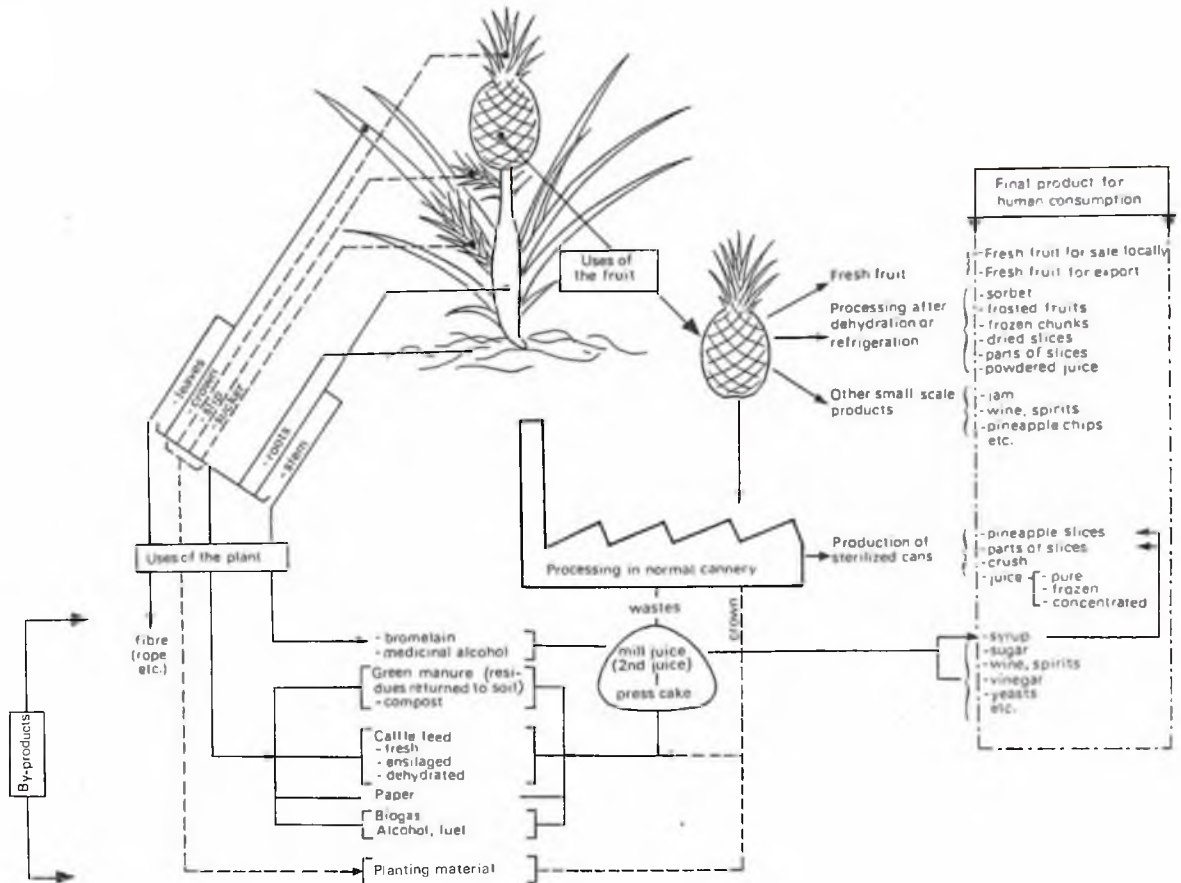
2.1.3.2

Utilisation

The fruit is the main reason for cultivating pineapple although Bartholomew and Malezieux (1994) have reported that other useful products like fibre for producing a special silk for clothing can be obtained from the leaves and stem.

The composition of the fruit is detailed in section 2.2.2 of this study. The pineapple is a delicious fruit and due to its relatively high sugar content (12 - 18°Brix), it can be classified as an energy food (Py *et al.*, 1987). According to Huet (1958) one glass of juice (approximately 150cc) contains an average of 75 Calories. Although not in large quantities, the fruit contains all the vitamins except vitamin D.

A study conducted by Estanove (1982), summarising potential uses for the pineapple plant as a whole is presented in Fig. 2.2.



2.2 The Pineapple Fruit - Handling and Market Requirements

2.2.1 Harvesting and Fruit Preparation

The fragility of the pineapple fruit flesh calls for care in harvesting and subsequent handling and transportation in order to ensure that pineapples get on the market in peak condition. King (1972), asserts that in spite of their robust appearance, pineapples particularly many varieties of the cayenne group, are very delicate and extremely susceptible to bruising and other mechanical injury. Premium quality fruit are obtained when fruits are harvested at the optimum stage of development. The optimum conditions for harvesting is a subjective operation which is market or consumer demand driven but economic limitations can play a determining role (Korang-Amoako, 1995).

When fruits are picked unripe they never attain the fine appearance of fruits picked fully ripe. Immature fruits cannot be ripened always successfully artificially and it may have an acid taste and may develop a distinctive yellow tinge (King, 1972).

Be that as it may, an important criterion for judging when to harvest is the sugar content of pineapple (Soler, 1992; Py *et al.*, 1987). The sugar content increases very rapidly during the last stages of development of the fruit on the plant. Thus fruits should be harvested at the last stages of growth as possible taking into consideration the dictates of market demand.

The harvesting operation is accomplished manually or mechanically (as in very large plantations). After harvesting fruits are sorted into size, shell colour, fruit weight and defective fruits. The bracts at the bases are removed and the peduncle trimmed to the required length. Fruits destined for the export market are usually given a fungicidal treatment to control the menacing effect of the fungus *Thielaviopsis paradoxa*. Pineapples can also be waxed to reduce shrinkage and physiological disorders.

2.2.2

Pineapple Composition

TABLE 2.2 General analysis and nutritive value of ripe pineapple fruit flesh after Duckworth (1966) and Dull (1971)

Constituents	Fresh Weight (g/100g)	
	(Dull, 1971)	(Duckworth, 1966)
Sugar Content	10 - 18	9.7 - 12.1
- Sucrose	5.9 - 12.0	-
- Glucose	1.0 - 3.2	-
- Fructose	0.6 - 2.3	-
Cellulose	0.43 - 0.54	-
Pectin	0.06 - 0.16	-
Titrateable acidity (as Citric Acid)	0.6 - 1.62	3.8 - 7.0 (m-equiv)
Ash	0.30 - 0.42	0.12 - 0.42
Water	81.2 - 86.2	77 - 91
Fat	-	Trace - 0.31
Calories (Cal)		46 - 57
Fibre	0.30 - 0.61	0.27 - 1.2
Nitrogen	0.045 - 0.115	-
Ether extract	0.2	-
Pigments (ppm of Carotene)	0.2 - 2.5	
Carotene (mg)	0.13 - 0.29	-
Xanthophylla (mg)	0.03	0.01 - 0.12
Esters (ppm)	0.2 - 2.5	
Calcium (mg)	7 - 16	12 - 32
Iron (mg)	0.3	0.3 - 0.6
Iodine (mg)	0.006 - 0.107	
Phosphorus	6 - 21	
Potassium	11 - 330	
Sodium	14	
Sulphur	7	
Vitamins	($\mu\text{g}/100\text{g}$)	
p-Aminobenzoic acid	17 - 22	
Folic	2.5 - 4.8	
Niacin	200 - 280	
Panthenic acid	75 - 163	
Thiamine	69 - 125	
Vitamin A (as alcohol)	0.22 - 0.04	
Ascorbic Acid	10 - 25	

2.2.3

The Pineapple Market

Pineapples are cultivated either for local consumption or for export. The export market is serviced by air freighted or sea freighted pineapple. In Ghana air freighting of pineapple is done by private cargo planes or by existing commercial airlines. Sea freighting is done by reefer vessels (refrigerated vessels) or by reefer containers (refrigerated containers).

Generally fruits that are exported (by sea or air) are destined for either the fresh fruit market or for the cannery (Kay, 1965). Recently, minimally processed pineapples in polyethylene has been reported (Dixie, 1995).

The general market requirement for fruits destined for Europe has been described by Stier (1994). The fruit should have a good appearance, must come to complete ripeness and colour, it must be clean and free from damage, and free from any foreign smell or taste. According to Stier (1994) fresh fruit has been classified into 4 grades or classes depending on quality:

- Class Extra: Highest quality. Strictly sorted and graded fresh fruit of uniform colour and taste. This class is seldomly used in practise.
- Class 1: Normal good quality. Some small blemishes are permitted, but the general good appearance and keeping quality may not be affected. This is the class which comprises the bulk of imported fresh fruit.
- Class 2: Marketable quality. Some blemishes are permitted but no signs of diseases, over-ripeness or beginning decay.
- Class 3: Still marketable quality, but this class is not allowed in the trade with developing countries.

The package has to be strong, good looking and undamaged with labels corresponding to standard regulations and in accordance with governmental permission.

Air-freighted pineapples fetch a premium price in European markets. In 1992, air-freighted Ghanaian pineapples were sold Freight on Board (FOB) to European buyers at US \$0.45/kg contrasting with the price of about US \$0.25/kg for standard quality sea-freighted pineapples from La Cote d' Ivoire (GEPC, 1994).

Pineapples defined as high quality, should have good gugetative and organoleptic properties. It should have a brix value of 12-14% or better (Soler, 1992; Behnke, 1994) acid content of 12-18% meq (Soler, 1992) sugar to acid ratio of One (1) (Soler, 1992) translucency higher than 30% but not more than 40% (Soler, 1992; Behnke, 1994), shelf life of at least 1 week (air transported fruit) or 3-4 weeks (Sea transported) (Behnke, 1994). However Korang-Amoako (1995) and Obu (1995) have indicated that these requirements vary significantly depending on the importer or commercial house.

2.3 **Factors Affecting Fruit Quality**

2.3.1 **Plant Nutrition And Fruit Quality**

The effect of plant nutrition on the post harvest quality of the pineapple fruit has been well documented (Py *et al.*, 1987; Mustafa 1989; Osei-Wusu 1995). Mustafa (1989) has reported that the application of phosphorus (P) fertilizer to pineapple resulted in decreased levels of the sugar and acid content of fruit. This observation is also shared by (Tay *et al.*, 1968 and Tay, 1972). Pan (1957) observed that poor quality fruits were produced when P applications were added to smooth cayenne pineapples. While Lin Chin and co-workers (1964) have

indicated that P application negatively affected fruit flavour. However Su (1969) has shown that ascorbic acid concentration increased with improvement in phosphorus fertilization. Low ascorbic acid content is reported to promote endogenous browning of refrigerated pineapples (Teisson, 1977).

The key element in the composition of the pineapple fruit appears to be potassium (Py *et al.*, 1987). Martin-Prevel *et al.* (1961) have reported that an increase in K concentration in the plant results in an improvement in the flavour and aroma while an increase in flesh firmness have also been observed (Py and Tisseau, 1965). Less satisfactory flesh colour which remains white but improved shell colour have been reported when K fertiliser was used (Py *et al.*, 1957; Teisson and Pinon, 1979).

By far the most marked effect of K on pineapple fruit is on the sugar content and fruit acidity which increase with supplies of K to the plant (Tay *et al.*, 1968; Gailard, 1970; Marchal *et al.*, 1980). Ascorbic acid which is directly linked to free acids in pineapple is also subjected to the same influence of potassium (Su, 1959a). Teisson *et al.*, (1979 b) have reported that an improvement in potassium nutrition is one of the most effective ways of preventing internal browning. Several authors (Jacob and Uexkull, 1963; Sanford, 1968; Chaing, 1969; Teisson, 1980) have found that potassium has a beneficial effect on the storability of pineapple. It promotes fruit compactness and resistance to bruising thus potentially prolonging the shelf-life.

Nitrogen is known to be the main determinant in fruit weight (Py *et al.*, 1987). Numerous authors Py *et al.* (1957); Dadson (1968); Gailard (1970) ; Singh *et al.* (1977); Marchal *et al.* (1980) have observed the influential effect of increasing nitrogen nutrition to be a reduction in free acids in the fruit. While a reduction in total soluble solids have

occasionally resulted (Abutiate and Eyeson, 1973; Sing *et al.*, 1977).

2.3.2 Climatic Influence On Fruit Quality

The main influence of climate on fruit quality appears to be temperature, moisture and altitude.

2.3.2.1 Effect Of Temperature

Bartholomew and Malezieux (1994) have reported that the table quality, flesh colour, shell and crown appearance and the storability of the pineapple fruit are markedly influenced by Temperature. The main components of the eating quality of pineapple are flavour, sugar content and titratable acidity (King, 1972; Py *et al.*, 1987; Soler, 1992; Bartholomew and Malezieux, 1994).

Chandler (1958) and Collins (1960) have reported that the phenomenal increase in concentration of sugars that occurs in the last week before harvest intensifies with an increase in temperature. According to Py *et al.* (1987) the most important factor in determining fruit acidity is temperature.

Py and Tisseau (1965) and Lacoeyuilhe and Gicquiaux (1971) contend that at high altitude where temperatures are cooler or during cold seasons (Green, 1963) fruits tend to be more acidic. The wide range in titratable acidity (.3g - 1.5g/100g fruit) in pineapple is mainly due to temperature (Hamner and Nightingale, 1946; Heut, 1958) and more precisely to maximum temperature variations (Teisson, 1979) with fruit flesh becoming very fragile (Py and Tisseau, 1965).



The development of fruit aroma appears to increase with increasing temperature (Silvestein, 1971) but decreases beyond 27°C (Yow, 1959).

The fruit flesh colour and translucence are also altered by temperatures, although the effects are not well characterized (Bartholomew and Malezieux, 1994). However (Teisson, 1979) has observed that storing harvested fruits at high temperature (48°C) makes the flesh highly translucent within 24 hours. This assertion is supported by Py *et al.* (1987) who observed that in warmer environments flesh colour is yellow and tends to be more translucent. Fruit quality is considered optimum when mean air temperature is around 25°C (Py and Tisseau, 1965). The role of temperature in such physiological disorders and anomalies as internal browning, green ripe phenomenon, multiple crowns and sun scald have been well documented (Teisson, 1977; Paul and Rohrbach, 1985; Galan Sauco *et al.*, 1988; Broadley, 1993). Temperature can also influence the development of diseases (Frossard, 1978; Newhook *et al.*, 1978) and pest (Ventura, 1982).

2.3.2.2

Effect Of Moisture And Altitude

There is little available information on the effect of humidity and moisture stress on the post harvest fruit quality (Bartholomew and Malezieux, 1994). However Dixie (1993) has observed severe shrinkage and weight loss of Ghanaian pineapples exported to Europe and has described it as “worryingly high”. A lack of shell lustre, corky micro-fissures and unsatisfactory crown conditions have been reported to occur under droughty conditions although irrigation improves all conditions particularly the appearance of the shell (Combres, 1981).

Too much water is reported to increase fruit fragility (Green, 1963). It can result in cellular lesions and promote the phenomenon of green ripe (Ginsgurg, 1953; Huet, 1953). Collins (1960) intimates that fruits harvested during a rainy period have poor keeping ability, as high moisture plays a role in pest and disease enhancement (Py *et al.*, 1987).

The effect of altitude is closely linked to temperature. Collins (1960) has reported that if water supply is not limiting fruits harvested at high altitude tend to be less well filled and have prominent, pointed fruitlets. (Py *et al.*, 1987) have observed that pineapples harvested at high altitude have whitish flesh, although it remains unclear whether the lack of colour is due to the absence of carotenoids or to increased flesh porosity, which would make the fruit more opaque, thus obscuring the carotenoids.

2.3.3 Biotic Consideration

The main biotic factors affecting fruit quality are pest and diseases. Pineapples are attacked by fruit flies, but they do not survive in the fruit (Salunkhe and Desai, 1984). In Latin America gummosis of the fruit caused by the Lepidoptera (*Thecla basilides*) is widespread but is relatively unknown in other continents (Py *et al.*, 1987). Gummosis which causes serious distortions of the fruit by the penetrating larva and subsequent formation of a hard gum by the exudate can cause serious economic losses when whole fields are attacked (Py *et al.*, 1987).

By far the most important diseases of the pineapple fruit are the black rot (*Thielaviopsis paradoxa*) and the brown spots (*Penicillium funiculosum*). The black rot has been found in all the major pineapple producing countries and can be a serious problem (Cook, 1975; Korang-Amoako, 1995). It is a wet, soft rot of pineapple fruit core and pulp

tissue that assumes a characteristic bright yellow colour and from which emanates a distinctive odour of ethylacetate (Salunkhe and Desai, 1984). From the outside juice can be seen oozing through the shell which collapses under the slightest pressure (Frossard, 1978b). The brown spots or fruitlet core rot has extremely varied symptoms, which are either internal or external but normally attacks the fruitlet (Py *et al.*, 1987). They appear as varying degrees of softness that extend round the ovarian loculi (Guerout, 1974a). The economic impact of the disease can be very considerable especially in the fresh fruit cannery industry (Guerout, 1974a; Soler 1992; Mourichon, 1995).

2.4 Physiological Disorders and Fruit Quality

The Pineapple fruit is subject to a wide variety of physiological disorders. In the following, three important fruit disorders would be reviewed.

2.4.1 Sunburn And Green-Ripe Phenomenon

If pineapple fruits in the field are excessively heated by the sun on one side, they may suffer from "Sunburn" (Broadley *et al.*, 1993). The excessive heating of the fruit is due to its dark green colour (Py *et al.*, 1987). In serious cases of Sunburn, Broadley *et al.* (1993) have reported browning of the epidermis severely mishapened fruits and changes in the flesh, which becomes translucent, fragile (Py *et al.*, 1987) and has reduced titratable acidity (Teisson, 1979). In extreme cases, internal cracking which becomes apparent during processing (Green, 1963), death of shell and flesh which predisposes the fruit to disease

pathogen (Broadley *et al.*, 1993) have been the result of sunburn.

The phenomenon of green-ripe like sunburn is promoted by irradiation and high temperature (Py *et al.*, 1987; Broadley *et al.*, 1993; Bartholomew and Malezieux 1994). According to Bartholomew and Malezieux (1994) green-ripe fruits results in environments, where temperature causes a disjunction between the development of shell colour and internal maturity. Green ripe fruits appear to be influenced by several factors but it occurs most frequently in hot periods and is commonly associated with the beginning of the rainy season (Green, 1963). Green-ripe fruits make it difficult to estimate maturity (Bartholomew and Malezieux, 1994) and is less acceptable in the fresh fruit market because it does not develop an appealing colour. Py *et al.*, (1987) have observed that green-ripe fruits lack acids but are rich in sugars and have significant levels of alcohol which can be due to the development of yeasts. The extreme fragility of the fruit makes them unsuitable for canning and export to the fresh fruit market. Lacoeuilhe (1978a) has reported that the phenomenon appears to be encouraged by a low K/N ratio in the plant and the higher the nitrogen the greater the effect. Although in itself the factor cannot induce the anomaly, but only render the fruit sensitive to it (Pinon, 1980).

2.4.2 Internal Browning

Internal browning is one of the major problems of pineapple storage. Internal browning (also known as blackheart or endogenous brown spot) is a physiological disorder induced by low temperatures and gibberillic acid (Zhou *et al.*, 1995) but the higher the temperature the faster the symptoms develop (Teisson *et al.*, 1979a). Internal browning is thus favoured by temperature extremes.



The visual symptoms of the disorder has been describe by (Smith and Glennie, 1987; Py *et al.*, 1987). It begins with a small brown translucent sport forming at fruitlet bases close to the core. Darkening within the fruit core is variable. However, as the disorder progresses the spots tend to enlarge and darken to the point where in severe cases the whole flesh becomes black. No symptoms are evident externally and affected fruits therefore cannot be culled (Smith, 1983).

In the following, the role of low temperature, ascorbic acid content and fruit enzyme systems in the development of Internal Browning are discussed.

2.4.2.1 Low Temperature (Post Harvest Refrigeration)

The role of low temperature in promoting the physiological malady, Internal Browning, has been very well documented (Teisson, 1977; Teisson, 1979; Smith, 1983; Bartholomew and Paul, 1984; Py *et al.*, 1987; Tang *et al.*, 1995, Zhou *et al.*, 1995). Zhou *et al.*, (1995) have reported that low temperature increased the polyphenol oxidase activity and the content of its substrates such as catechol, chlorogenic acid and caffeic acid to accelerate the development of internal browning. Tang *et al.*,(1995) studied the post-storage behaviour of pineapple for up to two weeks after storage at 5, 7 and 12°C and concluded that the symptoms were more serious in fruits stored at 12°C than 5 or 7°C. Abdullah and Rohaya (1995) have observed that fruit quality was maintained throughout storage at 10°C for up to four weeks but rapidly deteriorated after being exposed for one week at ambient temperature following refrigeration. Although storage temperature is the main factor inducing internal browning, Broadley *et al.*, (1993) have reported that fruits exposed to low temperature both before or after harvest can be prone to the disorder. It is generally reported that symptoms

show when fruits which mature or are stored at 12°C or less are returned to physiological temperatures 18 - 30°C (Teisson, 1977; Paul and Rohrbach, 1985; Galan Sauco *et al.*, 1988). Smith (1983) reveals that 21°C causes chilling in pineapple and leads to internal browning. This is the highest temperature reported yet and is an interesting observation in that such a temperature is much higher than any known to cause chilling or internal browning.

2.4.2.2 Significance of Ascorbic Acid

Due to its economic significance, internal browning has been of much interest to Van Lelyveld and De Bruyn (1976; 1977) and Swarts (1991) in South Africa and Teisson (1977) in La Cote d'Ivoire.

These authors after Miller and Heilman (1952) link the degree of internal browning to a lack of ascorbic acid concentration sufficient to counteract phenolic oxidation. The concentration of ascorbic acid plays an extremely important role and if concentrations are sufficiently high the development of symptoms is usually inhibited long enough for the fruit to be marketed under normal conditions (Py *et al.*, 1987).

Pimpimol and Siriphanich (1993) working with two cultivars of pineapple (*Smooth Cayenne* and *Queen*) at two temperatures (8 or 12°C) found that fruit ascorbic acid content was apparently related to the development of internal browning. In both cultivars fruits containing high ascorbic acid content (> 8 mg/100ml juice) only developed slight browning, whereas those with a low content (4 - 6mg/100ml juice) showed severe browning.

Although the ascorbic acid content of pineapple has been associated with pineapple susceptibility to internal browning, Abdullah and Rohaya (1995) have reported that N36 cultivar upon subjection to low temperature storage did not show any significant differences

in the levels of ascorbic acid as compared to other cultivars stored under ambient conditions. The ascorbic acid concentration in pineapple has been linked to that of free acidity in the flesh (Py *et al.*, 1987). In that circumstance all factors that tend to increase fruit acidity, particularly an increase in potassium nutrition (Lacoeuille, 1978a; Teisson *et al.*, 1979b), can reduce the incidence of internal browning.

2.4.2.3 The Role of Enzymes in Internal Browning

Enzymatic browning is a phenomenon which occurs in many fruits and vegetables. When fruit tissue is bruised, cut, peeled, diseased or exposed to any abnormal conditions it rapidly darkens on exposure to air as a result of the conversion of phenolic compounds to brown pigments (Vamos - Vignyazo, 1981; McEvily *et al.*, 1992). Browning of fruits is generally due to the action of polyphenoloxidase on monophenolic compounds in the presence of oxygen to hydroxylated o-diphenols, which is oxidised to o-quinones (Mayer and Harel, 1979; Vamos-Vignyazo, 1981). The quinones that are produced are known to condense and react nonenzymatically with other phenolic compounds, amino acid etc. to produce a complex of brown polymers with indeterminate structures (McEvily *et al.*, 1992; Sapers and Miller, 1992).

In the case of internal browning in pineapple, the oxidation reaction taking place is not due to true polyphenol oxidase, but due to peroxidases acting as oxidases (Teisson, 1977) which appear after the fruit has been subjected to low temperature storage (Teisson, 1977; Smith, 1983; Tang *et al.*, 1995; Zhou *et al.*, 1995). Refrigeration induces modifications in phenolic

compounds (Dieudonne, 1977) in particular a compound that is closely related to chlorogenic acid that is involved in the browning process of many fruits (Py *et al.*, 1987). Gortner and Singleton (1965) reported the presence of peroxidase activity in ripe pineapple fruit. The relatively very slow process of internal browning according to Ricard and Nari, (1966) and Py *et al.* (1987) is due to peroxidase acting as oxidase. Ricard and Nari (1966) have linked this to the problems of auxin regulation in the apex related to flowering which in the process of breaking down Indo-Acetic Acid (IAA) undergoes the same type of reaction.

2.4.2.3.1 Peroxidase Activity

Peroxidase appears to be ubiquitous to the living state having been identified in animal, plant, microbial and viral systems (Scott, 1975). Peroxidase is a common constituent of higher plants and may occur at concentrations up to several per cent of fresh weight basis (Gasper *et al.* 1981).

Peroxidase can contribute to deteriorative changes in texture, colour, flavour and nutrition both in raw foods such as fruits and vegetables and in processed products (Scott, 1975). The general reaction mechanism of Peroxidase has been outlined by (Amada *et al.*, 1995)

The reaction consist of the following steps.

1. Peroxidase (Fe III) + H₂O₂ ----> Compound I (Fe(IV)) + H₂O
2. Compound I + AH₂ ----> Compound II (Fe IV) + AH°
3. Compound II + AH₂ ----> Peroxidase (Fe III) + AH°
4. 2 AH° ----> A₂H₂ or A + AH

Peroxidase catalyses the decomposition of H_2O_2 with the liberation of free radicals instead of oxygen (Burris, 1960). The free radicals released are highly phytotoxic (Wang, 1995). Purvis and Shewfelt (1993) have reported that free radical processes are involved in several membrane associated disorders including chilling injury. Gasper *et al.* (1981) have observed that peroxidases are ubiquitous enzymes that have diverse biochemical functions in higher plants and are involved in the response of plants to stress. Chilling stress has been shown to enhance peroxidase activity in mango fruit (Zamberman *et al.*, 1988) avocado fruit (Van-lelyveld and Bower, 1984) and storage at 5°C in Zucchini squash (Wang, 1995).

2.4.2.4 Assessment of Internal Browning

No objective method of assessing the internal browning of pineapple was found in the literature. Browning in citrus and most fruit juices have commonly been characterised by measuring the colour development as a function of time and expressed in terms of the kinetics of the reactions (Johnson *et al.*, 1995). Many researchers have hypothesized the appearance of brown pigments as either zero-order or first-order kinetics (Warmbier *et al.*, 1976; Saguy *et al.*, 1978b; Stamp and Labuza, 1983; Toribio and Lozano, 1986; Barbanti *et al.*, 1990; Cohen *et al.*, 1994). Rouseff *et al.* (1989) have suggested that since a variety of browning pigments with varying stabilities are formed, monitoring the colour change might be misleading. However measuring the intensity of browning spectrophotometrically is a useful measure of the extent or intensity of browning (Johnson *et al.*, 1995)

2.5 Quality Management Approach (QMA)

The pineapple fruit like all living organisms are made up of tissues and cells in which occur the physiochemical and pathological processes associated with life. These cells are subject to complex metabolic reactions that convert available sugars in the presence of oxygen to carbon dioxide, water and energy. Much as this is a natural phenomenon it remains largely undesirable because it promotes the process of continuous deterioration which detracts from market and consumer expectation. Several quality management systems have been initiated to ameliorate or contain the process of deterioration in post harvest pineapple.

In the following, some available QMA are briefly discussed.

2.5.1 Crop Husbandry Practices

This consists of a collection of operations on the production line that ensures that top quality fruits are harvested for the market. Py *et al.*, (1987) and Salunkhe and Desai (1984) have emphasised the importance of the choice of planting material, site selection and the cultivation systems as major factors in the determination of the final quality of the pineapple fruit. Py *et al.* (1987) have shown that planting materials that are wholesome devoid of pest and diseases and have a known pedigree are more likely to produce the best quality fruit. They also contend that the choice of site depends on certain factors linked to the physical environment such as water supply, drainage, nutrient status of soil and climatic considerations.

The cultivation system used are varied but according to Salunkhe and Desai (1984) it is most often determined by the market whose two main criteria are quantity and quality. The

effective manipulation of agronomic and climatic conditions coupled with economic and social dictates are central in all cultivation systems (Bartholomew and Malezieux, 1994).

2.5.2 Refrigerated Storage

One of the oldest and most popular method for prolonging the shelf life of perishable produce is cold storage. The object of refrigerated storage is to restrict deterioration without causing abnormal ripening or other undesirable changes, thus maintaining the produce in a condition acceptable to the consumer for as long as possible.

Refrigeration has played an important role in aiding the shipment and maintenance of the quality of fruits for an extended period. The methods of cooling fruits and vegetables has been described by Wills *et al.*, (1989). Produce may be cooled by means of cold air (room or forced air cooling), cold water (hydro-cooling), direct contact with ice, and evaporation of water from the produce (evaporative cooling, vacuum cooling).

The temperature of fruit and vegetables at harvest is close to that of ambient air and could be as high as 40°C. At this temperature respiration rate is extremely high and storage life brief (Wills *et al.*, 1989). Pineapple flesh temperature have been reported to reach as high as 54.5°C under ambient temperature of 24.5°C (Nightingale, 1942; Soler, 1992). At such high temperature some compositional changes in the fruit occur (Bartholomew and Malezieux, 1994). Fruit quality is considered as optimum when mean flesh temperature is around 25°C (Py and Tisseau, 1965). When pineapple fruits are to be held over a long distance or for a period of several days, refrigeration becomes important in slowing down the process of ripening and senescence (Py *et al.*, 1987). Swarts (1991) working with queen pineapples, three-quarters ripe and with 10% sugar studied the effect of precooling

temperatures (2 - 20°C) and recommended 24 hour precooling at 12-14°C as important in reducing field and respiratory heat and also in maintaining fruit quality. Precooling according to (Pantastico, 1975) improves shelf life and enhances flavour.

Salunkhe and Desai (1984) have reported that storing pineapple (smooth cayenne) at half-ripe stage at temperatures between 7.5 to 12.5°C gives it a shelf life of about 2 weeks. Py *et al.* (1957) studied the effect of low temperature storage on fruit quality and recommend a storage temperature of 8.5°C for South African pineapples. According to Bartholomew and Paull (1986) for every 6°C decrease in storage temperature about one additional week of storage life is gained for fruits showing 25% shell yellowing. Paull (1971) concluded after studying fruits showing 25% shell yellowing and stored at 7°C that the maximum storage life of fruit was 4 weeks. Tisseau-Renee (1982) has observed that storage at a temperature of less than 7°C may lead to serious deterioration of the tissue. He reported that when temperature return to around 20°C (approximate temperature in retail shops) there was a marked drop in acidity over a few days with subsequent break down of the tissue starting in the epidermal and sub-epidermal tissue.

Akamine and Goo (1971) and Pimpimol and Siriphanich (1993) have reviewed the literature on the effect of temperature on pineapple post-harvest and have reported that most authors agree that storage at 8°C is the optimum temperature for fruits harvested at a relatively advance stage of ripening. At this storage temperature, humidity should be nearly at saturation level and the air should be renewed where possible (Akamine and Goo, 1971). Low storage temperature though beneficial has a major problem in the acidification of pineapples (Py *et al.*, 1987). According to them the lower the temperature and the longer the storage period, the greater the increase. Indeed Tisseau-Renee *et al.* (1981) have shown that

in the smooth cayenne cultivar there is a 35% increase in acidity in fruits stored at a temperature of 8°C for a period of 10 days.

Prolong refrigeration is known to cause modification in fruit flavour due to modifications in aromatic substances (Swarts, 1991).

Bartholomew and Malezieux (1994) have reported that storage conditions during the ten day transport period between West Africa and Europe in reefer containers or vessels at $8 \pm 0.2^\circ\text{C}$ and at a humidity of 90% can induce chilling injury. In La Cote d'Ivoire where night temperatures are high all year round, Lacoeuilhe (1978) and Teisson *et al.*, (1979) report that chilling injury leading to internal browning is only experienced when fruits are exposed to physiological temperatures after refrigerated transport or storage at 8°C.

It can be deduced from the foregone that refrigerated storage though desirable, on it's own, can cause serious quality management problems if careful considerations are not taken during storage.

2.5.3 The Use of Surface Coatings : Glazing

Several types of surface coatings have been applied successfully for preservation of fresh products. Mixtures of sucrose, fatty acids and esters have been used for coating fresh fruits and vegetables to extend shelf life and minimise quality changes (Banks 1984; Chu, 1986; Santerre *et al.*, 1989). "Corn-zein" coating has been used on nuts to extend their marketing period (Cosler, 1958). Fruit coating with waxes, "Pro-long", and n.o-carboxymethylchitosan have been reported beneficial (Banks, 1984; Smith and Stow, 1984; Banks 1985; Meherink and Lau, 1988; El Ghaouth *et al.*, 1992).

The application of coatings can be a useful post harvest tool but would not improve

poor quality products. Wills *et al.*, (1989) have outlined the objective for using post-harvest waxes and coating material:

- to reduce moisture loss and subsequent loss of appearance and marketability due to shrivelling and wilting;
- increase the shelf life by modifying respiration (slowing down the intake of oxygen and the escape of carbon dioxide);
- reduce disease development by covering injury sites on the product, so providing a barrier to infection;
- act as a carrier for fungicides or insecticides that need to be applied; and
- to give aesthetic appeal to the product by adding surface lustre.

Coatings are applied by brushing, dipping, spraying, fogging or foaming onto produce or produce is conveyed through a tank contain the coating material (Jarimopas and Niamhom, 1990).

The post-harvest storage life of pineapples could be extended up to 2 or 3 weeks at 11.1°C and 1 week at room temperature when fruits are dipped in surface coating material, drained and packed into well ventilated cartons (Ewing *et al.*, 1980). The treatment also reduced browning. Pimpimol and Siriphanich (1993) reported that wax coatings were effective in reducing internal browning in *Smooth cayenne* and *Queen* varieties of pineapple stored at 8 or 12°C for up to 30 days. Yusof and Salleh (1992) have shown that “semperfresh” coating and polyethylene wax emulsion significantly delayed moisture loss and colour change in papaya although the sugar content and titratable acidity increased with storage at 10°C. 'd' Anjou' and 'Bartlett' pears coated with “pro-long” (a sucrose-fatty acid ester), and "Nutri-Save" were firmer, had higher acid levels and greener skin colour than

comparable control fruits at different storage durations in 0°C air (Meheriuk and Lau, 1988).

Paull and Rohrbach (1985) studying symptom development of chilling injury in pineapple reported that waxing fruit before or immediately after exposure to chilling temperatures reduced chilling injury symptoms. Wilson-Wijeratnam *et al.*, (1995) considered waxed and non-waxed fruits held at 10°C for minimum of 14 days under specific controlled atmosphere (CA) conditions. They reported that symptoms associated with internal browning were reduced by CA storage particularly when combined with wax treatment.

Non-coated and coated tomatoes have been compared by Park *et al.*, (1994) and they have shown that coated fruits had better firmness retention, delayed colour change and weight loss, while shelf-life was extended by 6 days.

El Ghaouth (1992) reports that chitosan coating decreased the O₂ and raised the CO₂ levels within tomato fruits stored at 20°C, with greater effect at higher coating concentrations. Reduction of the respiration rate and ethylene production as a result of coating with edible films have also been reported for banana (Banks, 1984), apples and pear (Meheriuk and Lau, 1988), and tomato fruit (Nisperos and Baldwin, 1988).

The effectiveness of fruit coatings depends primarily on selection of appropriate coatings which can result in beneficial internal gas composition (Kader *et al.*, 1989; Park *et al.*, 1993). Coating on fruits that exceed a critical thickness can cause detrimental effects by reducing internal O₂ and increasing CO₂ concentrations leading to anaerobiosis (Park *et al.*, 1994). Anaerobiosis has been reported in apples and bananas (Banks, 1984; Smock, 1940). Tomatoes coated with a thick corn-zein film resulted in rapid weight loss (Park *et al.*, 1993). An increased incidence of decay has also been reported in cucumbers (Risse *et al.*, 1987).

It is evident from the foregone that a desirable fruit coating should be able to preserve



the quality of the fruit and extend the shelf life without creating problems of anaerobiosis or fruit decay.

2.5.4 **The Use of Irradiation**

Studies conducted by the University of Hawaii on the effect of gamma radiation on the shelf life of fresh pineapple have shown that irradiation with 50 krad dose extends the shelf life of pineapple, as judged by the delay in degreening of the fruit (Upadhyia and Brewbaker, 1966) without impairing the physical, chemical and organoleptic characteristics of the fruit (Upadhyia *et al.*, 1967; Wenkan and May ., 1968).

An irradiation dose of 30 to 500 krad was found to induce the formation of cytotoxic substances in pineapple (Upadhyia *et al.*, 1967). These substances, however, disappeared in fruit irradiated at 30 to 50 krad after 8 days of storage at 17.8°C but they persisted in fruit irradiated at 100 or 500 krad. Upadhyia *et al.* (1967) reported that like untreated fruits, storage conditions of 7.2 to 12.8°C and about 90% relative humidity are optimum for irradiated pineapples to extend their storage life. Pablo *et al.* (1975) concluded that a low-dose irradiation may be a feasible method of extending shelf life of fresh pineapples, which can tolerate a dose of about 50 krad (Brewbaker *et al.*, 1965).

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1. Procurement And Preparation Of Pineapple Fruit

Fruits with known crop history were freshly harvested early in the morning (6 - 8 am) as intended for export from a major pineapple exporter (Jei river farms located about 11km from Kasoa in the central region). They were sorted and graded into size, weight, shell colour and crown conditions.

3.1.2 Preparation Of Test Materials

3.1.2.1 Preparation Of Polymeric Coating

The coating material (stafresh 7055, a wettable emulsion) was purchased from a local representative of ICI (Chemico Ltd.). 0, 5, 7.5 and 10% concentrations (v/v) were prepared where appropriate according to the procedure outlined by the manufacturer using freshly boiled but recently cooled water. The mixture was manually stirred for about 15 minutes to ensure uniform dispersion of coating material in solution

3.1.2.2 Preparation Of Antifungal Medium

The fungicide used (Thiabendazole, a wettable emulsion) was also obtained from Chemico Ltd. Two levels 0 and 0.1% (100ppm) were prepared according to the procedure outlined by the manufacturer.

3.1.2.3 Preparation Of Cocktail Of Polymeric Coating And Fungicidal Medium

The procedure as outlined in 3.1.2.1 and 3.1.2.2 was followed except that the treatment medium contained both the polymeric coating and fungicide

3.2 Methods

3.2.1 Prestorage Operations

3.2.1.1 Field Operations

Freshly harvested fruits were sorted, graded and manually dipped and swirled in a plastic container containing the test medium (3.1.2) for about 45 seconds. Fruits were placed in ventilated plastic containers and allowed to air dry for about 15 - 30 minutes before precooling.

3.2.1.2 Precooling

Treated fruits were precooled on-farm in an air-conditioned room (Temperature 21 ± 2.0 RH = 82 ± 2.6) for up to 6 hours to reduce field and respiratory heat before fruits were weighed and placed in experimental treatment.

3.2.2 Storage Operations

3.2.2.1 Refrigerated Storage

Weighed fruits were placed in cardboard boxes (6 fruits/box as used for export) and subjected to cold storage (8°C) at the Airways Catering Limited, Kotoka International Airport (KIA), Accra. The temperature and relative humidity were monitored daily.

3.2.2.2 Non Refrigerated Storage

As for 3.2.2.1 weighed fruits were placed under ambient temperature ($28.9 \pm 1.2^{\circ}\text{C}$) in a customs bonded warehouse in KIA and the RH and Temperature were monitored daily.

3.3 EXPERIMENTAL PROCEDURE

3.3.1 To Evaluate The Effect Of Fruit Coatings On Selected Physical And Chemical Quality Of Post Harvest Pineapple

3.3.1.1 The Effect Of A Polymeric Coating On Post Harvest Quality Of Pineapple

The study was conducted using a 4 x 2 x 4 factorial design. The factors investigated were as follows:

- i. polymeric coating (0, 5, 7.5, 10%)
- ii. storage condition (8°C and ambient (28.9°C))
- iii. storage intervals (0, 4, 7 and 10 days)

Each experimental unit contained a minimum of six fruits with two replications. 100 fruits in all were used with mean fruit weight before storage of 1670 ± 80 g. Dependent variables measured were as follows. Internal Fruit Temperature, Translucency, Texture, Vitamin C, % Sugar, Titratable Acidity, pH, and Astringency. The Shell Colour and Crown Condition were also measured but on daily basis. The Temperature and Relative Humidity of the storage environment were also monitored daily throughout the storage period.

3.3.1.2 The Effect Of Polymeric Coating And Anti Fungal Treatment On Pineapple Quality

The study was conducted using a 2 x 2 x 2 x 4 factorial experiment with two replications. The factors investigated were as follows :-

- i. polymeric coating (0, 5%)
- ii. Antifungal coating (0, 0.1%)
- iii. storage temperature (8°C, ambient)
- iv. storage interval (0, 4, 7, 10 days)

Each experimental unit contained a minimum of twelve (12) fruit with mean fruit weight (before storage) of 1620 ± 30 g. A total of 104 fruit were used for the experiment.

Dependent variable measured were as follows.

Internal Fruit Temperature, Translucency, Vitamin C, Sugar Content , Titratable Acidity, pH and Astringency. The Shell Colour Break, Crown Withering Index, Room Temperature and Relative Humidity were evaluated daily throughout the period of storage.

3.3.2 To Determine The Shelf-life And Shrinkage Characteristics Of Pineapple

3.3.2.1 The Effect Of Gestation And Storage On Day-Night Shrinkage Of Pineapple

The study was conducted using a 2 x 2 x 10 factorial layout. The factors investigated were as follows.

- i. Gestation Period (140 and 160 days after floral induction)
- ii. Investigation Time ((Day (6am - 6pm); Night (6pm - 6am))
- iii. Storage Interval (Daily for 10 days)

Each experimental unit contained six fruit with mean fruit weight of $1667 \pm 35\text{g}$. A total of 12 fruit were used in the experiment.

Dependent variables measured were as follows Shrinkage Evolution, Shell Colour Break and Crown Withering Index.

All measurements including the Temperature and Relative Humidity were monitored twice daily (6am and 6pm).

3.3.3 To Study The Effect Of Fruit Coating On The Post Harvest Physiology Of Pineapple: Fruit Respiration

The study was conducted using the following procedure. Freshly harvested fruits with a gestation period of 145 days after floral induction were treated with 0 and 5% polymeric coating. Fruits were allowed to dry for about 30 mins and then subjected to cold storage (8°C) for a minimum of 10 days.

3.3.3.1 Evaluation Of Head Space

After ten days of cold storage one set of fruit each of 0 and 5% coating were placed individually in a transparent plastic container of 5 litre capacity. The lid-container interface was hermetically sealed with paraffin wax. The mid section of the lid was removed and

replaced with polythene sheet(0.33mm gauge) for ease of penetration by a syringe.

After 14 days of cold storage, 1 ml head space of gas in the 0% coated fruit was drawn using a gas tight syringe and quickly injected into a gas chromatograph (Mikrolab Aarhus ML GC 82-12 VLD) for analysis. This was repeated after 6hr.

The second set of fruit (also with 0 and 5% coating) were not placed in containers after 10 days but were redrawn into physiological temperature (25°C) and allowed to acclimatise for three days in cardboard crates after which fruits were subsequently placed in sealed containers.

Head space analyses were then evaluated 1 hour, 3 hours, 24 hours and 30 hours after placing fruit in containers. Gas sample analysed were CO₂, O₂ and N₂.

3.3.4 To Evaluate The Post Storage Behaviour Of Pineapple After Low Temperature Storage (LTS)

3.3.4.1 The Effect Of Non-Isothermal Storage On The Physicochemical Quality Of Pineapple: Whole Fruit

The study was conducted using a 2 x 2 x 4 factorial arrangement with two replicates.

The factors investigated were

- i. Polymeric Coating (0, 5%)
- ii. Antifungal Coating (0, 0.1%)
- iii. Temperature Equilibration Interval (0, 1, 3, 5 Days)

Each experimental unit contained a minimum of 12 fruits with mean fruit weight (before storage of $1610 \pm 15\text{g}$). A total of 100 fruits were used for the experiment.

Dependent variables measured were as follows. Internal Fruit Temperatures, pH, Titratable Acidity, Vitamin C and Sugar Content.

3.3.4.2 The Effect Of Non-Isothermal Storage On The Physicochemical Quality Of Pineapple: Apical, Mid And Basal Section Of Fruit

The study was conducted using a $2 \times 3 \times 6$ factorial arrangement. The factors were

- i. Polymeric Coating (0, 5%)
- ii. Fruit Section (Apical, Mid, Base)
- iii. Temperature Equilibration Interval (0, 1, 2, 3, 4, 5 Days)

Each experimental unit contained twenty fruits. A total of 40 fruits were used with mean fruit weight of $1650 \pm 12\text{g}$.

3.3.5 Studies On The Peroxidase Activity In Post Harvest Pineapple

3.3.5.1 Optimisation Of The Method For Determining Peroxidase Activity In Pineapple Using The Central Composite Rotatable Design

A three factor combination at $K = 3$ was used. Where $K = \text{factor}$

FACTOR	LEVELS				
pH	3	3.6	4.2	5.4	6
O-dianisidine (%)	0	.125	.25	.4	.5
H ₂ O ₂ (%)	0	.05	.125	.25	.25

Tab. 3.1 **Factor Combinations From The Design Matrix**

O-dianisidine Concentration (%)	pH	H ₂ O ₂ Concentration (%)
0.10	3.6	0.05
0.10	5.4	0.2
0.40	3.6	0.2
0.40	5.4	0.05
0.25	4.5	0.125
0.25	4.5	0.125
0.10	3.6	0.2
0.10	5.4	0.05
0.4	3.6	0.05
0.4	5.4	0.2
0.25	4.5	0.125
0.25	4.5	0.125
0.5	4.5	0.125
0.0	4.5	0.125
0.25	6	0.125
0.25	3	0.125
0.25	4.5	0.25
0.25	4.5	0.0
0.25	4.5	0.125
0.25	4.5	0.125



3.3.5.1.1 Preparation Of Enzyme Extracts

Peroxidase was extracted from pineapple according to the procedure described by Kermasha and Metche (1988) with the following modification.

Freshly harvested pineapple with a gestation period of 145 days after floral induction were sectioned into the basal, mid and apical sections and peeled with a sterilised and clean knife. Sections were chopped into small sizes of approximately 5g each. An ice cold solution (about 2°C) of 12.5% Sucrose was added to each section (1:5 W/W) and blended at high speed for approximately 45 seconds in a warring blender to form paste. The resulting homogenate was filtered through a cheese cloth and centrifuged for 15 min at 6500 x g to separate sinking pulp and bits of fruit eyes. The pellet was discarded and the clear supernatant was assayed for peroxidase activity.

3.3.5.1.2 Assay of Peroxidase Activity

Peroxidase activity was assayed by measuring the increase in absorbance at 460 nm (23.0°C) with a spectrophotometer (Shimadzu UV 002). The reaction medium consisted of 0.1ml enzyme extract, hydrogen peroxide (0.1 ml, 0 - 0.25%) and the volume was completed to 3.0 ml with sodium acetate buffer (0.05M, pH 3.2 - 6.07). The reaction was initiated by adding a substrate solution containing o-dianisidine (3,3'-dimethoxy benzidine; 0 - 0.5%) for 2 minutes and the reaction stopped with equal volume of 2N H₂SO₄.

3.3.5.2 The Effect Of Polymeric Coating , Thermal Treatment And Reaction Time On The Peroxidase Activity Of Pineapple

The procedure as outlined in 3.3.5.1.1 and 3.3.5.1.2 were followed, except that fruits were treated with 0 and 5% polymeric coating and held at 8°C for 10 days and exposed to ambient temperature (28.9 ± 1.2 °C) for 2 days before extraction procedure was followed. Assay of peroxidase activity was carried on juice previously conditioned at three temperatures viz.: 22, 30 and 45°C for 2hr. The reaction medium consisted of 0.1ml enzyme extract, 0.1ml H₂O₂ (0.2%); 2.8ml acetate buffer (pH 6.07) and 0.1ml 0-dianisidine (.5%). Activity was evaluated after 2, 4 and 6 minutes.

3.4 DATA COLLECTION AND ANALYSES

3.4.1 Data Collection

3.4.1.1 Chemical Analyses

Chemical analyses was done on the juice extract. Fruits were manually chopped into small sizes (2-5g) and blended (blender) at high speed for about 45 seconds with a warring blender and filtered through a cheese cloth into a 600ml clean beaker. Portions were drawn and used for the various analysis.

3.4.1.1.1 pH and Titratable Acidity (TA)

The pH of the juice extracted was measured with a pH meter (TOA Electronics, Japan). For TA 10ml aliquots of juice were pipetted into a conical flask containing 100ml of distilled

water (previously boiled but cooled). The aliquots were titrated against 0.1 N NaOH to a phenolphthalein (1%) end point. The acidity was calculated as g citric acid/100g fruit.

3.4.1.1.2 Vitamin C (Ascorbic Acid)

The procedure outlined by AOAC method 43.051-55 was followed.

3.4.1.1.3 Sugar Content

This was performed on the juice extract using a Delta refractometer (Range 0 - 50% Sugar W/W) (Bellingham + Stanley Ltd. England) and data was expressed as percentage of Sugar content.

3.4.1.1.4 Astringency Index (AI)

Astringency was quantified as the ratio of the titratable acidity and the sugar content of pineapple.

$$AI = \left[\frac{\text{Titratable Acidity (g citric acid /100g fruit)}}{\text{Sugar Content (\%)}} \right]$$

3.4.1.2 Physical Determinations

3.4.1.2.1 Texture (Pulp Firmness)

This was determined using a penetrometer (gullimex model FT 327) with a 0.8mm plunger tip. Three determinations at the mid section of fruit were taken equidistantly with 2 replications.

3.4.1.2.1.1 Sample Preparation

About ½" - ¾" diameter disc of peel using a fruit peeler (gullimex fruit peeler) was made at three equidistant points on the mid section of the fruit.

3.4.1.2.1.2 Texture Determination

Fruits were held firmly in one hand and the penetrometer held between the thumb and forefinger against the fruit and pressed with increasing pressure slowly till the plunger tip penetrated into the pulp to a depth of about 0.8mm. The reading on the dial in Kilogramme (Kg) was measured as firmness of the fruit.

3.4.1.2.2 Storage Temperature, Internal Fruit Temperature And Relative Humidity

This was measured using an Instant Action Hygrometer (IAH). Storage temperature and relative humidity (RH) was measured using IAH6200 PT100 9762, with temperature sensitivity range of -9.9 - 199.9°C and RH range of 2 - 98%.

Internal fruit temperature was measured using IAH 6200 PT100 0273 with a plunger tip of .3mm diameter and 15cm long. The plunger was penetrated fully into the fruit from the base close to the core region and allowed to acclimatise for about 10 - 15 seconds before reading was taken. Readings were done in triplicates.

3.4.1.2.3 Mass Shrinkage

Mass Shrinkage loss (S_L) was defined as weight loss suffered by pineapple due to natural water loss.

Unit of measure: Ratio of decrease in weight (W) to initial weight (weights were measured using sartorius scale model 9100)

$$\%S_L = \left[(W_I - W_F) / W_I \times 100 \right]$$

W_I = Initial weight reading

W_F = Final weight reading

3.4.1.3 Physiological Determination

3.4.1.3.1 Shell Colour Evolution

The shell colour of fruits were compared with the standard chart for West Africa (SCWA) pineapples with the following grades.

1 = 1/8 Shell ripe (yellow) 2 = 1/4 ripe 3 = 1/2 ripe 4 = 3/4

5 = Whole shell ripe

6 = Over ripe (with dark brown patches)

3.4.1.3.2 Translucency Index (T1)

It was determine as follows. A transverse section of the fruit was made at the mid section. The total length of translucent portions of the fruit was measured with a ruler and expressed as a percentage of the diameter. Triplicate readings were made and the mean value was used as the extent of translucency. The following scale was used.

1	=	none (no sign of translucency)
2	=	less than 10% translucency
3	=	10 - 30% "
4	=	30 - 50% "
5	=	over 50% "

3.4.1.3.3 Crown Withering Index (CWI)

CWI was evaluated by rating on a 1 - 3 scale: where

- 1 - Firm, dark green, fresh leaves
- 2 - Limp, some leaves brown (mostly basal leaves)
- 3 - Dry, flaccid and most leaves brown (more than half of crown)

3.4.1.3.4 CO_2 , O_2 and N_2

Peak heights from 1ml headspace sample injected into gas chromatograph were evaluated and compared to Air and CO_2 standards. The amount of gas evolved or present was expressed as ml gas / kg fruit / hr.

3.4.1.4 Biochemical Determination

3.4.1.4.1 Endogenous Browning

The extent of internal browning of the fruit was determined following the procedure of Meydev *et al.* (1977) with the following modification. The pineapple fruit was peeled, chopped into small bits and blended at high speed with a warring blender. The slurry was filtered using a cheese cloth and then centrifuged for 10 minutes at 3500 x g. The supernatant was diluted 1:1 with absolute ethanol and allowed to stand for about 1 hour. An additional centrifugation at 3500 x g for 10 minutes completed clarification. The light absorbance of the supernatant was measured at 420nm as an index of internal browning using the Shimadzu UV 002 spectrophotometer.

3.4.1.4.2 Peroxidase Activity

The procedure as outlined in 3.3.5.1.2 was used and the Peroxidase activity was defined as the increase in light absorbance (A) at 460nm (23.0°C) by 0.001/min/g fresh weight of pineapple.

3.4.2 DATA ANALYSES

3.4.2.1 Statistical Analyses

The data collected was analysed using the multi-factorial analysis of variance procedure. Significant differences between treatment means were tested using the Multiple Range Test (MRT) with the Least Significant Difference (LSD) procedure.

Simple linear correlation analysis was also employed to estimate and test the degree of association between any two dependant variables investigated.

Linear and Stepwise Multiple Regression procedure were also used to generate mathematical models for predicting the quality of pineapples. All statistical procedure were accomplished using the computer software STATGRAPHICS Ver. 4.2 (Statistical Graphics Corp., STSC Inc. USA).

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4.0 RESULTS AND DISCUSSION

The results of this study were divided into five main categories:

- a) Results of the effect of fruit coatings on selected physical and chemical quality of post-harvest pineapple.
- b) Results of the shelf-life and shrinkage characteristics of pineapple.
- c) Results of the effect of fruit coating on the physiology of pineapple: fruit respiration.
- d) Results of the post storage behaviour of pineapple after low temperature storage.
- d) Results of the study of peroxidase activity in post harvest pineapple.

The statistical analyses of the results of this study were based on the multifactorial analysis of variance procedure, application of a multiple regression procedure and the use of simple linear regression approach as described earlier in chapter three section 3.4.2.

The analyses were divided as follows:

- i) Analysis of variance (ANOVA)
- ii) multiple range test using the least significant difference (MRT(LSD))
- iii) generating models using the stepwise multiple regression procedure. The results of the ANOVA, MRT(LSD) and the models generated are presented in Tables 4.1 to 4.26 in this chapter.

4.1 On the Effect of Surface Coating on the Physicochemical Quality of Post-Harvest Pineapple

4.1.1 The effect of a polymeric coating on the post-harvest quality of pineapple.

4.1.1.1 Vitamin C (Ascorbic Acid) Content

Vitamin C is an important vitamin because, apart from the nutritional benefits (especially for the prevention of the disease scurvy) it cannot be synthesized by the human body (Wills *et al*, 1989). Pimpimol and Siriphanich (1993) have reported that the susceptibility of pineapple to chilling injury and the black heart disorder is dependent on the concentration of vitamin C in the fruit.

The ANOVA summary Table (Table 4.1) shows that the vitamin C content of the fruit was significantly influenced by the storage temperature, the polymeric coating and the storage interval. Means separation using the (MRT (LSD)) revealed that low temperature storage (8.0 °C) had a higher mean vitamin C content (10.59mg/100g fruit) than the value for ambient (28.0 °C) storage (8.42 mg/100g) (Table 4.2) and (Figure4.1A). Abdullah and Rohaya (1995) have reported that chemical quality characteristics like ascorbic acid in pineapple have a better retention under low temperature than ambient storage.

Means separation for the effect of the polymeric coating on the vitamin C content showed that coating at 7.5% gave the highest mean vitamin C content (10.05mg/100g) after ten days of storage. However this was not significantly different from coating at 5% or 10% (Table.4.2) and (Figure 4.1b). The least vitamin C content (8.75mg/100g) was observed in non-coated fruits which was also not significantly

Table 4.1 ANOVA Summary Table (showing only F-values of Quality characteristic studied)

Sources of variation	Astringency Index	Vitamin C	Sugar Content	Titrateable Acid	Pulp Firmness	pH	Pulp Temperature	Translucency
Storage Temperature (ST)	.386	52.396 *	27.736 *	4.885	1000.00 *	2.345	1000.00 *	28.172 *
Polymeric Coating (PC)	14.773 *	4.348 *	.154	7.211 *	4.952 *	1.006	2.325	2.041
Storage Interval (SI)	185.022 *	39.607 *	172.187 *	19.073 *	889.777 *	4.250 *	1000.00 *	14.254 *
ST x PC	1.693	.930	1.317	1.386	3.936 *	1.968	2.82	2.041
ST x SI	18.888 *	2.318	10.774 *	3.080	450.110 *	1.816	1000.00 *	3.462
PC x SI	3.759 *	1.640	.789	1.707	2.756	.909	1.334	1.000

* means significant at $P \leq 0.05$

Value without (*) means effect was not significant at $P \leq 0.05$

Table 4.2 Summary of means (MRT (LSD))* for factors⁺ significantly affected by treatment

Treatment	Level	Astringency Index	Vitamin C	Sugar Content	Titrateable Acidity	Pulp Firmness	pH	Pulp Temperature	Translucency
ST (°C)	8		10.590 b	11.920 b		4.467 b		18.900 a	3.250 a
	28		8.422 a	11.347 a		2.255 a		32.816 b	3.968 b
PC (%)	0	.079 c	8.753 a		.905 c	3.276 a			
	5	.077 bc	9.235 ab		.879 bc	3.308 ab			
	7.5	.067 a	10.053 b		.799 a	3.351 ab			
	10	.074 b	9.984 b		.838 ab	3.448 b			
SI (days)	0	.055 a	11.66 a	13.685 c	.749 a	4.705 a	4.00 c	40.500 d	3.000 a
	4	.075 b	10.355 b	11.538 b	.859 b	3.321 b	3.885 ab	28.475 c	3.375 a
	7	.083 c	8.632 c	10.675 a	.890 bc	2.858 c	3.858 a	19.228 b	4.000 b
	10	.087 c	7.377 d	10.636 a	.923 c	2.560 d	3.961 bc	18.931 a	4.062 b

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

LSD - Least Significant Difference

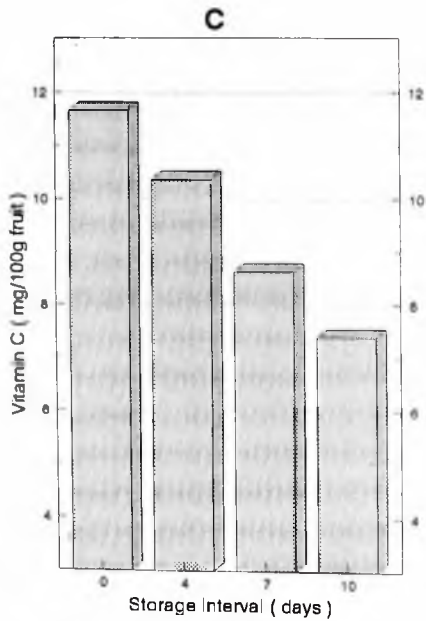
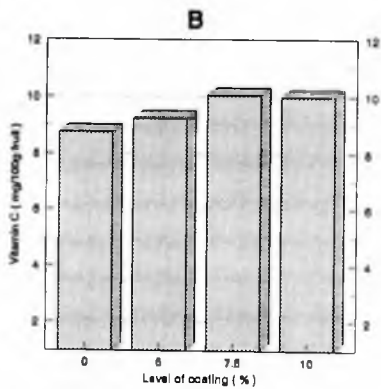
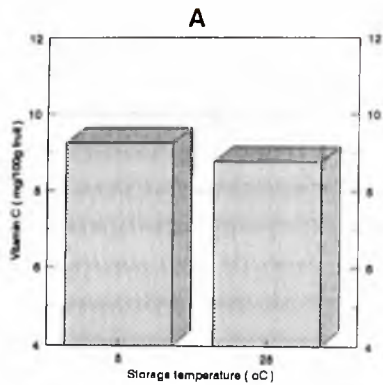
Figure 4.1 Means plot for the effect of

A) Storage temperature after 10 days storage

B) Polymeric coating (0,4,7 and 10 %) and

C) Storage interval after 0,4,7, and 10 days

on the ascorbic acid content of pineapple



different from coating at 5% (Table 4.2). The degradation of ascorbic acid is known to occur by both oxidative and non-oxidative mechanisms (Saguy *et al.* 1978a and Robertson and Samaniego 1986). Although the rate of oxidative degradation has been determined to be 10-1000 times faster than the non-oxidative degradation (Heulin, 1953 and Kefford *et al.*, 1958). Surface coating of fruits form a semi-permeable barrier which restricts the rate of oxygen intake across the pineapple shell into the interior. The reduced oxygen levels within the fruit tissue would slow metabolic processes and thus the rate of ascorbic acid degradation would be slower for coated than for non-coated fruits.

Means separation for the effect of storage interval on the vitamin C content revealed a decreasing trend from a mean value of (11.66mg/100g) on 0 day storage (harvest day) to a mean value of (7.38mg/100g) after ten days of storage (Table 4.2) and (Figure 4.2). This represents a reduction of 36.7% of fresh juice vitamin C content. Achinewhu (1995) concluded after storing pineapple at room temperature (30-32°C) for two weeks that ascorbic acid content was reduced to between 59% to 65% of the fresh juice. The difference in Achinewhu's observation could be due to the elevated temperatures under which he did his study and the longer period of storage. Results of ANOVA reported in Table 4.1 has shown that temperature and the duration of storage has a significant effect on the vitamin content.

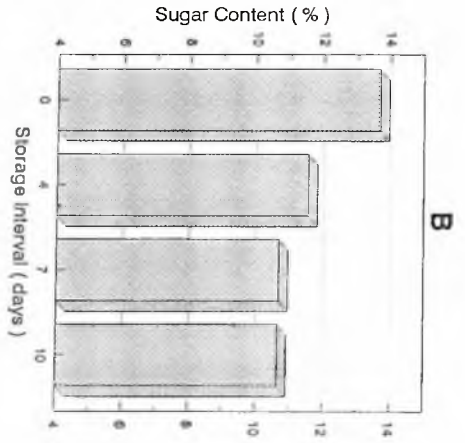
4.1.1.2 Sugar Content

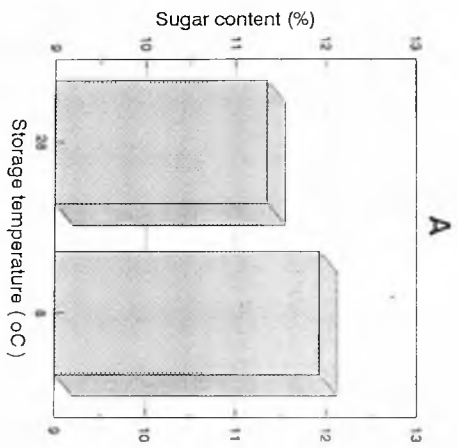
The sugar content of pineapple is an indispensable requirement for the organoleptic quality of the fruit. The results from the analysis of the study (Tab 4.1)

showed that the sugar content of the fruit was significantly influenced by the temperature of storage, the interval of storage and the interaction between storage temperature and interval. This suggests that the effect of the temperature of storage on the sugar content of the fruit did not act independently but was dependent on the duration of storage.

Means separation for the effect of storage temperature on the sugar content of the fruit showed that low temperature storage had a significantly higher mean value (11.92%) than the value (11.35%) representing ambient storage (Table 4.1) and (Figure 4.3a). Pineapple contains fermentable sugars such as glucose and sucrose that are easily metabolized. The metabolic pathway involved in respiration in plants results in sugar conversion which is temperature dependent (Dull, 1971). Probably, the lower rate of respiration as encountered in low temperature storage might have accounted for the difference in sugar content after ten days of storage.

Means separation (Table 4.2) for the effect of storage interval on the sugar content of pineapple indicates that the interval of storage has a depressing effect on the sugar content. Harvest day (0 day storage) sugar content showed a higher mean value (13.69%) than the rest of the storage intervals, (Table 4.2) and (Figure 4.3b). The lowest mean value (10.64%) was registered on the tenth day of storage. The value was not significantly different from the value observed (10.67%) in day 7 of storage. There are conflicting observation by many workers as to the behaviour of pineapple sugar under low and ambient temperature storage. Mohammed and Wickham (1995) have reported





an accelerated ripening of fruit accompanied by an increase in sugars after four days of storage under ambient temperatures, although under low temperature storage (10°C)

there was no significant change in the fruit sugars up to 12 days of storage. Abdullah and Rohaya (1995) however observed a deterioration in sugar levels after a week under ambient temperatures with no consistent pattern in the sugar levels under low temperature storage. Plant nutrition and climatic conditions just before harvest are known to have a marked influence on sugar levels of post harvest pineapple.

4.1.1.3 Titratable Acidity

The titratable acidity was influenced by the level of fruit coating and the duration of storage. The analysis of variance of the data (Table 4.1) showed that polymeric coating and the storage interval had a significant effect on the titratable acidity.

Means separation further revealed that the effect of the polymeric coating on the level of acidity was highest (.905g/100g) in non-coated fruits and lowest (.799g/100g) in 7.5% coating (Figure 4.4a). There was no significant difference between 0% and 5% coating, 5% and 10% coating and 10% and 7.5% coating (Table 4.2)

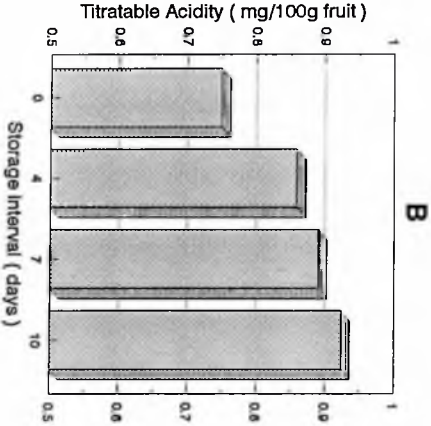
Means separation for the effect of storage interval on the titratable acidity showed an increasing tendency with increasing storage interval (Figure 4.4b). Acidity was lowest (.749g/100g) on 0 day storage and highest (.923g/100g) after ten days of storage (Table 4.2). The acidity level after 4 days of storage was not significantly different from 7 days of storage which was also not significantly different after 10 days of

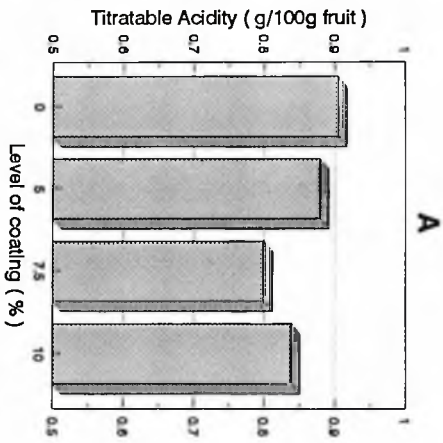
Figure 4.3 Means plot for the effect of

A) Polymeric coating after 10 days and

B) Storage interval after 0,4,7, and 10 days

on the titratable acid content of pineapple





storage (Table 4.2). Acidification of pineapple is a well known phenomenon under low temperature storage (Py *et al* 1987; Soler, 1982 and Teisson,1979). However the results of this study indicates that the phenomenal acidification occurs under both ambient and low temperature storage and is attributable more to the duration of storage rather than the temperature of storage. Although acid levels were slightly higher in low temperature storage, there was no significant difference between that and ambient storage (Table 4.2).

4.1.1.4 Astringency Index (AI)

Astringency is an important parameter in the sensorial and organoleptic properties of the pineapple fruit. The characteristic sweet pineapple flavour and aroma is dependent on the level of acids and sugars present in the fruit (Py *et al.* 1987). In this study a novel attempt was made to quantify astringency as “astringency index”. This factor was influenced by the polymeric coating, storage interval and the interactions between the storage interval and polymeric coating and also the storage interval and storage temperature. The analysis of variance (ANOVA) of the data showed that the polymeric coating and storage interval had a significant effect on the index of astringency (Table 4.1). The ANOVA also showed that the interaction between the storage interval and the storage temperature and the storage interval and the polymeric coating were also significant (Table 4.1). This suggests that the storage interval did not act independently on the astringency but was affected by the level of coating and the temperature of storage.

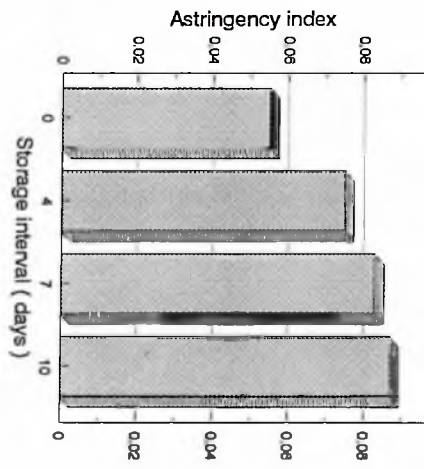
Mean separation of treatment using the multiple range test (Least Significant Difference(LSD) further revealed that coating at 7.5 % had the lest astringency (0.67)

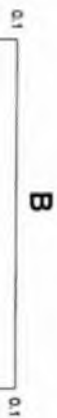
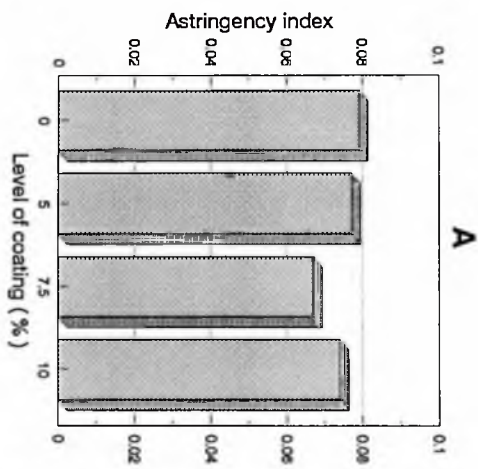
Figure 4.4 **Means plot for the effect of**

A) Polymeric coating after 10 days and

B) Storage interval after 0,4,7, and 10 days

on the astringency index of pineapple





while 0% coating had the highest index of astringency (.079) (Figure 4.10). A high astringency suggests either a high acidity or low sugar content. The effect of the polymeric coating on the sugar content of the fruit was not significant therefore the high astringency in the non-coated fruit could be attributed to the high mean acid levels (Table 4.2).

Means separation for the effect of the storage interval on astringency showed an increasing astringency with increasing storage days. Fruits on harvest day (Day 0) were least astringent (0.055) and ten days of storage gave the highest astringent fruits (0.087) (Figure 4.1b).

4.1.1.5 Pulp Firmness (Texture)

Fruit firmness or texture is an important quality factor in many fruits and vegetables. It has been employed as a useful index in determining fruit maturity, harvest dates and its eating quality (Kader 1983). The ANOVA summary table (Table 4.1) shows that the texture of the fruit was significantly influenced by the temperature of storage, the level of coating and the interval of storage.

Means separation (Table 4.2) for the effect of storage temperature on the firmness of the fruit showed that fruits were almost twice (4.47kg) as much firmer under low temperature than under ambient storage (2.25kg). Bourne (1982) concluded after studying the effect of temperature on firmness of some raw fruits and vegetables, that cold storage gave a consistently higher firmness value than fruits held under room temperature.

Figure 4.5 **The effect of**

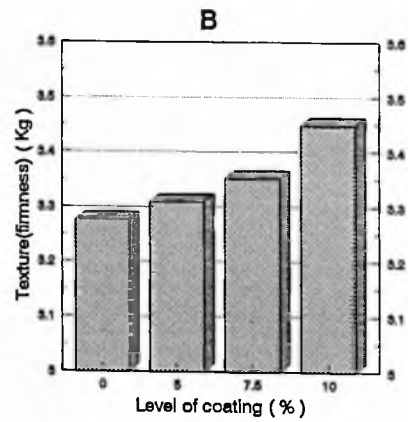
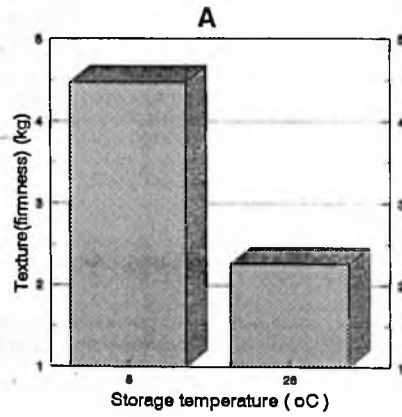
A) Storage temperature

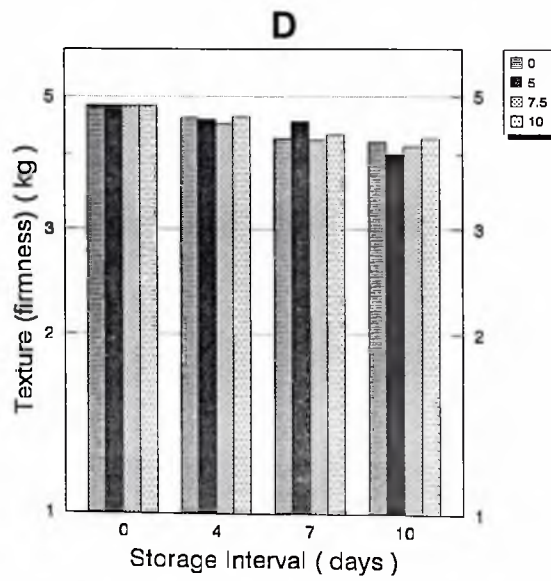
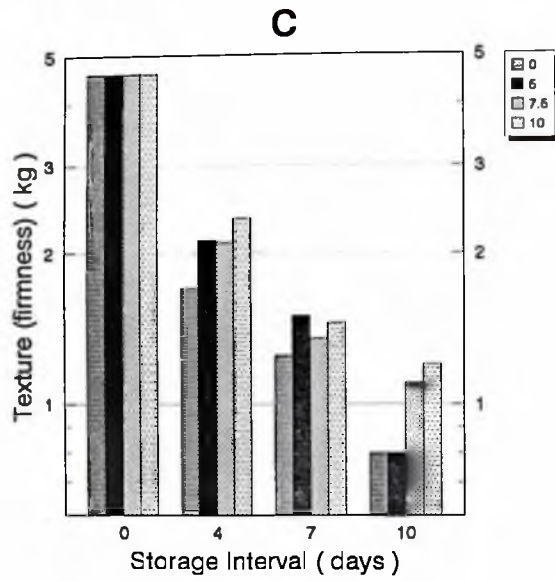
B) Polymeric coating(0,5,7.5, and 10%)

C) Storage interval under ambient temperature (28 OC) and

D) Storage interval under low temperature (8 OC)

on the texture of pineapple after 10 days of storage.





Means separation for the effect of the polymeric coating on the firmness of the fruit revealed that firmness increased as the level of coating was increased. Mean fruit firmness was highest (3.448kg) at 10% coating and least (3.27kg) at 0% coating (Table 4.2) and (Figure 4.5b). Statistically, however, there was no significant difference between 0, 5 and 7.5% coating and also 5, 7.5 and 10% coating (Table 4.2). This implies that the significant difference in the effect of coating on the firmness of the fruit can be attributed to the difference in firmness for non-coated (0%) fruits and that of 10% coating which was significantly different from each other.

The separation of means for the effect of storage interval on the firmness of the fruit revealed that there was a consistent loss of firmness with increasing storage interval (Table 4.2). This observation was more noticeable under ambient temperatures (Figure 4.5C) than under low temperature storage (Figure 4.5D). Loss of firmness was delayed in coated than non-coated fruits. Park *et al*, (1992) reported that coated tomatoes showed lower respiration and O_2 consumption than non-coated tomatoes and had a better firmness retention. In this study, it was probable that a reduction in the rate of respiration of coated pineapple coupled with a retention of moisture created by the film of coating on the fruit surface might have accounted for the delayed loss of firmness in the coated fruits.

4.1.1.6 pH and Pulp (Internal) Temperature

The inference from the ANOVA table (Table 4.1) indicates that the pH of the fruit juice was influenced by the interval of storage.

Figure 4.6

The effect of storage interval on the pH of pineapple after 0,4,7and 10 days of storage under

A) ambient temperature(28 °C) and

B) low temperature storage (8 °C)

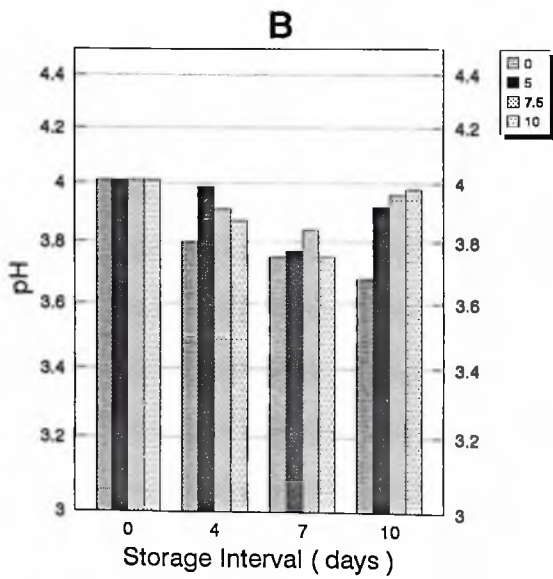
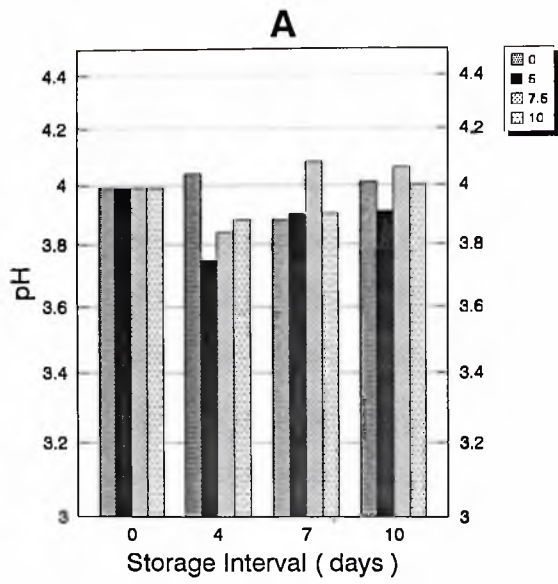
Legend

0 = 0% coating

5 = 5% coating

7.5 = 7.5% coating

10 = 10 % coating



Means separation revealed that the mean value of the juice was highest (4.00) on harvest day (0 day storage) and lowest (3.86) after one week of storage (Table 4.2). The pH values did not follow any consistent trend under ambient storage (Figure 4.6A) but there was an observed drop in pH up to the seventh day of storage under low temperature storage and a significant increase by the tenth day of storage (Figure 4.6B).

The ANOVA table (Table 4.1) indicates that keeping fruits under different temperature and at different intervals has a significant effect on the internal temperature of the fruit.

Separation of means for the effect of storage temperature on the internal temperature of the fruit showed that low temperature storage had a lower mean pulp temperature value (18.9°C) than ambient storage (32.8°C) (Table 4.2). This is not unexpected since the thermosensitive pineapple fruit pulp is known to respond to changes in external temperatures (Bartholomew and Malezieux, 1994).

A look at the effect of storage interval on the internal temperature of the fruit after separation of means showed that there was a significantly decreasing mean fruit temperature with increasing storage interval (Table 4.2).

4.1.1.7 Translucency

Translucency is an important attribute in determining the eating quality of pineapple. A highly translucent fruit is judged as over-ripe while fruit with low translucence is generally considered unripe and has low aesthetic and consumer appeal.





Translucency as revealed by the ANOVA table was influenced by the temperature of storage and the intervals at which the storage was done (Table 4.1).

Means separation (Table 4.2) further revealed that the effect of ambient temperature storage resulted in a higher mean translucency value (3.97) which was significantly different from the contribution of low temperature storage to translucency (3.25). Under ambient storage, mean temperature values were higher (32.8°C) than low temperature storage (18.9°C). Bartholomew and Malezieux (1994) reported that the fruit flesh colour and translucence are altered by temperature changes. While Teisson's (1979) observation that high temperatures make fruit flesh highly translucent agrees with the findings of this study.

Means separation for the effect of storage interval on the translucency of the fruit showed that translucency increased with increasing storage interval (Table 4.2). However the difference between 0 day and 4 day storage were not significantly different. While 7 day and 10 day storage were also not significant. Therefore, the real difference in translucency can be explained by the differences in the 0 day storage and that of the 7 day storage. Figure 4.7a shows that under ambient temperature, four days were enough to make non-coated fruits highly translucent, while this was attained after 7 days at 10% coating. After 10 days storage, 5% and 7.5% coating, showed relatively lower translucency values. Figure 4.7b indicates that under low temperature storage, the level of translucency was the same for all the treatments although there was a noticeable increase after 7 days of storage for all the treatment.

Figure 4.7

The effect of storage interval on the translucency of pineapple after 0,4,7and 10 days of storage under

A) ambient temperature(28 °C) and

B) low temperature storage (8 °C)

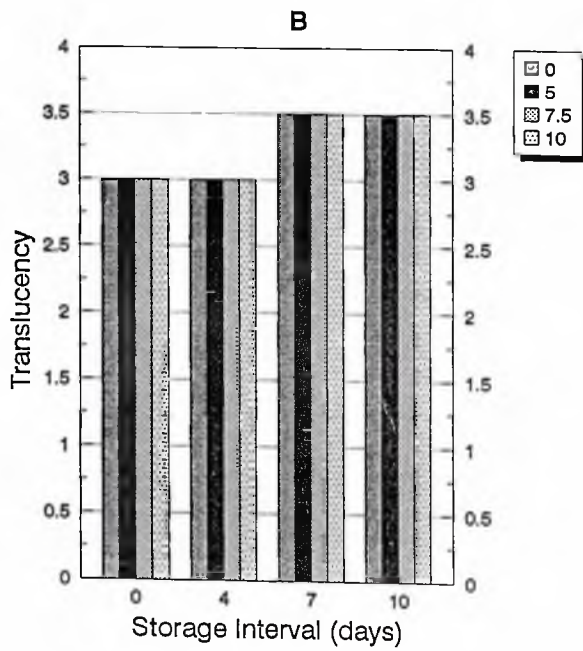
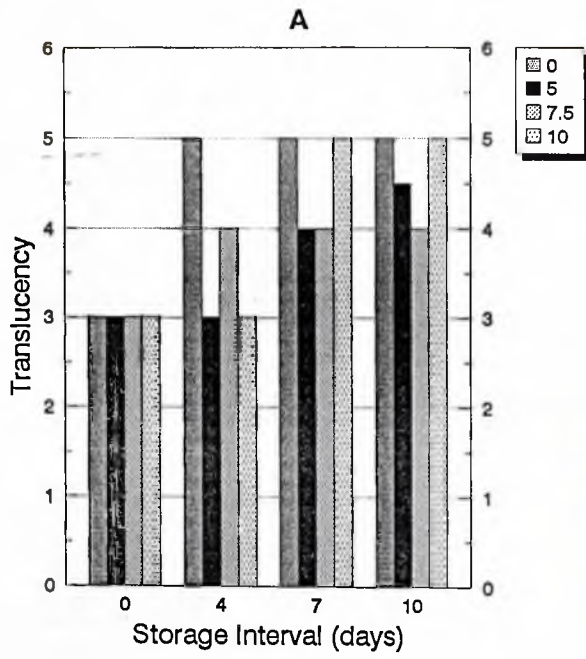
Legend

0 = 0% coating

5 = 5% coating

7.5 = 7.5% coating

10 = 10 % coating



4.1.2 The Effect Of Polymeric Coating And Anti-Fungal Treatment On Pineapple Quality.

This study was conducted to evaluate the contribution of fungicide application (a widespread practice by pineapple exporters in Ghana) to the overall post-harvest pineapple quality. Four treatment combinations were made and applied to the fruit. Viz.:

- no fungicide and no polymeric coating
- fungicide and no polymeric coating
- no fungicide and polymeric coating
- fungicide and polymeric coating

The results of the data analysed are presented in Tables 4.3 and 4.4 .

4.1.2.1 Vitamin C

The ANOVA summary table (Table 4.3) shows that the vitamin C content of the fruit was affected by the storage temperature, the polymeric coating and the interval of storage. Although fruits without fungicides had a slightly higher mean vitamin C content the effect was not significant (Table 4.4). The results also showed that low temperature storage (8 °C) enhanced vitamin C retention (Table 4.4).

Mean separation for the effect of the polymeric coating also showed that 5% coating of fruits enhanced the vitamin C retention (Table 4.4)

Increasing the interval of storage had a depressing effect on the vitamin C content of the fruit (Table 4.4). However, it was observed that there was no significant difference between 0 and 4 days and 7 and 10 days of storage interval. Thus the real difference in

Table 4.3 ANOVA Summary Table (showing only F-values of Quality characteristic studied)

Sources of variation	Astringency Index	Vitamin C	Sugar Content	Titratable Acid	pH	Pulp Temperature	Translucency
Storage Temperature (ST)	6.94*	46.02*	74.18*	.014	4.59	1000*	28.96*
Polymeric Coating (PC)	3.47	7.87*	7.87*	1.748	.001	15.23*	10.426*
Fungicide (F)	.96	.237	2.85	.221	.031	.305	.129
Storage Interval (SI)	2.34	4.66*	2.69	3.64*	3.1	1000*	24.498*
ST x PC	7.52*	3.59	17.44*	2.84	.006	9.07*	15.57*
ST x F	1.06	.244	2.88	.211	.001	.115	1.158
PC x F	5.19*	.024	7.14*	2.24	.336	2.08	1.158
ST x SI	17.99*	1.081	6.38*	15.30*	9.11*	1000*	5.62*
PC x SI	.688	1.63	1.57	.44	1.26	1.817	2.188*
F x SI	1.69	1.9	.439	1.63	.879	.610	.129

* means significant at $P \leq 0.05$

Value without (*) means effect was not significant at $P \leq 0.05$

**Table 4.4 Summary of means (MRT (LSD))* for factors⁺ significantly affected by treatment**

Treatment	Level	Astringency Index	Vitamin C	Titratable Acidity	Sugar Content	Pulp Temperature	Translucency
ST (°C)	8	.0731b	16.57b	.757a	10.34a	15.89a	3.22a
	28	.0667a	14.24a	.755a	11.48b	29.68b	3.69b
PC (%)	0	.67a	14.92a	.741a	11.10b	22.72a	3.59a
	5	.72a	15.88b	.771a	10.73a	22.86b	3.31b
F (%)	0	.68a	15.49a	.751a	10.8a	22.78a	3.29a
	0.01	.71a	15.32a	.761a	11.02a	22.80a	3.31a
SI (days)	0	.067a	16.01b	.711a	10.6a	37.86c	3.00a
	4	.069a	16.07b	.748ab	10.94a	17.67a	3.25ab
	7	.069a	14.85a	.750ab	11.08a	17.82b	3.58b
	10	.075a	14.67a	.815b	11.02a	17.86b	4.00c

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

LSD - Least Significant Difference

vitamin C content can be attributed to differences in the vitamin C content on 4 and 7 day interval of storage.

4.1.2.2 Sugar Content

In this study the sugar content was significantly affected by the storage interval and polymeric coating. However the interaction between fungicide application and polymeric coating, and polymeric coating and storage interval on storage temperature were also significant on the sugar content of pineapple (Table 4.3).

Separation of means for the effect of storage interval showed that fruits stored in ambient temperature (28 ° C) had a higher mean sugar content than fruits stored under low temperature (8 ° C) (Table 4.4). This contrast sharply with an earlier observation in section 4.1.1.2 where storage under low temperature (28 ° C). It is not clear whether the application of fungicide might be responsible for this coating the fruit at 5% concentration observation.

resulted in lower mean sugar content while fruit coating as revealed by (Table 4.4) had a depressing effect on mean sugar content after ten days of storage. Non-coated fruits had a higher mean sugar content (11.10%) than coated fruits (10.73%). In an earlier study as reported in Table 4.1 and section 4.1.1.2, although non-coated fruits had a slightly higher mean sugar content than coated fruits the effect was non-significant.

4.1.2.3 Titratable Acidity And pH

The titratable acidity of pineapple was affected by the storage interval and the interaction between the storage interval and storage temperature.

Separation of means for the effect of storage interval, showed that acidity increased with increasing storage interval (Table 4.4).

Table 4.4 also shows that there was a slightly higher but non-significant increase in the level of acidity due to low temperature storage, polymeric coating and the application of fungicide. The observation of pineapple acidity in this study agrees with an earlier observation in section 4.1.1.3 which suggest a general increase in pineapple acidity with increasing storage interval.

There was a non-significant influence of all the individual treatment on the pH however the pH of the fruit was influenced by the interaction between the storage interval and storage temperature.



4.1.2.4 Astringency Index

Analysis of variance from results of this study showed that only storage temperature had a significant effect on astringency (Table 4.3). However, the interaction between storage temperature (ST) and polymeric coating (PC), PC and fungicide (F) and ST and storage interval were significant at $p \leq 0.05$. Thus suggesting that ST did not act independently on the astringency index but depended on the interaction between other parameters in the study.

Multiple range analysis using the least significant difference (LSD) to separate mean's (table 4.4) showed that the effect of storage temperature on astringency could be attributed to differences in treatment means between fruits stored under ambient temperature (28 °C) and that stored under low temperature (8 °C). Fruits stored under low temperature had a higher astringency index (.0731) than fruits stored under ambient temperatures (0.0667).

4.1.2.5

Pulp Temperature.

The ANOVA summary table indicate that the pulp (internal) temperature of the fruit was influenced by the storage temperature, the polymeric coating and the storage interval.

There was a significant interaction between the storage temperature and the polymeric coating and the storage interval and the storage temperature. Thus suggesting that the pulp temperature of the fruit was dependent on the temperature of storage and the interval at which storage was done (Table 4.3 and 4.4).

Mean separation confirmed that at the end of 10 days of storage the temperature of the fruit was higher in fruits stored at ambient (28 °C) than at cold (8 °C) temperatures (Table 4.4).

Again fruits coated with 5% polymeric coating showed a higher (22.86 °C) mean temperature than non-coated fruits (22.72 °C) (Table 4.4).

The effect of storage interval after mean separation showed that pulp temperature decreases sharply from 37.86 °C on day one to 17.67 °C by the forth day. There was a slight but significant increase from day 4 to day 7 (17.82 °C) and a slight but non significant increase by Day 10 (17.86 °C). The sharp drop in mean fruit temperature from day 4 is obviously the contribution of refrigeration at 8 °C.

4.1.2.6. Translucency

This was influenced by the storage temperature, polymeric coating and storage interval. There were significant interaction between storage temperature and storage interval and storage temperature and polymeric coating (Table.3).

Mean separation revealed that fruits stored at ambient temperature (28 ° C) had a higher mean translucency (3.69) than fruits stored at cold temperature (8 ° C) which had a translucency of 3.22 (Table 4.4).

Mean fruit translucency was higher (3.59) in non-coated fruits than coated fruits (3.31). In an earlier study in section 4.1.1 although non-coated fruits showed a slightly higher translucency than coated fruits the effect was non-significant. It is uncertain whether the contribution of fungicide in this study may have influence on the outcome. However, the result of this study shows that there was non-significance in the effect of fungicide on translucency although fungicide applied fruit showed a slightly higher translucency (Table 4.4).

Table 4.4 also showed that translucency increased with increasing storage interval. After 10 days of storage, translucency had increased from 3 on day 0 (harvest day) to 4 on day 10.

4.2 **On The Shelf-life And Shrinkage Characteristics Of Post-Harvest Pineapple**

4.2.1 **The Effect Of Gestation And Storage On The Day- Night Shrinkage Of Pineapple**

4.2.1.1 **Shrinkage Evolution.**



The mass shrinkage characteristics of pineapple is of great significance to the post harvest management of the fruit for export. Apart from its contribution to quality deterioration (Dixie, 1995; Soler, 1992), it influences the overall economic returns from export, its shelflife and consumer appeal (Dixie, 1993; Dixie, 1995).

Analysis of variance of the data (Table 4.5) showed that the gestation period, time of investigation and the storage interval were highly significant in influencing shrinkage in post harvest pineapple. Mean separation (Table 4.6.) further revealed that mean shrinkage evolution was highest in fruits harvested at 160 days after floral induction (FI) (3.52%) than fruits harvested at 140 days FI (2.73%). This observation is significant since there is the generally held believe that the longer the fruit stays on the plant after FI the better the eating quality. It is important to note from this study that there is a potential risk of shrinkage from prolonging the harvest date beyond 140 days FI.

The effect of the time of investigation on shrinkage evolution can be attributed to differences in treatment means for day and night evaluations (Table 4.6). Day time evaluation showed a slightly lower but significant mean shrinkage (3.10%) evolution than night time evaluation (3.15%). Pineapple is known to exhibit Crassulacean Acid Metabolism (CAM) a physiological phenomenon characteristic of epiphytes and

Table 4.5 ANOVA Summary Table (Showing Only F Values Of Parameters Evaluated)

Sources Of Variation	Shrinkage Evolution	Shell Colour Break	Crown Withering Index
Gestation (G) (Days)	1000.00**	65.06**	1000.00**
Investigation Time (D) (Period)	120.9**	7.83*	00.00
Storage Interval (SI) (Days)	1000.00**	80.34**	1000.00**
G X D	512.82**	1.32	1000.00**
G X SI	1000.00**	1.79	1000.00**
D X SI	9.463*	.344	1000.00**

* = significant at $P \leq 0.05$ ** = significant at $P \leq 0.01$

Table 4.6 Summary of means (MRT (LSD))* for parameters significantly affected by treatment

Treatment	Level	Shrinkage Evolution	Shell Colour Break	Crown Index	Withering
G (days after FI)	140	2.73a	4.53a	1.6a	
	160	3.52b	5.05b	1.75b	
D (days)	day (6am - 6pm)	3.10a	4.70a	-	
	night (6pm-6am)	3.15b	4.88b	-	
S I (days)	1	.239a	3.37a	1.00a	
	2	.904b	3.63a	1.00a	
	3	1.537c	4.00b	1.00a	
	4	2.137d	4.37c	1.00a	
	5	2.775e	4.63c	2.00b	
	6	3.419f	5.13d	2.00b	
	7	4.050g	5.37d	2.00b	
	8	4.695h	5.75e	2.25c	
	9	5.383i	5.75e	2.25c	
	10	6.093j	5.87e	2.25c	

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

G = gestation

D = Investigation Time

SI = Storage Interval

LSD - Least Significant Difference

FI = Floral Induction



Table 4.7A ANOVA For Full Regression Of Shrinkage Evolution Showing Lack-Of-Fit

SOURCE	SS	df	MS	F _{RATIO}	P _{VALUE}
TOTAL	294.442	79			
MODEL	293.665	5	58.733	5596.92	.0001
ERROR	0.776542	74	0.0104		
LACK OF FIT	0.333648	34	0.0098	0.8852	
PURE ERROR	0.442894	40	0.01107		

Table 4.7B Model Fitting Results Showing Coefficients Of The Variables

VARIABLE	SE	R ²	SCB	R ²	CWI	R ²
B ₀	.141	-	.700	-	2.033	-
X ₁	-.367*	.002	-	-	.525*	.0122
X ₂	.287**	.93083	.125**	.78120	.454**	.85424
X ₂ ²	.0037*	.0002	-	-	-.014	.07857
X ₁ X ₂	.210**	.06561	.035*	.03566	-	-
R ²	-	.99764	-	.81686	-	.94531
F-Ratio	-	5596.92**	-	82.52**	-	207.407**

B₀ = CONSTANT X₁ = GESTATION PERIOD (DAYS) X₂ = STORAGE INTERVAL (DAYS) SE = SHRINKAGE (%)

SCB = SHELL COLOUR BREAK CWI = CROWN WITHERING INDEX

* = SIGNIFICANT AT P ≤ 0.05

** = SIGNIFICANT AT P ≤ 0.01

xerophytes (Kluge and Ting, 1978). In CAM plants the stomata open at night and close during the day to allow assimilation of CO₂ from the atmosphere. This mechanism allows water loss to be reduced to a minimum (Young in Bartholomew and Kadzimin, 1977). This phenomenon probably accounts for the slightly lower shrinkage evolution during the day.

The contribution of storage interval to shrinkage as revealed by mean separation (Table 4.6.) showed that mean shrinkage increased with increasing storage interval. Mean shrinkage was least (.239%) on day 1 and highest (6.093%) on day 10.

A model generated to predict shrinkage evolution could explain over 99.8% of variation within the model. Storage interval alone could explain 93.% of the variation. Analysis of variance of the model (Table 4.7A) showed that it was highly significant ($p \leq 0.01$) and did not suffer from lack-of-fit. Further ANOVA also showed that all the variables within the model were significant (Table 4.7B). Shrinkage could be predicted by the model :

$$Z = .0141 - .367X_1 + .287X_2 + .0037X_2^2 + .210X_1X_2$$

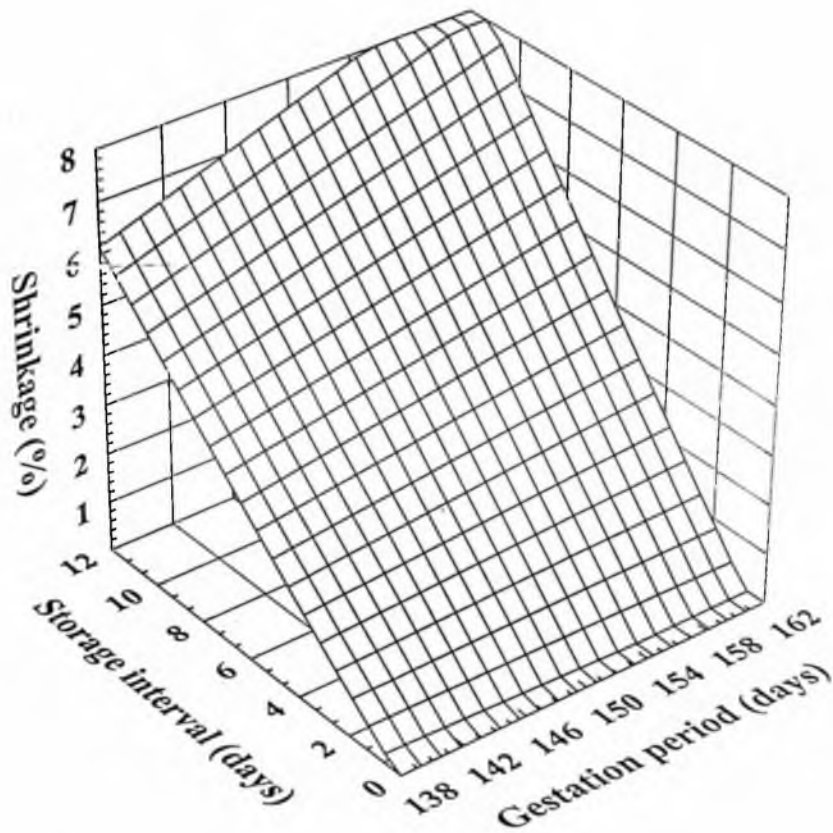
Z = Shrinkage Evolution.

X₁ = Gestation Period

X₂ = Storage Interval

The response surface plot Figure 4.8 indicates that shrinkage increased with increasing storage interval and the effect was enhanced when fruits were harvested beyond 140 days after floral induction.

Figure 4.8 **Response Surface Plot for the effect of storage interval and gestation period on the shrinkage characteristics of pineapple**





4.2.1.2. Shell Colour Break (SCB)

Pineapple shell colour is probably the most important quality attribute for consumer acceptance. It is no wonder that numerous quality standards involving shell colour have emerged from the world pineapple trade (Py *et al*, 1987). King (1972) reports that shell colour with about 75% to 100% deep yellow or orange shade and very little or no blemish is considered excellent in the world market for pineapple.

Analysis of variance of the data (Table 4.5) showed that SCB was influenced by the gestation, investigation time and the storage interval. There was also a significant interaction among all the treatments.

Mean separation to evaluate the effect of gestation on SCB (Table 4.6) showed that harvesting fruits at 160 days F1 gave a higher mean SCB (3.52) than harvesting fruits at 140 days F1 (2.73).

Again mean separation (Table 4.6) To evaluate the effect of investigation time on shell colour break revealed that mean night evaluation had a significantly higher SCB(4.88) than mean day evaluation (4.70). This observation is not unexpected since day evaluation preceded night evaluation by as much as 12 hours by which time, changes in shell colour may be physiologically noticeable. Radiance (sunlight intensity) and light have been reported to accelerate SCB (Bartholomew and Malezieux, 1994). Prolonging storage interval as revealed by mean separation (Table 4.6) accelerated SCB irrespective of the gestation of the fruit. During the maturation and storage of many fruits there is a change in skin colour from green to orange or red. This change is attributed to the loss of chlorophyll and the unmasking and synthesis of carotenoids with time (Mackinney, 1961).

A mathematical model generated using the stepwise multiple regression technique could explain over 81% of variation within SCB (Table 4.7). The interval of storage

contributed over 78% of the variation in the model. Thus indicating that the model depended significantly on the contribution of the storage interval. The interaction between the gestation period and storage interval was also significant. The model is given by

$$Z = .700 + .125X_2 + .035X_1X_2$$

Z = Shell Colour Break.

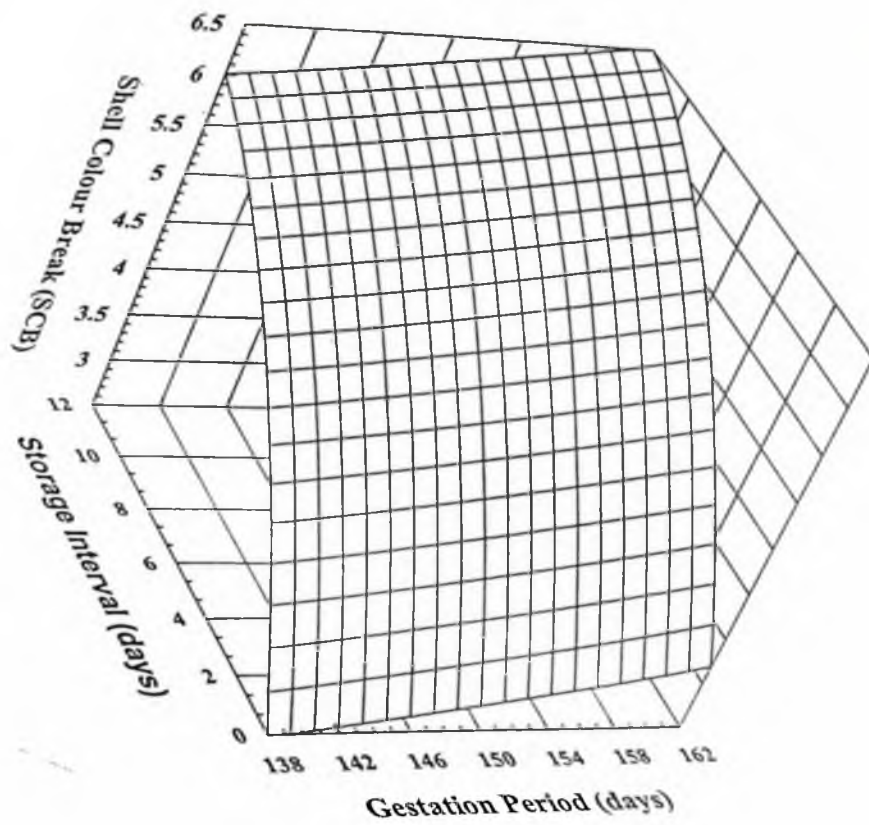
X₁ = Gestation Period

X₂ = Storage Interval

Analysis of variance of the model showed that the model was significant at $p \leq 0.01$ (Table 4.7).

The response surface plot Figure 4.9 indicates that shell colour break was accelerated with increasing storage interval and fruits harvested at 160 days after floral induction (FI) were prone to breaking faster than fruits harvested at 140 days FI.

Figure 4.9 **Response Surface Plot for the effect of storage interval and gestation period on the shell colour break of pineapple**



4.2.1.3. **Crown Withering Index (CWI)**

For the fresh fruit market the condition of the crown is considered as a leading quality characteristic of pineapple (King, 1972).

Kay (1965) and King (1972) have reported that crown leaves that are turgid and bright green with a good shell colour attract premium price. However, leaves turning brown at the edge or tip, detract from the accepted appearance of the fruit and usually reduces its market value.

Analysis of variance of the data showed that the crown withering index (CWI) was significantly influenced by the gestation period and storage interval (Table 4.5). There was also a highly significant interaction between all the independent variables in the study.

Mean separation for the effect of gestation on CWI revealed that fruits harvested at 160 days FI had a higher mean withering index (1.75) than fruits harvested at 140 days FI (1.6). Thus suggesting that the longer fruits are kept on the field after floral induction the greater the propensity towards crown withering after harvest.

Mean separation for the effect of storage interval (Table 4.6) revealed that the actual withering of crown leaves was noticeable only after 5 days of storage where an index of (2.0) was noticed. This condition remained the same up to 7 days before yet another noticeable change on day 8 (2.25) which was maintained through out the rest of the storage period. It can be concluded from this study that irrespective of the harvest maturity (i.e. harvesting at 160FI or 140FI) pineapple fruit has an inherent ability to maintain the freshness of the crown up to about 5 days after harvest under ambient temperatures (28 ± 2 °C). This ability probably can be attributed to its xerophytic ontogeny.

A model generated to predict the crown withering index could account for over 94% of variation within the model. Again storage interval alone could account for over 85% of this variation. However there was a significant contribution to the model by the gestation period and the quadratic term of the storage interval (Table 4.7). Analysis of variance of the model itself showed that the model was highly significant ($p < 0.01$) in predicting CWI (Table 4.7). The model is given by

$$Z = 2.033 + .525X_1 + .454X_2 - 0.014X_2^2$$

Z = Crown Withering Index

X₁ = Gestation Period

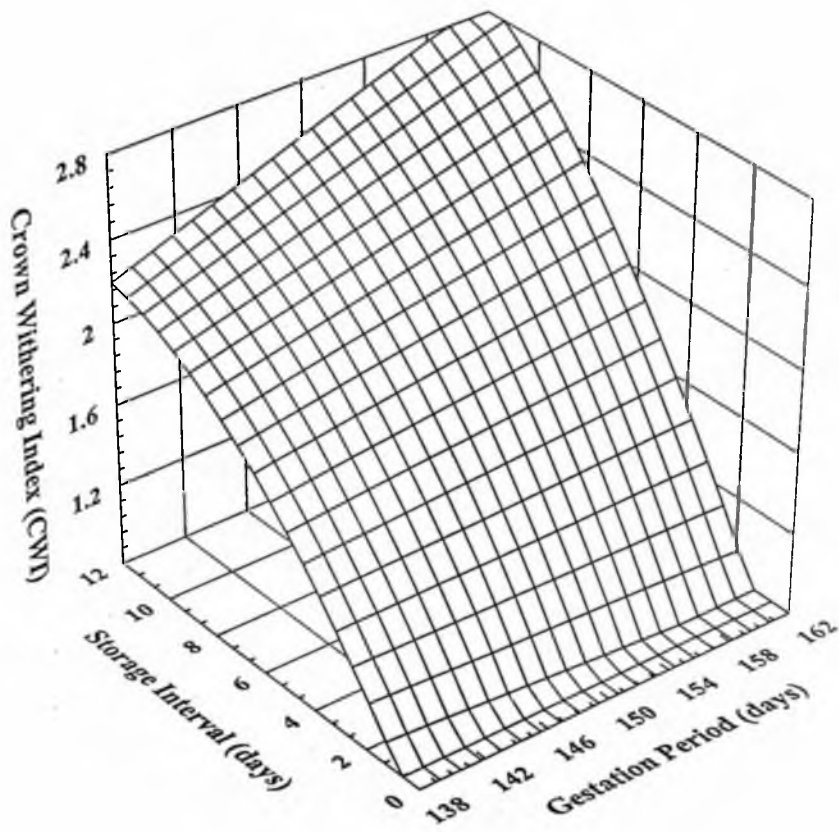
X₂ = Storage Interval

R² = .94531 (94.53%)

The response surface plot Figure 4.10 indicates that crown withering index was pronounced with increasing storage interval with fruits harvested at 160 days FI prone to withering faster than fruits harvested at 140 days FI.



Figure 4.10 Response Surface Plot for the effect of storage interval and gestation period on the crown withering index of pineapple





4.2.2 The Effect of Fruit Coating and Storage Interval on the Shelf Life and Shrinkage Evolution of Post-Harvest Pineapple.

4.2.2.1. Shrinkage Evolution (Ambient Temperature)

Under ambient temperatures, the shrinkage evolution of pineapple was influenced by the presence or absence of a polymeric coating, the level of fungicide applied and how long fruits are held in store. ANOVA of the data showed that the polymeric coating, fungicide and storage interval had significant effect ($P \leq 0.05$) on shrinkage evolution of pineapple. (Table 4.8) The interactive effect of the polymeric coating and the fungicide also significantly influenced shrinkage. This suggests that the polymeric coating and the fungicide were inter-dependent in influencing shrinkage in pineapple under ambient temperatures (Table 4.8). Means separation using the LSD revealed that the influence of the polymeric coating on shrinkage was due to coating at 5% level which had a significantly lower mean shrinkage value (3.41%) than the non-coated fruits which showed (3.68%) shrinkage (Table 4.9). In field handling of pineapples, the natural surface coating layer of the fruit is easily destroyed. This enhances transpiration and shrinkage in the fruit. This study has shown that coating at 5% was sufficient in reducing shrinkage by at least 8% after 10 days of ambient storage. The beneficial effects of surface coating on minimising weight loss or shrinkage of fruits has been the subject of numerous studies and reviews. (Banks, 1984; Chu, 1986; Park *et al*, 1994)

Means separation for the effect of fungicide on shrinkage loss showed that shrinkage was greater in non-fungicide applied fruits (3.80%) than fungicide applied

Table 4.8 ANOVA Summary Table (showing only F-values of parameters studied)

Sources of Variation	Shrinkage (A)	Shrinkage (C)	SCB (A)	SCB (C)	CWI (A)	CWI (C)
Polymeric Coating (PC) (%)	8.284 *	14.923 *	1000.00**	36.283 **	47.284 **	9.00*
Fungicide (F) (%)	30.261*	1.256	.822	1.82	3.349	1.00
Storage Intervals (SI) (days)	187.526*	933.727**	248.491 **	8.817 **	99.112 **	4.556*
PC x F	49.487 *	33.632 *	3.339	5.685 **	10.624 *	1.00
PC x SI	.767	2.352	33.613 **	6.100 **	4.495 *	4.556 **
F x SI	.843	.254	2.193	.816	1.241	1.00

* = significant at $P \leq 0.05$

** = significant at $P \leq 0.01$

A = ambient temperature (28.9°C) C = low temperature storage (8.0 °C)

SCB = Shell Colour Break

CWI = Crown Withering Index

Table 4.9 Summary of means (MRT (LSD))* for parameters significantly affected by treatment

Treatment	Level	Shrinkage (A)	Shrinkage (C)	SCB (A)	SCB (C)	CWI (A)	CWI (C)
PC (%)	0	3.68 b	1.48 b	3.94 b	2.208 b	1.87 b	1.049 b
	5	3.41 a	1.42 a	2.683 a	2.016 a	1.55 a	1.00a
F (%)	0	3.80 b					
	0.01	3.29 a					
SI (days)	1	.54 a	.267 a	2.0 a	2 a	1 a	1 a
	2	1.24 b	.567 b	2.16 a	2 a	1 a	1 a
	3	1.88 c	.787 c	2.67 b	2 a	1 a	1 a
	4	2.51 d	1.096 d	2.83 b	2 a	1 a	1 a
	5	3.16 e	1.432 e	3.33 c	2 a	1.5 b	1 a
	6	3.87 f	1.652 f	3.50 cd	2.a	1.83 b	1 a
	7	4.53 g	1.842 g	3.75 de	2.25 b	2.42 c	1 a
	8	5.20 h	2.052 h	3.83 ef	2.25 b	2.42 c	1 a
	9	5.88I	2.299i	4.08 f	2.25 b	2.75 c	1.08 ab
	10	6.66 j	2.540 j	5.00g	2.38 b	2.75 c	1.16 b

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

LSD - Least Significant Difference

Table 4.10 Model Fitting Results Showing Coefficients Of The Variables

VARIABLE	SH _A	R ²	SH _C	R ²	SCB _A	R ²	SCB _C	R ²	CWI _A	R ²	CWI _C	R ²
B ₀	-2.65	-	.35	-	1.68	-	1.74	-	.84	-	.943	-
X ₁	2.18**	.00512	.20**	.00143	-	-	.184**	.01462	-	-	.0798*	.0692
X ₂	.80**	.93764	.29**	.98550	.633**	.57362	.073	.03064	.149*	.01088	-	-
X ₃	1.47**	.01354	-.26**	.00176	-	-	-	-	-	-	-	-
X ₂ ²	-	-	-	-	-	-	.007**	.35114	.018**	.83716	.005*	.23477
X ₁ X ₃	-1.32**	.03027	.18**	.00144	-	-	-	-	-	-	-	-
X ₂ X ₃	-	-	-	-	-	-	-	-	.016	.00471	-.0035	.01701
X ₁ X ₂	-.08**	.00381	-.02**	.0035	-.233**	.3577	-.068**	.34405	-.06*	.05845	-.024*	.252
R ²	-	.98657	-	.99363	-	.94939	-	.7405	-	.91120	-	.57298

B₀ = CONSTANT X₁ = POLYMERIC COATING (%) X₂ = STORAGE INTERVAL (DAYS) X₃ = FUNGICIDE (%) SH = SHRINKAGE (%) SCB = SHELL COLOUR BREAK
 CWI = CROWN WITHERING INDEX A = AMBIENT STORAGE C = LOW TEMPERATURE STORAGE * = SIGNIFICANT AT P ≤ 0.05 ** = SIGNIFICANT AT P ≤ 0.01

fruits (3.29%) (Table 4.9). George and co-workers (1985) reported that bananas treated with thiobendazole (The same used in this study) showed reduced weight loss.

The contribution of storage interval to shrinkage as shown by the separation of means (Table 4.9) revealed increasing shrinkage with storage. The greatest increase in mean shrinkage (6.66%) was registered after 10 days of storage while one day after storage mean shrinkage was (.54%) less than one percent.

A model generated from step-wise regression analysis to predict shrinkage evolution in pineapple under ambient temperatures could explain 98.6% of variation in shrinkage (Table 4.10). Storage interval alone could account for 93.7% of variation in shrinkage (Table 4.10). Further ANOVA of the variables in the model showed that polymeric coating and fungicide application were significant at $p \leq 0.01$ (Table 4.10). All the interactions studied were also significant in predicting shrinkage under ambient conditions (Table 4.10). The predictive model is given by

$$Z = -2.65 + 2.18X_1 + 0.80X_2 + 1.47X_3 - 1.32X_1X_3 - 0.08X_1X_2$$

X_1 = Polymeric Coating (%)

X_2 = Storage Interval (days)

X_3 = Fungicide level (%)

Z = Shrinkage Evolution

$$R^2 = 98.6 \%$$

4.2.2.2 Shrinkage Evolution (Cold Storage)

Shrinkage evolution under cold temperature (8.00 ± 0.2 °C) was influenced by the level of coating, storage interval and the interaction between the polymeric coating and fungicide level.

The separation of means (Table 4.9) for the effect of the level of coating revealed that mean shrinkage was lower in coated fruits (1.42%) than non-coated fruits (1.48%). From (Table 4.9), the influence of storage interval had an increasing effect on shrinkage with increasing storage. Shrinkage was lowest one day after storage (.267%) and highest (2.540%) after ten days of storage.

Although fungicide had no significant effect on shrinkage under cold temperature, the interaction between fungicide and polymeric coating had significant effect on shrinkage. This implies that the influence of the polymeric coating on the shrinkage evolution did not act independently but was dependent on the level of fungicide applied (Table 4.8).

A model developed to predict pineapple shrinkage under cold temperature could explain over 99.3% of variation in shrinkage. 98.5% of the variation in shrinkage was accounted for by the storage interval alone (Table 4.10). Further ANOVA of the variables in the model showed that all the variables were significant at $p \leq 0.01$.

Thus shrinkage under cold temperature could be predicted as follows

$$Z = 0.35 - 0.20X_1 + 0.29X_2 - 0.26X_3 + 0.18X_1X_3 - 0.02X_1X_2$$

X_1 = Polymeric Coating (%)

X_2 = Storage Interval (days)

X_3 = Fungicide level (%)

Z = Shrinkage Evolution

$$R^2 = 99.3 \%$$

4.2.2.3 Shell Colour Break (Ambient Temperature)

Analysis of variance of the data showed that the shell colour under ambient conditions was significantly affected by the level of coating applied and the duration for which fruits were held (Table 4.8). There was a significant interactive effect of the polymeric coating and the storage interval on the shell colour of the fruit. The polymeric coating and the interval of storage did not act independently but were inter-dependent on each other for the shell colour break (Table 4.8). Mean separation for the effect of the polymeric coating on the shell colour showed that coating the pineapple shell at 5% concentration was effective in delaying shell colour break (Table 4.9). Again mean separation for the effect of the interval of storage on shell colour indicated that shell colour break (SCB) was provoked by increasing storage time with the highest SCB recorded on the tenth day and the least on the first day, although there were non-significant increases in some days (Table 4.9). A model developed to predict SCB under

ambient temperature could explain over 94.9 % of variation within SCB(Table 4.10). Over 57.3% of the variation was explained by the interval of storage while the remaining 37.5% was accounted for by the interaction between the level of coating and the interval of storage.

$$Z = 1.68 + .633X_2 - 0.223X_1X_2$$

X_1 = Polymeric Coating (%)

X_2 = Storage Interval (days)

Z = Shrinkage Evolution

$$R^2 = 94.9 \%$$

4.2.2.4 Shell Colour Break (Cold Storage)

The ANOVA summary table (Table 4.8) indicates that the shell colour of pineapple under cold storage temperature was significantly influenced by the level of coating and the interval of storage. Significant interactive effects of polymeric coating and fungicide and polymeric coating and storage interval was also noticed.

Mean separation (Table 4.9) for the effect of polymeric coating on SCB revealed that SCB was lower in coated fruits than non-coated fruits. Non-coated fruits recorded (2.208 units) higher than (2.016 units) by coated fruits. Delayed colour change in coated fruits have been reported in tomatoes (Buescher, 1979; Yang and Chinnan, 1987), pear (Meheriuk and Lau, 1988) and oranges (Smith and Stow, 1984).

Means separation (Table 4.9) for the effect of storage interval on SCB showed that the real influence of storage interval could be attributed to change in SCB from the seventh day . A model generated to predict SCB under cold storage temperature (Table 4.10) could explain 74% of variation in shell colour break. The quadratic term of the storage interval accounted for 35% of the variation while the interaction between the polymeric coating and the storage interval could also explain over 34% of the variation. Further ANOVA of variable in the model revealed that the polymeric coating was a significant variable in predicting the SCB in this study.

$$Z = 1.74 + .184 X_1 + .073 X_2 + .007 X_2^2 - 0.068 X_1 X_2$$

X_1 = Polymeric Coating (%)

X_2 = Storage Interval (days)

Z = Shrinkage Evolution

$$R^2 = 74.05 \%$$

4.2.2.5 Crown Withering Index (Ambient)

The ANOVA summary table (Table 4.8) indicates that the polymeric coating and the interval of storage significantly influenced the Index for the withering of the crown. The interaction between the polymeric coating and fungicide and the polymeric coating and storage interval was significant in the evaluation of the crown withering Index (CWI).

Means separation showed that coating at 5% concentration was effective in retarding CWI (Table 4.9). Again the effect of the storage interval after the separation of means showed that crown withering effectively began after the fourth day and progressed to the ninth day. Despite these increases in CWI, there was no significant difference from the fifth to the seventh day and from the eighth to the tenth day.

Under ambient temperature the following model was generated to predict CWI (Table 4.10). The model could explain over 91% of variation in CWI.

$$Z = .840 + .149 X_2 + .018X_2^2 - .06X_1X_2 - 0.016X_2X_3$$

X₂ = Storage Interval

X₃ = Fungicide

X₁ = Polymeric Coating

$$R^2 = 91.11\%$$

Z = Crown Withering Index

The quadratic term of duration was highly significant ($p \leq 0.01$) after further ANOVA and could explain over 83% of variation within the CWI (Table 4.10). Other significant variables were duration and the interaction between duration and polymeric coating.

4.2.2.6 Crown Withering Index (Cold Storage)

Analysis of variance of the data (Table 4.8) showed that CWI was influenced by the polymeric coating and the interval of storage. There was also a significant interaction between polymeric coating and storage interval on CWI. Suggesting that the influence of the polymeric coating was dependent on the storage interval and vice versa.

Separation of means (Table 4.9) suggested that there was practically no change in the condition of the crown when fruits were coated at 5% concentration and kept in cold temperature ($8.00 \pm 02^{\circ}\text{C}$). Even for the non-coated fruits, the mean change in CWI was only slight (1.049) (Table 4.9)

ANOVA was significant for storage interval although means separation showed that the real difference in CWI can be attributed to a change in CWI on the ninth and tenth day (Table 4.9). The model generated from the regression analysis to predict CWI in cold storage temperature could explain about 57% of variation within CWI (Table 4.10). Further ANOVA revealed that the level of coating, the quadratic term of duration and the interaction between the level of coating and the storage interval were significant to the model for CWI (Table 4.10). The predictive model is given by :-

$$Z = .943 + .0798X_1 + .005X_2^2 - .0035X_2X_3 - .024X_1X_2$$

X_1 = Polymeric Coating

X_2 = Storage Interval

X_3 = Fungicide

$$R^2 = 57.3\%$$

Z = Crown Withering Index

4.3 On The Effect Of Fruit Coating On The Post Harvest

Physiology Of Pineapple: Fruit Respiration

4.3.1 Post-Harvest Respiratory Activity

Kader (1992) has asserted that the rate of deterioration (perishability) of harvested commodities is generally proportional to the respiration rate and temperature is the environmental factor that most influences this deterioration rate. Fruit and vegetable respiration is classified as either climacteric or non-climacteric. A climacteric respiratory pattern is characterised by a sudden surge in respiration rate with a concomitant increase of carotenoid pigment (yellowing of skin) or anthocyanins (red, blue, and purple colours) with the loss of chlorophyll (green skin). The respiratory surge peaks to a point where in the fruit it is considered to have the best eating quality (Biale and Young 1981) and then the rate begins to fall. However, in non-climacteric fruits the sudden surge phenomenon is non-existent and the respiration rate shows a steady decline after harvest although the decrease in chlorophyll and increase in carotenoid and anthocyanins are still evident.

4.3.2 Characteristics Of The Fruit Used In The Study

	Coated	Non Coated
Mean Fruit Weight (Kg)	1.9857	1.9672
Fruit Diameter (cm)		
Base	41	42
Mid	40	40
Apex	33	34
Fruit Length with Crown	41	38
Fruit Maturity (Days after floral induction)	145	145

4.3.3 Storage Conditions

	Temperature	Relative Humidity
Cold	8.0 ± 0.2	90 - 94%
Ambient	23 ± .8	88 - 91%

4.3.4 Operating Conditions

Equipment : Gas Chromatograph Mikrolab Aarhus
(ML GC 82-12 VLD Serial Nr 12-552)

Conditions

Oven temperature	60 °C
Attenuation	10 x 4
Detector Current	160Ma
Flow Rate	50 ml He/min
Chart Speed	30 cm/hr
Chart voltage	5mV

Table 4.11 Gas Retention Time (Sec)

Gas	Atmospheric Standard	CO ₂ Standard	CF	NCF ¹	NCF ²
CO ₂	-	42	45	45	38
O ₂	212	-	190	197	195
N ₂	243	-	220	225	227

1 = Ambient

2 = Low Temperature Storage

NCF = Non Coated Fruit

CF = Coated Fruit

4.3.5 Calculation of Rate of Respiration

The procedure outlined by the manufacturers of MicroLab Aarhus (ML GC 82-12 VLS Serial Nr 12-552) was followed.

Atmospheric Standard: 1 ml of atmospheric air gave peak heights containing

4 units of O₂ on chart \cong 20.9% O₂

10 units of N₂ on chart \cong 78.1% N₂

CO₂ Standard: 1 ml of pure (100%) CO₂ gave peak heights equivalent to 81 units

This implies that :

4 units of O₂ \cong 20.9ml/100ml

10 units of N₂ \cong 78.1 ml/100ml

81 units of CO₂ \cong 100 ml/100ml

$$\text{Sample gas (Yml)} = \frac{\text{X(ml)} \times \text{y (unit)}}{\text{x (unit)}}$$



X = ml gas obtained from standard

x = equivalent unit of peak height of Standard gas

Y = ml gas calculated

y = equivalent unit of peak height of sample gas

Rate of Respiration (R₀) is given by the amount of O₂ or CO₂ produced or consumed (ml) per kilogramme fruit per hour.

$$R_0 = Y \text{ ml kg Fruit}^{-1} \text{ hr}^{-1}$$

Holding Time - is defined as the time taken (*hr.*) to measure **Yml** of gas evolved or consumed by **Xkg** of pineapple fruit in a sealed container.

Table 4.12. The Effect Of Polymeric Coating, Holding Time And Storage Temperature On CO₂ Evolution In Post Harvest Pineapple

Holding Time (hr)	CO ₂ Evolution (CE) (ml/kg fruit)			change in CE (ml/kg fruit)			Rate of CO ₂ Respiration (ml/kg/hr)		
	5%A	0%A	0%C	5%A	0%A	0%C	5%A	0%A	0%C
.5	1.09	1.42	-	0.00	0.00	-	2.18	2.84	-
3	.93	1.57	-	-0.16	0.15	-	0.31	0.52	-
24	9.82	14.96	6.27	8.73	13.54	-	0.41	0.62	.26
30	10.29	15.79	5.97	9.2	14.37	-	0.34	0.53	0.19

5% = 5% Coating

0% = non-coating

A = Ambient temperature

C = Cold temperature

4.3.6 Rate of Respiration - CO₂ Evolution

The results of the study shows that generally CO₂ production per kilogramme fruit increased with increasing holding time, irrespective of whether fruits were coated or non-coated (Table. 4.12)

CO₂ production was lower for coated fruits under ambient temperature at all holding times (Table 4.12). After holding fruit at ambient temperature for 30 mins, CO₂ evolution in non-coated fruits (1.42 ml/kg fruit) was over 23% higher than for coated fruits (1.09 ml/kg fruit). This percentage increase rose to nearly 41% after three hours of holding before dropping to steady at 34% after 24 and 30 hrs respectively over the evaluation period (Table 4.12). CO₂ production was lowest in this study for non-coated fruit kept under low temperature and evaluated at 24 hrs (6.27 ml/kg fruit) and 30 hrs

(5.97 ml/kg fruit) as compared to the results obtained for coated and non coated fruits under ambient temperatures (Table 4.12). The respiration rate of a produce is an excellent indicator of the metabolic activity taking place in the produce. Metabolic activities are enzyme driven and depend among others on temperature. Thus the rate of respiration is temperature dependent. therefore it would be expected that as produce are subjected to reduced temperatures, the rate of respiration would be lowered. Evaluation of peak heights for CO₂ production profiles after 24 hrs and 30 hrs holding time showed that non coated fruits kept under low temperature had the lowest peak heights followed by coated fruits under ambient temperatures and then non coated fruits under ambient temperature (Figure 4.11A)

The rate of change of CO₂ evolution in coated and non-coated fruits also showed an increasing trend with increasing holding time (Table 4.12). However the change for coated fruits at 3hr holding time showed a negative value (-0.16 ml/kg fruit) indicating a fall in the rate of change. The rate of change in the CO₂ production under ambient temperatures for coated and non coated fruits after 30 mins and 3 hr respectively were comparable (Figure 4.11A), but marked differences in the rate of change was observed after 24 hrs and 30 hrs (Table 4.12) and (Figure 4.11A).

Figure 4.12A shows that the respiratory activity followed a non climacteric pattern. This was characterised by a fall in the rate of respiration with increasing holding time (Table 4.12). This observation agrees with that reported by Baile and Young (1981) and the conclusion of Dull *et al.* (1967) who after studying pineapples harvested at different stages of growth and held at varying times concluded that the pineapple fruit exhibited a non-climacteric pattern of respiration.

Figure 4.11 Effect of fruit holding time on

A) CO₂ evolution

B) O₂ utilisation

C) N₂ residue of pineapple

held for 0.5, 3, 24 and 30 hrs

legend

0% = non coated fruit

5% = 5% coated fruit

A = ambient storage (23⁰C)

C = low temperature storage (8⁰C)

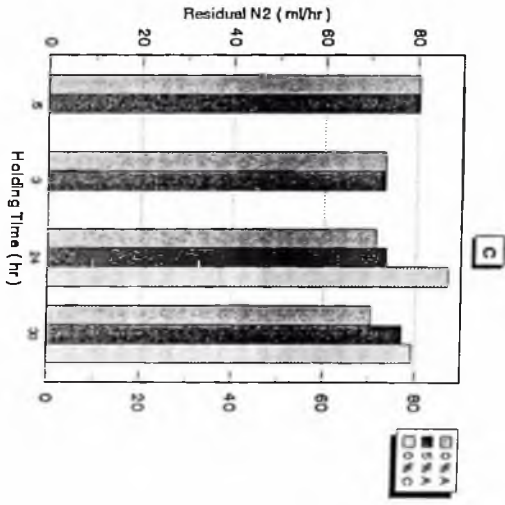
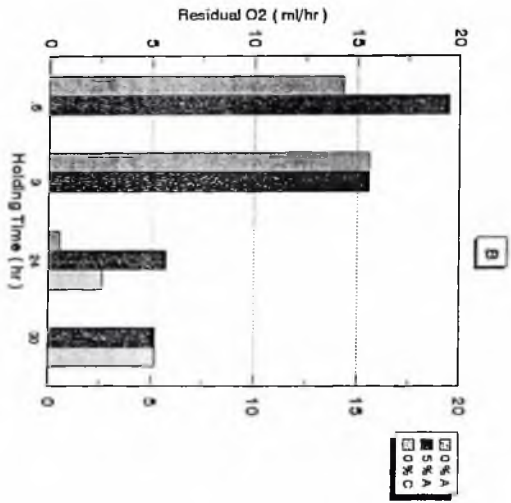
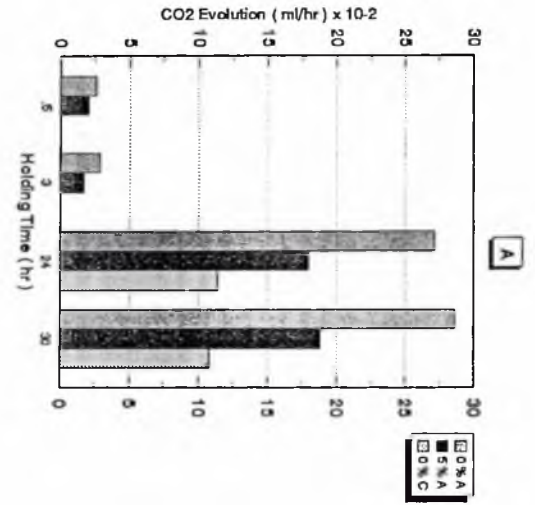


Table 4.13 The Effect Of Polymeric Coating, Holding Time And Storage**Temperature On O₂ Utilisation In Post-Harvest Pineapple.**

Holding Time (hr)	O ₂ utilisation (OU) (ml/kg fruit)			Change in OU (ml/kg fruit)		Rate of o ₂ utilisation (ml/kg/hr)		
	5% A	0%A	0%C	5% A	0%A	5% A	0%A	0%C
.5	9.85	7.29		0.00	0.00	19.7	14.58	
3	7.88	7.96		-1.97	0.67	2.63	2.65	
24	2.89	.26	1.33	-6.96	-7.03	0.12	0.01	0.6
30	2.63	.01	1.59	-7.22	-7.28	0.09	.0003	.05

5% = 5% Coating 0% = non-coating A = Ambient temperature C = Cold temperature

4.3.7 Rate of Respiration - O₂ Utilisation

The results of the study showed that there was a general decline in O₂ availability with increasing holding time (Table 4.13). O₂ levels were higher at all holding times for coated fruits than for non coated fruits at ambient temperature except after 3 hr of holding where non coated fruits showed higher O₂ availability. Available O₂ in the storage atmosphere dropped to 29.34% of the original value for coated fruits and to only 3.57% for non-coated fruits after 24 hr holding time at ambient temperature (Table 4.13). After 30 hr of holding, there was practically no O₂ available for non-coated fruits while coated fruits showed 26.7% available O₂ for utilisation (Table 4.13) and (Figure 4.11B).

Oxygen is required for normal respiration in fruits. The beneficial effects of low O₂ on fruits have been reported by Kader *et al.*(1989). However total O₂ depletion as observed for non-coated fruits in this study has a deleterious effect on storability and fruit quality. After 30 hr. of holding the pineapple shell showed moldiness and inconsistent ripening for both coated and non coated fruits. Non-coated fruit shell showed a more advanced moldiness and intense severity. Park *et al* (1993) reported anaerobiosis and accelerated decay in oxygen depleted chitosan coated tomatoes. The rate of O₂ respiration (Figure 4.12B) also showed a climacteric pattern for both coated and non-coated fruits. Available O₂ dropped with increasing holding time with the rate faster in non-coated fruit (Table 4.13).

4.3.8 Respiration Quotient and Residual Nitrogen

The respiration quotient (RQ) quantifies the variations due to the separate measurements of the CO₂ evolved or the O₂ consumed as respiration rate. RQ is a useful measure of the rate of respiration (Wills *et al*, 1989). The RQ is defined as

$$\frac{\text{CO}_2 \text{ Produced (ml)}}{\text{O}_2 \text{ consumed (ml)}}$$

The data obtained for the respiration quotient (Table 4.14) shows that there was not much change in the rate of respiration up to 3hrs of holding time for both coated and non-coated fruits. Although the rate of respiration was slightly higher for non-coated fruits (Table 4.14). However after 24hrs of holding time the RQ rose to 1.25 and

Table 4.14 The Effect Of Polymeric Coating, Holding Time And Storage**Temperature On The Respiration Quotient (RQ) Of Pineapple.**

Holding Time (hr)	Respiration Quotient	
	5%A	0 %A
.5	0.00	0.00
3	0.08	0.22
24	1.25	1.92
30	1.27	1.97

5% =5% Coating 0% = non-coating A = Ambient temperature C = Cold temperature

Table 4.15 The Effect Of Polymeric Coating, Holding Time And Storage**Temperature On N₂ In The Storage Atmosphere Of Post-Harvest Pineapple.**

Holding Time (hr)	N ₂ residue (ml/kg fruit)			Change in N ₂ residue (ml/kg fruit)	
	5% A	0%A	0%C	5% A	0%A
.5	40.58	40.99	-	0.00	0.00
3	36.98	37.36	-	-3.6	-6.3
24	37.18	36.35	44.43	-3.4	-4.64
30	38.98	35.86	40.39	-1.6	-5.13

5% =5% Coating 0% = non-coating A = Ambient temperature C = Cold temperature

Figure 4.12 The Effect Of Fruit Holding Time On

(A) Respiration Rate (CO₂ Evolution)

(B) Respiration Rate (O₂ Availability)

Of Coated And Non-Coated Pineapple

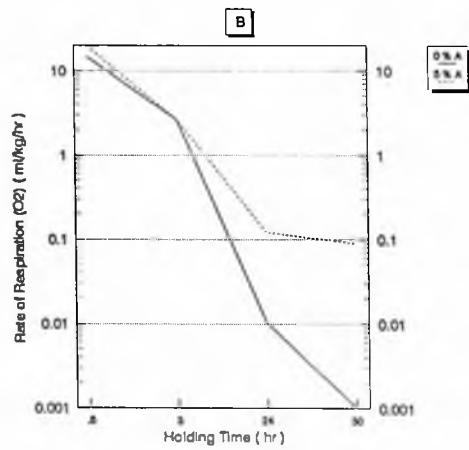
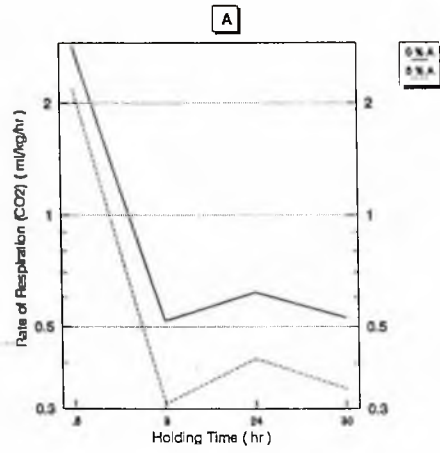
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0% = non coated fruit

5% = 5% coated fruit

A = ambient storage (23⁰C)

C = low temperature storage (8⁰C)



1.92 for coated and non coated fruits respectively at ambient temperature. 30 hrs of holding resulted in an elevation of the RQ for non-coated fruits to (1.97), while the value for coated fruits (1.25) was comparatively lower at ambient temperature.

Wills *et al* (1989) have indicated that the measurement of RQ gives some guide as to the type of substrate that is being respired. A low RQ suggests some fat metabolism and a high RQ suggests organic acids metabolism. They have also reported that complete oxidation of glucose gives an RQ of 1 whereas for malate RQ = 1.3. The results of the study on O₂ utilisation (Table 4.13) showed that by the 24 hr holding time, oxygen was virtually depleted in the storage environment of the non-coated fruit under ambient temperature. When the fruits were split after 30 hrs of holding time, they gave a fermented odour with a highly translucent basal section.. Thus the relatively higher RQ reported for non-coated fruits after 24hr agrees with the assertion by Wills *et al.* (1989) that a high RQ is generally indicative of fermentation reactions taking place in the fruit.

The importance of nitrogen in the storage atmosphere is to purge the oxygen available to low levels (Kader, 1980). The results of the study (Table 4.15) shows that Nitrogen levels showed a complete decline in all the treatments studied. The rate of change of N₂ residue showed a decreasing rate with increasing holding time for coated fruits and in increasing rate with increasing holding time for non-coated fruits at ambient temperature (Table 4.15) and (Figure 4.11C).



4.4 On the Post Low Temperature Storage (LTS) Behaviour of Pineapple.

4.4.1 The Effect Of Non-Isothermal Storage On The Physicochemical Quality Of Pineapple: Whole Fruit

4.4.1.1 Vitamin C

The vitamin C content of the pineapple fruit was influenced by the coating treatment and the interval for equilibrating the temperature after LTS. ANOVA on the data collected showed that the polymeric coating had a significant effect on the vitamin content after LTS (Table 4.16).

Mean separation revealed that fruits applied with polymeric coating at 5% concentration gave a higher mean vitamin C retention (14.54 mg/100g fruit) than non-coated fruits (10.6 mg/100g fruit) five days after LTS. (Table 4.17). Statistically, the level of fungicide applied to the fruit did not seem to influence the vitamin C content. However, photographic evidence from a longitudinal section of the fruit suggest that fungicidal application at 100 ppm (.1%) enhanced the predisposition of the fruit to internal browning with or without the polymeric coating (Figure 4.13A,B and C). The degree of internal browning has been linked to a lack of ascorbic acid concentration sufficient to counteract phenolic oxidation (Teisson, 1977). Figure 4.13A,B and C shows that 5% coating without fungicide was sufficient in counteracting any visible sign of

Table 4.16 ANOVA summary table (showing only F values of parameters evaluated)

Sources of variation	Astringency Index	Vitamin C	Sugar Content	Titrateable Acid	pH	Pulp Temperature
Polymeric Coating (PC)	1.18	13.30*	.261	.38	1.05	1.2
Fungicide (FL) (%)	2.68	1.02	1.1	.78	.5	4.8
Temperature Equilibration Interval (TEI)	17.46 *	18.06*	4.58	6.29	38.05*	1000.00*
PC X FL	0.01	1.5	.98	.07	.5	1.2
PC X TEI	2.13	3.25	1.72	1.14	6.08	2.2
FL X TEI	1.23	.18	1.01	.78	.82	.200

* means significant at $P \leq 0.05$

Value without (*) means effect was not significant at $P \leq 0.05$

Table 4.17 Summary of means (MRT (LSD))* for factors⁺ significantly affected by treatment

Treatment	Level	Astringency Index	Vitamin C	pH	Pulp Temperature
PC (%)	0		10.6a		
	5		14.54b		
TEI (days)	0	.087b	16.3b	3.46ab	8.7a
	4	.086b	15.00b	3.46a	28.12a
	7	.076a	10.77a	3.53b	28.02b
	10	.069a	8.22a	3.67c	28.15b

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

LSD - Least Significant Difference

Figure 4.13 Longitudinal sections of

- A) pineapple after 15 days of cold storage (8^o C)**
- B) pineapple after 10 days of cold storage and 5 days at ambient (28^oC)**
- C) pineapple after 10 days of cold storage and 2 days at ambient (28^o C)**

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide

A



W0F1

W0F0

W1F1

W1F0

B



W0F1

W0F0

W1F1

W1F0

C



W0F1

W0F0

W1F1

W1F0

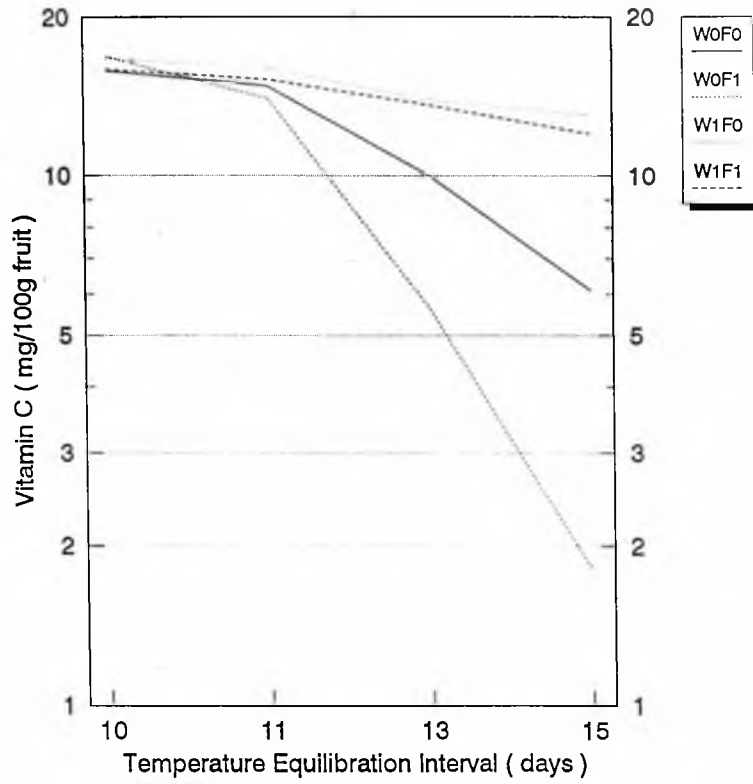
Figure 4.14 The effect of temperature equilibration interval on the vitamin c content of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide



internal browning 5 days after LTS. A plot of vitamin C content against temperature equilibrating interval (Figure 4.14) shows that vitamin C retention was better enhanced with polymeric coating than without. Non-coated fruits applied with or without fungicide had poor vitamin C retention with the effect showing increasing severity one day after LTS up to the fifth day. The duration taken to equilibrate fruits released from low temperature storage to ambient temperatures had a significant effect on the vitamin C content of the fruit. (Table 4.16).

Separation of means for the effect of the temperature equilibration interval (TEI) revealed that vitamin C content decreased with increasing equilibration interval. Statistically there was no significant difference between day 10 and 11 on the one hand and day 13 and 15 on the other hand. Thus the real difference in mean vitamin C content with respect to TEI can be attributed to the change in vitamin C content in day 11 and 13 (Table 4.17).



4.4.1.2 Titratable Acidity and Sugar Content

Analysis of variance of the data showed that the sugar content and titratable acidity was not influenced by any of the parameters studied (Table 4.16). However a noticeable decline in titratable acidity (Figure 4.15) was statistical not significant. Figure 4.16, However showed that not much difference existed in the sugar content.

Figure 4.15 The effect of temperature equilibration interval on the titratable acidity of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide

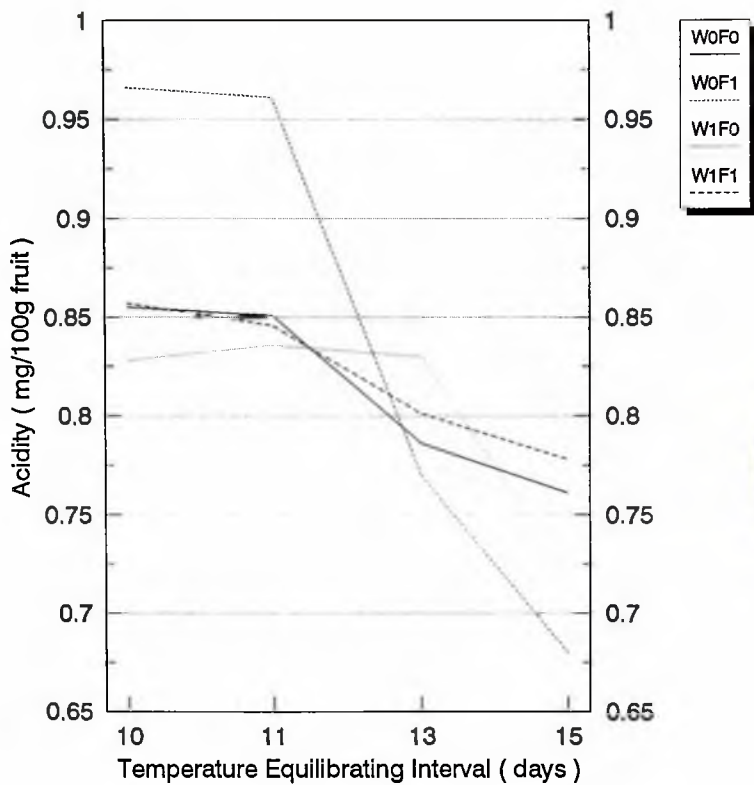


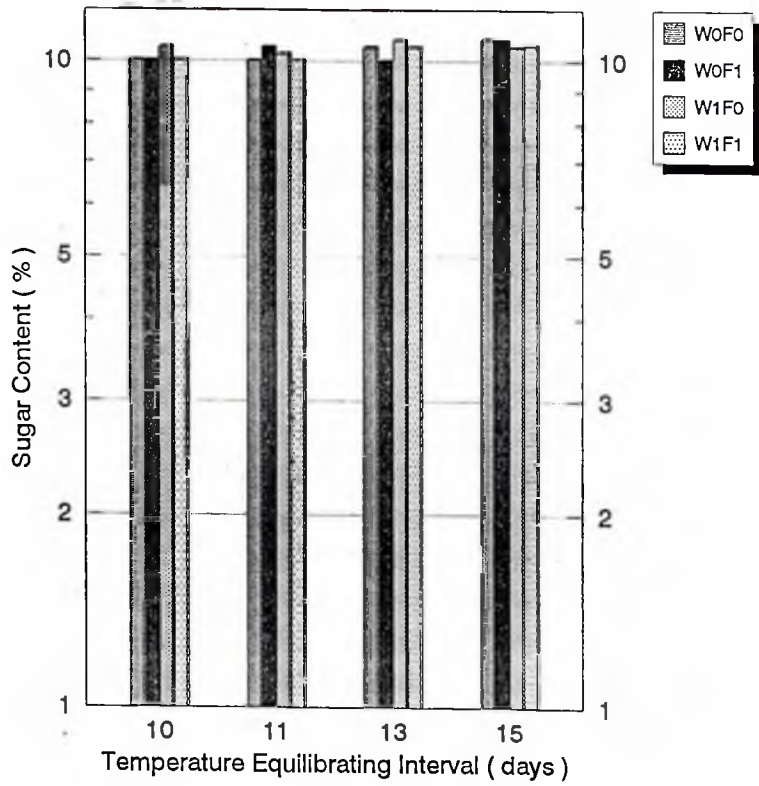
Figure 4.16 The effect of temperature equilibration interval on the sugar content of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide



4.4.1.3 Astringency Index (AI)

Astringency is an important parameter in the organoleptic properties of pineapple quality after low temperature storage (LTS) because of the tendency of pineapple to acidify during LTS (Teisson, 1979). Analysis of variance of the data collected showed that the temperature equilibration interval (TEI) had a significant effect on the astringency characteristic of the pineapple after LTS (Table 4.16). Multiple range analysis of the significance of TEI on astringency using the LSD revealed that as TEI increased fruits became less astringent (Table 4.17). The analysis also shows that there was no significant difference in the astringency index in fruits just removed from LTS (day 10) and one day after LTS (day 11). However, differences existed in day 11 and day 13 fruits, that is one day and three days after LTS but there was no significant difference in the day 13 and day 15 fruits. Thus the critical period for evaluating astringency in pineapple during this experiment appears to be between day 11 and day 13 after LTS. A plot of the Astringency Index against the Temperature Equilibration Interval (Figure 4.17) showed that fruits treated only with fungicide were the most astringent when fruit were released from LTS but lost astringency to become the least astringent after 5 days of LTS (day 15). The highest astringent fruits after day 15 were observed in fruits that had both the polymeric coating and fungicide.

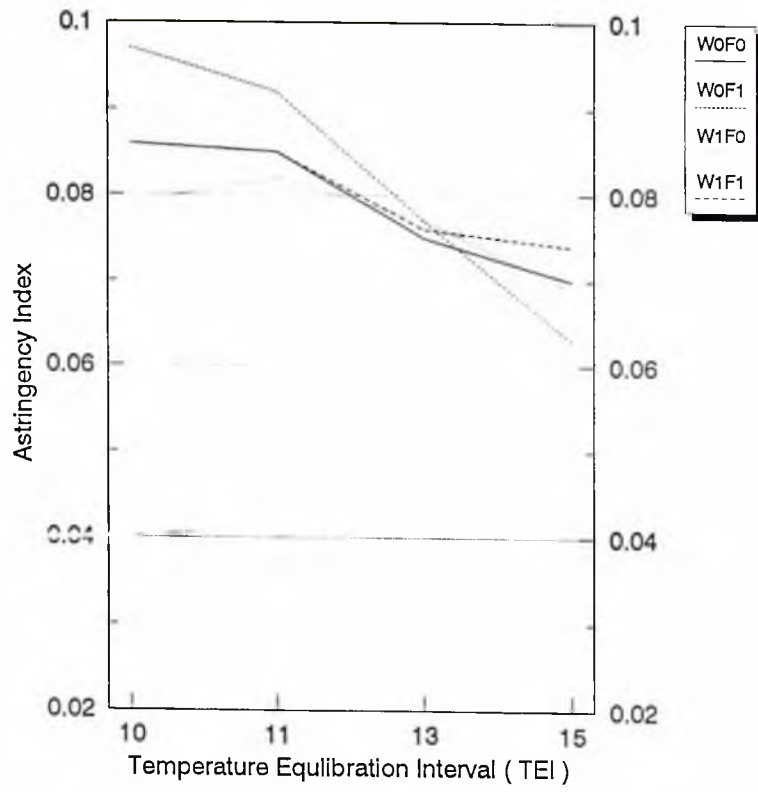
Figure 4.17 The effect of temperature equilibration interval on the astringency index of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide



4.4.1.4 pH and Pulp Temperature

The pH of the juice extracted from the fruit was influenced by TEI. Analysis of variance of the data showed that TEI had a significant effect on the pH (Table 4.16).

When means were separated (Table 4.17) for the effect of TEI on pH, it was observed that the pH increased with increasing TEI. However, there was non-significance in juice pH in day 10 and 11 (Table 4.17). This observation is important to the incidence and intensity of browning in pineapple flesh. The results of this study suggest that while vitamin C content decreased with TEI (Figure 4.14), the value of the juice pH increased with TEI (Figure 4.18). This suggest that the vitamin C content has an inverse relationship with pH. That is as pH Increased, vitamin C content decreased. Braverman (1963) observed that the reaction of ascorbic acid in fruit juices and concentrates is very much dependent on pH, as the browning process is inversely proportional to pH over a range of 2-4. The results of this study (Table 4.17) and (Figure 4.13) suggest that browning in pineapple flesh intensified with increasing pH.

The internal temperature of the fruit was influenced by the temperature equilibration interval (TEI). Analysis of variance of the data showed that TEI had a significant effect on the internal temperature of the fruit (Table 4.16).

Means separation revealed that the difference attributable to TEI could be explained by the differences in internal temperatures on day 10 (day fruits were released from cold store) and day 11 (one day after release) (Table 4.17) and (Figure 4. 19). This observation is not unexpected since pineapple fruit flesh is

thermosensitive (Bartholomew and Maliezies, 1994) and would acclimatise once it has been removed from cold store (8°C) to ambient temperatures ($28 \pm .3^{\circ}\text{C}$).

Figure 4.18 The effect of temperature equilibration interval on the juice pH of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide

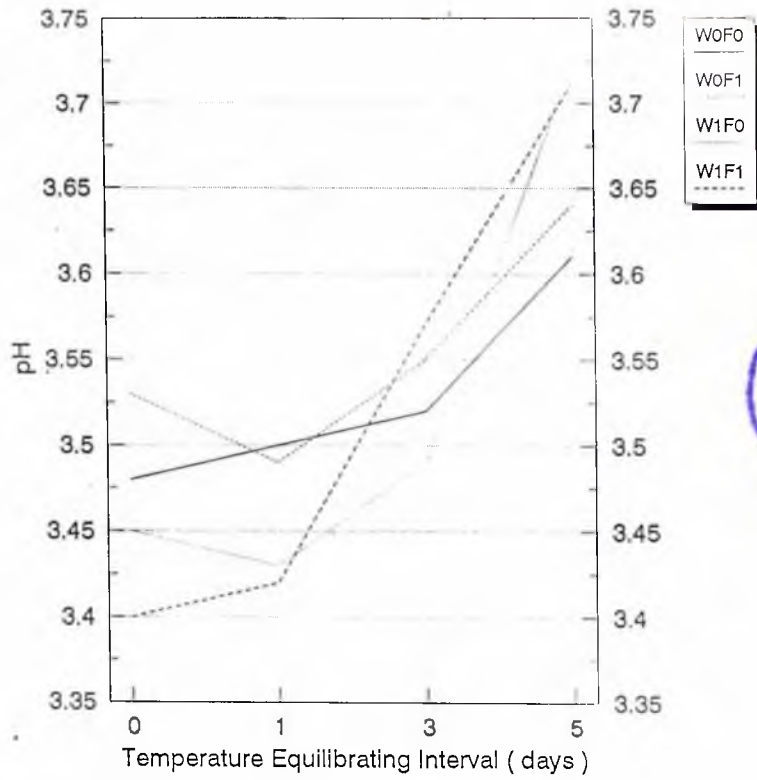


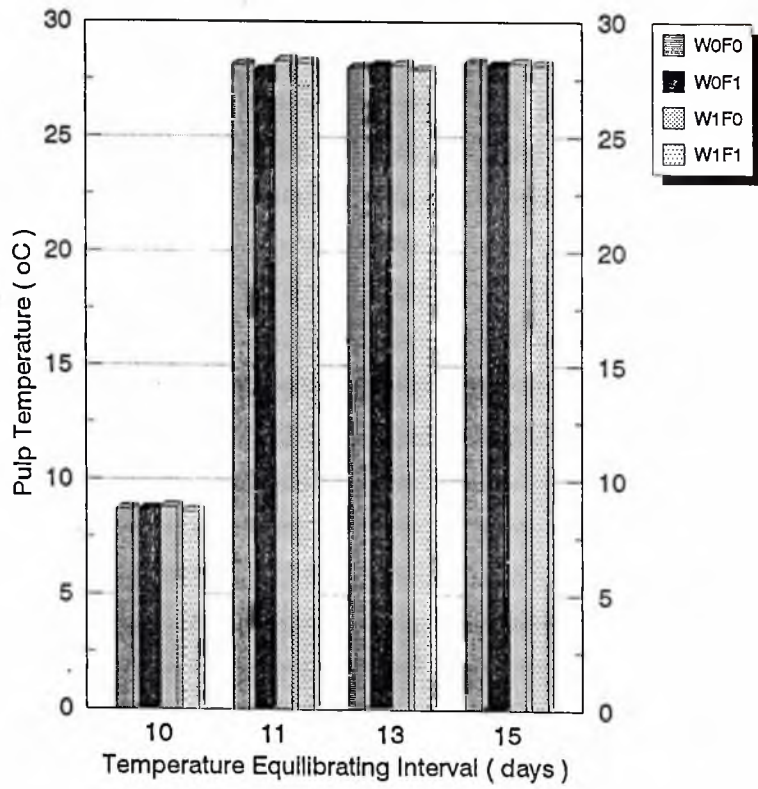
Figure 4.19 The effect of temperature equilibration interval on the pulp temperature of post low temperature stored pineapple.

W0F0 = no polymeric coating no fungicide

W0F1 = no polymeric coating but with fungicide

W1F0 = polymeric coating but no fungicide

W1F1 = polymeric coating with fungicide



4.4.2 The Effect Of Non-Isothermal Storage On The Physicochemical Quality Of Pineapple: Apical , Mid And Basal Sections Of Fruit

4.4.2.1. Browning Index

The internal browning of the fruit was affected by the section of the fruit evaluated, the level of coating applied and the temperature equilibration internal (TEI) Analysis of variance of the date (Table 4.20) indicates that there was a significant effect of the fruit section, polymeric coating and TEI on the index of browning of the pineapple fruit.

Mean separation for the effect of section on the browning index showed that browning was most intense at the mid section (355.87) and least intense at the apical section (159.39) please refer (Table 4.21) and (Figure 4.20 and 4.21). Internal browning appears to be characterised by the destruction of the ascorbic acid present in the fruits and is indicated by the darkening of the flesh of fruitlets, beginning near the attachment to the core in a region an inch or two above the base of the fruit (Kay, 1965). This assertion by Kay is similar to the observations made in this study, although other workers (Py *et al*, 1987 and Smith 1983) have reported initiation of internal browning at the base. What remains unclear is probably the definition of “the base”. Most researchers divide fruits transversally into two halves with the lower half referred to as the base.

Means separation for the effect of polymeric coating also showed that coating at 5% level was significant (142.42) in reducing internal browning as compared to non-coated fruits (362.58) (Table 4.21). Since internal browning in pineapple is enhanced by the oxidative destruction of ascorbic acid, it is probable that the reduced



permeability of the fruit caused by the coating might have reduced the rate of oxidative destruction of ascorbic acid in coated fruits.

Again separation of means showed that the effect of the temperature equilibration interval on the browning index of pineapple was such that browning intensified with increasing equilibration interval (Table 4.21).

The intensity of browning with increasing temperature equilibration fitted by simple linear regression models are presented below.

Table 4.18 Linear Regression Models For The Effect Of TEI On Browning Intensity Of Coated And Non-Coated Pineapple At The Apical, Mid And Basal Section Of The Fruit.

Fruit Section	Level of Coating(%)	Model	Correlation Coefficient	R ² (%)	F - Ratio
Apical	0	Y=193.7+5.2X	0.995	99.01	401.9**
	5	Y=85.9+5.2X	0.998	99.55	885.4**
Mid	0	Y=506.5+21.3X	0.854	72.89	10.7*
	5	Y=111.9+5.37X	0.975	95.03	76.4**
Base	0	Y=286.4+2.85X	0.996	99.31	576.6**
	5	Y=179+3.07X	0.997	99.53	840.4**

* = Significant at p<0.05
Y = Browning Index

** = Significant at <0.01
X = Temperature Equilibration Interval

In all the models generated, Temperature Equilibration Interval had a significant and positive correlation with browning index in all the fruit sections irrespective of the level of coating. Correlation coefficient was highest (0.998) in the apical section of the fruit at 5% level of coating and least (0.854) in non-coated fruits at the mid section of the fruit. All the models had high R² values and with the exception of non-coated fruits at the mid section (72.89%) all the other models could explain over 95% of variations in the models (Table 4.18).

Fig. 4.20 **The Intensity Of Browning Of Pineapple Juice Extracted From The Apical, Mid And Basal Sections Of The Fruit 7 Days Post Low Temperature Storage (8oC)**

A = Apical Section

M = Mid Section

B = Basal Section

0 = Non - coated fruit

5 = 5% coated fruit

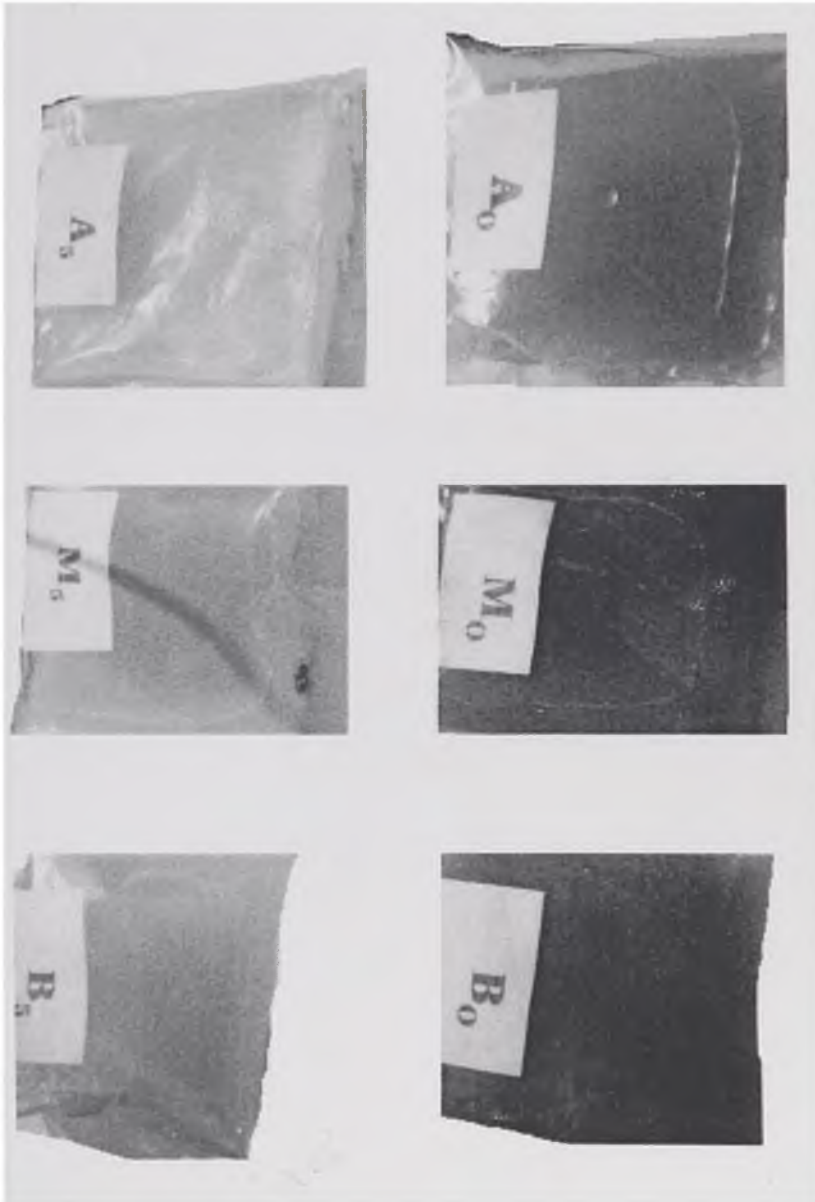


Figure 4.21 The Effect Of Temperature Equilibrating Interval On

The Internal Browning Of

A) Apical

B) Mid

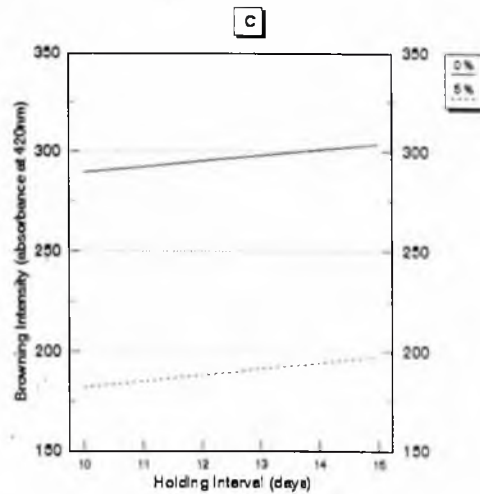
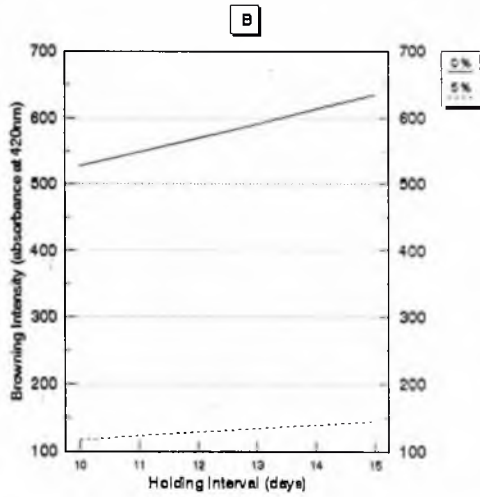
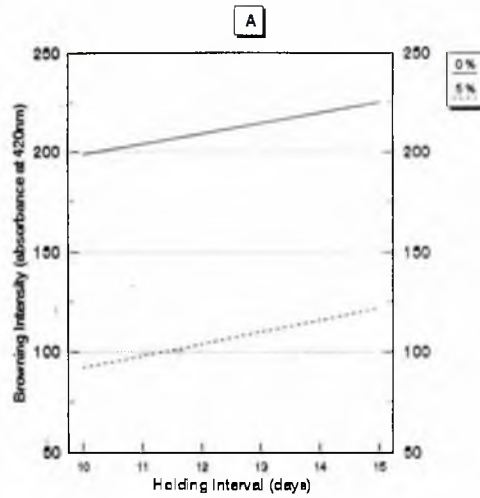
C) Basal

sections of the pineapple fruit after 0,1,2,3,4,and 5 days after cold storage(8°C).

legend

0% = Non Coated Fruit

5% = 5% Coated Fruit



4.4.2.2. Firmness Retention

The texture (firmness) of horticultural crops is an important determinant of its quality and is a major factor in stress management during handling and shipping of horticultural crop.

The analysis of variance of the results (Table 4.20) shows that the ability of the pineapple fruit to maintain firmness was significantly influenced by the section of the fruit investigated, whether fruits were coated or non-coated and the temperature equilibration interval (TEI).

Mean separation for the effect of fruit section on firmness of the fruit showed that as evaluation moved from the apical section of the fruit to the basal section, fruit firmness was significantly lost (Table 4.21). Mean fruit firmness was highest (4.34kg) in the apical section, followed by 3.22kg in the mid section and least (1.65kg) in the basal section.

Again Mean separation also revealed that coated fruits were significantly firmer (3.25kg) than non-coated fruits (2.89kg) (Table 4.21) and the effect was pronounced as you moved from the apical to the basal section (Figure 4.22). El-Ghaouth *et al.* (1992) have reported that the retention of firmness as a result of coating is generally explained by the modification of the endogenous levels of CO₂, O₂ and C₂H₄ which influences changes in the cell wall.

In an earlier study (section 4.3) it was observed that non-coated fruits under ambient temperature storage (23°C) showed higher CO₂ evolution than coated fruits .

Separation of mean for the effect of TEI (Table 4.21) on firmness also showed that firmness was lost with increasing temperature equilibration interval (Figure 4.22).

**Figure 4.22 The Effect Of Temperature Equilibrating Interval On
The Firmness Retention Of**

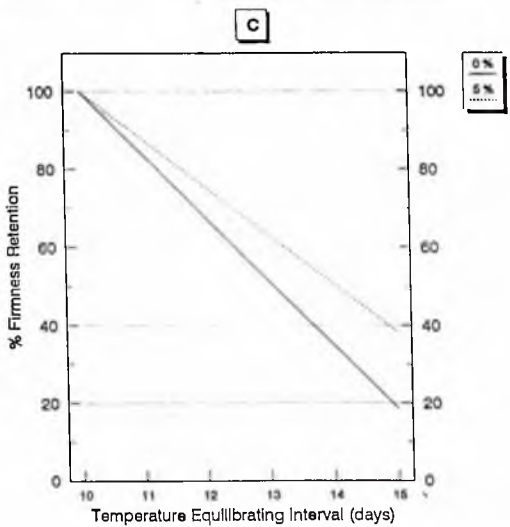
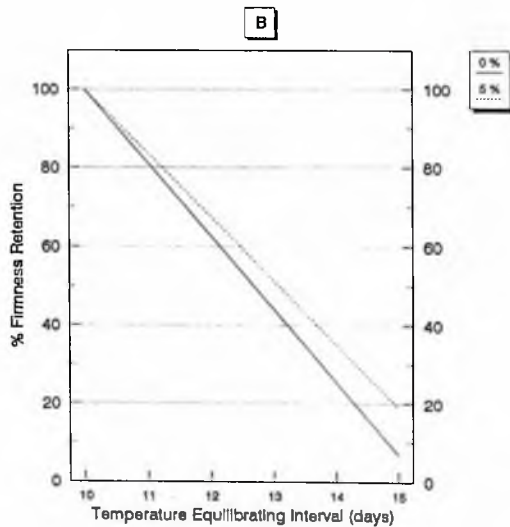
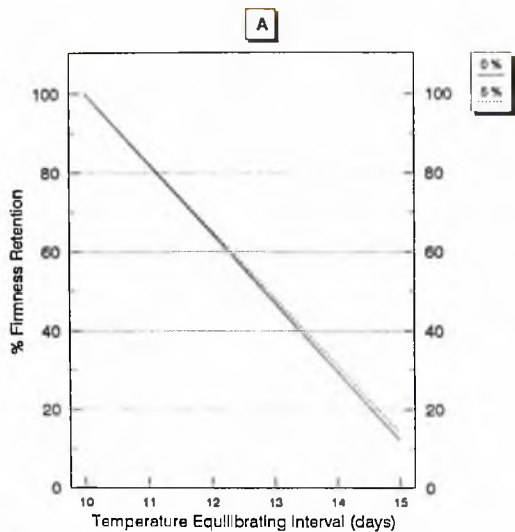
- A) Apical**
- B) Mid**
- C) Basal**

sections of the fruit after 0,1,2,3,4,and 5 days after cold storage(8°C).

legend

0% = Non Coated Fruit

5% = 5% Coated Fruit



Firmness retention with increasing TEI was fitted with simple linear regression models and are presented in Table 4.19.

Table 4.19 Linear Regression Models For The Effect Of TEI On Firmness Retention Of Coated And Non-Coated Pineapple At The Apical, Mid And Basal Section Of The Fruit.

Fruit Section	Level Of Coating(%)	Model	Correlation Coefficient	R ² (%)	F - Ration
Apical	0	$Y = 8.69 - 1.30X$	- 0.978	95.78	90.99**
	5	$Y = 9.4 - 1.39X$	- 0.983	96.61	113.97**
Mid	0	$Y = 6.82 - 1.07X$	- 0.962	92.50	49.33*
	5	$Y = 6.61 - .92X$	- 0.940	88.53	30.87*
Base	0	$Y = 2.86 - 0.4X$	- 0.995	99.10	442.10**
	5	$Y = 3.01 - 0.34X$	- 0.947	89.79	35.18**

* = Significant at < 0.05

Y = Firmness retention

** = Significant at p< 0.01

X = Temperature Equilibration Interval

4.4.2.3. Internal Temperature

The ANOVA summary table (Table 4.20) shows that the internal fruit temperature was significantly affected by all the parameters studied. There was also significant interaction between all the parameters. Thus suggesting that there was interdependence of the effect of fruit section, level of coating and temperature equilibration interval on the internal fruit temperature.

Mean separation (Table 4.21) shows that the effect of fruit section on internal fruit temperature was characterised by the basal section showing the highest mean fruit temperature (26.61 °C) followed by the mid section (26.44 °C) and then the apical section (26.37 °C). Statistically, there was no difference in internal fruit temperature

Table 4.20 ANOVA Summary Table (Showing Only F Values Of Parameters Evaluated)

Sources of variation	Sugar Content	Pulp Temperature	pH	Browning Index	Firmness Retention
Section (S)	184.77**	14.86*	17.91*	476.76**	552.66**
Polymeric Coating (PC)	.77	113.36**	9.45*	1000.00**	30.64*
Temperature Equilibration Interval (TEI)	33.8*	1000.00**	107.62**	5.09*	454.51**
PC X S	.63	6.0*	4.7*	486.93**	.22
S X TEI	2.02	3.17*	.76	1.34	47.49*
PC X TEI	1.21	18.61*	6.5*	85	1.03

* means significant at $P \leq 0.05$ ** means significant at $P \leq 0.01$

Value without (*) means effect was not significant at $P \leq 0.05$

Table 4.21 Summary Of Means (MRT (LSD))^{*} For Factors⁺ Significantly Affected By Treatment

Treatment	Level	Sugar Content	Pulp temperature	pH	Browning Index	Firmness Retention
Section of Fruit	Apical	9.99a	26.37a	4.11a	159.39a	4.34c
	Mid	13.09b	26.44a	4.30b	355.87c	3.22b
	Base	14.53c	26.61b	4.30b	242.26b	1.65a
PC (%)	0	-	26.28a	4.28b	362.58b	2.89a
	5	-	26.67b	4.19a	142.42a	3.25b
TEI (days)	10	14.10c	8.52a	3.73a	228.23a	5.01e
	11	14.37c	30.12cd	3.79a	244.62ab	4.58d
	12	12.31b	30.08cd	4.46b	253.05bc	4.05c
	13	12.12b	30.02bc	4.49b	255.56bc	2.57b
	14	11.39ab	30.20d	4.51b	263.35bc	1.19a
	15	10.96a	29.92b	4.44b	268.17c	1.02a

* means with the same letters within the columns of a treatment are not significantly different at $P \leq 0.05$

+values for factors shown in the table represents means of four treatments each with two replicates.

MRT - Multiple Range Test

LSD - Least Significant Difference

between the mid and the apical sections (Table 4.21). The observation that the basal section of the fruit showed the highest mean fruit temperature is important physiologically and probably accounts for the initiation of ripening, shell colour break, the high sugar content and relatively high loss of firmness that has been observed at the basal section of the fruit. Physical, chemical, physiological and metabolic changes in plant life are driven by enzymatic activity that is temperature dependent.

Mean separation (Table 4.21) shows that coated fruits had a significantly higher mean fruit temperature (26.67°C) than non-coated fruit (26.28°C).

Temperature equilibration interval as revealed by mean separation (Table 4.21) had significant effect on the internal fruit temperature. From day 10 (day of release from cold storage) when mean fruit temperature was 8.52°C the value rose in subsequent days up to day 15 (last day of evaluation) with mean temperatures ranging between 29.92 - 30.20 °C.

4.4.2.4. Sugar Content

The ANOVA summary table (Table 4.20) shows that significant differences exist between the different fruit section and the TEI on the sugar content of the pineapple.

The basal section as observed by mean separation (Table 4.21) had the highest mean sugar content (14.53%) followed by the Mid section (13.09%) and then the apical section (9.99%). This observation agrees with the finds of Dull (1971) who reported that the sugar content of pineapple decreased as you move from the base to the region below the crown (apex).



Increasing TEI as observed from mean separation (Table 4.21), resulted in decreasing mean sugar content. Pineapple fruit contains fermentable sugars (glucose, fructose and sucrose) that are active in fruit respiration (Dull *et al*, 1967) and are easily oxidised in the presence of oxygen to carbon dioxide and water, with the production of adenosine triphosphate (ATP) (ap Rees, 1974). This probably accounts for the decreasing sugar content with increasing TEI.

4.4.2.5. pH

Analysis of variance of the data (Table 4.20) showed that the pH of the juice extract was significantly affected by the section of the fruit evaluated, the level of coating applied to the fruit and the interval given for temperature equilibration.

Mean separation for the effect of fruit section on pH showed that the apical section had a lower mean pH value (4.11) than the mid and basal sections (Table 4.21). However, there was no difference in treatment mean between the mid and basal sections (Table 4.19).

5% fruit coating as revealed by mean separation was significant in presenting a mean fruit pH of 4.19 as compared to 4.28 in non-coated fruits.

Mean separation for the effect of TEI on pH showed a generally increasing pH with increasing TEI although day 15 showed a drop in pH. The trend was such that the real difference in pH can be attributed statistically, to the difference in pH between day 11 and day 12 (Table 4.21)

4.5 Studies On The Peroxidase Activity In Post-Harvest Pineapple

Ghanaian pineapples have high premium on the world pineapple trade because of its unique flavour, texture and colour attributes (Obu, 1996).

Peroxidase have been implicated in deteriorative changes in flavour, texture, colour and nutrition both in raw foods such as fruits and vegetables and in processed products (Burnette, 1977).

This study was conducted to investigate the contribution of peroxidase to deteriorative changes in post-harvest pineapple. The study was conducted in two parts.

Part one - deals with optimisation of the conditions for determining peroxidase activity in the pineapple fruit using the central composite rotatable design (CCRD)

Part two - this study looked at the effect of fruit coating and thermal conditioning on the peroxidase activity in pineapple.

4.5.1 Optimisation Of A Method For Determining Peroxidase Activity

Using The CCRD

The Central Composite Rotatable design (CCRD) was used with three factor combinations. The factors used were:

1. substrate (3,3'-dimethoxybenzidine) concentration (%)
2. pH of the buffer (Sodium acetate)
3. peroxide (H_2O_2) concentration (%)

The study was conducted on three sections of the fruit: the apical, mid and basal sections.

The results are presented in Table 4.22 at the end of this section.

4.5.1.1. Peroxidase Activity

The results of the study (Table 4.22) and the response surface plots (Figure 4.23, 24 and 25) demonstrates that the basal section of the fruit gave the highest response to peroxidase activity under the various treatment combinations. Peroxidase activity declined as you move from the basal to the apical section of the fruit. There was a direct relationship between pH or the juice extract from the various sections and peroxidase activity. The higher the pH of the juice extract the higher the peroxidase activity measured. Thus as pH of the juice extract decrease as you moved from the basal section of the fruit to the apical section of the fruit so did the activity (Table 4.22).

4.5.1.1.1. Effect Of pH And Substrate Concentration

Mathematical models generated from stepwise regression analysis on the data (Table 4.23) and the response surface plots (Figure 4.23) of the sections of the fruit showed a similar trend. When the pH of the buffer was low (2.5 to about 4) increasing the substrate concentration from (0-0.5%) gave zero or negligible response to peroxidase activity. However, when pH was increased beyond 4 up to 6 there was a rapid response to peroxidase activity with increasing substrate concentration. Figure 4.23A, B and C demonstrates that the optimum response to peroxidase activity seem to lie at pH 6 and 0.45% substrate concentration. Ketmasha and Metche (1988) reported 5.4 as optimum pH in haricot seed peroxidase, while Soler (1995) working with guaiacol as substrate reported 6.5 as optimum for pineapple peroxidase. The highest response to peroxidase activity was observed in the basal section of the fruit.



Table. 4.22 Optimisation Results Showing Factor Combinations And The Peroxidase Activity* In The Apical , Mid And Basal Section Of The Fruit.

O-dianisidine Concentration (%)	pH	H ₂ O ₂ (%)	Apical Section	Mid Section	Basal Section
0.1	3.6	0.05	.1	.24	0.08
0.1	5.4	0.2	4.02	2.5	4.46
0.4	3.6	0.2	.2	.23	.26
0.4	5.4	0.05	4.44	4.47	4.56
0.25	4.5	0.125	0.21	.28	0.36
0.25	4.5	0.125	0.23	.27	0.33
0.1	3.6	0.2	0.16	.14	0.48
0.1	5.4	0.05	2.9	2.92	3.24
0.4	3.6	0.05	0.19	.24	0.29
0.4	5.4	0.2	4.59	5.51	6.53
0.25	4.5	0.125	0.12	0.09	0.35
0.25	4.5	0.125	0.19	0.28	0.3
0.5	4.5	0.125	0.79	1.17	3.57
0.0	4.5	0.125	0.15	0.08	0.26
0.25	6	0.125	0.6	4.46	5.88
0.25	3	0.125	0.18	0.17	0.06
0.25	4.5	0.25	0.15	0.1	0.21
0.25	4.5	0.0	0.06	0.08	0.04
0.25	4.5	0.125	0.24	0.38	0.53
0.25	4.5	0.125	0.21	0.27	0.3

* activity = increase in light absorbance (A)/min/g weight

Table 4.23 Model Fitting Results Showing Coefficients Of The Variables In The Model

Variable	Base	R ²	Mid	R ²	Apex	R ²
B ₀	20.83	-	17.49	-	-1.66	-
X ₁	-23.85*	.10305	-	-	-	-
X ₂	-10.36*	.08594	-8.75*	.12033	-	-
X ₃	-	-	-28.54	.00896	-29.88*	.048
X ₁ ²	28.11*	.03335	6.18*	.06535	4.36	.03351
X ₂ ²	1.30*	.69045	1.09*	.68094	.159*	.43822
X ₃ ²	26.85*	.02489	58.64	.02038	148.05	.09624
X ₁ X ₂	3.15	.01588	-	-	-	-
X ₁ X ₃	-	-	4.17	.01229	-	-
R ²	-	.95356	-	.90825	-	.616009

X₁ = Substrate Concentration X₂ = pH X₃ = H₂O₂

Bo = Constant

* = Significant at $p \leq 0.05$ 

Figure 4.23 Response surface plot showing the effect of pH and substrate concentration on the peroxidase activity of the

A) Apical ($Z = -5.322 + 1.626X_1 + 1.3311X_2$)

B) Mid ($Z = -7.605 + 3.18X_1 + 1.1799X_2$)

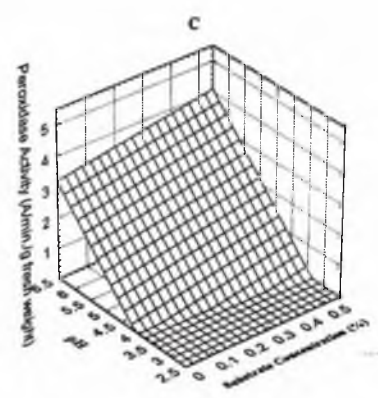
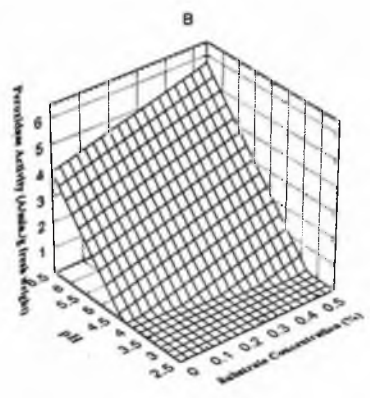
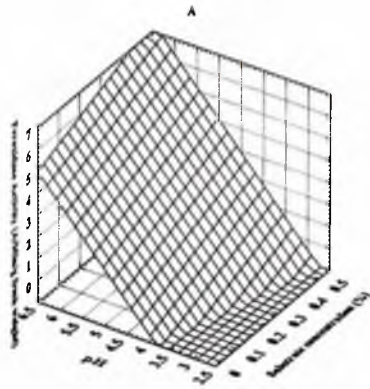
C) basal ($Z = -9.589 + 4.375X_1 + 2.244X_2$)

section of the pineapple fruit.

Z= peroxidase activity

X₁=substrate concentration

X₂ = pH



4.5.1.1.2 Effect Of H₂O₂ And pH

Table 4.23 and the response surface plots (Figure 4. 24A) show that at the apical section of the fruit, increasing the H₂O₂ concentration from 0 to 0.15% had an inhibitory effect on the peroxidase activity when pH levels were low (2.5 - 4). Beyond 0.15% concentration increasing H₂O₂ generally had an increasing effect on peroxidase activity. Again at all H₂O₂ concentrations, increasing the pH had an increasing effect on peroxidase activity. At the apical section the optimum response to peroxidase activity was observed at about 0.25% H₂O₂ concentration and pH of 6.

At the mid section of the fruit the response surface plot (Figure 4.24B) indicates that increasing the H₂O₂ concentration had little or no effect on the peroxidase activity. However, increasing pH up to 4 at all H₂O₂ concentration had an inhibitory effect on peroxidase activity. Beyond pH 4, increasing pH had a rapidly increasing effect on peroxidase activity up to pH of about 6. Beyond pH 6 the activity remained the same. Optimum activity at the mid section was observed at pH 6 and .28% H₂O₂ concentration.

At the basal section the models generated (Table 4.23) and the response plot (Figure4.24C) show that at low pH (up to 3) increasing H₂O₂ concentration had an inhibitory effect on peroxidase activity. Summer and Gjessing (1943) have shown that excess H₂O₂ has an inhibitory effect on peroxidase activity. However, in this study this trend was reversed beyond pH 3.5 where increasing H₂O₂ concentration had an increasing effect on the peroxidase activity. As observed in the other fruit sections, increasing pH initially had an inhibitory effect on the peroxidase but was reversed beyond pH 4 to about 6. The optimum response to peroxidase activity was observed at pH of about 6 and H₂O₂ concentration of about 0.20%.

Figure 4.24 Response surface plot showing the effect of H₂O₂ and pH concentration on the peroxidase activity of the

A) Apical ($Z = 6.605 - 21.921X_1 - 3.453X_2 + 53.546X_1^2 + 2.22X_1X_2 + 0.499X_2^2$)

B) Mid ($Z = 16.44 - 10.709X_1 - 8.58X_2 + 20.641X_1^2 + 1.352X_1X_2 + 1.32X_2^2$)

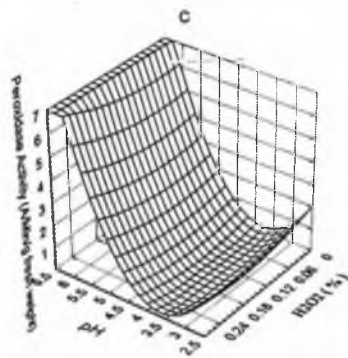
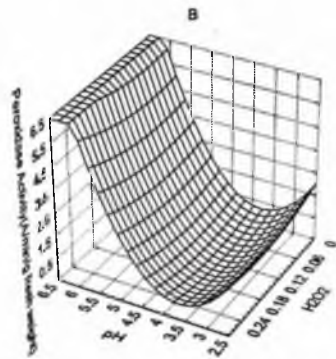
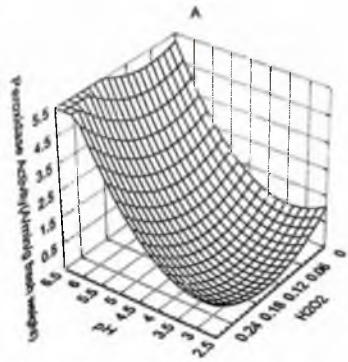
C) basal ($Z = 19.004 - 19.927X_1 - 9.84X_2 + 0.83X_1^2 + 5.22X_1X_2 + 1.27X_2^2$)

section of the pineapple fruit.

Z = peroxidase activity

X₁ = H₂O₂

X₂ = pH



4.5.1.1.3 Effect Of H₂O₂ And Substrate Concentration

Response surface plot (Figure 4.25A) shows that at the apical section, when substrate concentration was low (0 - 0.25%), increasing the H₂O₂ concentration up to about 0.15% did not result in any noticeable change in peroxidase activity. Increasing the H₂O₂ concentration beyond 0.15% resulted in an increase in peroxidase activity. Irrespective of the H₂O₂ concentration increasing the substrate concentration up to .25% seem to have an inhibitory effect on peroxidase activity. However, increasing beyond 0.25% substrate concentration resulted in an increase in peroxidase activity. Again at the apical section three high peaks (peroxidase activity) were observed: at high H₂O₂ concentration (0.25%) and low substrate concentration 0.05%; high H₂O₂ concentration (0.25%) and high substrate concentration (0.5%); at low H₂O₂ concentration (0.05) and high substrate concentration (0.5%). The highest activity however, was observed at low H₂O₂ (0.05%) and high substrate concentration (0.5%).

At the mid section the response surface plot (Figure 4.25B) shows that at low substrate concentration, increasing H₂O₂ has an inhibitory effect on peroxidase activity while at high substrate concentration (0.5%) increasing H₂O₂ has an increasing effect on the peroxidase activity. Increasing substrate concentration generally had an increasing effect on peroxidase activity and the effect was more pronounced at high H₂O₂ concentration. The maximum response to peroxidase activity was observed at H₂O₂ concentration of 0.25% and substrate concentration of 0.5%.

At the basal section irrespective of the substrate concentration employed the response plot (Figure 4.25C) shows that increasing the H₂O₂ concentration had an increasing effect on the peroxidase activity. At all H₂O₂ concentration increasing the substrate concentration initially had an inhibitory effect on peroxidase activity but beyond 0.25% to 0.5% substrate concentration, peroxidase activity increased rapidly.

Figure 4.25 Response surface plot showing the effect of H_2O_2 and substrate concentration on the peroxidase activity of the

A) Apical ($Z = 1.595 - 9.204X_1 - 6.629X_2 + 54.011X_1^2 - 11.333X_1X_2 + 19.34 X_2^2$)

B) Mid ($Z = 1.53 - 6.472X_1 - 4.603X_2 + 10.803X_1^2 + 17.222X_1X_2 + 11.261 X_2^2$)

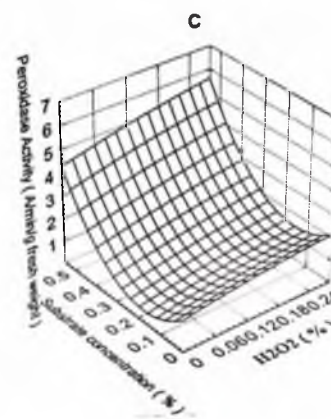
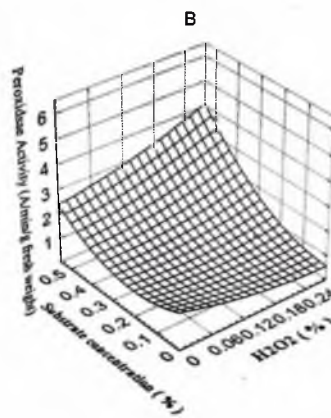
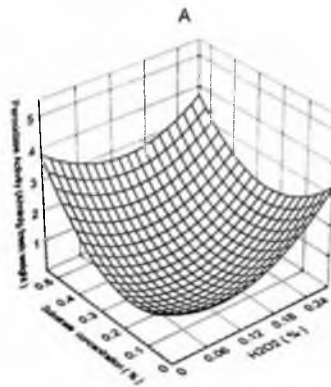
C) Basal ($Z = 1.377 + 4.219X_1 + 9.725X_2 - 5.312X_1^2 + 3.556X_1X_2 + 27.312 X_2^2$)

section of the pineapple fruit.

Z = peroxidase activity

X_1 = H_2O_2

X_2 = substrate concentration



4.5.2 Effect Of Polymeric Coating On Peroxidase Activity

4.5.2.1 Thermal Conditioning At 22 °C

The results of the study showed that when pineapple fruit were thermally conditioned at 22 °C, non-coated fruit showed a higher peroxidase activity than coated fruits irrespective of the time allowed for the reaction to proceed (Table 4.24).

Increasing the reaction time had an increasing effect on peroxidase activity although the activity per minute decline with increasing reaction time (Table 4.25).

The highest overall activity per minute was observed in non coated fruits when activity was determined after 2 min. of reaction time. The lowest overall activity was observed in juice extract from coated fruits when activity was determined after 6 min. of reaction time (Table 4.24).

4.5.2.2 Thermal Conditioning At 30 °C

30 °C thermal conditioning resulted in a noticeable decline in peroxidase activity per minute (PAM) in both coated and non-coated fruits when activity was measured after 2 min. of reaction time (Table 4.24) and (Figure 4.26A).

However when activity was measured after 4 min. of reaction time there was a noticeable upsurge in PAM for coated fruits as compared to the same treatment observed in fruit conditioned at 22 °C. However, non-coated fruit continued to show a decline in activity over similar treatment conditioned at 22 °C (Table 4.25) and (Figure 4.26B). A similar trend was observed when reaction time was allowed to proceed for 6 min. although the overall activity decreased with increasing reaction time (Figure 4.26C).

Table 4.24 Effect Of Thermal Conditioning And Reaction Time On Peroxidase Activity Of Coated And Non Coated Pineapple

Reaction Time (min.)	Conditioning Temperature					
	22 °C		30 °C		45 °C	
	0%C	5%C	0%C	5%C	0%C*	5%C*
2	6.4	5.57	4.75	4.9	4.94	5.38
4	7.67	7.31	7.2	7.65	5.98	7.65
6	8.64	7.52	8.25	8.84	7.35	8.84

Table 4.25 Effect Of Thermal Conditioning On Peroxidase Activity Per Minute Of Reaction Time Of Coated And Non Coated Pineapple

Reaction Time (min.)	Conditioning Temperature					
	22 °C		30 °C		45 °C	
	0%C	5%C	0%C	5%C	0%C	5%C
2	3.2	2.785	2.375	2.45	2.47	2.69
4	1.917	1.827	1.8	1.912	1.495	1.912
6	1.44	1.253	1.375	1.473	1.225	1.473

Table 4.26 Effect Of Thermal Conditioning And Reaction Time On % Loss In Peroxidase Activity Of Coated And Non Coated Pineapple

Reaction Time (min.)	0 % C			5 % C		
	22 °C	30 °C	45 °C	22 °C	30 °C	45 °C
2	0	26	23	0	12	3
4	0	6	22	0	-4	-4
6	0	5	15	0	-18	-18

*0%C = non coated fruit

*5% C = 5% coated fruit

Figure 4.26 **Effect Of Thermal Conditioning On Peroxidase
Activity Of Coated And Non-Coated Pineapple At**
A) 2 minute
B) 4 minute
C) 6 minute
Of Reaction Time

legend

0%C = Non Coated Fruit
5%C = 5% Coated Fruit

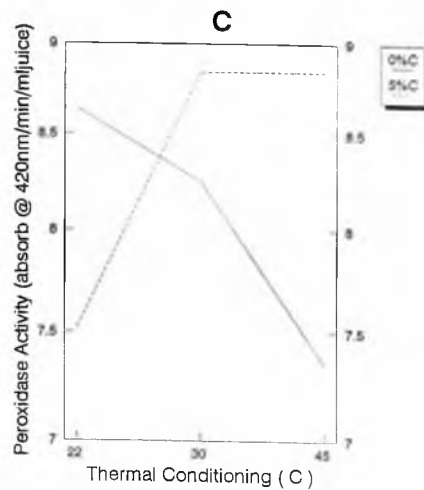
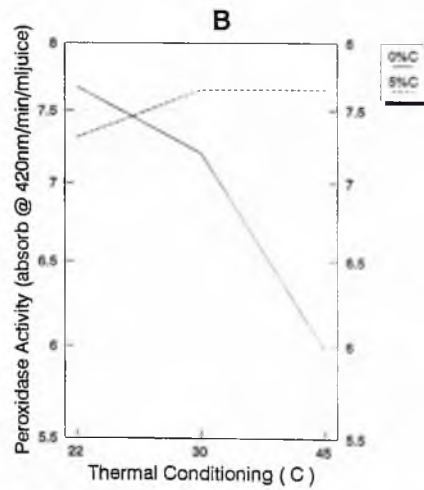
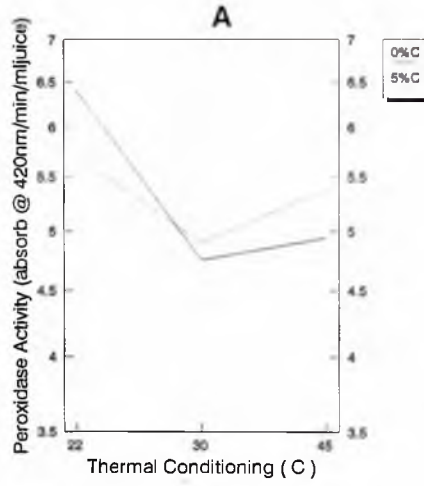


Figure 4.27 **Effect Of Thermal Conditioning On % Loss In Peroxidase
Activity Of Coated And Non-Coated Pineapple At**

A) 2 minute

B) 4 minute

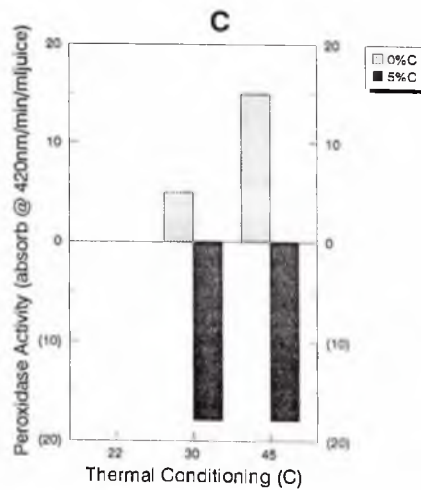
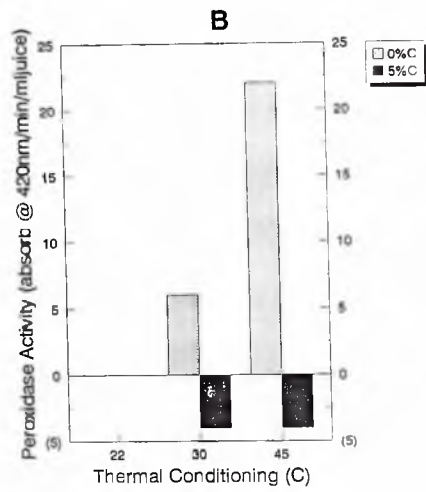
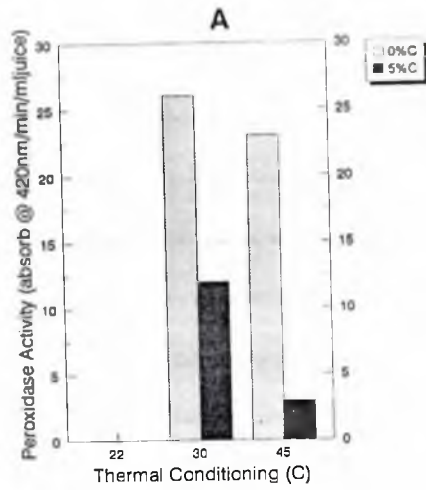
C) 6 minute

Of Reaction Time

legend

0%C = Non Coated Fruit

5%C = 5% Coated Fruit



4.5.2.3 Thermal Conditioning At 45 °C

When thermal conditioning was further elevated to 45 °C the behavioural trend of peroxidase as observed in conditioning at 30 °C was repeated. It was observed that when activity was measure after 2 min. of reaction time both coated and non-coated fruits showed a higher activity over similar treatment at 30 °C conditioning. The activity in coated fruits remained higher (Table 4.24).

PAM in coated fruits remained unchanged at 4 and 6 min. reaction time (i.e. same as that observed at 30 °C conditioning) (Table 4.25). However non-coated fruits showed a declining activity with increasing reaction time and elevated thermal treatment.

4.5.2.4 Isozymes

A logarithmic plot of PAM against thermal conditioning showed a biphasic curve for both coated and non-coated fruits at 2 min. of reaction time (Figure 4.27A). The biphasic curve is probably an indication of the existence of isozymes (heat labile peroxidase and heat resistant peroxidase) in the pineapple fruit.

Wang and Luh (1983) also observed a biphasic curve for plotting heat inactivation of soluble and bounded forms of asparagus peroxidase. Their data also showed that after heating solutions of asparagus peroxidase at 90 °C for 5 min., a small amount of residual activity remained.

When the reaction time was increased to 4 min. the plot indicates that the biphasism in non-coated fruits was lost as thermal conditioning increased (Figure 4.27B). However, the phenomenon persisted in coated fruits.

Heat resistant peroxidase was evident in the fact that elevating conditioning temperature from 30 °C to 45 °C for 90 min. resulted in no noticeable change in activity for coated fruit (Figure 4.27B and C).

Teisson (1977) has reported that peroxidase that are responsible for phenolic oxidation (the process that leads to internal browning) are highly thermolabile, especially in vitro and heating fruits for 24 hr. at 37 °C can reduce subsequent symptoms of internal browning. The contrasting observation in the activity of peroxidase in this study could probably be due to a shorter conditioning time i.e. 90 as against 1440 min. by Teisson although the conditioning temperature in this study was higher. Again this study did not isolate the various types of peroxidase existing in the pineapple fruit and which ones are associated with phenolic oxidation even though there is evidence (Figure 4.27A.B and C) that non-coated fruits which showed internal browning lost its biphasism when thermally treated at 30 °C and beyond.

4.5.2.5 Loss In Peroxidase Activity



The percent loss in PAM with increasing thermal conditioning (TC) made inconsistent observation. When peroxidase was measured at 2 min. of reaction time , elevating TC from 22 to 30 °C resulted in 26% loss of activity for non-coated fruit and 12% loss for coated fruit (Table 4.26). When TC was further elevated to 45 °C there was a slight gain in activity for non-coated fruits i.e. 23% loss. Coated fruits showed a remarkable gain in activity with only 3% loss from an earlier 12% loss.

When PAM was measured at 4 and 6 min. after the reaction time the loss in activity was observed to increase with increasing TC for non coated fruit while coated fruit showed a gain in activity (Table 4.26) and (Figure 4.27B and C). This observation suggest some form of regeneration although this cannot be readily explained. Powers *et al.*(1984) have demonstrated regeneration of asparagus peroxidase activity after heating partially purified preparations at 70 °C and reactivation at 25 °C. Regeneration of peroxidase at -18 °C has also been observed in peas (Pinsent, 1962). The regenerated activity in peas increased 4-7 % of the original activity and stayed the same upon further storage.

**5.0****Conclusion**

- 5.1 On the effect of surface coating on the physicochemical quality of post-harvest pineapple, it can be concluded that:
- Surface coating with the polymeric coating "Stafresh 7055" (a wettable emulsion) had a beneficial effect on the quality of post-harvest pineapple held either under ambient (28°C) or low temperature storage (LTS) (8°C).
 - 7.5% polymeric coating gave the overall best results although in most instances there was no significant difference between that and 5% or 10% coating. Incorporating thiobendazole (0.01%) in 5% coating did not seem to affect the chemical quality of pineapple held either under ambient (28°C) or low temperature storage (LTS) (8°C). However in post low temperature storage severe internal browning was observed by the application of fungicide.
 - Low temperature storage (8°C) gave the overall best quality attributes after 10 day of storage.
 - 5% coating at LTS was sufficient in maintaining the freshness of pineapple over 30 days with minimal quality detractions
- 5.2 On the shelf-life and shrinkage characteristics of post-harvest pineapple it can be concluded that:
- Prolonging the gestation period of pineapple beyond 140 days after floral induction (FI) before harvesting enhanced mass shrinkage.
 - Shrinkage of fruits was observed to be higher at night time (6pm-6am) than during the day (6am-6pm) when mean ambient temperature was 28°C .
 - Although fruits harvested at 160 days FI had a slightly higher crown withering index than 140 days FI, the pineapple crown has the ability to maintain freshness up to at

least five days after harvest under ambient storage.

- d) Lowering storage temperature from 28°C to 8°C was effective in reducing Mass Shrinkage, Shell Colour Break and Crown Withering Index by over 100%. Thus extending the shelf-life of the fruit by the same margin.
- e) 5% polymeric coating was effective in reducing mass shrinkage by at least 8% under ambient temperature (28°C) and by 5% under 8°C. Coating the fruit was effective in arresting shell colour break and withering of the crown.
- f) Applying thiabendazole as fungicide was also effective in arresting shrinkage.

5.3 On the effect of fruit coating on the post-harvest physiology of pineapple It can be concluded that

- a) Pineapple fruit var Smooth cayenne exhibited a non-climacteric form of respiration.
- b) CO₂ evolution from the fruit increased with increasing holding time. Fruit coating was effective in reducing CO₂ evolution and thus the rate of respiration.
- c) Rate of O₂ utilisation was also slowed in coated than non-coated fruits.
- d) The quantified respiration quotient (RQ) for coated and non-coated fruits suggest some form of organic acid metabolism, however the type of acid(s) could not ascertained.

5.4 On the post low temperature storage (LTS) behaviour of pineapple. It is concluded that:

- a) 5% polymeric coating of fruit was very effective in reducing the rapid deterioration of vitamin C and significantly arrested internal browning and textural changes (softening) in the pineapple fruit.
- b) Internal browning of fruit was evident 48hrs after removal from cold storage and rapidly accelerates with increasing temperature equilibration interval.
- d) Pineapple is a heterogenous fruit showing significant variation in chemical and

physical attributes as you traverse the fruit vertically and horizontally. Thus there is a rapid lost of firmness and acidity as you move from the apical through the mid to the basal section of the fruit. Sugars, pulp temperature and pH however increases from the apical to the basal section.

- e) Increasing the temperature equilibrium interval after LTS leads to rapid deterioration in texture and sugars and also leads to an increase in pH. This has serious organoleptic implications for consumers and importers buying fruits (previously held at 8⁰C) from warehouses and from groceries.
- 5.5 On studies on the peroxidase activity in the post-harvest pineapple it can be concluded that
- a) In the determination of peroxidase activity in post harvest pineapple, the pH of the medium and the concentration of the substrate are very important parameters. A pH range of 5.5-6 and 0.5% substrate (3,3'-dimetoxymetazidone) concentration were important in the determination of peroxidase activity in pineapple.
- b) Peroxidase activity decline as you moved from the basal to the apical section of the fruit.
- c) Peroxidase activity was higher in non-coated fruit (showing signs of internal browning) than coated fruit at ambient temperature (23⁰C), a condition that prevails in most groceries of importing countries.
- d) Isozymes (heat resistant and heat labile peroxidase) were observed when temperatures were conditioned at 30⁰C and 45⁰C. At these temperatures peroxidase activity was higher in coated than non-coated fruits.



5.6**Recommendations**

Further study is suggested in the following areas.

- 1) Evaluation of the effect and the rate of fertilisation on the physico-chemical quality of pineapple especially under different storage regimes in order not to mask or blow the effect of the coating treatment.
- 2) Ascertain the effect of time (month, day etc.) of harvesting on the physico-chemical quality of pineapple.
- 3) The effect of shrinkage on the chemical quality of pineapple.
- 4) Comparative study of the effect of a coating substance on the physico-chemical quality of the two popular varieties of pineapple (the Penambuco (sugar loaf) and Smooth cayenne.) in Ghana.
- 5) Isolation and classification of the different types of peroxidase in Ghanaian pineapple and which one(s) could be responsible for the blackheart (internal browning) phenomenon in pineapple.
- 6) Again heating whole fruit over several temperature regimes to ascertain the stability of the peroxidase enzyme and its potential of causing the blackheart disease.

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