CRANFIELD UNIVERSITY

SILSOE COLLEGE

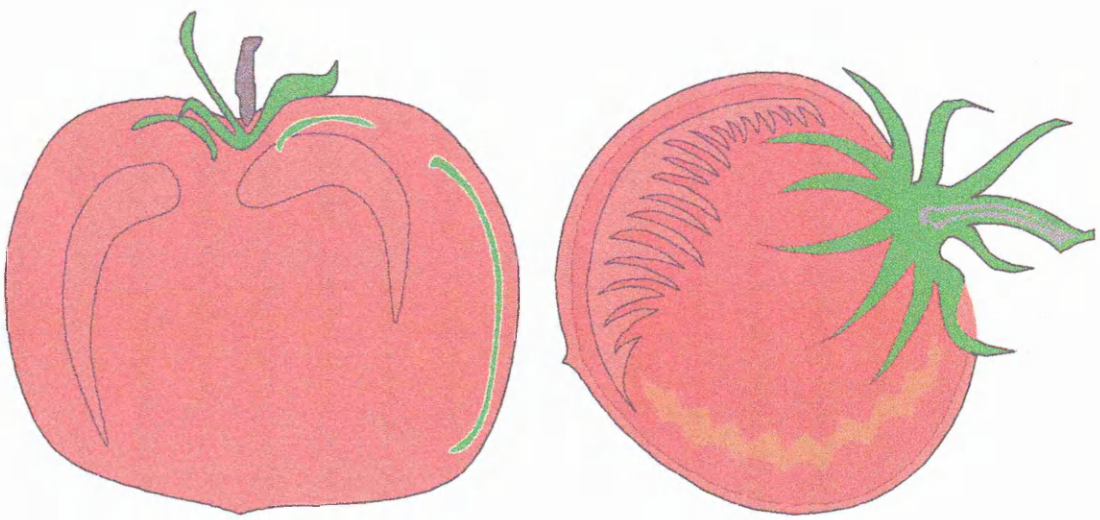
POSTHARVEST TECHNOLOGY DEPARTMENT

PhD THESIS, JULY 1995

ALI BATU

CONTROLLED AND MODIFIED ATMOSPHERE STORAGE OF TOMATOES

Supervisor: A. KEITH THOMPSON



This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at Postharvest Technology Department of Silsoe College Cranfield University

ABSTRACT

From the literature it was concluded that various factors could influence the storage life of tomatoes. These included harvest maturity, storage temperature, storage humidity and the level of gases in the storage atmosphere using modified atmosphere packaging (MAP) and controlled atmosphere storage (CAS). However, what was not clear from the literature was how (many of) these factors interacted and there was little information on the effect at long term MAP or CAS on eating quality of tomatoes. A series of experiments were, therefore, carried out to investigate the above factors. In order to carry out experiments preliminary tests were performed on tomatoes and compared to those given in the literature. These were to establish relevant quality criteria for the fruit in order to judge the comparative effects of the various treatments and included a texture measuring test and minimum criteria for objective colour measurements.

Storage humidity was shown to interact with fruit harvest maturity in that ripening time of fruits increased in high humidity levels. The quality of tomatoes harvested at the mature green stage of development and stored in low or medium humidity was approximately the same when they were ripe. However, fruit ripened at high humidity had a significantly better colour, were more acidic and firmer than those ripened at low humidities. Tomatoes harvested at the pink stage of maturity and ripened at low humidity levels were firmer, probably because the time taken to ripen was shorter than those ripened in medium and high humidity.

There were interactions between MAP and temperature in that MAP was more effective in delaying ripening at 13°C than at 20°C. MAP interacted also with

tomato harvest maturity where it was more effective in delaying ripening of fruit harvested at the mature green stage of maturity. Colour development was affected by storage temperature. In storage at 13°C maximum reddening occurred about 10 days later than in those stored at 20°C. There was an interaction between packaging films and ripening time of fruits. Tomatoes ripened later when they were sealed in films which were less permeable to O_2, CO_2 and water vapour than when they were sealed in higher permeable films. Packaging films also affected fruit firmness of tomatoes. All green tomatoes sealed in 25 micron thick polypropylene (PP) film were very firm even after 60 days of storage at 13°C or 20°C, compared to other films.

Ripening time and subsequent quality of fruits were influenced by their harvest maturity. Tomatoes harvested at the mature green stage and sealed in 50 micron thick polyethylene (PE50) or PP films had delayed development of the red colour after 30 days of storage and those tomatoes also had the lowest weight loss and the highest soluble solids after 60 days of storage. Storage temperature affected the acidity and total soluble solids (TSS) contents of fruits. These were higher at 13°C than at 20°C for those harvested at either the mature green or pink stage.

The CO_2 levels affected the colour changes of the tomatoes. The colour of tomatoes harvested at the pink stage of maturity did not change when they were stored in 6.4 % CO_2 with 5.5 % O_2 and 9.1 % CO_2 with 5.5 % O_2 even after 50 days and in some cases after 70 days storage. The red colour development of the tomatoes exposed to less than 6.4 % CO_2 increased, whereas red colour (Minolta $a^*.b^{*-1}$ values) decreased with CO_2 levels above 9.1 % during storage.

There were differences in ripening of tomatoes between MAP and CAS where mature green fruits in MAP ripened earlier than the same fruits in CAS. The differences were probably due to ethylene accumulation in MAP which would not occur in CAS because of the continuous gas flushing.

It was concluded that with the combination of reduced temperature and MAP or CAS, fruit could be stored for 60 or 70 days and still be marketable in terms of appearance, firmness, flavour and overall acceptability.

ACKNOWLEDGEMENTS

Firstly, I would like to thank sincerely Allah (c.c.) for giving me this extremely valuable opportunity to be able to study on my PhD and furthermore studies as a scientist. I am very grateful to Turkish government for awarding me the scholarship that enabled to make this study possible and I would also like to thank to my employers, the Food Science and Technology Department of the Agricultural Faculty of Gaziosman Pasa University, for giving me permission to study at Silsoe College of Cranfield University.

Secondly, I would like to express my gratitude and indebtedness to my supervisor, Professor A. Keith Thompson for his encouragement, patience, persistence and for especially endless help in many ways for the success of this study.

A grateful acknowledgement is due to Dr. Brian Clarke, the chairman of thesis committee, for his valuable comments and advices, and since appreciation to Professor Ed Morris, the thesis committee member, for always his constructive criticisms and suggestions.

Many thanks are expressed to Allen Hilton and Stephen Ferguson for their technical assistance and to Mrs Pam Cook for her kindness and patience in many ways.

I would like also to thank all other staff in the Postharvest Technology Department and all my friends at Silsoe.

Finally, I am very indebted and grateful to my dear wife Inci for particularly her prayers, love, patience and understanding, my lovely son Heysem Suat and my very tiny daughter Seniha Nesibe and all my parents for their endless support and encouragement. I hope that this study will be beneficial for mankind.

TABLE OF CONTENTS

TITLE **Page**

Chapter 5 Humidity Effects on Storage Quality of Tomatoes

Chapter 6 Modified and Controlled Atmosphere Storage of Tomatoes

LIST OF FIGURES

Figures

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATIONS

CAS: Controlled atmosphere storage
CA: Controlled atmosphere
MAP: Modified atmosphere packaging
PE20: 20 micron thick polyethylene
PE30: 30 micron thick polyethylene
PE50: 50 micron thick polyethylene
PVC: Polyvinylchloride
PVdC: Polyvinylidene chloride
LDPE: Low density polyethylene
HDPE: High density polyethylene
PE: Polyethylene (in plastic)
PE: Pectinesterase (in enzyme)
PC: Polycarbonate
EVA: Ethylene vinyl acetate copolymer
UPVC: Unplasticised polyvinyl chloride
PET: Polyethylene tetraphthalate
EVOH: Ethylene vinyl alcohol
ns: Statistically not significant
TSS: Total soluble solids
cv: Cultivar
RH: Relative humidity
MMV1: First minimum marketable value
MMV2: Second minimum marketable value
MSc: Master of Science
PhD: Doctoral of Philosophy
PO_2: Permeability to oxygen
PCO_2: Permeability to carbon dioxide
N: Normal in chemicals, and Newton in firmness
MS: Maturation stages when the tomatoes were harvested
NaOH: Sodium hydroxide
$CaCl_2$ Calcium chloride
KCl: Potassium chloride
NaCl: Sodium chloride
O_2: Oxygen

CO_2: Carbon dioxide

N_2: Nitrogen

WVTR: Water vapour transmission rate

W_o: Original weight of tomatoes just after harvest

W_1: Weight at sampling time

PPG13: Tomatoes harvested at mature green (G) stage sealed in polypropylene (PP) and stored at 13°C.

PE50G13: Tomatoes harvested at mature green (G) stage sealed in 50 micron thick polyethylene (PE50) and stored at 13°C.

PPG20: Tomatoes harvested at mature green (G) stage sealed in polypropylene (PP) and stored at 20°C.

PE50G20: Tomatoes harvested at mature green (G) stage sealed in 50 micron polyethylene (PE50) and stored at 20°C.

PP'P'13: Tomatoes harvested at pink ('P') stage sealed in polypropylene (PP) and stored at 13°C.

PE50'P'13: Tomatoes harvested at pink ('P') stage sealed in 50 micron polyethylene (PE50) and stored at 13°C.

APPENDICES

SYMBOLS

µ:	Micron
kg:	Kilogram
g:	Gram
m^3:	Cubic meter
ml:	Millilitre
N	Newton
mm	Millimetre
cm	centimetre
d	day
l	litre
%	percentages
°C	degree centigrade
m	meter
h	hour

Chapter 1. GENERAL INTRODUCTION

Extending the shelf life of produce is one of the ultimate goals of postharvest research and is very important for both domestic and export marketing. Shelf life 'is the time period that a product can be expected to maintain a predetermined level of quality under specified storage conditions' (Shewfelt, 1986). Fruit and vegetables are living and respiring tissue. After harvesting, ripening continues. Climacteric fruit and commodities may become over ripe very rapidly at the ambient temperature. This can result in loss of quality, restricted shelf life and, in some instances, wastage of fruit during marketing (Geeson at al., 1985). The quality of fresh fruit and vegetables is determined by appearance, colour, firmness and flavour (Risse et al., 1985). Specifications for monitoring the maintenance of 'high quality' or 'saleable quality' are more difficult to set and vary with a commodity and even varieties of the same commodity. Several techniques are used to preserve postharvest quality and extension of shelf life of fruit and vegetables. Extension of the shelf life of tomatoes could be achieved by retarding the rate of physiological processes (Shewfelt, 1986). A vegetable store will be successful only if it will keep the produce in good condition with minimum deterioration (Lindsay and Neale, 1981).

One of the ways to extend shelf life is to optimise the environmental conditions (Risse et al., 1985), which are temperature, humidity and atmospheric composition (Hatton and Cubbedge, 1982). Manipulation of the environmental conditions is usually performed to lower respiration and growth of decay organisms without inducing physiological injury (Shewfelt, 1986). The rates of growth of fungi and bacteria are markedly influenced by the storage environment (Snowdon, 1990).

Temperature is major factor in the control of postharvest injuries and decay organisms. In general the lower the storage temperatures (above the chilling temperatures and freezing point) the slower the growth of micro-organisms and the longer will be the shelf life of produce (Shewfelt, 1986) and the higher the temperature the higher the rate of respiration and the more quickly the produce approaches the end of its life (Cheng et al., 1988).

Relative humidity is another important environmental factor in shelf life and disease of fruit and vegetables (Kader, 1987; Sommer et al., 1992). Low relative humidity can increase transpirational losses and lead to desiccation, increased respiration, and an unmarketable product (Kader, 1992). High humidity causes moisture condensation and this high humidity environment is favourable for microbial growth, resulting in decay of the commodity (Zagory and Kader, 1988).

Another important factor for storage is the gaseous environment. The composition of gases in the storage atmosphere can affect the storage life of produce. When O_2 levels in plant cells fall, the rate of chemical reaction decreases and metabolism is reduced. If the O_2 level in the cells is low there may be undesirable changes in the chemicals which contribute to the flavour and aroma of the crop. Physiological disorders in fruits, associated with high CO_2 levels, may be associated with this disruption of the respiratory pathway leading to an accumulation in the crop cells of alcohol and acetaldehyde (Zagory and Kader, 1988). After the ripening of fruit the respiration rate declines, a process of senescence sets in, off-flavours develop and dying tissues become increasingly susceptible to attack by decay organisms. (Snowdon, 1990). Refrigeration and the use of low temperatures is the fundamental technique used to retard deterioration and to maintain fruits and vegetables in the freshest condition for as long as possible or as long as required after harvest (Geeson, 1984). However, in some

cases low temperature alone may be insufficient to retard the ripening of fruits or prevent deterioration such as leaf senescence, loss of flavour or texture and microbial attack which can occur during storage (Anon, 1991). Under these circumstances, modified or controlled atmosphere used either at ambient temperature or in conjunction with refrigeration, may provide an effective means of retarding deterioration, maintaining the quality or extending the storage life of crops (Geeson, 1984).

Tomato production varies from area to area in Turkey. However, outdoor tomato production is between July and early October. Tomato prices are very low during that period particularly during August and the first half of September. After early October the volume of production decreases and the price of tomatoes in the market becomes higher. Outside the field tomato season local greenhouse growers supply some fruits but not earlier than March. These are at high cost due to shortage of supply and because greenhouse economics are unfavourable with rising energy costs. Tomato production could be increased during the summer period with lower production costs in Turkey (and in developing countries) if prolonged storage were available for the fruits. The techniques of modified atmosphere packaging (MAP) or controlled atmosphere storage (CAS) might make the extended storage of tomatoes feasible (Thomas et al., 1982). Therefore field tomatoes could be stored within MAP or CAS and marketed when prices are high.

Many researchers have studied postharvest life of mature green (Dennis et al., 1979; Hobson, 1981; Yang et al., 1987; Ramana et al., 1987; Yang and Chinnan, 1988a and Geeson, 1989) and part-ripe tomatoes (Hobson, 1981 and Geeson et al., 1985). Maturity at harvest is very important to composition and quality of tomatoes. This is especially a problem with tomatoes picked green since it is difficult to differentiate between mature and immature green fruits. Mature green

and advanced mature green tomatoes will usually attain a much better flavour at the table ripe stage than those picked at the immature or partially mature stages (Grierson and Kader, 1986). The harvesting of tomatoes before ripening has an effect, not only on the peak sugar content, but also on the development of the full flavour spectrum, thus affecting consumer acceptability (Hobson and Grierson, 1993).

These studies were conducted to investigate the technical possibility of long term storage of tomatoes, and the effects of different combinations of established postharvest treatments on the length of storage and the quality of the tomatoes after storage. The study is divided into:

1. General introduction (Chapter 1)
2. Reviews of the literature and the formation of the hypothesis which can be used in tomato storage (Chapter 2)
3. The design and methods of experiments to test the hypothesis (Chapter 3 and 4)
4. Effect of humidity variations in tomato storage (Chapter 5)
5. Effects of modified atmosphere packaging (MAP) and controlled atmosphere storage (CAS) on tomatoes (Chapter 6)
6. The interactions between temperature and MAP and CAS on tomatoes (Chapter 7)
7. Evaluation of sensory qualities of tomatoes were kept in MAP and CAS (Chapter 8)
8. Conclusions and further recommendations (Chapter 9)

Chapter 2. Literature Review

2.1. Origin and History of Tomato

The origin of the tomato (*Lycopersicon esculentum* Mill) was the western sea board of South America close to the equator. It was unknown in Europe, Asia and Africa and it is said to have been first brought into cultivation in central and southern America (Goodenough, 1991) and brought to Europe by Columbus in 1498 (Hobson and Davies, 1971). It was also recorded that the seeds were transferred from south America to Italy by 1544 (Hobson and Grierson, 1993) and to England in 1576 (Hobson and Davies, 1971). Although the tomato was a popular vegetable by the 1500s in Europe it did not gain wide acceptance in the USA until mid 1800s but today it is the most popular vegetable grown in the garden (Splittstoesser, 1984). Due to its value as a crop, this species has become widely disseminated all over the world.

2.2. Fruit Anatomy

The tomato plant is the focus of a large agricultural industry and although it is botanically a fruit it is almost universally treated as a vegetable (Splittstoesser, 1984). In 1893 the tomato was adjudged botanically to be a fruit by the U.S. Supreme Court but in the common language of the people it was a vegetable (Goodenough, 1991). Tomato fruits are composed of flesh (pericarp walls and skin) and pulp (placenta and locular tissue including seeds) (Figure 2.1).

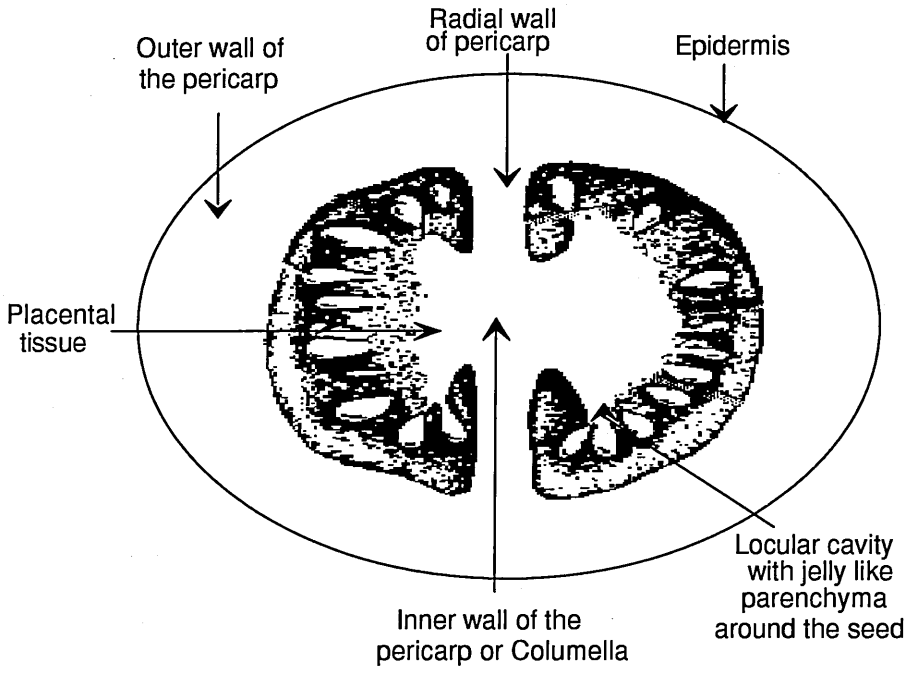


Figure 2.1. Anatomy of tomato fruits with bilocular structure (Hobson and Davies, 1971; Ho and Hewitt, 1986).

2.2.1. Pericarp

The body of the fruit develops from the ovary wall which surrounds and encloses the seeds, is known as the pericarp (Hobson and Davies, 1971) (Figure 2.1). The pericarp is divided into the outer wall, radial walls (septa) which separate adjacent locules and the inner walls (columella) (Ho and Hewitt, 1986). The locular cavities appear as gaps in the pericarp, and contain the seeds embedded in a jelly-like tissue originating from the placenta. The number of locules in normal fruit varies from two upwards, and is more or less characteristic for each cultivar (Goodenough, 1991).

2.2.2. Fruit Skin.

The fruit skin, consists of outer epidermal layer plus two to four layers of thick-walled hypodermal cells (Ho and Hewitt, 1986).

2.2.3. Placental Tissue

Early in fruit development the placenta starts to expand into the locules to engulf the seeds within the first 10 days and fills the entire locular cavity in the following few days. In immature fruits, the placental tissue is firm, but as the fruits mature the cell walls begin to break down, and the locular tissue of mature green fruit becomes jelly-like (Ho and Hewitt, 1986).

2.3. Growth

Tomatoes are a warm season crop and require only a small growing space. They do not grow in cold weather. They should be grown where they will receive at least 6 hr of direct sunlight. Tomatoes do not set fruit at temperature above 30 °C and below 15°C (Splittstoesser, 1984).

2.4. Fruit Quality

2.4.1. Size and Shape

After fertilisation, the number of cells in a tomato fruit increases dramatically over a period of 2-3 weeks. The average size of different cultivars of tomato fruit can vary. The shape is also largely under genetic control, although nutrition and environment can also have an influence (Stevens and Rick, 1986). Consumers expect tomatoes to be reasonably round and uniform in shape, slightly wider than deep, and having an average of three locules resulting from crossing a

bilocular line with a multilocular one (Picha, 1986; Stevens, 1986). The shape of the fruit results from the differential growth of the ovary at the polar and equatorial dimension prior to antithesis. Furthermore, if the growth of the epicarp is much greater than that of the placental tissue after antithesis, the fruit become puffy or angular (Ho and Hewitt, 1986).

2.4.2. Colour

For the consumer, colour is an extremely important indicator of eating quality characteristics of tomatoes. Many different type of pigments have been isolated in tomato fruits which contribute to their colour including carotenoids (Gould, 1983b). The most abundant carotenoid of the tomato is lycopene and the red colour of the tomatoes is determined primarily by their lycopene content which comprises approximately 83 % of those pigments present (Gould, 1983b). β-carotene is the other principal carotenoid of red tomatoes (Stevens and Rick, 1986). In modern cultivated varieties chlorophyll reaches a peak in concentration relatively early in the growth of the fruit. In normal fruit chlorophyll is replaced by oxygenated carotenes and xanthophylls during ripening. Phytofluene (which is colourless) increases towards ripeness, whereas β-carotene peaks a little before full colour development. Quantitatively by far the most important compounds which contribute to colour of ripe fruit is lycopene (Hobson and Grierson, 1993). Most European cultivars have an orange pigment in the skin (Baker et al., 1986), thus the lycopene in the ripened flesh gives as orange-red external colour (Gould, 1983b).

Most consumers prefer uniform red coloured tomatoes. Since colour is an indicator of tomato ripeness, several subjective rating scales and colour charts have been developed for classifying the stage of tomato ripeness. Those included in the US

standards (USDA, 1975) are shown in Table 2.1. Objective methods of colour evaluation include high reflectance measurement and light transmittance techniques. Determination of pigment content can also be used to indicate tomato colour changes (Grierson and Kader, 1986) (Table 2.1).

Table 2.1. USDA ripening classes of tomatoes (Grierson and Kader, 1986).

Score	Class	Description*
1	Green	Entirely light-to dark-green, but mature
2	Breaker	First appearance of external pink, red or greenish-yellow colour; not more than 10 %
3	Turning	Over 10 % but not more than 30 % red, pink or orange-yellow
4	Pink	Over 30 % but not more than 60 % pinkish or red
5	Light-Red	Over 60 % but not more than 90 % red
6	Red	Over 90 % red; desirable table ripeness

*All percentages refer to both colour distribution and intensity

2.4.3. Composition

The sugar content, mainly in the locule walls, reaches a peak when the fruit is fully ripe, while the malic acid falls quickly as the fruit turns red. The citric acid content is much more stable throughout the ripening period, and much of the acidity is to be found in the locular contents (Picha, 1986; Stevens, 1986).

2.4.3.1. Sugar

Sugars are one of the major contributors to tomato fruit quality. In general the total sugar content increases progressively throughout maturation and ripening (Table 2.2) and ripening from the mature green stage to red ripe (Davies and Kempton, 1975), and there is a particularly pronounced rise which occurs with the appearance of yellow pigmentation (Hobson and Davies, 1971). The quantity of sucrose found

Table 2.2. Composition of juice from whole fruit and locules (variety Potentate) at six stages of ripening (Hobson and Davies, 1971)

		1	2	3	4	5	6
	No. of samples	Green	Green yellow	Yellow orange	Orange	Orange red	Red
Whole fruit							
Titratable acidity (meq/100 ml)	3	7.47	9.5	9.19	8.36	8.27	7.14
Reducing sugars (g/100 ml)	3	2.93	3.31	3.37	4.43	3.57	3.6
Total solids (g/100 ml)	3	4.46	5.00	5.08	5.00	5.18	5.10
Locules							
Titratable acidity (meq/100 ml)	3	14.5	17.1	15.8	14.2	13	11.2
Reducing sugars (g/100 ml)	3	2.13	2.55	2.59	2.75	2.95	3.24
Total solids (g/100 ml)	2	4.54	4.99	5.06	4.91	4.93	5.13

Table 2.3. Average composion of seven varieties of tomato fruit (Hobson and Davies, 1971)

Variety	Titratable acidity (meq/100 ml)	Reducing Sugar (g/100 ml)	Sugar:acid ratio	Total soluble solids (g/100 ml)
Potentate	7.71	3.19	0.42	4.82
Radio	7.87	3.07	0.40	4.80
E.S.5	7.99	3.21	0.41	4.83
Moneymaker	8.09	3.13	0.39	4.80
Delicious	9.13	2.91	0.33	4.75
Ailsa Craig	9.34	3.28	0.36	5.17
L.M.R. 1	10.38	3.03	0.30	5.02

in tomatoes is so small that it may be ignored for all practical purposes. Sucrose rarely exceeds 0.1 % on a fresh weight basis. Reducing sugars which usually make up from 50 to 65 % of tomato total soluble solids and constitutes 1.5-3.5 % of the fresh weight (Hobson and Davies, 1971). These are mainly glucose and fructose (Gould, 1983a).

2.4.3.2. Organic Acids

Table 2.4. Malic and citric acid in the fruit of tomato varieties (Hobson and Davies, 1971)

Variety	Acidity in fresh tissue (meq/100 ml)		Percentage of total acidity		Malic:citric acid ratio
	Malic	Citric	Malic	Citric	
Moneymaker	239	458	26	51	0.52
Radio	313	502	28	45	0.62
Ailsa Craig	288	612	24	51	0.47
Potentate	254	463	26	48	0.55
E.S.5	304	526	26	45	0.58
Ware Cross	313	696	24	54	0.45
L.M.R. 1	192	736	16	60	0.26
Delicious	146	649	13	60	0.23
Immuna	90	878	7	66	0.11

The acid in tomatoes is generally considered to be predominantly citric, and the next most abundant organic acid is malic acid in fresh juice or whole fruit (Gould, 1983a). Hobson and Davies (1971) reported that malic acid concentration falls as the tomato ripens while citric acid increased up to the yellow green stage of ripeness and then either falls or shows no subsequent significant change. On the other hand, it has also been reported that both citric and malic acids increased steadily throughout maturation and ripening, while the titratable acidity rose to a peak as the fruit changed colour and then declined somewhat. It has been reported that in a study 250 tomato accessions the variation of percentage of citric acid ranged from 0.40 to 0.91 % (Stevens and Rick, 1986).

2.4.3.3. Starch

While immature tomatoes contain considerable amounts of starch, it is only a minor constituent of ripe fruit. Hobson and Davies (1971) reported that they were unable to

detect starch in young fruit up to 10 days from fertilisation but the starch content subsequently increased to a maximum at 8 weeks old, shortly before the fruit began to change colour, and then it disappeared rapidly as ripening proceeded. Low O_2 atmospheric storage inhibited starch degradation and subsequent sugar formation. The inhibition was more distinct in the early than in the late stages of storage. When fruits were stored in 1 % O_2 and 99 % N_2, loss of starch was completely inhibited for 60 days. This result indicated that a low O_2 atmosphere, such as 1 % O_2, is an ideal environment for extending the storage life of mature green tomatoes (Salunkhe and Wu, 1973).

2.4.4. Taste and Flavour

Changes in carbohydrates, organic acids, proteins, amino acids and lipids can influence the flavour of fresh fruit and vegetables (Kader, 1986). Tomato flavour involves the perception of the taster and is influenced by the aromas of many chemical constituents. The relation between sugars and acids are very important in determining the flavour in tomatoes. Fructose and citric acid are more important to sweetness and sourness than glucose and malic acid (Grierson and Kader, 1986). Acid content of the fruits is not only related to their sourness but is highly correlated with flavour of the fruits. Variation in acid content has a more dramatic effect on flavour than the limited variation is sugar content that exists among most cultivars. (Stevens and Rick, 1986). The taste is thus mainly determined by the sweetness induced by the reducing sugars, plus some sucrose in cherry tomatoes, and sourness caused by the organic acid content.

The harvesting of tomatoes before full ripeness has an effect not only on sugar content but also on the development of a full flavour spectrum, affecting consumer acceptability (Picha, 1986; Stevens, 1986). Sugar and acid contents change during

ripening. According to Ottosson and Wiberg (1977) the maximum acid content is reached at breaker stage. High acid and low sugars will produce a tart tomato while high sugars and low acids will result in a bland taste. When both sugars and acids are low, the result is tasteless, insipid tomatoes (Grierson and Kader, 1986). A high content of both compounds indicate good taste composition (De Bruyn et al., 1971) with a tomato which has a high sugar and a high acid content being favoured (Stevens, 1986).

2.4.5. Texture

Flesh firmness is an important criterion both for transportation and storage of tomato fruit. It is directly related to its shelf life. It affects the susceptibility of fruits to damage, and consequently their consumer acceptability. The peak of fruit ripeness is associated with a narrow range of firmness values. Firmness of pericarp tissue is a key component of both processing and fresh market tomato cultivars (Stevens and Rick, 1986). Most consumers prefer firm fruits which do not lose much juice when sliced (Kader et al., 1978b).

Most fruit soften during ripening. This is a major quality attribute that dictates shelf life. Tomato fruit softening can arise because of loss of turgor and cell wall degradation. Several processes occurring in the fruit contribute to softening. Loss of turgor is associated with postharvest dehydration of the fruit during storage. Another factor related to softening is cell wall degradation which usually consists of apparent dissolution of the pectin-rich middle lamella region of the cell wall (Tucker, 1993). It was reported that during ripening there is a loss of neutral sugars, in most fruits, and the changes in the sugar side-chains may then allow desegregation of the pectic mosaic (Hobson, 1993; Tucker, 1993). Pectin is a natural constituent of ripe

tomatoes. It is formed between the cells which make up the red tissues, cementing them together (Gould, 1983a). Softening has been interpreted as a change in the pectin materials cementing the cell walls and is characterised by the solubilisation of pectic substances (Goodenough, 1991).

The textural quality of tomatoes is influenced by skin toughness, flesh firmness and internal fruit structure. The enzymes involved in textural changes in tomato fruit are mainly polygalacturonase (PG), pectinesterase (PE), β-(1-4) glucanase (or cellulase) and β-galactosidase. It was thought that PG was very effective on tomato fruit softening and Hobson (1965) found earlier a close link between the firmness of tomato fruits and the PG activity. Its activity is closely associated with the rate at which pectins become solubilized, and PG is also responsible for depolymerisation of the pectin chain (Hobson and Grierson, 1993). Recently Tong and Gross (1989) found that there was no clear relation between firmness and PG activity of tomatoes. Hobson and Grierson (1993) reported that PG is not the primary determinant of softening of tomatoes. They also reported that the reduction of PG activity largely prevented pectin depolymerisation, but had little effect on solubilisation of pectin or firmness of fruit measured by probe penetration. Hobson (1993) also reported that although a significant amount of softening and ripening took place, PG activity was too low to be involved.

A selected pectolytic enzyme, PE is also found in tomato fruit; changes in activity occur during ripening so it may also be implicated in softening (Hobson and Grierson, 1993). It is possible that PG and PE occupy different sites in the cell wall and middle lamella, thus adding a further control point over their activities (Brady et al., 1987). It was reported that a PG gene introduced into tomato in the sense orientation,

designed to be transcribed to produce sense in mRNA, also down-regulates PG activity (Hobson and Grierson, 1993). Hobson (1993) reported that the reduction in PG activity by at least 98 % improved survivability and the processing quality of transgenic fruit. Reducing ethylene synthesis in transgenic fruit has shown that expression of the PG gene is largely unaffected, although PG mRNA does take longer to reach maximum levels in these low ethylene fruits (Hobson and Murray, 1994). This has been genetically engineered so that fruit have reduced ethylene synthesis. The result is that the fruit can be harvested fully ripe but will be still firm which makes it less susceptible to injury during postharvest handling.

Clearly, tissue softening is a complex process, and entails more than increased PG activity. Consequently, other explanations must be sought for changes in texture that occur during ripening (Hobson and Grierson, 1993). Some other factors may be involved in the solubilisation of cell wall uronides, such as glycaneses non-enzymatic mechanism of pectin degradation, methyl esterification of pectic carboxyls, or Ca^{+2} binding between adjacent carboxyls and between pectic chains (Tong and Gross, 1989). In this case calcium ions are chelated by regions of de-esterified galacturonic acid residues on adjacent polymers (Buescher and Tigchelaar, 1975), and large number of possible bonds would be expected to hold adjacent polymers firmly together (Tucker, 1993).

Cell wall structure is very important for texture changes of fruits. Cell wall in which cellulose fibrils, which were coated with hemicellulose are found embedded in a matrix composed of pectin and protein. Cellulose consists of linear chains of β(1-4)-linked glucose residues which aggregate together via hydrogen bonds to form fibrils (Tucker, 1993). Similar bonds attach the hemicellulose, mainly xyloglucans, to the cellulose fibres, and xyloglucans probably also span the melieu between the

microfibrils. The pectic substance typically consists of a backbone of (1-4)α-D-galatosyluronic acid residues interspersed to varying degrees with rhamnosyl residues. These rhamnosyl units can form the attachment point for side chains of galactosyl or arabinosyl units. Cross-linking by calcium forms a complex whose stability increases with the chain length. The relation between the cell wall and ripening has been closely linked with Ca^{+2} metabolism. Increasing tissue Ca^{+2} levels by as much as fourfold significantly delayed ripening and therefore softening of tomato fruit (Wills et al, 1989). Calcium ions are thought to stabilise soluble polymeric chains in the cell wall through adjacent carboxyl groups and through interpolymer associations, with calcium ions sandwiched between the inner faces (Hobson, 1993). The pectic substance became increasingly soluble as the calcium complex breaks down and as calcium is found particularly in the middle lamella, its degree of solubility leads to loss of cell cohesion. This change in texture by fruits during ripening has been linked with the loos of neutral-sugar side chains, a change in the components being incorporated into the cell wall enzymes which than promote ripening and the disintegration of calcium-pectate (Hobson, 1993).

2.5. Storage of Tomato Fruits

2.5.1. Effects of Varieties/Cultivars

There are hundreds of tomato cultivars available. Fruits come in a number of shapes, sizes and colours. The main crop types produce medium to large fruit of various maturities. Orange or yellow fruit cultivars when ripe are frequently considered to be lower in acid, but the acid content is similar to main crop cultivars.

Those cultivars have higher sugar content and taste sweeter. Paste cultivars contain less water in the fruits are used for paste, catsup or canning (Splittstoesser, 1984). Stevens et al., (1977) worked on those aspects of the chemical content of fruits most responsible for variation in flavour of six fresh market tomato cultivars and found that there was significant quantitative variation among cultivars.

2.5.2. Harvest Maturity

One of the primary factors in maintaining quality and extending the postharvest life of fresh fruits and vegetables is harvesting at the optimum maturity (Kader, 1992). Harvesting maturity is very important to composition and quality of tomatoes. The harvesting of tomatoes before ripening has an effect, not only on the peak sugar content, but also on the development of the full flavour spectrum, thus affecting consumer acceptability (Grierson and Kader, 1986). Determining the maturity is especially a problem with tomatoes picked green since it is difficult to differentiate between mature and immature green fruits. Advanced mature green tomatoes will usually attain a much better flavour when subsequently ripened than those picked at the immature or partially mature stages. Riper fruit are also much more susceptible to physical injuries and water loss because of increased softness (Grierson and Kader, 1986). Ripeness stage at harvest affects fruit composition and quality. Tomatoes accumulate acids, sugars, and ascorbic acid during ripening on the vine (Sakiyama and Stevens, 1976; Betancourt et al., 1977). Grierson and Kader (1986) reported that tomatoes picked at less than table-ripe and ripened at 20°C were evaluated by panellists as being less sweet, more sour, less tomato-like and having more off-flavours than those picked at the table-ripe stage.

2.5.3. Transpiration and Water Loss

Water loss can be one of the main causes of deterioration resulting in loss of saleable weight and thus is a direct loss in marketing. Minimising the water loss after harvest can be profitable for marketing. A loss in weight of only 5 % will cause many perishable commodities to appear wilted or shrivelled, thus reduce their market value. Controlling the rate of water loss from the produce primarily involves lowering the capacity of the surrounding air to hold additional water by lowering the temperature or increasing the humidity, that is, by reducing the vapour pressure difference between the produce and the air or providing a barrier to water loss (Wills et al., 1989).

2.5.4. Temperature

It is well established that the rate of deterioration of most agricultural produce is a direct function of temperature. Many authors have investigated the relationship between temperature and deterioration rate or quality loss of the fruits. Reducing the temperature from 20°C to 7.5°C generally increased the fruit firmness but decreased their colour. But the colour of overripe fruits was slightly paler than ripe fruit (Hobson, 1989). Between 12°C and 19°C, colour development was much more regular than at lower temperatures (Efiuvwevwere and Thorne, 1988).

2.5.4.1. Low Temperature

Temperature is a major factor in the control of decay causing organisms, respiration and transpiration. In general, the lower the storage temperature (above freezing point) the longer the shelf life of the fruit or vegetable (Shewfelt, 1986). Optimum temperature to be used during cold storage depends on the degree of ripeness of the tomatoes. Optimum storage temperature of turning tomatoes is between 12°C and

13°C (Anon, 1991). Exposure of tomatoes to temperatures below their freezing point results in freezing injury. Tomato fruits are susceptible to chilling injury, if held at too low a temperature (Kader, 1986). There is agreement in the literature on the minimum storage temperature of mature green tomatoes which does not result in chilling injury. The range of chilling temperature for unripe tomatoes was reported to be between 0°C and 12.5°C (Kader et al., 1978a). The optimum storage temperature in MAP storage was observed to be 12.6°C (Parsons et al., 1970) and 12.5°C by Kader et al., (1978a). Risse and Miller (1984) also reported that for maximum shelf life a temperature range between 13°C to 20°C was the most suitable for tomatoes. Ripe fruits can safely be held for a few days at 6°C to 10°C (Hobson, 1987). For example, reducing O_2 or increasing CO_2 can overcome the impact of low temperature injury on the ripening process (Lyons et al., 1979). Chilling injury occurs when tomatoes are exposed to temperatures above their freezing point and below 12.5°C (Grierson and Kader, 1986), 12.8°C (Morris and Kader, 1974), 12°C (Thorne and Alvarez, 1982) or 11°C (Hobson and Grierson, 1993). The length of the period depends on the temperature (Grierson and Kader, 1986). Chilling injury is a physiological response to low temperature and results in symptoms that affect product acceptability (Shewfelt, 1986). The major symptoms of chilling injury in tomatoes are surface pitting, uneven ripening or inhibition of ripening and increased fungal infection (Rhodes, 1980), acceleration of senescence (Morris, 1982; Morris and Kader, 1974) and the softening of tomatoes (Grierson and Kader, 1986). The symptoms usually become apparent only after the transfer of the chilled fruit to higher temperatures (Morris, 1982). Exposure to chilling temperatures adversely affects tomato flavour before other symptoms of chilling become apparent. Hobson (1987) reported that the packaging of tomatoes had more influence than storage in air on the development of chilling injury at 5°-7.5°C.

Several tests have been carried out to determine the critical time-temperature combinations in relation to chilling injury of fruits harvested at various stages of ripeness. Morris and Kader (1974) reported that for 'mature green' and 'breaker', the critical time-temperature combinations are approximately, 1 day at 0°C, 3 days at 5°C, 5 days 7.2°C or 8 days at 10°C. The results indicate that 8.5°C is the minimum that can be tolerated by green orange (turning) fruit (Hobson, 1987). Storage of mature green tomatoes at 9°C or 11°C in 5 % O_2 and CO_2 atmospheres resulted in enhanced fungal spoilage compared to storage under identical conditions at 13°C (Dennis et al., 1979).

Storage at chilling temperatures markedly affected fruit colour. Thorne and Efiuvwevwere (1988) reported that poor colour development after chilling was attributed to the disorganisation of fruit structures. Tomato acids increased during chilling as indicated by the decline in titratable acidity. Tomato firmness declined throughout 15 days of low temperature storage and then increased. The effect of storage temperature on chilling-induced quality changes in tomatoes varies with cultivar, duration of storage (Hobson, 1981) and ripeness of the fruit (Abou Aziz et al (1974). The relationship between duration of chilling and the development of its symptoms is difficult to assess and incompletely understood (Efiuvwevwere and Thorne, 1988).

2.5.4.2. High Temperature

In addition to chilling stress, some commodities are susceptible to heat stress. Thorne and Alvarez (1982) found that storage above 27°C disrupted ripening of tomatoes. Cheng et al., (1988) also reported that tomatoes stored at 37°C evidenced

a significant delay in colour development during postharvest ripening from that of the control sample at 20°C. The delaying in colour development was attributed to inhibition of lycopene biosynthesis (Lurie and Klein, 1992). It is also reported that the softening process in tomatoes was slowed during 6-day storage at 33°C, but proceeded normally after transfer to 20°C and ethylene production was suppressed when tomatoes were held at 33°C (Buescher, 1979b).

2.5.5. Humidity

Relative humidity (RH) is defined by Wills et al (1989) as 'the ratio of the mole fraction of water vapour in a given mass of a moist air sample to the mole fraction in an air sample of the mass when saturated at the same temperature and pressure'. During fruit storage, humidity is a controllable factor that has assumed increasing importance (Shirazi and Cameron, 1992). Most of the major pathogens affecting the postharvest life of tomato fruit need an environment with a water activity of more than 0.80 for their growth (Troller and Christian, 1978). The reduction of humidity to levels below the critical water activity of micro-organism is an effective way to limit their growth. Generally recommended levels of 85 % to 95 % R.H. (Hardenburg et al., 1986) for storage of fresh produce represent a compromise to prevent excessive weight loss while providing some control of microbial spoilage.

Humidity can affect disease development in tomatoes. Dennis et al (1979) reported that approximately 2 % of mature green tomato fruit were infected after 4 weeks storage at 90% and 95 % RH whereas 24 % were infected at 98 % RH. The weight loss (excluding that due to fungal decay) from fruit during this period was approximately 5 % at 90 % RH compared to 2 % and 1 % respectively at 95 % RH and 98 % RH as used for tomatoes to create an environment where moisture can

easily condense on the fruit depending on the water vapour transmission rate of the packaging film (Bedrosian and Schiffman, 1979). Inside packages RH can be reduced by using films with a high water vapour transmission rate but cannot be controlled to a specific level using this approach alone. Desiccants such as $CaCl_2$ have been used to lower RH in the package (Bedrosian and Schiffman, 1979). Compounds, such as sorbitol, xylitol and NaCl absorb relatively little moisture until RH increases to a critical level (Shirazi and Cameron, 1992). They also showed that in control packages using 10 grams of xylitol, KCl, NaCl or sorbitol held the RH was held at 78 % to 79 %, 84 % to 85 %, 73 % to 76 %, and 72 % to 74 % for 48 days, respectively, in packages with a single tomato fruit (70-90 g).

2.6. Atmospheric Composition

2.6.1. Controlled Atmosphere Storage (CAS)

Tomato quality changes continuously during ripening after harvesting. The speed and magnitude of these changes depends on the temperature and harvest maturity. This can result in loss of quality and restricted shelf life since overripe fruit may be too soft and unacceptably red (Geeson et al., 1985). Delaying ripening and extending the shelf life of tomatoes is very important for domestic and export marketing. Generally the shelf life of tomatoes is extended by refrigerated storage (Risse et al., 1985). Cooling is the most widely utilised technique for prolonging the life of perishable produce but CAS is a very important technique usually used in conjunction with refrigeration in maintaining quality. It extends the post harvest life of fresh fruit and vegetable beyond cooling alone (Ben-Yehoshua et al., 1981; Ben-Yehoshua, 1985 and Peleg, 1985) or where refrigeration alone is not enough to guarantee long term quality (Anon, 1990). Kader (1992) defined CAS as the modification of O_2, CO_2

and/or ethylene concentrations in the atmosphere surrounding the commodity to levels different from those in air. Generally reducing the O_2 concentration of the storage atmosphere decreases the respiration rate of fruits and vegetables (Geeson, 1984). CAS is used effectively to extend the storage life of seasonal perishable products. This technique can be used for many fruits and vegetables; however it is primarily used for apples and pears (Hardenburg et al., 1986).

CAS is also used effectively to extend the storage life of tomatoes. Salunkhe and Wu (1973) worked on the long term CAS of tomatoes and found that lycopene content of tomatoes did not increase until 60 days of storage in 1 % O_2 and 99 % N_2 at 23°C whereas it inhibited pigment formation until 40 days after harvest in 3 % O_2 and 97 % N_2. This means that the ripening of tomatoes was delayed, but they did not analyse the eating quality of tomatoes in this experiment. Yang et al., (1987) also showed that off-flavour scores of mature green tomatoes after 45 days storage were much higher in ambient conditions and much higher than those stored in other CAS conditions. But they did not report whether the tomatoes kept in CAS had acceptable flavour or not after 45 days storage. Yang and Chinnan (1988a) found that higher off-flavour scores was occurred after 45 days of storage of tomatoes in 5 to 15 % CO_2 all in 5 % O_2 whereas they had lower off-flavour scores after 30 days storage. Parsons et al., (1970) reported that all tomatoes were considered to have acceptable flavour after 6 weeks storage in CAS.

2.6.1.1. Ethylene Effects

The effect of introducing ethylene to in-storage climacteric fruits such as tomatoes at the preclimacteric stage is to initiate and accelerate ripening if the concentration of the gas is above the required threshold (Watada, 1986). Ethylene is produced by fruit

as a part of the ripening process (McGlasson, 1985). Geeson et al., (1986) reported that all mature green tomato fruits stored in atmospheres containing 1 $\mu l.liter^{-1}$ or more ethylene ripened satisfactorily through orange colour to the normal full red colour when transferred to air at 20°C. CAS can reduce ethylene production, but the hormone can still build up to significant levels in CAS rooms. It has been shown that reduction in these ethylene levels improves the storage life and reduces disorders in certain crops (Dover, 1989). The synthesis of polygalacturonase only occurs in response to ethylene (Grierson and Tucker, 1983; Grierson et al., 1987). Ethylene has been implicated in several postharvest physiological disorders of horticultural crops. The incidence and severity of these disorders depends upon the physiological age of the commodity, temperature, ethylene concentration and duration of exposure to ethylene (Kader, 1985a). High levels of ethylene in the storage atmosphere can cause undesirable flavours and increased sugar losses in cabbages, and flavour losses in onions (Watada, 1986). Exposing the mature green tomatoes to ethylene can result in the rapid breakdown of chlorophyll. This effect has been shown in a wide variety of green coloured crops (Kader, 1985a). Higher levels of decay were also observed in the presence of ethylene for a variety of crops (Watada, 1986). Firmness of many fruit and vegetables decreases with ethylene treatment and exposure to ethylene can reduce their storage life (Kader, 1985a).

2.6.1.2. Oxygen Effects

Many chemical reactions in crops are catalysed by enzymes and the reactions require molecular oxygen. If the O_2 level in the cell is too low there may be undesirable changes in the chemicals which contribute to the flavour and aroma of the crop (Bishop, 1990). The minimum O_2 level required to avoid fermentation and to ensure aerobic metabolism depends on the kind of crop as well as on duration of

exposure. O_2 concentration has to be below 8 % to have a significant effect on fruit ripening, the lower the O_2 concentration, the greater the effect, but it must not be less than 2% (Kader et al., 1989). Vegetable crops reacting positively to CAS conditions usually require a minimum O_2 content of 1-3 % in the storage atmosphere (Weichmann, 1989). When O_2 content is below 2 %, most vegetables react with a sudden increase in CO_2 production (Isenberg, 1979). Kader (1980) reported that lowering O_2 levels to about 2 % can be injurious to fruits because of anaerobic respiration and the potential development of off-flavours. Low O_2 and high CO_2 concentration were found to have the same effect in reducing the respiration rate (Yang et al., 1987). Elevated CO_2 levels (above 1 %) also retard fruit ripening and their effects are additive to those of reduced O_2 atmosphere (Kader et al., 1989). If the O_2 level in the cells is low there may be undesirable changes in the chemicals which contribute to the flavour and aroma of the crop (Zagory and Kader, 1988). Irregular shaped brown areas develop that may be superficial or slightly sunken when mature green tomatoes are exposed to less than 2 % O_2 (Grierson and Kader, 1986).

CAS conditions reduce respiration rates as long as the levels of O_2 and CO_2 are within those tolerated by the commodity. This, combined with the decreased ethylene production and reduced sensitivity to ethylene action, result in delayed senescence and sensory quality of non-fruit vegetables (Kader et al., 1989). When mature green tomatoes were stored for six weeks at 12.8°C the fruit kept much better in an atmosphere containing 3% O_2 than in air.

2.6.1.3. Carbon dioxide effects

The effect of CO_2 on extending the storage life of crops appears to be due to a reduction in their respiration. Where the level of CO_2 in the store is increased its

level within the crop tissue will also increase (Baumann, 1989). Depending upon the vegetable, CO_2 concentration, and length of exposure, elevated CO_2 causes various problems during storage or transit. In general CO_2 build-up to concentration above 5-10 % or more should be avoided in CAS (Herner, 1987). Depending on cultivar and exposure time, subjecting mature green tomatoes to CO_2 levels above 3-5 % can result in CO_2 injury and some detrimental effects on the colour of tomatoes during CAS (Kader, 1986). Symptoms include retarded and irregular ripening, premature softening, and the appearance of brown spots at the blossom-end (Grierson and Kader, 1986). At high CO_2 concentrations (15 % or more), off-flavour is usually produced. In some case, off-flavour may be due to an accumulation of ethanol (Ulrich, 1975). When CO_2 concentration is above 20 %, a significant increase in aerobic respiration occurs and can irreversibly damage the tissue and cause physiological disorders in fruit. CO_2 injury may be associated with the disruption of the respiratory pathway leading to an accumulation in the crop cells of alcohol and acetaldehyde (Kader, 1987). Recent reports show that brief exposure to high CO_2 levels (20-100 %) had a beneficial effect on the shelf life of some fruit and vegetables (Kubo et al., 1989).

High CO_2 levels can also affect ethylene evolution in the crops. Buescher (1979a) found that the a rate of ethylene evolution declined with increasing time of exposure to 5 and 10 % CO_2, while in 20 % CO_2 it reached a minimum after 4 days and then remained constant. In 40 and 60 % CO_2, the rate of ethylene development declined for 3 days then increased with additional exposure. Suppression of the O_2 uptake rate during high CO_2 exposure was accompanied by a decrease of ethylene development. Suppression of ethylene production was also observed in tomatoes, pears and apples during exposure to high CO_2 levels (Kubo et al., 1989). In addition

to that, CO_2 appeared to be a competitive inhibitor of C_2H_4 action (Burg and Burg, 1967).

Colour development was inhibited in tomatoes exposed to CO_2. Loss of chlorophyll from fruits was delayed and the formation of lycopene and β-carotene of tomato fruits was inhibited when they were stored at high CO_2 and low O_2 in controlled atmospheres. The lower the O_2 and the higher the CO_2 the greater the inhibition, especially of lycopene. Exposure of fruits to more than 10 % CO_2 for 4 and 7 days reduced the number of saleable fruits. The severity of CO_2 injury to fruits increased with increasing concentration of CO_2 and duration of exposure (Buescher, 1979a).

2.7. Modified Atmosphere Packaging (MAP)

Extension of the shelf life by the slowing down of ripening has also been achieved by packaging tomatoes in sealed polyethylene and other types of polymeric films. When the fruit or vegetable has been enclosed within a plastic film, a modified atmosphere can be established by introducing or generating the required gas or gas mixture, or by allowing the respiration of the enclosed plant material to consume O_2 and to produce CO_2 within the sealed space (Wills et al., 1989). This method is called modified atmosphere packaging (MAP). MAP is used to extend the storage life of seasonal perishable products and can be used for many fruits and vegetables (Hardenburg et al., 1986). Modification of the atmosphere depends on many factors, primarily the respiration rate of the plant tissue, the permeability of packaging films (Roberts, 1990) and surface area of the packaging material (Geeson, 1989). Successful application of MAP totally depends on the accurate control of oxygen and carbon dioxide contents as well as on the temperature, relative humidity and storage time (Peleg, 1985). MAP of fruit and vegetables involves the inhibition of very

complex, biologically active materials. This technique involves ensuring that micro-climatic conditions are able to maintain the sensory and the nutritive values of food from production to consumption (Barmore, 1987).

The disadvantage of packaging fruit vegetable within plastic films is that they can influence the rates of cooling and warming of the commodity. Film wrapped produce usually requires a longer cooling time than unwrapped produce. The harmful effects of MAP are the initiation of certain physiological disorders and the increased susceptibility to decay when the commodity is physiologically injured by too low O_2 or too high CO_2 concentration (Kader, 1985b). El-Grooni and Sommer (1981) pointed out that decreasing O_2 levels to below 1 % and CO_2 levels above 10 % are needed to significantly suppress fungal growth. O_2 and CO_2 levels beyond those tolerated by the commodity can induce physiological disorders such as brown stain, internal browning and surface pitting (Herner, 1987).

Geeson et al., (1985) showed that tomatoes had better flavour and texture after 20 days (14 days in MAP and 6 days in perforated bags) at 20°C than the sample of fruits maintained at these temperature in perforated control packs throughout storage. Saguy and Mannheim (1975) found that tomatoes had acceptable flavour stored in MAP in various gas concentrations after 21 days at 25°C. Risse (1989) also reported that fruits stored in MAP for 3 weeks at 13°C were firmer and easier to slice than unsealed tomatoes kept at the same temperature. Floras et al., (1987) found that at 18 days MAP tomatoes in some treatments developed a very good taste and overall acceptability. Riquelme et al., (1994) reported that tomatoes harvested at breaker stage and packed in polymeric film (in 2-5 % O_2 and 8 % CO_2) for 23 days at 15°C and showed that no changes in quality when ripened in ambient conditions.

2.7.1. Factors Affecting MAP

2.7.1.1. Resistance within the commodity to diffusion of O_2, CO_2

Most fruit and vegetables are tolerant of O_2 levels down to 1-5 % and CO_2 levels up to 5-10 % (Kader, 1980). However, plant enzymes involved in O_2 utilisation can function in an environment of less than 1 % O_2. The difference between external O_2 (or CO_2) available within the cell is determined largely by the resistance of the plant organ to gas diffusion (Zagory and Kader, 1988).

2.7.1.2. Optimum Relative Humidity (RH).

Low relative humidity can increase transpiration and lead to desiccation and increased respiration (Kader, 1987). One of the benefits of MAP in general is the maintenance of an adequate RH. But it can get too high, causing moisture condensation and conditions favourable for microbial growth, resulting in the surface damage and decay of the commodity. Condensation on the film package surface may affect the gas permeability properties of the film. Most common films have a relatively good barrier to moisture vapour because they maintain high internal humidity even in dry, ambient conditions (Zagory and Kader, 1988). A relative humidity of around 90 % plus for leafy vegetables and 85-90 % for fruits and most other vegetables would be ideal (Paine and Paine, 1992b). The relative humidity of the storage atmosphere has a marked effect on the storage life of vegetables. Traditionally, the recommended range of relative humidities for vegetables is 90 to 95 % (McKeown and Loughead, 1980). Van den Berg and Lentz (1977) reported less disease in many crops held at very high RH (98-100 %) compared to crops held at 90-95 %, and they recommend RH of 98-100 % for vegetable crops.

2.7.2. Plastic Films Commonly Used in MAP

Respiration plays a major role in the postharvest life of fresh fruits, and especially vegetables, due to the loss of substrate, oxygen requirement, carbon dioxide production and the release of heat energy (Kader, 1987). Extension of the storage life of fresh plant produce is thus dependent on applying modified atmospheres to limit respiration (Bishop, 1990). An adequate O_2 concentration must be available to maintain aerobic respiration. On the other hand, reduction of O_2 concentration to less than 10 % provides a means for controlling respiration rate and slowing down senescence (Kader, 1987).

Although many plastic films are available for packaging purposes, relatively few have been used to wrap fresh produce. Even fewer have gas permeabilities that make them suitable to use for MAP. Thermoplastics are very common films used for packaging which have the ability to soften when heated, and harden when cooled (Rouffignac, 1990). Packaging materials commonly used in MAP are polyethylene (PE), polyvinylchloride (PVC) and polypropylene (PP) (Kader et al., 1989). Low density polyethylene (LDPE) is the most widely used film. PVC is used for wrapping in the pre-packaging industry. PP is heat shrinkable and it is a good moisture barrier (Salunkhe et al., 1991; Zagory and Kader, 1988). Film permeability is critical and choice will depend on the respiration rate of the produce. The greatest problems occur in matching respiration rates to film permeability (Paine and Paine, 1992b).

2.7.2.1. General Characteristics of Films:

Polymers used in making film have different mechanical and chemical characteristics. Nitrogen, oxygen, carbon dioxide and the water vapour permeabilities of polymers are important from the point of view food packaging (Varsanyl, 1986;

Roberts, 1990). Maintenance and even improvement of the quality of tomatoes sealed in plastic film is dependant on the barrier properties of the packaging material. The barrier properties of the package are mainly related to its permeability to the gases which affect the quality of the tomatoes and water vapour.

2.7.2.1.1. High Density Polyethylene (HDPE)

Density ranges between 941-965 kg/m^3 (Crawford, 1985). HDPE has a higher melting point, is harder, is generally much more crystalline (Paine and Paine, 1992a), more resistant to chemicals, has lower water transmission properties (Rouffignac, 1990), and is stiffer and stronger than other films (Levy and Dubois, 1977).

2.7.2.1.2. Low density Polyethylene (LDPE)

Density ranges between 910-925 kg/m^3 (Crawford, 1985). LDPE is widely used for the manufacture of carrier and wrapping bags (Rouffignac, 1990) and is relatively inert chemically and almost insoluble in all solvents at room temperature. Vapour permeability is low but many organic vapours and essential oils pass rapidly through LDPE. Its permeability to oxygen is fairly high. It has higher vapour tolerance, puncture resistance and impact strength than HDPE (Greengrass, 1993).

2.7.2.1.3. Polypropylene (PP)

The density of PP was around 900 kg/m^3; In film form, PP is widely used in packaging (Crawford, 1985). PP is similar chemically to LDPE . Its melting point is higher than LDPE, but it is easier to seal and will stand steam sterilisation (Paine and Paine, 1992a). PP provides a much greater barrier to gases, seven to ten times that of PE (Greengrass, 1993).

2.7.2.1.4. Polyvinylchloride (PVC)

PVC is a moderate barrier to moisture vapour (Greengrass, 1993). Chemically, it is resistant to weak or strong acids and alkalis. It is soluble in esters and ketoses and is attacked by aromatic hydrocarbons (Paine and Paine, 1992a). PVC is hard and brittle, but can be softened when heated. PVC and its derivatives are widely used in many forms of packaging. Its permeability varies, but it is generally resistant to chemicals and solvents. The unplasticised form (UPVC) is the most widely used thermoformable base web for MAP (Greengrass, 1993). A PVC copolymer variable polyvinylidene chloride (PVdC) film, is widely used in the home and in stores for wrapping foods such as cheeses, as its permeability to water and gases is comparatively low (Rouffignac, 1990).

2.7.2.1.5. Other films

There are some other films available in the market such as polycarbonate (PC), ethylene vinyl acetate copolymer (EVA), polystyrene (PS), polyamides (nylons) and ethylene vinylalcohol (EVOH). PS is not suitable for MAP because of its poor gas and water vapour barrier properties. Polyamides are also not suitable for MAP because they are hygroscopic and the mechanical properties are altered by water absorption. EVOH is a moisture sensitive, very high gas barrier material (Greengrass, 1993). Polyethylene tetraphthalate is another film (polyester or PET) which can be used in various forms in MAP (Paine and Paine, 1992a).

2.7.2.2. Permeability of the MAP films

One of the very important factors of films to be considered from the point of food packaging is their gas permeability. The permeability of a particular film depends on several factors including the nature of the gas, the polymeric structure and thickness

of the film, storage temperature and relative humidity (Day, 1988). The relative humidity inside the package is dependent on the water produced by the crop and the permeability of the film. The equilibrium composition of the gases inside the package depends on the rate of respiration of the produce in the pack, the gas permeability of the film and its surface area (Frith, 1991). If the permeability of the pack allows less oxygen to diffuse into the pack than is consumed by the respiration of the crop, the pack O_2 level will decline. Similarly, if the permeability of the pack allows less CO_2 to escape than is produced by the respiring fruit, then CO_2 will accumulate within the package. As the concentration of O_2 decreases and that of CO_2 increases, the rate of diffusion of these gases through the packaging material will also continue to increase (Geeson et al., 1981; Gorris and Peppelenbos, 1992). The rate at which O_2 diffuses into the pack will increase until it is equal to the rate at which O_2 is taken up by the respiring fruit, and similarly the rate at which CO_2 passes out of the pack increases until it is equal to the rate of CO_2 production by the fruit. When this point is reached, little further change in the concentration of O_2 and CO_2 within the pack occurs, and a state of equilibrium is reached. The time taken to reach this position is known as the '*equilibrium time*' (Geeson et al., 1981 and Geeson et al., 1985).

Vegetables vary greatly in their respiration rate. Root, tuber, and bulb vegetables normally have a low respiration rate. Fruit and vegetables that are picked mature, such as tomato and melons, respire at a lower rate than those picked immature, such as green beans, peas, sweet corn, and okra (Kader, 1987; Paine and Paine, 1992b). Plant parts with vegetative tissues, such as asparagus, broccoli, and green onions, have very high respiration rates. In general the degree of perishability of fresh vegetables is parallel to their respiration rates (Kader, 1987). Low density polyethylene and polypropylene which have higher permeability rates than other films

could be useful for produce such asparagus, broccoli, green onions leeks, sweet corn, etc. which have very high respiration rates. Films which have low gas permeabilities would only be suitable for those commodities with very low respiration rates (Zagory and Kader, 1988).

When the oxygen supplies to the respiring crop are low, anaerobic respiration may occur. Anaerobic respiration involves the production of partially oxidised products such as alcohols, aldehydes etc. It is therefore essential that the O_2 atmosphere inside the film is at a level which ensures this does not occur. Packaging film with low WVTR results in excessively high internal RH which encourages rotting (Geeson, 1989).

2.7.2.3. Selection of Films

The packaging material selected is crucial to the success of MAP. This is why films of correct permeability should be chosen for the MAP of respiring fruit and vegetables (Day, 1988). If the permeability of the film is too much atmosphere modification takes place and the produce continues to respire almost unchecked, while if the permeability is too low, too little O_2 can pass into the pack and anaerobic conditions will occur with the subsequent rotting of the produce (Roberts, 1990). If a film of correct permeability is chosen, a desirable equilibrium modified atmosphere can be established when the rate of O_2 and CO_2 transmission through the package equals to that produced or consumed during the product's respiration (Day, 1993). An ideal film must let more CO_2 exit than O_2 enter. CO_2 permeability should be somewhere in the range 3-5 times greater than the O_2 permeability, depending upon the desired atmosphere (Zagory and Kader, 1988).

If commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within the sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration (Smith et al., 1987). In order to achieve and maintain a satisfactory atmosphere within a package, the gas permeabilities of the selected film must be such that they allow O_2 to enter the package at a rate offset by the consumption of O_2 by the commodity. Similarly, CO_2 must be vented from the package to offset the production of CO_2 by the commodity (Zagory and Kader, 1988).

2.8. Hypobaric Storage

Hypobaric storage is a form of CAS in which the produce is stored in a partial vacuum (Salunkhe and Wu, 1974). The vacuum chamber is vented continuously with water saturated air to maintain O_2 levels and to minimise water loss (Wills et al., 1989). Ripening of fruits is retarded by hypobaric storage, due to the reduction in the partial pressure of O_2. Reduction in the availability of O_2 by hypobaric storage results in reducing respiration rate and ethylene production rate of tomatoes, and decreases their sensitivity to ethylene (Morris and Kader, 1979). Salunkhe and Wu (1974) reported that the ripening of green tomato fruits was retarded and the storage life extended by hypobaric storage. It was also reported that storage life of apples, pears and potatoes was significantly extended (Salunkhe and Wu, 1974) and that the reduction of the green colour of parsley and spinach during storage was delayed (McKeown, 1980) by hypobaric storage. However, hypobaric stores are expensive to construct because of the low internal pressure required (Wills et al., 1989).

2.9. Summary, objective and development of a hypothesis

Previous studies have demonstrated that tomatoes harvested at the mature green stage can be stored in CAS or MAP conditions for an extended period and then ripen quickly at ambient temperatures. Some investigations indicated that there were differences between tomato varieties in their response to damage to fruit firmness or retardation of ripening during CAS and MAP. As shown in the literature many of the experiments were conducted over just 3 weeks time and the maximum storage time studied was 30 days. Some researchers reported that tomato flavour was acceptable after 20 or 30 days storage in controlled atmospheres, but what was not known was the effects of long term storage (more than 30-40 days) on tomato flavour.

Manipulation of the storage temperature, fruit maturity at harvest and the level of CO_2 or O_2 could be used to extend the period of availability of the tomatoes. However, organoleptic characteristics such as flavour, sweetness and sourness are important to the consumer as well as texture and appearance. The hypothesis was that there would be a combination of harvest maturity, storage temperature, humidity and gaseous environment which would enable long term storage of tomatoes while still producing ripe fruit with organoleptic qualities which were acceptable to the consumer. It was further hypothesised that the appropriate storage conditions could be achieved with a combination of refrigerated storage and plastic film packaging which would reduce the cost of storage compared to techniques such as controlled atmosphere storage.

The specific objectives of this study were as follows;

1) To investigate the effect of storage at different humidity levels on subsequent fruit ripening and fruit qualities of tomatoes.

2) To develop a modified atmosphere packaging system, using different packaging films and different levels of CO_2 and O_2 in order to retard deterioration and extend the storage life and keeping quality of tomatoes harvested at the pink and the mature green stage of maturity without detrimentally affecting their organoleptic qualities.

3) To determine the effects of various levels of CO_2 (0.2-15.6 %) atmospheres in a 5.5 % O_2 on ripening behaviour and related biochemical changes of tomatoes during long term storage.

4) To determine instrumental colour and firmness measurements of tomatoes harvested at different stages of maturity and stored long term under various gaseous environments involving 0.2 to 15.6 % CO_2 concentrations in 5.5 % O_2.

5) To compare the internal environment conditions which develop within retail packaging of tomatoes sealed within various packaging films, and to evaluate the effects of conditions within the packs on the rate of ripening and shelf life and sensory quality of fruit.

6) To determine the effect of environmental gas compositions and storage period on the respiration rate, firmness and sensory attributes of tomatoes harvested at the mature green and the pink stage of maturity after long term CAS and MAS.

7) To investigate the effects of temperature on: 1) the chemical composition of "Liberto' and 'Criterium' tomato varieties; 2) and the possible retardation of ripening in fruits harvested at the mature green stage of maturity; 3) the keeping quality of tomatoes harvested at pink stage of maturity. To extend their season of availability.

Chapter 3. MATERIAL AND METHODS

3.1. Plant Materials.

Tomatoes were obtained from the greenhouse at the Silsoe Research Institute. In the study, freshly harvested tomatoes (cv 'Liberto' in 1993 and 'Criterium' in 1994) at either the pink or mature green stage of maturity were used. Maturity was judged for the pink stage as when a pinkish, red or reddish yellow colour was evident on between 30 and 60 % of the external surface of each fruit. Mature green fruit were entirely light to dark green, but mature and capable of ripening (Grierson and Kader, 1986).

3.2. Storage Systems

3.2.1. Modified Atmosphere Packaging (MAP) System

Both cultivars of tomatoes were used in the MAP experiment. The tomatoes were sorted for size, colour and physical damage. Only undamaged fruits, free of disease, 50-55 mm in diameter and with an absence of apparent defects were selected for all the experiments and all the tomatoes were dipped into 100 ppm fungicide thiabendazole for 5 minutes to reduce the microbial load. They were then dried at ambient temperatures (18-20°C) to remove excess surface moisture.

The tomatoes were then divided into two groups, one group was left unwrapped and the others were placed on individual polystyrene trays (15 cm x 25 cm) and then heat-sealed in polyethylene films (obtained from Courtaulds Packaging,

Plate 3.1. Modified Atmosphere Packaging system

Hawkfield Way, Bristol, B514 OBD, England) of either 20 μ (PE20), 30 μ (PE30) or 50 μ (PE50), polyvinyl chloride 10 μ (PVC) (obtained from British Alcan Consumer Products Limited, Raans Road, Amersham, Bucks, HP6 6JY, England) or polypropylene 25 μ (PP) (obtained from Courtauld Packaging). Sealing was done with a Hulme Martin heat-sealer. A 1 cm diameter round silicon rubber septum was attached to each test film using double sided adhesive tape then over-sealed with adhesive cellulose tape to prevent leaks. In each experiment, each pack contained 6 fruits with a total weight of 500±25 g, therefore giving similar ratios between weight of fruit and area of film. The area of permeable film was approximately 260 cm^2 and the volume of free space (900 ± 50 ml) within the pack. Tomato packages were kept in temperature controlled rooms at 13 (12.8-13.7)°C and 78 ± 3 % RH or 20 (19.5-20.8)°C and 54 ± 3 % RH for 2 months. Sample trays from each treatment were removed from storage every 10 days for objective and subjective analysis.

3.2.2. Controlled Atmosphere Storage (CAS)

Fruits which were subjected to controlled atmosphere storage experiments were exposed to the required gas mixture in a closed system. In the study, freshly harvested 'Criterium' tomatoes at either the mature green or the pink were used. Six tomatoes were placed in each of 12 plastic boxes (18 cm length, 9 cm depth and 11 cm width) which were placed in air tight 50 litre polyethylene containers (Model C217, Mailbox International Ltd, Cheshire, UK.), so that there were 72 tomatoes in per container. The containers were connected to channels of a gas distributor (Mercury, UK. serial No.ss13306) by PVC tubing of 6.5 mm internal diameter. The gas distributor was connected to a computer controlled gas blender (Signal Instrument Co. Ltd. Surrey, UK., 850 series) which was

Plate 3.2. Mercury gas distributor with (A) computer controlled Signal gas blender and (A) A non gas tight CAS container

connected to compressed oxygen, carbon dioxide and nitrogen cylinders. Controlled atmosphere combinations between oxygen and carbon dioxide and nitrogen were made according to the gas concentration needed in each controlled atmosphere container. After sealing the containers, the O_2 content was rapidly reduced by flushing with a mixture of the desired concentration of gases. The appropriate atmospheres were obtained within a maximum 24 hours after harvest. The gas output from the gas blender and the controlled atmosphere storage containers were monitored for oxygen and carbon dioxide levels twice a day during the first week of experiments then twice a week using an Oxystat 2 Fruit Store Analyser fitted with an Infra Red Gas Analyser and a Paramagnetic Oxygen Analyser type 770 (David Bishop, Sussex, UK.).

One experiment was carried out on CAS of tomatoes at 13°C in 0.2 (0.1-0.3) %, 3.2 (2.9-3.3) %, 6.4 (6.2-6.5) %, 9.1 (8.8-9.3) %, 12.2 (12.1-12.5) % or 15.6 (15.2-15.7) % of CO_2 all with 5.5 (5.3-6.0) % O_2. Another experiment was at 15°C in 3.2 (2.9-3.3) %, 6.4 (6.2-6.5) % and 9.1 (8.8-9.3) % of CO_2 again all at 5.5 (5.3-6.0) % O_2. Other samples of tomatoes were kept in 20.9 % O_2 and 0.3 % CO_2 as a control in each temperature. In control treatments CO_2 concentration increased to 0.3 % because of CO_2 production of tomatoes in storage containers. Skin colour, firmness, weight loss, titratable acidity and total soluble solids were measured on samples every 10 days and at the end of 60 days storage sensory evaluation was also carried out.

3.3. Storage Conditions

3.3.1. Temperatures.

Fruits were stored within MAP and CAS in a controlled temperature room (2.1x2.4x2.1m^3). Temperatures were controlled automatically by a thermostat at 13°C and 20°C for MAP in 1993 and 13°C and 15°C for CAS in 1994. Temperatures variation was ± 0.5° C. There was an internal air circulation system.

3.3.2. Relative Humidity.

The relative humidity in the rooms used in this experiments was between 80-85%. Water vapour was supplied by an Ultra Salton Humidifier and measured by using either a digital psychrometer or by thermohygrograph.

3.4. Assessment of Fruit Quality.

Two ways were used for the assessments and evaluation of fruit quality. In the first, some biochemical and physical measurement and analyses (objective methods) were used to determine the condition of tomato fruits at harvest and at intervals during storage. The second was sensory evaluation (a subjective method) which was carried out by taste panel after fruits had ripened. The following parameters were measured.

3.4.1. Objective Methods.

3.4.1.1. Assessment of Fruit Colour

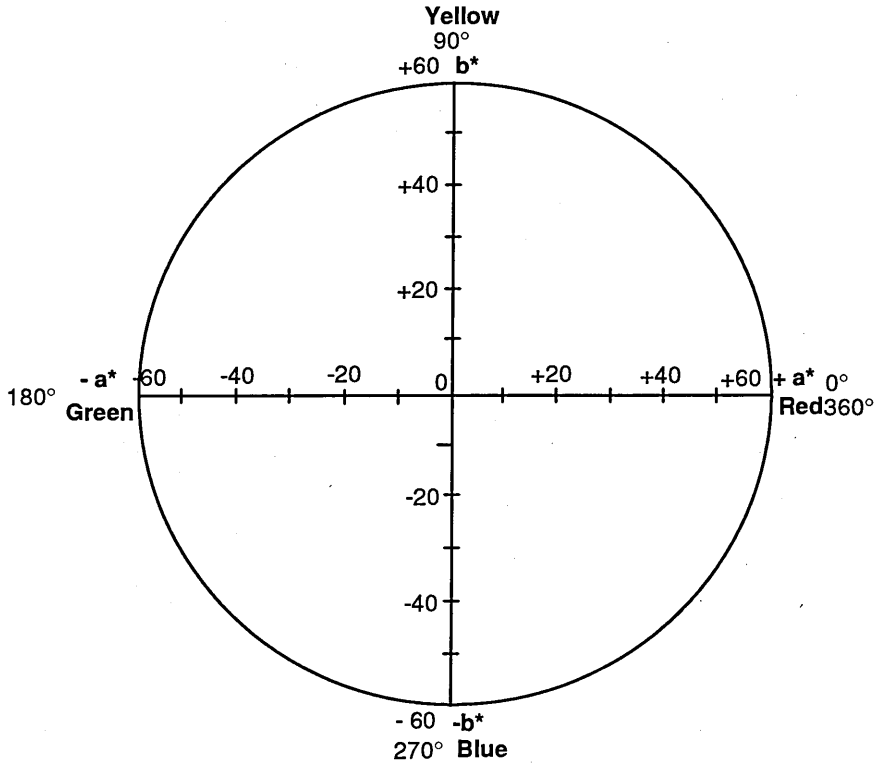


Figure 3.1. CIELAB colour space diagram (Anon, 1992; Weatherall and Lee, 1991).

The skin colour of tomatoes was measured with a Tristimulus Minolta Chromometer (Minolta model CR 200) employing '0°' viewing angle and 8 mm viewing aperture. Because of colour variation of the fruits, average readings at three predetermined points on the circumference of the fruits were recorded. The instrument was calibrated against a standard white plate (Y=93.9, x=0.313,

y=0.321 or L*=79.6, a*=-1.2, b**=2.8) (Anon, 1992). Results were record in, a*, b* and a*/b* values (Appendix 4-7) (Hobson et al., 1983; Tijskens and Evelo, 1994; Yang and Chinnan, 1988b). A positive a* value corresponding to the degree of redness while a negative value corresponds to the degree of greenness. A positive b* value compared to the degree of yellowness and the negative one represents the blueness (Figure 3.1).

3.4.1.2. Assessment of Flesh Firmness

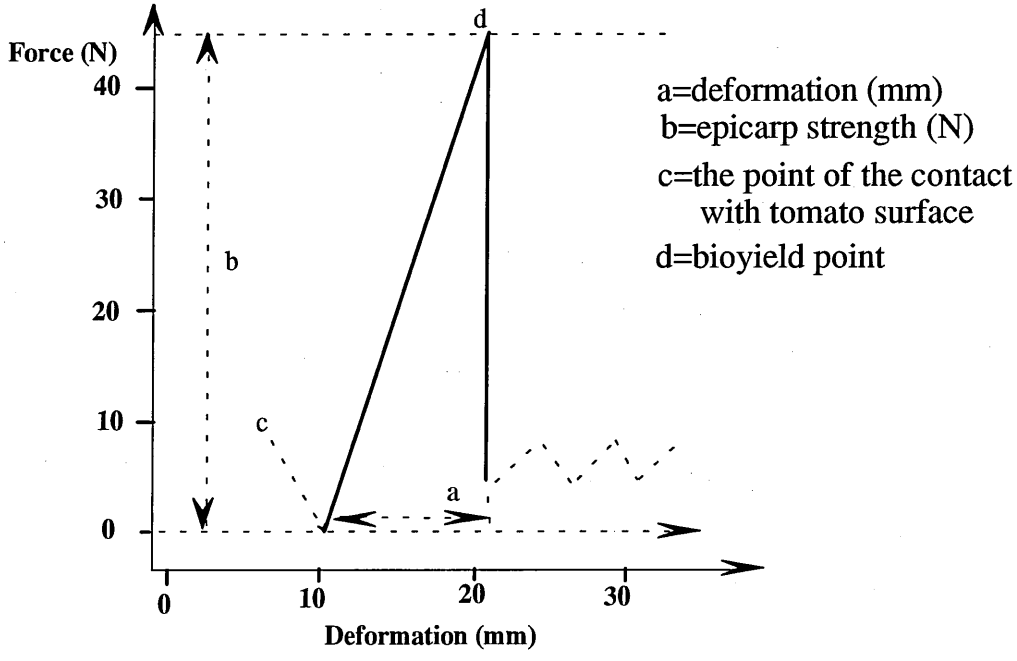


Figure 3.2. Typical force/deformation curve obtained during penetration of individual tomato

A destructive deformation test was used to evaluate fruit firmness according to Batu and Thompson (1993) by applying a constant 50 N force with an Instron Universal Testing Machine, model 1122. During the measurement of firmness,

the probe used should be as large (in diameter) as possible, it is important that the entire surface of the probe be in contact with the fruit surface. Therefore a probe of 6 mm in diameter and made of stainless steel was used in this experiment. It proved to be the most suitable for tomato fruits 50-55 mm in diameter. The cross-head and the chart speed was 20 mm minute^{-1}. The amount of force (N) which was required to penetrate through the skin to the tomato flesh and deformation (mm) values were recorded. Three textural characteristics were determined from the force/deformation curve in Figure 3.2. Epicarp strength was the force (N) at the bioyield point. Deformation was the distance (mm) travelled by the probe from first contact with the tomato skin to the bioyield point. Firmness (N mm^{-1}) was defined as the average slope of the force/deformation curve or was defined as the amount of force (N) required to penetrate of 6 mm dia through the skin to fruit flesh, over deformation (mm) (Adegoroye et al., 1989).

3.4.1.3. Total Soluble Solids.

Six replicate samples of 12 fruits from each treatment were homogenised in a laboratory blender at high speed for 1 min. The homogenates were filtered through 'MN 126/60' filter paper and the total soluble solids (TSS) content of the resulting clear juice samples determined by placing 2-3 drops of the undiluted juice in a bench top Atago digital refractometer model PRI (Atago Co. Ltd). Total soluble solids content was expressed in terms of the percentage of fresh weight of tomato fruit (Stevens et al., 1979; Kopeliovitch et al., 1982).

3.4.1.4. Titratable acidity.

Titratable acidity was determined by titration of extracted tomato juice. Two aliquots each of 10 ml tomato juice were titrated to pH 8.1 with 0.1 N NaOH using a Jenway Digital pH meter (Model 3020) and the results were converted to percent of citric acid according to the following equation and expressed in terms of fresh weight of tomato fruit (Rangana, 1979).

$$\text{Acid \%} = \frac{\text{Volume of NaOH x Normality x Volume made up x Equivalent weight of citric acid x 100}}{\text{Volume of the sample taken for estimation x Weight of sample taken x 1000}}$$

3.4.1.5. Weight Loss %.

The weight of each tomato was taken separately and recorded just before storage to an accuracy of ±0.01 g using a Mettler balance Model P1200 then they were reweighed at each sampling time and cumulative weight loss was calculated as follows;

$$\% \text{ weight loss} = \frac{W_0 - W_1}{W_0} \times 100$$

where: W_0 = Original weight of tomatoes just after harvest

W_1 = Weight at sampling time (fruit weight just after storage)

3.4.1.6. Decay

During the 60 days storage period, samples of fruit were taken after each 10, 20, 30 ,40 ,50 and 60 days storage, with two packages (having 6 tomatoes each) from each treatment for analysis. Fruits were considered to be decayed when any disease symptoms appeared on any part of the fruits. Those disease symptoms were identified as being one of Fuserium rot, blue mould rot, rhizopus rot, sour rot or alterneria rot on the basis of descriptions given by Snowdon (1991) and Sommer et al., (1992). The number of fruits that were decayed was expressed as a percentage of the total number of fruits (12) at each sampling time.

Percentage of decayed fruit = $\frac{A}{B} x100$

A: Number of decayed fruit at each sampling time

B: Total number of fruits (12) taken for analysis at each sampling time

3.5. Subjective Assessment (sensory evaluation)

For sensory evaluation, stored and control tomatoes were used. Mature green or pink tomatoes stored for 60 days in various modified atmosphere packaging films or within various controlled atmosphere environment were included. Control tomatoes were harvested from the same plants at the pink stage and stored for 7 days at 13°C until reaching a light red (marketing stage) or a full red colour. Samples were evaluated by using scales for tomato flavour, sweetness, sourness, firmness (finger feeling) and acceptability level. Ten semi-trained judges were selected from a pool of MSc and PhD students from different countries. Those panellists were screened for taste acuity for tomatoes and

trained to use the score sheet. Tomatoes were scored according to their quality on a scale between 1 and 5. Where:

sweetness: 1=not sweet, 5= very sweet

flavour: 1= weak flavour, 5= strong tomato flavour

sourness: 1= very sour, 5= not sour

firmness: 1= very soft, 5= very firm.

acceptability: 1=not acceptable, 5= highly acceptable

3.6. Water Vapour Permeability of Films

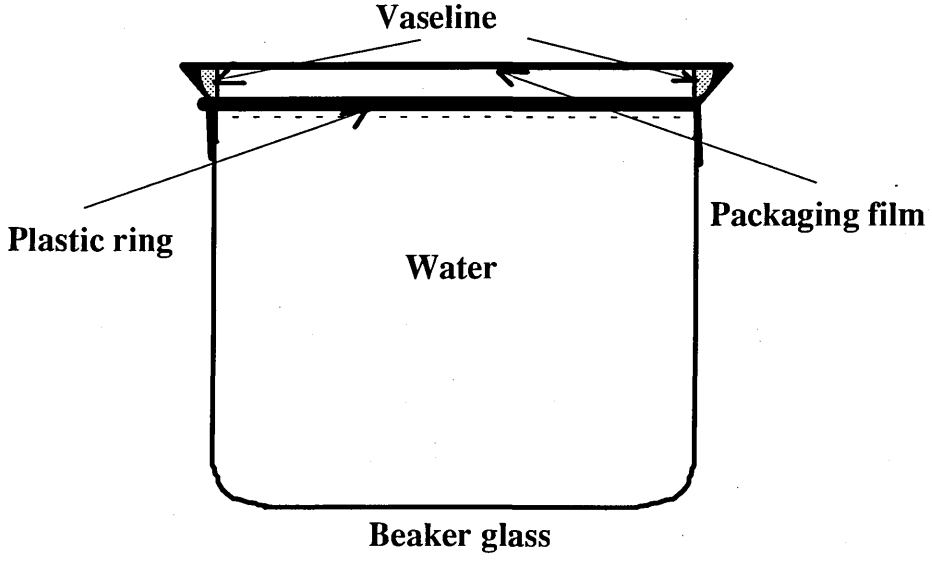


Figure 3.3. Water vapour transmission apparatus

A gravimetric method was used (Brown, 1981). The 500 ml beaker glasses were filled with water and the packaging film was sealed onto the lip of the 500 ml beaker glass using wax (which has a very low permeability rate to water vapour) between the film and these glasses. Then the film was secured with a plastic ring (Figure 3.3). The initial weight of the every 500 ml beaker glasses were tared. The assembly was then placed in a temperature and humidity controlled room at either 13°C or 20°C for 24 hours then they were weighed again. The rate of weight change after 24 hours was used to calculate the quantity of water vapour which has permeated through the film per unit area of the packaging films. The results were expressed as g m^{-2} 24 h^{-1}.

3.7. Permeability Measurements of Packaging Films

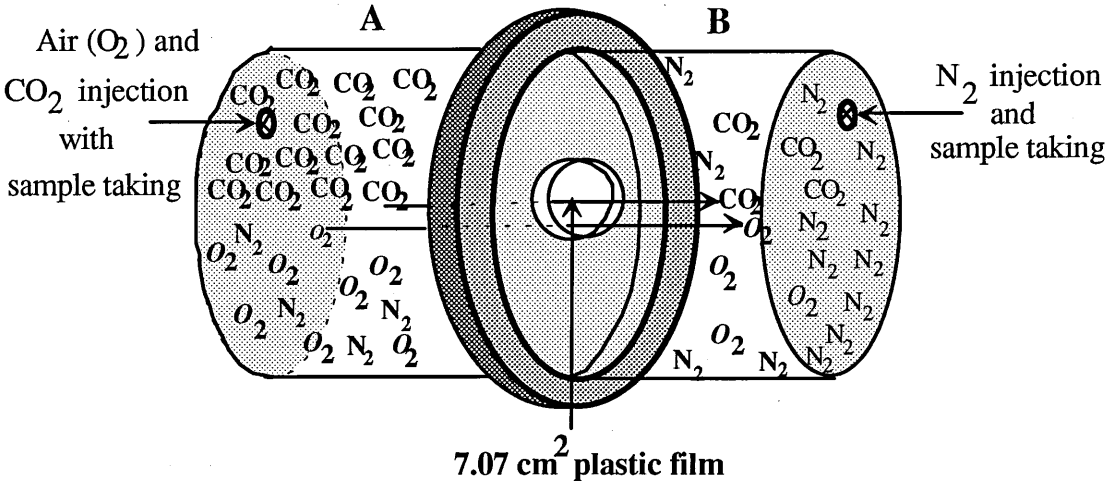


Figure 3.4. A two chamber gas jar which enclosed the individual packaging films as a permeable membrane to measure their gas transmission properties.

Permeability characteristics of the plastic films were tested under normal atmosphere conditions. An area 7.07 cm^2 was clamped tightly between the two plastic chamber. The plastic film was the only permeable membrane between the two gas chambers (Figure 3.4). Each end of the jar comprised a volume of 370 ml. Four vessels were used at the same time. Two of them were used to measure film permeability to CO_2 and two of them were used for O_2. For measurement of CO_2 permeability a mixture of 10 % CO_2 and 90 % N_2 was injected. In the opposite end 100 % N_2 was injected. For O_2 measurement the left hand side had air and the right hand side 100 % N_2. Initially 10 ml samples were taken from the both sides of the vessels to determine initial levels of CO_2 and O_2. The plastic vessels were kept in a temperature controlled room at either 13°C and 20°C. After 24 hours gas samples from both ends of the vessel were taken and the CO_2 and O_2 levels were analysed by gas chromatography (see 3.8). The difference between initial results and those after 24 hours were used to calculate the quantity of CO_2 and O_2 which permeated through the packaging films in 24 hours. The results were expressed as ml m^{-2}. d^{-1}.

3.8. Gas Measurements

To measure the gas levels inside the MAP containing fruit the concentration of carbon dioxide and oxygen around the fruit inside the plastic films were analysed daily by withdrawing ten millilitre gas samples from each package using a hypodermic needle and syringe. Those samples were then injected into a Carlo Erba Instrument GC 8000 Series Gas Chromatography equipped with a hot wire detector. The flow rate of the carrier gas (argon) was 40 ml min^{-1} and detector, oven, and attenuation temperatures were 120°C, 70°C and 128°C, respectively.

3.9. Statistics

The experiments were designed as complete randomised factorial designs. Two replicates [two packages for MAP (see Section 3.2.1) and two boxes for CAS (see Section 3.2.2), each box or package had 6 tomatoes] were used in each treatment. At every sampling time (every 10 day during 60 days storage) 24 measurements were recorded by measuring two points on the circumference of the 12 fruits for colour and firmness evaluation. These colour and firmness data were reduced to 6 means of 24 measurements. One figure corresponds to the mean of four measurements. These four measurements also correspond to two fruits at each sampling time. For weight loss, acidity and TSS one measurement was taken from each fruit at each sampling time. In this case 12 measurements were recorded at each sampling time. For statistical analysis a mean of two measurements was taken. These data were subject to analyses of variance (ANOVA) using a Genstat statistical package. Treatment effects reported were significant according to an F test at the 5 % probability level. Data for the different experiments were analysed separately. Significant differences between the treatments were detected using least significant differences (LSD). To compare the means LSD was calculated using standard errors of difference of means from ANOVA analyses multiplied by the appropriate standard deviation t value obtained from tables. Standard errors of means and percentage of coefficient variation were also calculated from the ANOVA analyses (Steal and Torrie, 1987).

RESULTS AND DISCUSSIONS

Chapter 4. Determination of Acceptable Levels of Tomato Firmness and Colour Values.

4.1. Introduction

For fresh tomatoes the two quality attributes that are most important to buyers and consumers are texture and skin colour (Tijskens and Evelo, 1994). Texture is influenced by flesh firmness and skin strength (Kader et al., 1978b). Softening during storage, distribution and ripening of tomatoes can be a major problem because it may increase their susceptibility to damage. The degree of fruit firmness has been used as an indication of fruit quality (Burton, 1982a), and firmness may be the final index by which the consumer decides to purchase a given batch of tomatoes (Gormley and Egan, 1978). Fruit firmness can be determined in several ways. Many kinds of machines have been developed which can measure firmness by destructive methods. The Instron Universal Testing machine is the most common and most accurate one used for this purpose (Kader et al., 1978b).

Tomato colour can be determined instrumentally, chemically or visually. Instrumental measurement is commonly used for measurements of colour of fruits and vegetables because it gives more accurate information than other methods (Bakker et al., 1986). The most common instrument used is a colour difference meter and a model of the Minolta Chroma Meter (produced by Minolta Camera Co., Ltd, Japan) which uses the 1976 CIE L* a* b* colour space technique.

There is contradictory information about the results of colour and firmness measurements in literature. There is no satisfactory information on whether a measure of firmness or colour values of tomatoes by Minolta are within the acceptable levels required by consumers. This chapter reports on studies on the changes in firmness and colour of two tomato varieties 'Liberto' and 'Criterium' at the time of picking and again after storage.

The main objectives of the work described in this chapter were:

1) To determine the minimum level of consumer acceptance for the firmness of tomatoes
2) To determine the effect of skin on measurements of tomato firmness
3) To determine the colour values of marketable tomatoes

4.2. Material and Methods

In the first experiment 200 tomato fruits from two varieties of tomatoes at pink, light red and red stages of maturity were harvested from SRI glasshouse, 'Liberto' in 1993 and 'Criterium' in 1994 and then stored at 20°C. Twenty fruits were separated into the five firmness classes by finger feel 'A', 'B', 'C', 'D' and 'E' of the firmest fruit coloured light red. The 'A' firmness class was selected on the day of harvest, while those for the other classes were sorted out later when the tomatoes reached the approximate texture on the basis of finger feel firmness. The results were expressed as arbitrary percentages of maximum acceptability. Categorisation was tested using a triangle test method. For example, three fruits were offered to ten different judges in order to differentiate three samples, which two of them belonged to one group, and which belonged to the other group. On a

subjective basis only 'A', 'B' and 'C' were considered acceptable for marketing. These judgements were made by a ten-member panel.

A destructive deformation test was used to evaluate fruit firmness. Epicarp strength was the force (N) at the bioyield point. Deformation was the distance (mm) travelled by the probe from first contact with the tomato skin to the bioyield point. Firmness (N mm^{-1}) was defined as the average slope of the force/deformation curve (see Chapter 3).

The five different acceptability levels of tomatoes were;

A : Just picked at the pink or light red stage of maturity, very fresh and easily marketable

B : Picked at the pink or light red maturation stage and stored for 2-3 days, but they remained very firm and there was no indication of softness by finger touching test. Easily marketable.

C : Stored tomatoes, although they were slightly soft their firmness was good enough for making salads and slicing. Marketable.

D : Stored tomatoes. They were softer than C acceptability level and not good enough for making salads but could be used for cooking or production of tomato paste. Poor market quality.

E : Overripe tomatoes. They were very soft and softer than D acceptability

level. They could be used for cooking or production of tomato paste. Very poor market quality.

In the second experiment, 30 tomatoes were used and the effect of removing the skin on firmness was measured using the destructive force/deformation test. Three treatments (skinless, cut skin and normal) were carried out on the same tomatoes around the equatorial line of fruits (Plate 4.1). The experiments were repeated with 10 different tomatoes.

Skinless: 1 cm x 1 cm area of tomatoes skin was cut to 2-3 mm depth then the skin was removed very carefully.

Cut skin: The skin was cut in the same way as the skinless but skin was left in place.

Normal: The skin was not cut and the fruit were left intact.

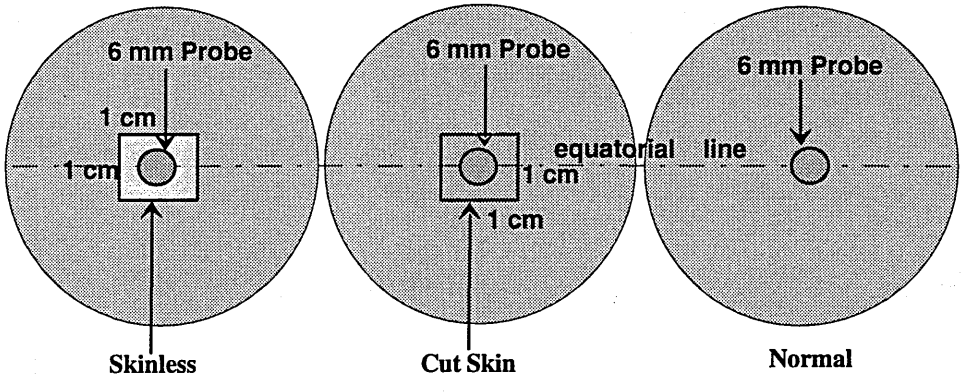
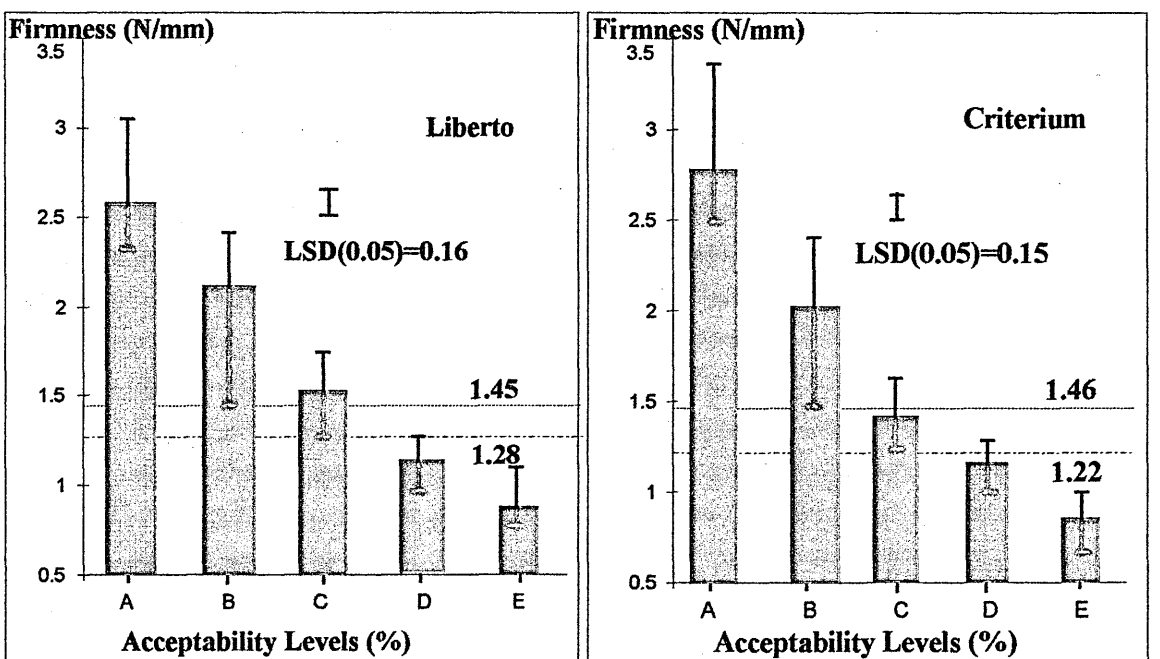


Plate 4.1. Application of firmness measurements on treated tomatoes

4.3. Results

4.3.1. Determination of the Minimum Acceptable Firmness Levels

The relationship between subjective firmness values, which are very important for marketing, and objective firmness evaluation (acceptability levels; determined by finger feel firmness) of tomatoes was investigated. The minimum acceptable firmness values of tomatoes for marketing was determined using a force/deformation test.



For Liberto, 1.45 Nmm^{-1}: very firm, 1.28 Nmm^{-1}: slightly soft but good enough for making salad
For Criterium, 1.46 Nmm^{-1}: very firm, 1.22 Nmm^{-1}: slightly soft but good enough for making salad

Figure 4.1. The relationship between measured firmness values and subjective market acceptability levels of tomatoes (cv's 'Liberto' in 1993 and 'Criterium' in 1994). The vertical lines represent maximum and minimum values.

As expected the firmness values of tomatoes decreased with decreasing acceptability levels over the range of 'A' (freshly harvested) to 'E' (overripe). There was a significant (P=0.05) decrease in both varieties (Figure 4.1). There was a consistent decrease in firmness values of 'Liberto' between 'A' and 'D' acceptability levels. This decrease was between 'A' and 'C' acceptability levels for 'Criterium'. In both varieties there was a variation between maximum and minimum firmness values at 'A' and 'B' acceptability levels. Those variation levels were smaller than the others at 'C', 'D' and 'E' acceptability levels.

According to the results of this research on the basis of objective firmness evaluation, it was found that the minimum marketable level (MMV1) of tomato firmness at which an individual tomato fruit could be acceptable for sale at retail level, was, about 1.45 N mm^{-1} and 1.46 N mm^{-1} for 'Liberto' and 'Criterium' respectively. At these levels the fruit had a 'B' marketability score. However, the second minimum marketable value (MMV2) which was given to fruit which were judged could still be used in the home and which may still be marketable and capable of being sliced easily was 1.28 N mm^{-1} and 1.22 N mm^{-1} for 'Liberto' and 'Criterium', respectively. These had a score of 'C' marketability. For firmness values below 1.22 N mm^{-1} it is very difficult to sell this kind of tomato and very difficult to slice or to use them for salads. For the firmness values of tomatoes above 1.28 N mm^{-1} (slightly soft, MMV2) they could be used for salads. If their firmness is above 1.46 N mm^{-1} (very firm, MMV1) they are easily marketable. The two varieties behaved in a similar way (Figure 4.1).

4.3.2. Skin Effect on Firmness Evaluation

As would be expected it was found that skinless or cut skin tomatoes required a lower penetration force and resulted in lower deformation values during penetration than normal fruits picked at either mature green or the pink stages of maturity (Table 4.1). The force required for penetration of the probe through tomato flesh between cut skin and normal was significantly different (P=0.05) between all treatments of tomatoes harvested both at mature green and pink stages of maturity. It was also found that there was a significant difference in deformation values of tomatoes both harvested at mature green and pink stages of maturity.

Table 4.1. Firmness and deformation values of tomatoes harvested at pink and mature green stage of maturity which were tested as skinless, cut skin and normal.

	Epicarp Strength (N)					Deformation (mm)				
	Skinless	Cut Skin	Normal	$LSD_{(0.05)}$	CV %	Skinless	Cut skin	Normal	$LSD_{(0.05)}$	CV %
Green	14.94	21.03	22.27	1.10	6.10	7.81	8.06	8.43	0.34	5.90
Pink	2.96	5.85	10.50	0.56	5.40	2.63	5.29	6.87	0.29	5.20

It was found that there was no difference in measurement of firmness due to cutting the skin of green tomatoes (Figure 4.2). However, differences were significant (P=0.05) when the skin was removed from the green tomatoes. This was the reverse for pink tomatoes. There was no difference in flesh firmness between cut and skinless pink tomatoes whereas it was significantly (P=0.05) higher in normal and cut skin treatments of tomatoes harvested at green maturity stage (Figure 4.2).

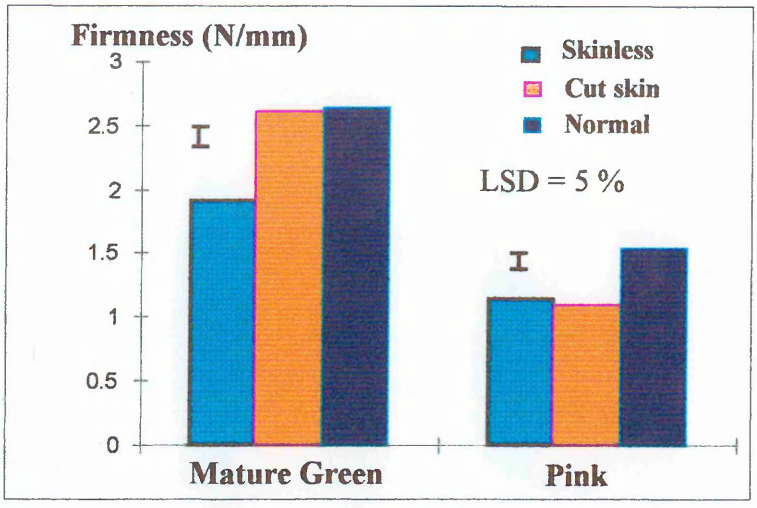


Figure 4.2. Firmness values of tomatoes harvested at green and pink stage of maturity which were tested when either skinless, cut skin or normal (see plate 4.1)

4.3.3. Relationship of Tomato Colour With Ripeness

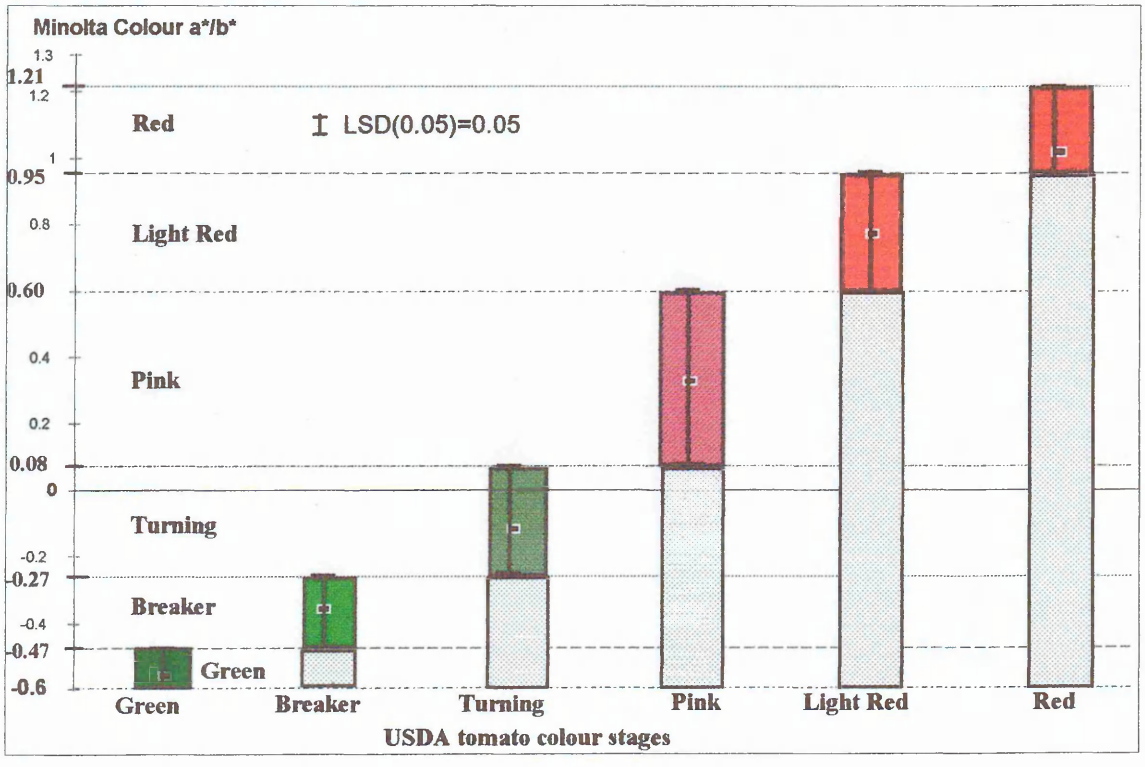


Figure 4.3. Mean of the Minolta Colour (a*/b*) values of tomatoes at USDA stages (vertical lines represent maximum and minimum values)

Mature Green

Breaker

Turning

Pink (USA)

Orange (UK)

Light Red

Red

Plate 4.2. USDA tomato colour stages

The Minolta colour a*/b* values of the surface of tomatoes correspond to the six USDA colour stages which are used for estimation of the colour values. The measurement of the colours in terms of CIELAB a* and b* values enables objective evaluation of tomatoes when classified according to USDA colour stages.

Minolta colour a*/b* values increased with increasing USDA colour stages (Figure 4.3) Minolta (CIELAB) a*/b* values were less variable for mature green tomatoes (range from -0.59 to -0.47). These values at the breaker stages of tomatoes were also negative (-) (range from -0.47 to -0.27). Separation values between the turning and pink stages were found to be 0.08. The light red stage is the one that is commonly marketed. It was found that at this stage the Minolta a*/b* values ranged from 0.60 to 0.95. The red stage of USDA tomato colour is a little overripe for normal maturity. Tomatoes which reached the red colour might have had a long overall storage time or might have stayed on the vine too long. The Minolta colour values at the red stage had a colour range from 0.95 to 1.21. Minolta a* and b* values of tomatoes at USDA maturation stages are included in Appendix 3.

4.4. Discussion

The variation between minimum and maximum values of fruits which had 'A' and 'B' acceptability levels (very firm) is slightly higher than the variations of other acceptability levels. This variation might be due to some difficulty in categorisation, especially of fruits which had 'A' and 'B' acceptability levels. All fruits were firm when touched with the fingers. It is very difficult to determine the texture of the inner structure of the fruits by hand but it is possible to determine the firmness of the fruits by very sensitive machines. The Instron machine gave

accurate values which were varied, but all of the fruits were very firm. Categorisation was easier for softer ('C', 'D' and 'E') fruits by touch.

As would be expected removing the skin before measuring tomato firmness was found to affect their firmness values. However, just cutting the skin did not reduce the force required for green tomatoes whereas it significantly affects pink tomatoes. The differences in firmness between fruit harvested at the pink or mature green stage could be related to properties of the skin which change during maturation and ripen. As it was shown the texture of the cellular structures of the fruit below the skin also changed during maturation and ripening so that the machine measurements will be affected by both the skin and sub-skin cellular characteristics. These results confirm the studies of Kader et al., (1978b) who reported that skin removal also resulted in lower penetration force values for fruit picked at different ripeness stages and that firmness decreased with increasing ripeness. They also pointed out that although removing the skin is recommended for textural measurements of other fruits (apples, pears, etc.) it is not essential for tomatoes, which was supported by this work. This could be due to the thinness of tomato flesh. Tomatoes are juicier than apples, and it is more difficult to measure the firmness of tomatoes without skin. However, it is important to specify whether the skin was removed or not in reporting firmness measurements and to note that damage to the skin of part ripe tomatoes is very important for determining the fruit firmness whereas not too important for mature green fruits.

Variation in colour readings between maximum and minimum values increased during ripening of tomatoes and is most variable at the pink stage of maturity. This is because of colour instability at this stage of maturity. The colour was not

completely pink at the pink stage of maturity whereas tomatoes were predominantly green in colour at green and breaker stages and predominantly red in colour at the light red and red stages. It is very difficult to say this for the pink stage. There is some interpretation difference between scientists: Grierson and Kader (1986), and Yang and Chinnan (1988b) define this stage as 'pink' whereas Hobson and Davies (1971) and Gould (1988b) call it 'orange'.

Chapter 5. Humidity Effects on Storage Quality of Tomato

5.1. Introduction

Ripening of the tomatoes was found to be delayed significantly when they were stored in MAP (Yang et al., 1987). Since MAP films provide high humidity around the fruits (Paine and Paine, 1992c) this might be a factor involved in ripening (Thompson et al., 1974). Very little definite information appears available on humidity effects on tomato ripening. It was reported that storage at high humidity has been found to delay ripening of tomatoes when compared with storage at low humidity (Thompson et al., 1974). Thus higher humidity can lead to condensation on produce and these conditions are very favourable for microbial growth, resulting in decay of commodity (Zagory and Kader, 1988). There is no available information on the relation between humidity levels and the postharvest evaluation of tomatoes.

The objectives of this study therefore was to investigate the effect of humidity levels in controlled environments on the ripening characteristics of tomatoes harvested at different maturation stages. The main reason for this was MAP affects many constituents of the storage environment of the fruit and the experiment was designed to differentiate between the O_2 and CO_2 effects and the humidity effect on delaying ripening.

5.2. Material and Methods

5.2.1. Fruits

In the experiment tomatoes (cv Criterium) were harvested at either the green and pink stage of maturity from a greenhouse at Silsoe Research Institute.

5.2.2. Storage Treatments

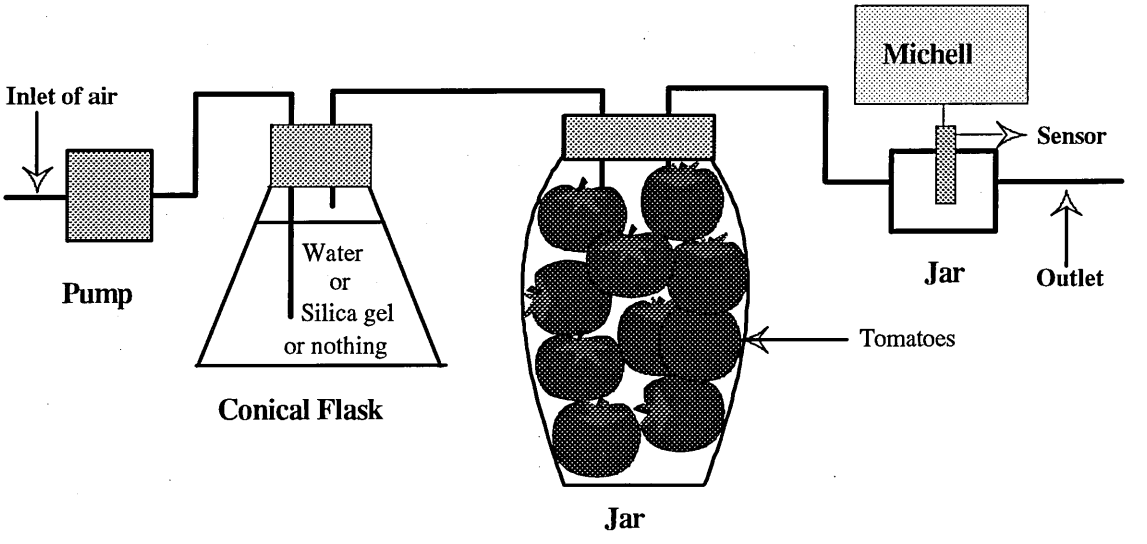


Figure 5.1. Schematic Illustration of Set up of the Relative Humidity Experiment

Ten fruits were placed in nine 3-litre air tight glass jars each with an inlet and outlet (Figure 5.1). Air at three levels of relative humidity were passed through the inlet into the jars of fruit continuously at 6 litre min^{-1} and the outlet gas was passed over the sensor head of a Michell dew point meter every 6 hours to measure the relative humidity. Conical flasks of 500 ml capacity were connected to the outlet of the pump. These flasks were filled with water to provide high (92-96 %) humidity, the three others were filled with dried silica gel to provide low (60-65 %) humidity in the air and the remaining 3 were left empty and ambient air

(medium humidity, 76-80 %) was passed through them. The air was pumped to the three conical flasks to provide the three levels of humidity maintained above. Experiments were set up in a temperature controlled room at 20 (± 1) °C, and continued until the fruit ripened. Each experiments was repeated two times.

5.2.3. Analysis

Skin colour, weight loss, titratable acidity and total soluble solids were measured as described in Chapter Three. The same statistical analysis techniques were also used. A non destructive deformation test was used to evaluate fruit firmness according to Floros et al., (1987). A maximum compression force of 1 N was applied to the fruit surface with a 6 mm diameter round stainless steel probe in an Instron Universal Testing Machine, model 1122. An appropriate full scale compression load deflection was chosen. The chart speeds was 50 mm minute^{-1} and cross-head speed was 1 mm minute^{-1}. Measurements were made on each fruit at 2 positions around its equator. The deformation (mm) due to application of the 1 N compression force was measured.

5.3. Results

Ripening of the tomatoes was significantly (P=0.05) delayed when they were kept in a high humidity environment (Table 5.1). There was no significant difference between high and medium humidity levels on ripening time of tomatoes harvested at pink stage of maturity and it took 10.13 to 14.41 days. Ripening time was shorter under low humidity than medium or high humidity. Those tomatoes ripened within 5.23 days at low humidity to reach the same ripening stage. Green tomatoes ripened within 12.83 days at low humidity but those at high humidity did not ripen fully and were still at the pink stage of maturity after 15 days of storage whereas the fruits at medium humidity levels were fully ripe after 14.92 days.

Table 5.1. Relative humidity effect on tomato quality when they were picked at green and pink stage and stored at 20°C until they ripe (except green fruit stored in high humidity).

Humidity Levels (%)	MS[1]	Ripening Time (days)	Minolta Colour (a*/b*)	Firmness[2] Deforma-tion, mm)	Titratable Acidity (%)	Total Soluble Solid (%)	TSS Acid Ratio	Weight Loss (%)
High	Pink	10.41	0.81	0.71	0.26	4.60	17.69	2.41
Medium	Pink	10.13	0.83	0.95	0.24	4.70	19.58	5.12
Low	Pink	5.23	0.83	0.56	0.27	4.64	17.18	4.62
High	M. Green	>15.00	0.42[3]	0.65	0.35	4.72	13.49	3.03
Medium	M. Green	14.92	0.82	0.90	0.26	4.95	19.03	6.63
Low	M. Green	12.83	0.83	0.83	0.26	4.85	18.65	7.23
	LSD=5 %	1.21	0.12	0.09	0.02	0.12	1.10	0.65

1: Maturation stages when tomatoes were harvested, 2: Smaller values are firmer
3 : Still pink after 15 days of storage,

There was no significant (P=0.05) difference between medium and low levels of humidity on firmness, total soluble solids and titratable acidity of tomatoes harvested at the mature green stage when they had ripened, but in the high humidity environment firmness, TSS and titratable acidity of tomatoes were significantly different than fruits stored in medium and low humidity (Table 5.1). There was no significant difference between the three humidity levels for total soluble solids levels of tomatoes harvested at the pink stage of maturity when they were fully ripe. But the difference in titratable acidity and firmness values of those treatments were significant.

As would be expected it was found that weight loss significantly decreased as humidity increased. Although there was no significant difference on weight loss values green and pink tomatoes stored within low and medium humidity levels, the weight loss of tomatoes stored at high humidity was significantly (P=0.05) less than the others.

5.4. Discussion

In the result of this experiment weight loss of tomatoes was inversely related to the RH levels in the storage environment as reported by Riquelme et al., (1994) and the lower RH gave the highest weight loss (water loss) and their ripening time was shorter than others. Dennis et al (1979) showed that weight loss (excluding that due to fungal decay) from the tomatoes during 4 weeks storage was approximately 5 % at 90 % RH compared to 2 % and 1 % at 95 % and 98 % RH respectively. Risse (1987) also reported that film wrapped (approximately 100 % humidity environment) tomatoes had a lower fresh weight loss than non wrapped tomatoes (Kawada and Hale, 1980). The reason for this is that by increasing the RH in the storage environment this reduces the water losses (weight losses) from fruits and it also reduces the vapour pressure differences between the produce and the air in the storage atmosphere (Wills et al., 1989), therefore, respiration becomes slower and ripening decreases in high RH. Lower RH is directly correlated with increasing the water vapour deficit which cause higher transpiration and consequently higher weight losses (Van Den Berg, 1987) thus stimulating fruits respiration rate (Kader, 1987a). Tomatoes harvested at the mature green stage and stored in medium and low RH environments had higher than 5 % fresh weight loss. The finger feel firmness of tomatoes which had lost about 5 % in weight was considered acceptable (even being slightly softer) for slicing. This was confirmed with Day (1993) and Risse (1987) who reported that weight losses of 5 % are usually enough to observe the initiation of fruit softness on many kinds of produce.

Tomatoes harvested at the mature green stage of maturity and kept at high humidity had a significantly (P=0.05) lighter colour (the colour at the market stage) and were more acidic and firmer than those ripened at the lower humidities.

Delayed fruit ripening, firmer fruit with higher acid could be due to reduction of ethylene production in a high humidity environment (95-100 %) because of

saturation of intercellular space within the fruits (Wilkinson, 1970 and Kader, 1985a). It was also reported that the higher RH gives the slower respiration rate (Kader, 1987a). Risse (1987) reported that film wrapped (approximately 100 % humidity environment) tomatoes had longer storage life, and were much firmer than non wrapped tomatoes. Another reason for delayed ripening in higher RH is most likely water losses (especially higher than 5 %; Kader, 1987a) in lower RH increased ethylene production of fruit which causes it to increase its ripening rate and to hasten senescence (Van Den Berg, 1987). Therefore, ripening rate of tomatoes was increased and their ripening time was decreased in low RH environment. Tomatoes harvested at the pink stage of maturity and ripened at low humidity were firmer and had higher titratable acidity and normal TSS levels. These differences in ripening could explain why the time taken to ripen was shorter than those ripened in medium and high humidity.

There is no available information on the relation between humidity levels, the changing on acidity and TSS values of tomatoes. But at seems to be consistent that in high RH, ripening time of fruit takes longer than at lower RH and the fruit remain less red in colour. Acid and TSS values of the tomatoes were correlated with ripening rate of the fruits. So, the less ripe fruits gives the higher acidity and lower TSS.

Chapter 6. Modified Atmosphere Packaging (MAP) and Controlled Atmosphere Storage (CAS) of Tomatoes

6.1. Introduction

Tomato quality changes continuously during ripening after harvesting. A vegetable store will be successful only if it will keep the produce in good condition with minimum deterioration when it was compared with freshly harvested fruits by the customers. Cool or cold storage techniques can be used to extend the period of supply by short or long term storage. But it is very difficult to slow down the respiration rate, and hence ripening rate of tomatoes with these techniques because fruits will suffer chilling injury especially if it is necessary to store the fruits such as tomatoes over long periods.

Ripening of tomatoes can be delayed by holding them in low O_2 and high CO_2 than air. The modification of storage atmosphere also may help to reduce development of decay during storage. Therefore, MAP and CAS can be effectively used to extend the storage life of tomatoes.

The specific objectives of the work described in the present chapter were as follows;

1) To investigate the permeability levels of plastic film packaging material and the effects of film permeability on the shelf life of tomatoes packed in them.

2) To develop a MAP system, using different packaging films, which would retard deterioration and extend the shelf life of tomatoes harvested either at the mature green or pink maturation stages without detrimentally affecting

their organoleptic qualities.

3) To determine instrumental colour and firmness changes of tomatoes stored in various gaseous environments.

4) To compare the initial environmental condition (particularly atmospheric composition) and evaluate the effects of conditions within packs on the rate of ripening and fruit during their shelf life.

6.2. Material and Methods

For plant materials, storage techniques and objective quality assessments see Chapter 3. In this chapter for MAP in 1993 'Liberto' variety and for CAS in 1994 'Criterium' variety of tomatoes were used.

6.3. Results

6.3.1. Modified Atmosphere Packaging of Tomatoes

6.3.1.1. Permeability of Packaging Materials

The relative permeabilities of the films to O_2, CO_2 and water vapour were determined at 13°C and 20°C. It was found that CO_2 permeability of the films was higher than O_2 permeability. Permeability quantities of all packaging films to CO_2, O_2 and water vapour were found to be higher at 20°C than 13°C and their

permeability ratios to CO_2 over O_2 between 13°C and 20°C were approximately similar (Table 6.1).

Table 6.1. Thickness, gas and water vapour permeabilities of some packaging films at 13°C and 20°C

Packaging Materials	Storage Temperature (°C)	cc $m^{-2}.d^{-1}$		PCO_2/PO_2	WVTR
		CO_2	O_2		
PE20	13	37109	6085	6.1	29.0
	20	46232	8561	5.4	72.5
PE30	13	31938	5349	5.9	24.9
	20	39480	6976	5.7	50.4
PE50	13	16168	3099	5.2	12.1
	20	22577	4224	5.3	19.5
PVC	13	35184	5580	6.3	21.1
	20	41798	7929	5.3	45.2
PP	13	8731	3736	2.3	16.7
	20	12339	4000	3.1	24.2

PE20: 20μ polyethylene, *PE30*: 30μ polyethylene, *PE50*: 50 μ polyethylene,
PVC: 10μ polyvinyl chloride, *PP*: 25μ polypropylene
WVTR: Water vapour transmission rate, PCO_2: permeability to CO_2, PO_2: permeability to O_2

6.3.1.2. Gas Compositions of Internal Atmosphere of Packages

This experiment was conducted for 7 days to determine the equilibrium concentration of CO_2 and O_2 during storage. In this case, three replicates (packages) from each treatment were prepared (see plate 3.1 and Section 3.2.1) using tomatoes harvested at mature green or pink stage of maturity. Then these sealed packages were left in temperature controlled rooms that half of the packages were kept at 13°C and another half of them were kept at 20°C. Then 10 ml gas samples were taken from each individuall packages every 24 hours to estimate the amount of CO_2 and O_2 by Gas Chromatography (see Section 3.8). Concentrations of O_2 decreased and CO_2 increased during the first few days of storage, after which a 'state of equilibrium' was reached between respiration of the produce and the diffusion of the gases through the film. This has previously

been described by Geeson and Browne (1983). The equilibrium concentration of O_2 in the packages was lower for the fruit stored at 20°C compared to the fruits stored at 13°C, and CO_2 concentration was slightly higher at 20°C than at 13°C.

Table 6.2. Times for concentration of CO_2 and O_2 to equilibrate and equilibrium concentrations (%) in experimental packages of mature green and pink tomatoes sealed in different packaging films at 13°C and 20°C.

Mature Green		O_2		CO_2	
Pack. Materials	Storage Temp (°C)	Equilibrium Time (days)	Equilibrium Concentration (%)	Equilibrium Time (days)	Equilibrium Concentration (%)
PE20	13	1.2-2.2	11.0-13.6	1.8-2.8	2.8-3.4
	20	1.0-1.2	10.8-11.8	1.8-2.8	3.0-3.6
PE30	13	1.0-2.4	7.4-8.2	2.6-3.8	2.8-4.0
	20	1.4-2.2	7.2-8.0	3.4-4.8	4.0-4.8
PE50	13	1.8-3.2	4.6-5.8	3.4-4.8	4.6-6.0
	20	1.8-2.6	4.4-5.4	3.0-4.8	7.6-8.2
PVC	13	1.2-2.2	10.6-12.0	1.8-3.2	3.9-4.6
	20	1.2-2.0	10.8-12.3	1.8-3.4	4.2-4.8
PP	13	1.8-2.6	4.6-5.8	2.8-4.2	11.0-12.0
	20	2.6-3.2	4.5-5.4	2.8-4.6	9.2-11.6

Pink		O_2		CO_2	
Pack. Materials	Storage Temp (°C)	Equilibrium Time (days)	Equilibrium Concentration (%)	Equilibrium Time (days)	Equilibrium Concentration (%)
PE20	13	1.2-1.8	11.4-12.6	1.8-3.0	2.8-3.4
	20	1.2-2.6	11.3-12.0	2.2-3.2	3.0-3.6
PE30	13	2.0-3.2	8.0-9.8	2.2-3.2	2.8-4.8
	20	2.2-3.0	7.8-9.4	2.0-3.2	4.0-5.2
PE50	13	2.2-3.8	4.2-4.8	3.4-4.8	4.6-6.0
	20	2.4-4.0	4.8-5.4	2.6-5.0	6.4-8.2
PVC	13	1.2-2.0	10.6-11.6	1.8-3.2	3.4-4.2
	20	1.3-2.4	11.0-11.8	2.2-3.2	3.8-4.4
PP	13	2.4-3.6	5.2-6.0	2.8-4.2	12.4-12.8
	20	2.6-3.8	5.4-5.8	1.8-3.2	13.8-14.2

PE20: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinil chloride, *PP*: Sealed with 25μ polypropylene

In the packages sealed in PE20 the internal atmosphere changed and concentrations of O_2 fell to 10.8-13.6 % from the 21 % and CO_2 rose from 0.03 % to 2.8-4.8 % for both pink and green tomatoes at 13°C and 20°C (Table 6.2). O_2 concentrations were similar at both temperatures when they reached their equilibrium concentration but it was lower in PE30 packages which contained pink tomatoes than for mature green tomatoes ones. CO_2 concentrations in PE30 films were similar for both pink and mature green tomatoes but they were slightly higher at 20°C than 13°C. In the packages sealed in PE50 the equilibrium concentration of O_2 was at 4.2-5.8 % for pink and green tomatoes at both temperatures. The equilibrium level of CO_2 was 4.6-6.0 % for mature green and pink tomatoes at 13°C and it was 6.4-8.2 % for both mature green and pink tomatoes at 20°C in PE50 films. Gas composition changes and equilibrium concentrations of O_2 inside the PVC films were very similar for either pink and green tomatoes at 13°C and ranged between 10.6-12.3 %.

The equilibrium level of CO_2 was similar at 13°C and 20°C and they were ranged between 3.6 % and 4.8 %. However it was slightly higher for mature green tomatoes (3.9-4.8 %) than the pink tomatoes (3.4-4.4 %) at both temperatures. In the package sealed in PP the equilibrium level of O_2 concentrations were similar to that in the PE50 packages at both temperatures for both pink and green tomatoes. The CO_2 concentrations were similar in both PP and PE50 and ranged between 11.0 % and 12.0 % at 13°C. CO_2 contents was higher at 20°C than 13°C for mature green tomatoes whereas it was lower at 20°C than at 13°C for pink tomatoes sealed in PP (Table 6.2).

6.3.1.3. Colour

• Normal colour changes of tomatoes occur from green (corresponding -a*) to red (corresponding +a*) during colour development. Yellowing (corresponding b*) of tomatoes is also clearly shown by the change in the level of (b*) values. The results indicate that colour changes can be expressed by a* or a*/b* (Tijskens and Evelo, 1994) (see Chapter 3). Concerning the changes in b* (which changed slightly, Appendices 4-7) the colour value of tomatoes was expressed as a*/b* by many authors (Tijskens and Evelo, 1994; Yang and Chinnan, 1988b; Yang et a., 1987). The effects of the interaction of storage temperature and packaging treatment on the colour development of tomato fruits during storage periods was highly significant (P=0.001) (Table 6.3).

Table 6.3. Mean squares from the analysis of variance of tomatoes during 60 days modified atmosphere packaging storage (for colour).

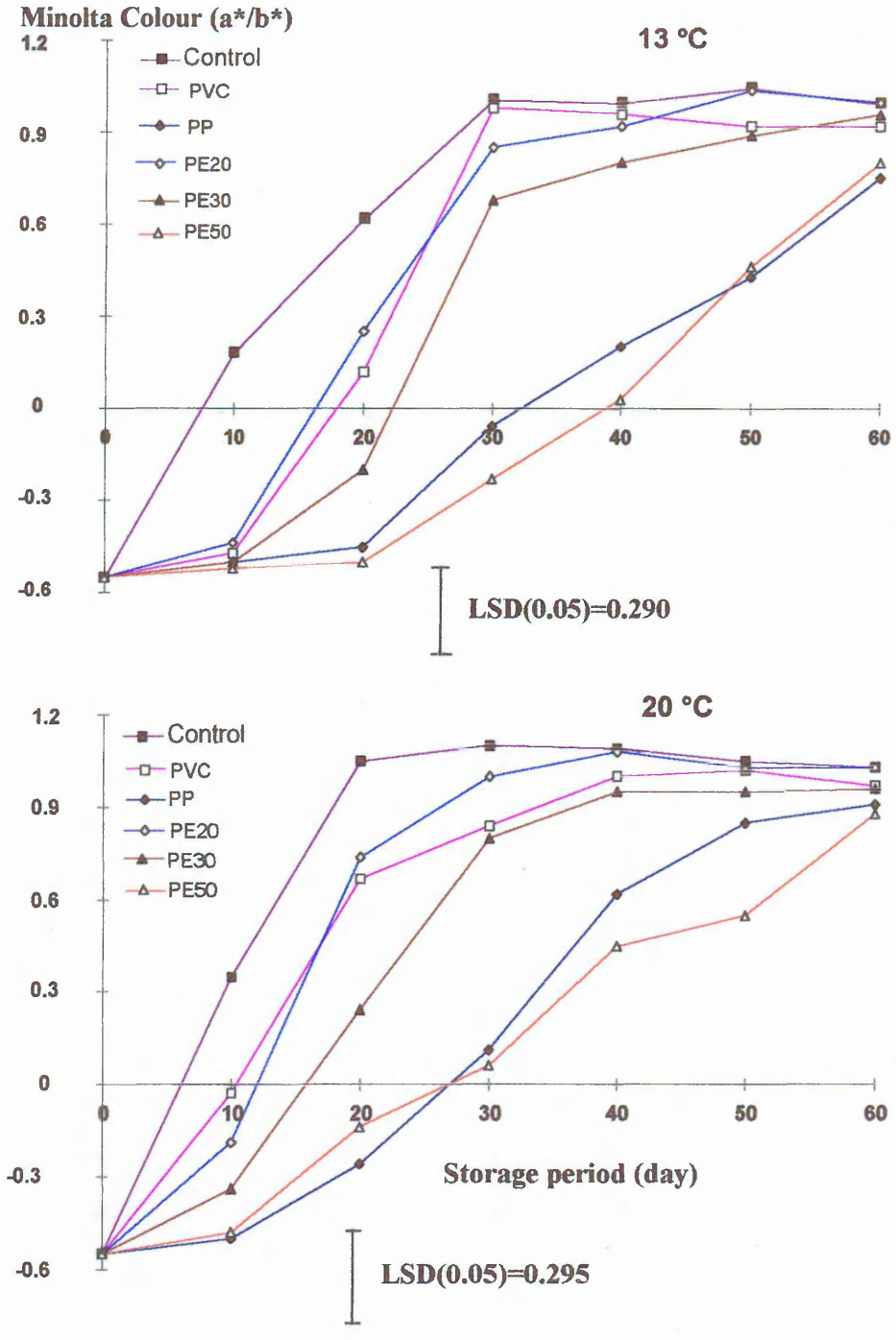
Source of Variation	df	Mature Green	Pink
Temperature (T)	1	4.36***	0.06*
Treatments (TR)	5	5.85***	0.24***
Storage (S)	5	15.68***	0.26***
TxTR	5	0.05^{ns}	0.02***
TxS	5	0.34***	0.06***
TRxS	25	0.51***	0.03***
TxTRxS	25	0.04***	0.01***
Residual	350	0.07	0.01
Total	421		

*** Fpr < 0.001 ** Fpr < 0.01 * Fpr < 0.05 ns= No significant interaction

The red colour development of mature green tomatoes increased significantly (P=0.05) during storage. The red colour development of mature green tomatoes sealed with PE50 and PP was retarded, even after 60 days storage when compared to PE20, PE30, PVC and especially to the control fruits at both 13°C and 20°C storage temperatures. Mature green tomatoes sealed in PE20 and

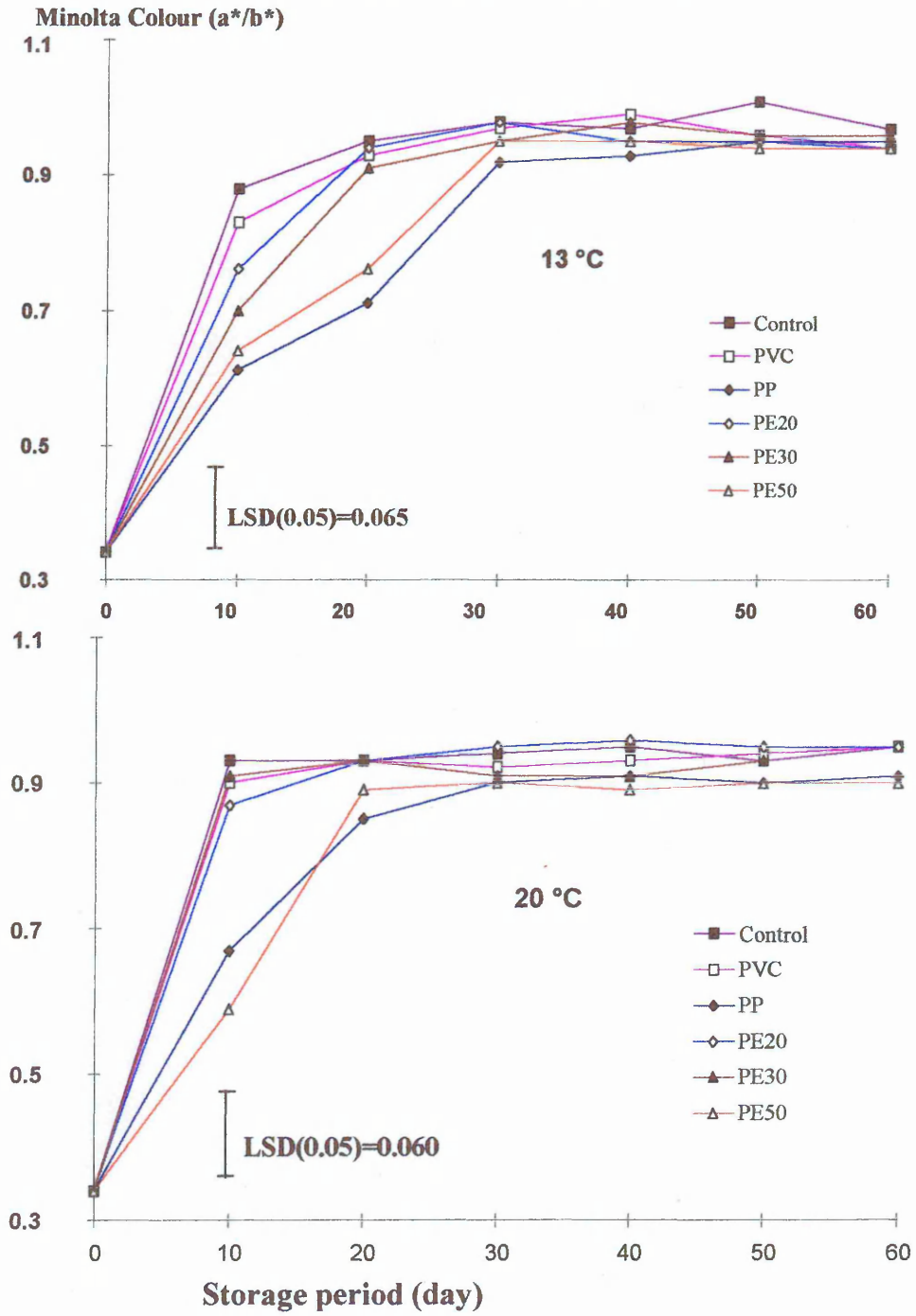
PE30 reached their reddest colour after 50 days while those in PVC reached it after 40 days at 13°C and tomatoes sealed in PE20, PE30 or PVC reached their reddest after 40 days at 20°C. The colour of the tomatoes sealed in PE20, PE30 and PVC film had not changed after 40 days at 13°C or 20°C and there was no significant (P=0.05) difference between them after that time. There was also no significant difference (P=0.05) between the colour values of all the tomatoes (harvested at both mature green and pink stage of maturity) sealed with PE50 and PP films throughout the storage period at both temperatures. Although their colour values increased steadily throughout the storage period (Figure 6.1 and 6), mature green tomatoes at harvest were still not fully red even after 60 days storage (Figure 6.1). After 50 days the colour of these tomatoes had just reached the pink stage of maturity. On the 60th day their colour was light red (the colour commonly found in the market). By that time the fruit colour was slightly darker if they were stored at 20°C rather than at 13°C.

The colour development of pink tomatoes sealed in PE50, PP and stored at 13°C was delayed until the 30th day of storage although control fruits reached a light red colour in 10 days. The colour values of fruits sealed with PE50 and PP were significantly (P=0.05) lower than other treatments until 30 days storage at 13°C. Full colour development was delayed until the 20th day of storage at 20°C for fruits in PE50 and PP films. There was no significant (P=0.05) difference between the treatments after 30 days storage at 13°C and after 20 days storage at 20°C. The fruits sealed with PE20, PE30 and PVC reached a light red colour by the 20th day (Figure 6.2). Control fruits reached a dark red colour in 10 days. The fruits sealed in PE20, PE30 and PVC films were nearly dark red at this time,



Control: unwrapped, *PE20*: Sealed with 20µ polyethylene, *PE30*:Sealed with 30µ polyethylene, *PE50*: Sealed with 50µ polyethylene, *PVC*: Sealed with 10µ polyvinyl chloride, *PP*:Sealed with 25µ polypropylene
Green: -0.62-(-0.49), *Breaker*: -0.48-(-0.26), *Turning*: -0.25-0,06 *Pink*: 0.08-0.56, *Light red*: 0.61-0,95 *Red*: 0.95-1.22

Figure 6.1. Minolta colour (a*/b*) changes of tomatoes harvested at mature green stage of maturity and stored at 13°C and 20°C in sealed various packaging films during storage



Control: unwrapped, *PE20*: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinyl chloride, *PP*:Sealed with 25μ polypropylene
Green: -0.62-(-0.49), *Breaker*: -0.48-(-0.26), *Turning*: -0.25-0,06 *Pink*: 0.08-0.56, *Light red*: 0.61-0,95 *Red*: 0.95-1.22

Figure 6.2. Minolta colour (a*/b*) changes of tomatoes harvested at mature green stage of maturity and stored at 13°C and 20°C in sealed various packaging films during storage

Plate 6.1. Some tomatoes stored in various MAP films. (A) at 13°C for 30 days; (B) at 20°C for 30 days; (C) at 13°C for 60 days and (D) at 20°C for 60 days

but by the 20th day they were a much darker red colour. The O_2 and CO_2 concentrations at this time are given in Table 6.2.

The colour stability of unwrapped tomatoes was maintained for 30 and 20 days at 13°C and 20°C respectively, although there was some slight increase in the colour values of tomatoes sealed in PE20 and PE30 film between 40 and 50 days. There were no significant (P=0.05) changes in the colour development of mature green tomatoes sealed in PP and PE50 before 20 and 10 days of storage at 13°C and 20°C respectively. After that time it increased steadily during the whole storage period at both temperatures. In contrast there was a significant (P=0.05) increase in the colour values of pink tomatoes sealed with PE50 and PP films within 20 and 30 days at 20°C and 13°C, respectively. The colour values of tomatoes sealed in PE20, PE30 and PVC increased on the 20th day of storage at 13°C. It was 10 days earlier at 20°C than 13°C. No significant (P=0.05) difference was observed in the colour values of mature green or pink tomatoes sealed with PVC and PE20 throughout storage period at 13°C and 20°C. The colour of unwrapped control fruits also increased within the first 10 day of storage at 13°C or 20°C.

6.3.1.4. Firmness

A destructive deformation test was used to evaluate fruit (see Chapter 3). Subjective estimate of fruit softness relating to the minimum that would be acceptable on the market was established as the minimum marketable value of tomatoes (cv 'Liberto'). Firmness has been described in Chapter 4 inasmuch as 1.28 N mm^{-1} is the second minimum marketable value (MMV2) and that this is

slightly soft but acceptable to use at home and even to sell in the market. 1.45 N mm^{-1} value is the first minimum marketable value (MMV1) and is very firm.

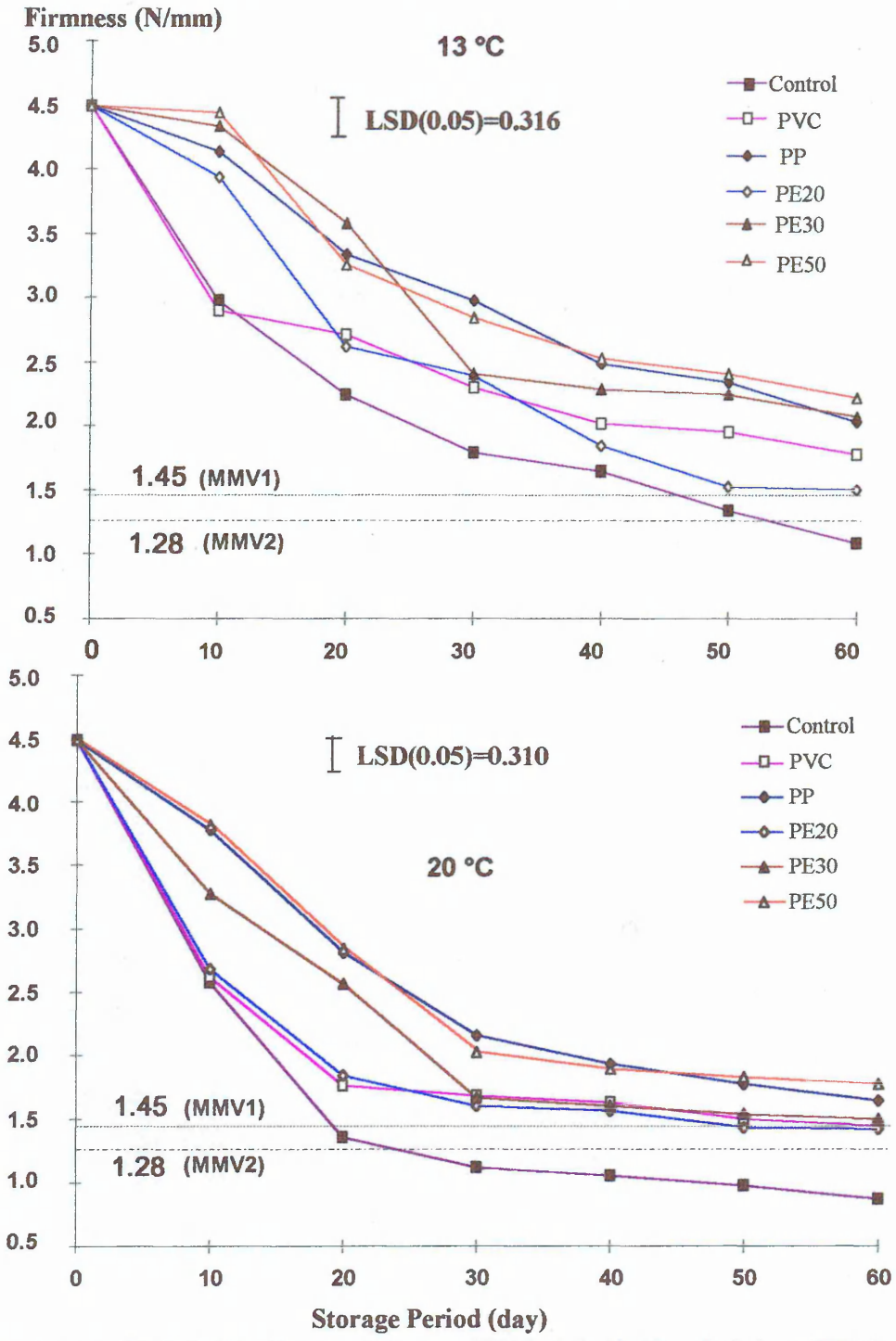
Table 6.4. Mean squares from the analysis of variance of tomatoes during 60 days modified atmosphere packaging storage (for firmness).

Source of Variation	df	Mature Green	Pink
Temperature (T)	1	37.54***	12.42*
Treatments (TR)	5	12.61***	7.17***
Storage (S)	5	37.51***	8.55***
TxTR	5	0.23*	0.40***
TxS	5	0.31***	2.13***
TRxS	25	0.75***	0.11***
TxTRxS	25	0.13ns	0.19***
Residual	350	0.11	0.05
Total	431		

*** Fpr < 0.001 * Fpr < 0.05 ns= No significant interaction

The effects of the interaction of storage temperature and packaging treatment on softening of tomato fruits was highly significant (P=0.001) (Table 6.4).

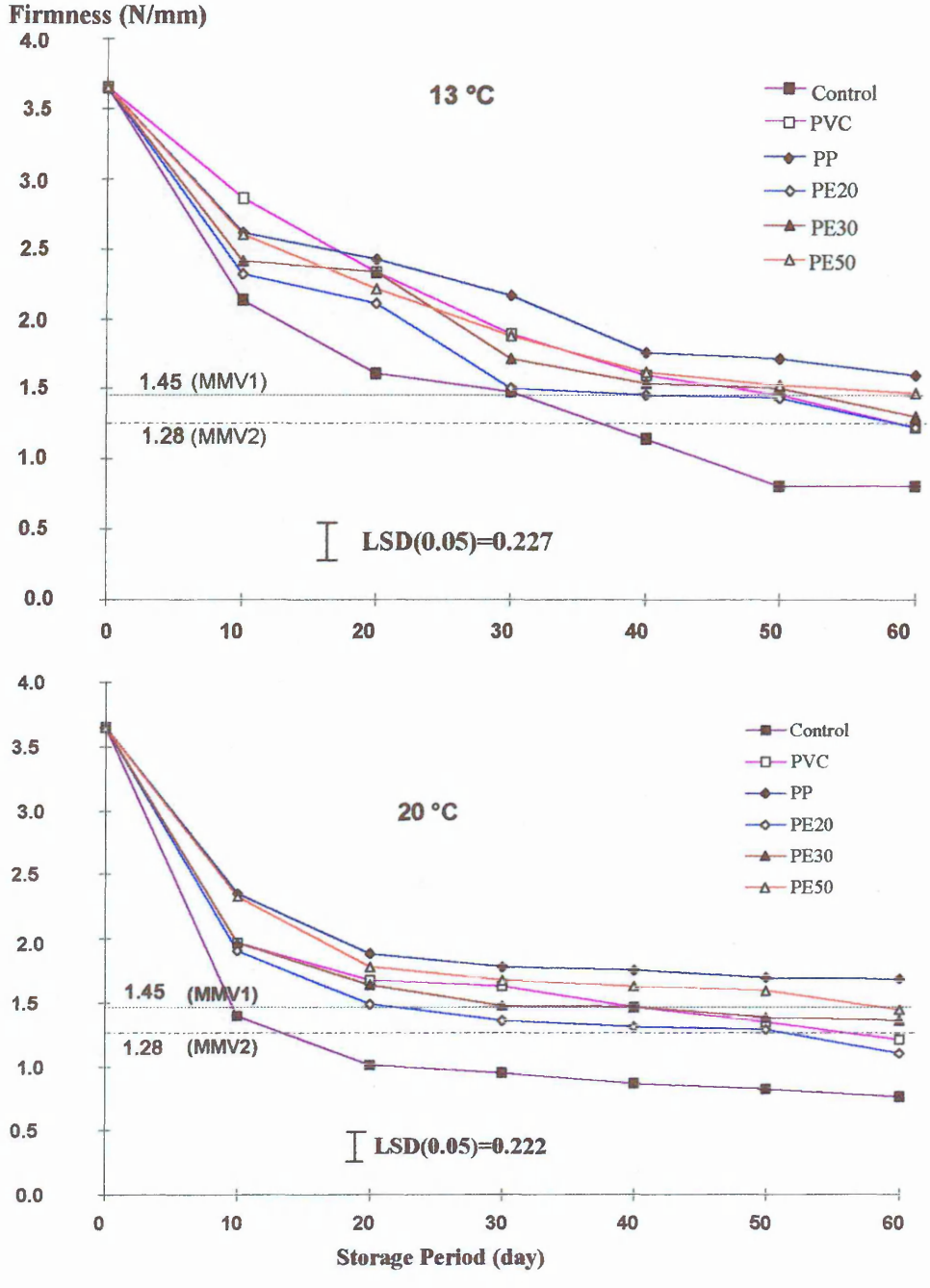
All fruit softened progressively during storage, but those sealed in plastic film softened significantly (P=0.05) more slowly than those stored unwrapped (Figure 6.3 and Figure 6.4). All mature green tomatoes in plastic films were very firm even after 60 days storage at 13°C (Figure 6.3). Unwrapped fruits were very firm until the 45th day of storage and even after 50 days they were only slightly soft with a firmness value of 1.34 N mm^{-1}. All mature green tomatoes sealed within PP, PE30 and PE50 films were very firm throughout the storage period even at 20°C. It was also found that the firmness of tomatoes sealed within PE20 and PVC films was still very high (above the MMV1) after 45 days and was still above the MMV2, after 50-55 days storage. Sealing pink tomatoes within PE50 and



Control: unwrapped, *PE20*: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinil chloride, *PP*: Sealed with 25μ polypropylene

1.45 N/mm^{-1}: very firm, 1.28 Nmm^{-1}: slightly soft but good enough for making salad

Figure 6.3. The changes of firmness values of tomatoes harvested at mature green stage of maturity and sealed in various thickness of various packaging films and stored at 13°C and 20°C.



Control: unwrapped, *PE20*: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinil chloride, *PP*: Sealed with 25μ polypropylene
1.45 N/mm^{-1}: very firm, 1.28 Nmm^{-1}: slightly soft but good enough for making salad

Figure 6.4. The changes of firmness of tomatoes harvested at pink stages of maturity and sealed in various thickness of various packaging films and stored at 13°C and 20°C.

PP stored at either 13°C and 20°C delayed them becoming soft (higher than the MMV2 value) for at least 60 days. No significant (P=0.05) difference was found between the firmness values of tomatoes sealed in PE50 and PP throughout the storage period at both temperatures and when harvested at the mature green and pink stage of maturity (Figure 6.3 and 6.4). The firmness values of the remaining treatment were significantly (P=0.05) lower than PP and PE50.

Softening of pink tomatoes sealed within PE30 and PVC and stored at 13°C and 20°C was delayed until 50 and 40 days, respectively. Their firmness values were still higher than MMV1. After 60 days storage the firmness of tomatoes sealed in PE30 was still acceptable at both temperatures for use at home. The firmness value of fruits packed in PE20 film was 1.46 N mm^{-1} after 40, days and 1.44 N mm^{-1} after 50 days at 13°C. Firmness of tomatoes sealed in PE20 or PVC film and stored at 20°C was greater than MMV1 after 20 days and also greater than MMV2 after 50 days storage. Unwrapped pink tomatoes became slightly soft in 12-13 days at 20°C and in 35-36 days at 13°C (Figure 6.4). Mature green tomatoes stored at 20°C decreased in firmness until 30 days storage but after this time there were no significant (P=0.05) changes. Firmness of pink tomatoes reduced during the first 10 days storage but there was no significant (P=0.05) decrease between 20 and 60 days at 20°C.

6.3.1.5. Weight Loss

The effects of the interaction of storage temperature and packaging treatment on weight loss of tomato fruits was highly significant (P=0.001) (Table 6.5).

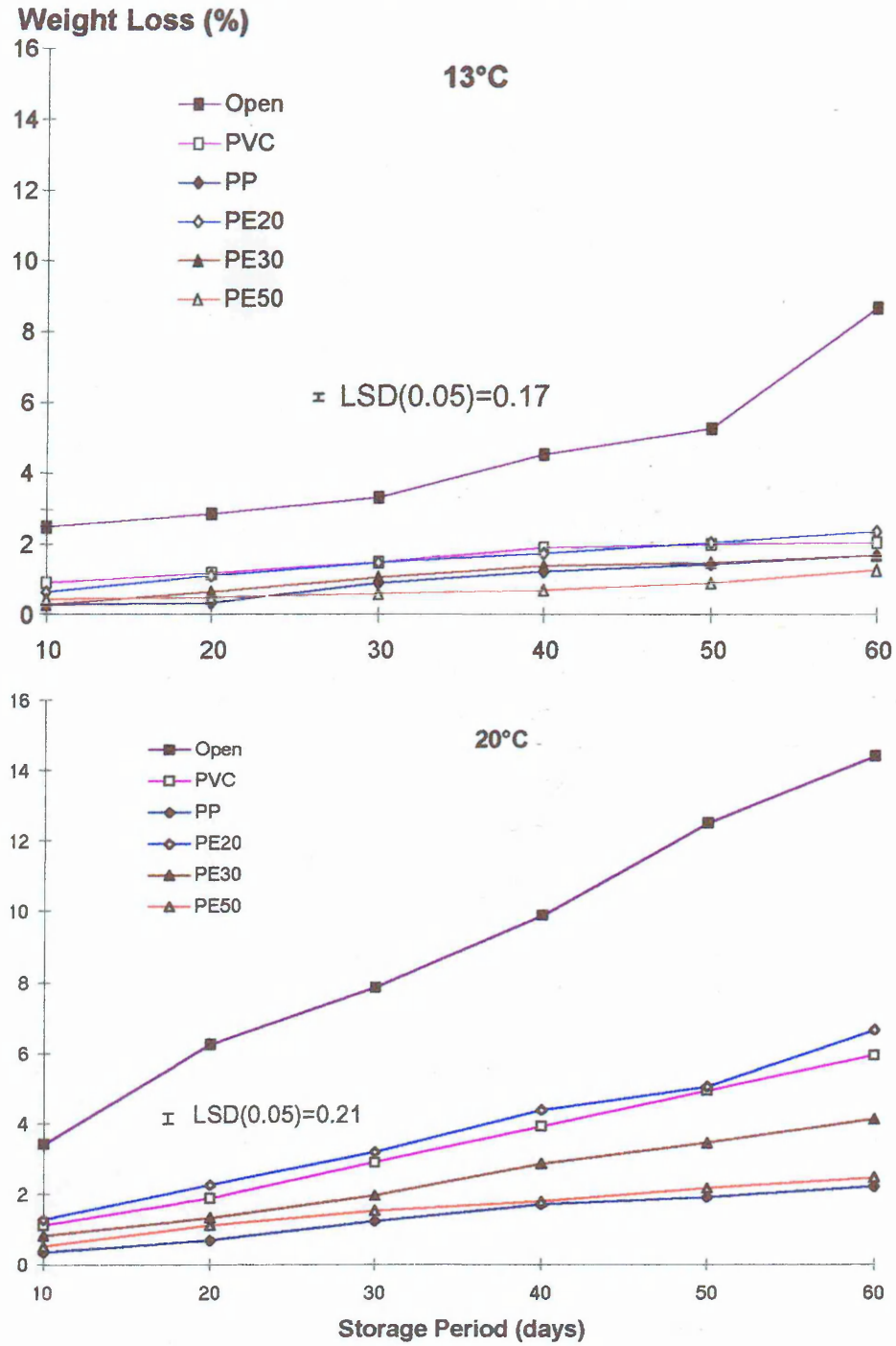
Weight loss of the plastic film packed fruits was significantly (P=0.05) lower than unwrapped fruits and increased throughout the storage period both for mature green or pink tomatoes at 13°C and 20°C (Figure 6.5 and 6.6).

Table 6.5. Mean squares from the analysis of variance of tomatoes during 60 days modified atmosphere packaging storage (for weight loss).

Source of Variation	df	Mature Green	Pink
Temperature (T)	1	234.29***	208.54***
Treatments (TR)	5	75.98***	330.50***
Storage (S)	5	220.38***	78.64***
TxTR	5	11.64***	14.64***
TxS	5	27.27***	1.89***
TRxS	25	7.12***	11.24***
TxTRxS	25	1.63***	2.01***
Residual	350	0.07	0.01
Total	421		

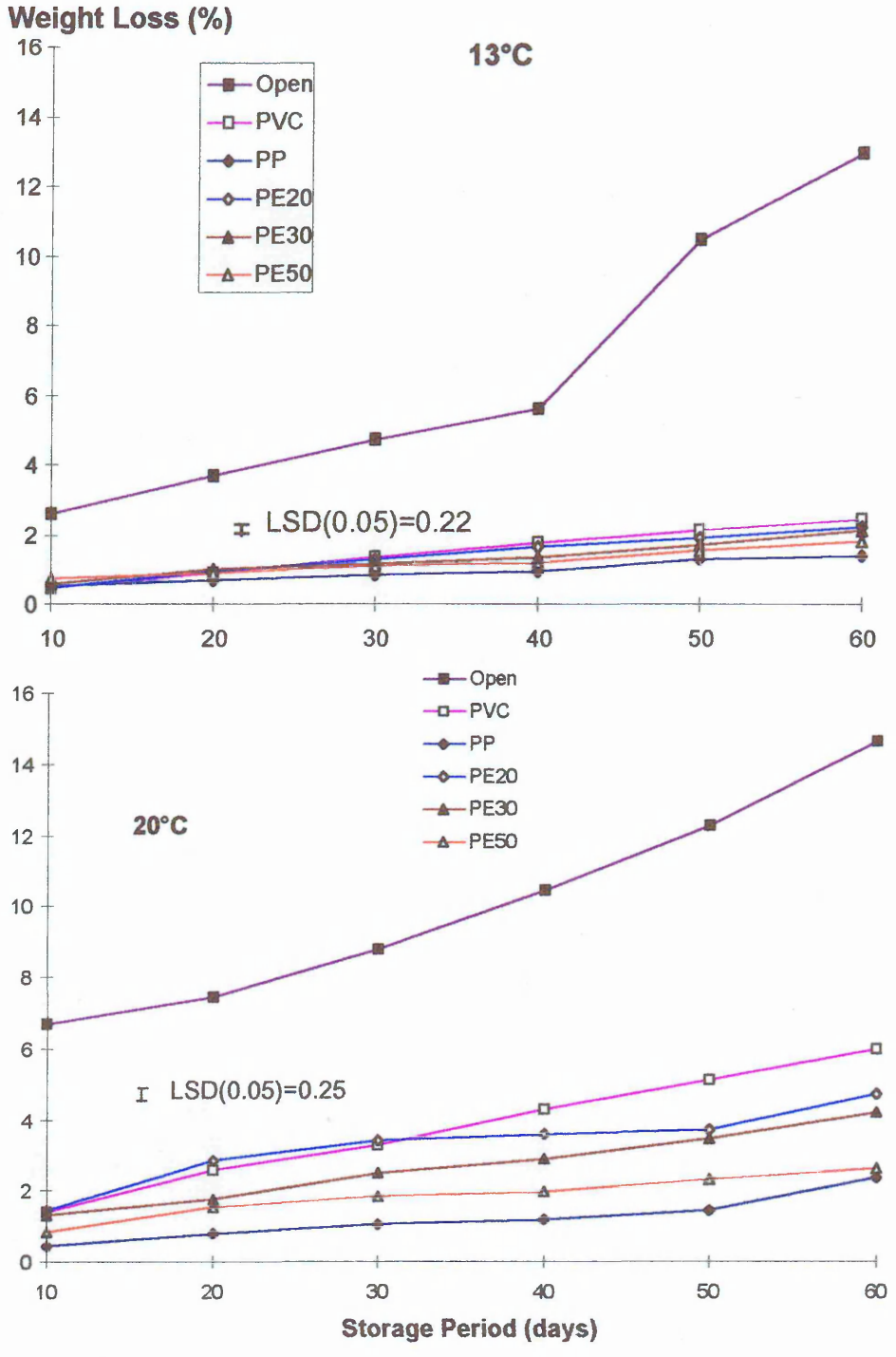
*** Fpr < 0.001

Generally weight loss of tomatoes harvested at the mature green or pink stage of maturity and sealed within PP was significantly (P=0.05) lower than in PE30 or PE50 at both temperatures but for mature green tomatoes at 13°C fruits sealed in PE50 had the lowest weight loss. Generally at both temperatures all fruits which were sealed in PVC and PE20 films had the highest weight loss. Weight loss of fruits sealed in PE30 and PE50 was similar and there was no significance (P=0.05) different between them. Fruits in PVC and PE20 had similar weight loss at 13°C. Weight loss of fruit sealed in different films was related to film permeability to water vapour. For example PP and PE50 had the lowest gas and water vapour permeability (see Table 6.1) and also had the lowest weight loss. Packaging prevented the higher weight loss of the fruits that were stored unpacked. Both mature green and pink tomatoes stored at 20°C had



Control: unwrapped, *PE20*: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinil chloride, *PP*: Sealed with 25μ polypropylene

Figure 6.5. Changes of weight loss of tomatoes harvested at mature green stage of maturity and sealed within different packaging films during storage at 13°C and 20°C.



Control: unwrapped, *PE20*: Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PVC*: Sealed with 10μ polyvinil chloride, *PP*: Sealed with 25μ polypropylene

Figure 6.6. Changes of weight loss of tomatoes harvested at pink stage of maturity and sealed within different packaging films during storage at 13°C and 20°C.

higher weight loss than fruits stored at 13°C and weight loss was also higher in pink fruits than in mature green fruits. Both mature green and pink tomatoes sealed in either PP or PE50 had less than 2 % weight loss after 60 days storage. Generally fruits sealed in PP had the lowest weight loss (Figure 6.5 and 6.6) but at 13°C it was PE50 for mature green tomatoes (Figure 6.5),

6.2.1.6. Titratable acidity

The effects of the interaction of storage temperature and packaging treatment on changes of titratable acidity of tomato fruits was highly significant (P=0.001) (Table 6.6). Titratable acidity of mature green tomatoes generally increased for the first 10 days of storage at 13°C and 20°C (Figure 6.7). After 10 days those acidity levels decreased throughout storage at 13°C and up to the 40th day of storage at 20°C

Table 6.6. Mean squares from the analysis of variance of tomatoes during 60 days modified atmosphere packaging storage (for titratable acidity).

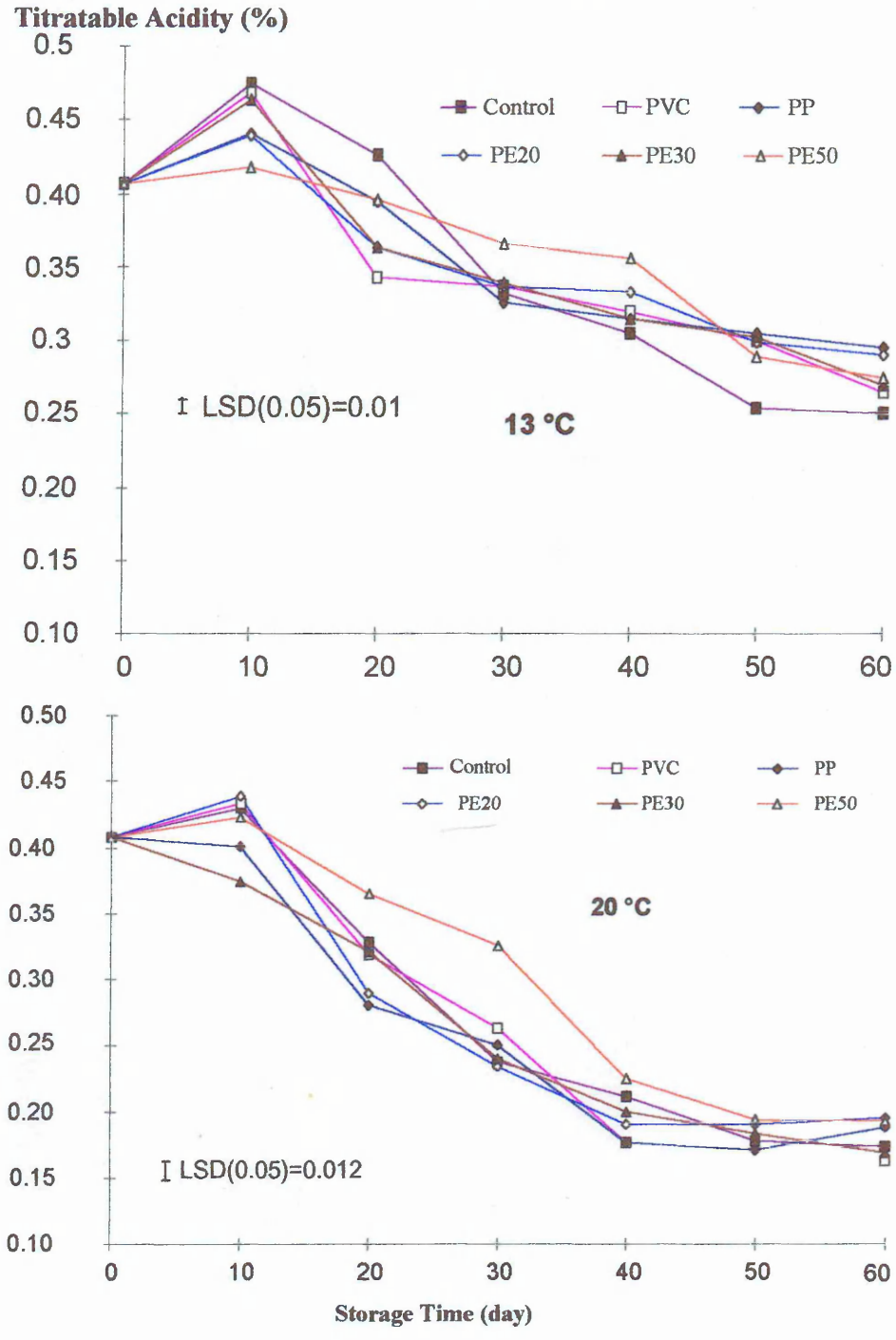
Source of Variation	df	Mature Green	Pink
Temperature (T)	1	0.781***	0.810*
Treatments (TR)	5	0.008***	0.017***
Storage (S)	5	0.496***	0.121***
TxTR	5	0.004***	0.002***
TxS	5	0.018***	0.010***
TRxS	25	0.006***	0.001***
TxTRxS	25	0.003***	0.001***
Residual	350	0.00	0.00
Total	431		

*** Fpr < 0.001 * Fpr < 0.05

Titratable acidity remained approximately the same and there was no significant (P=0.05) different between 40 and 60 days of storage at 20°C (Figure 6.7). Titratable acidity of those harvested at the pink stage of maturity fell during the

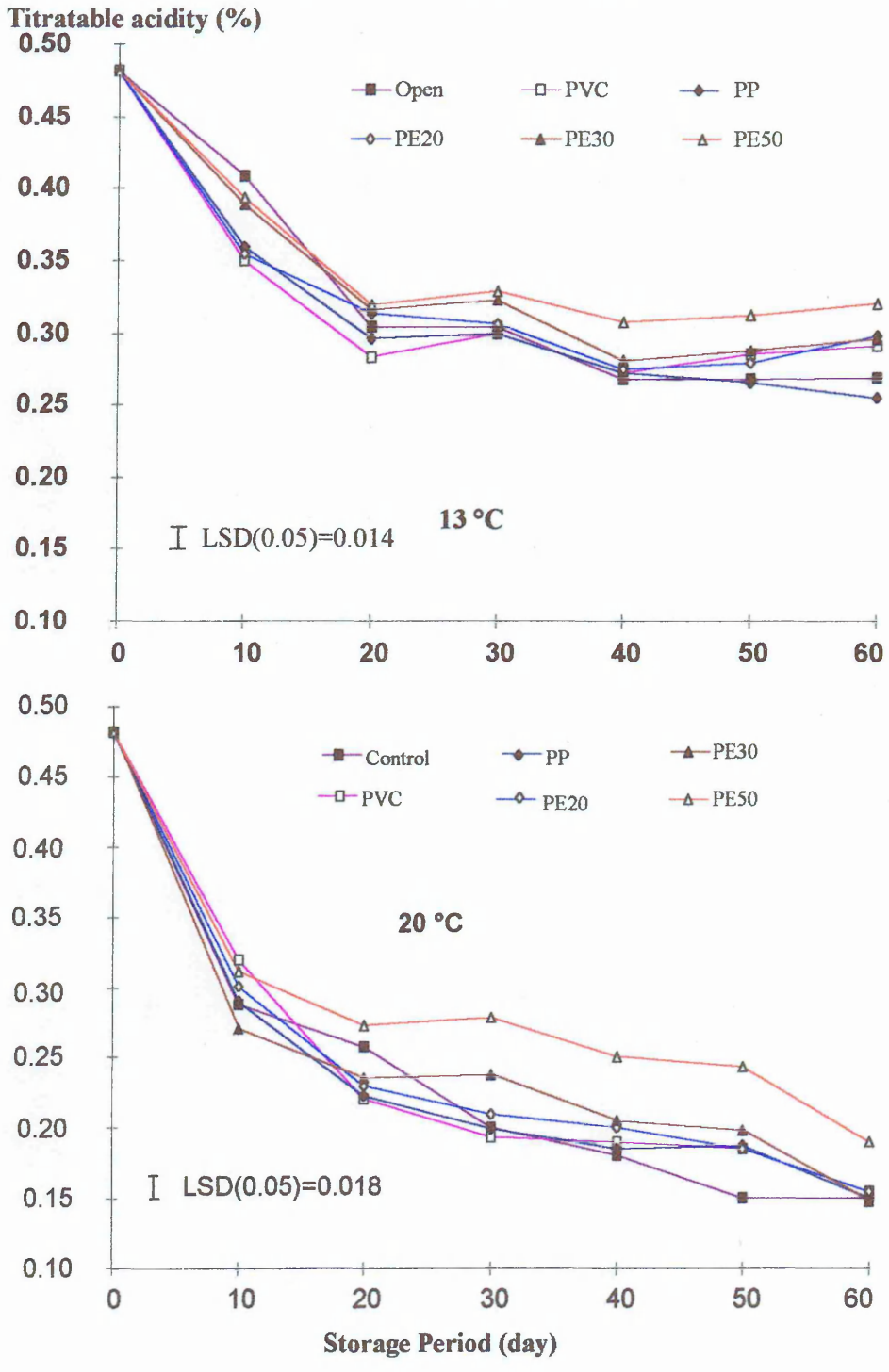
first 20 days storage at 13°C and then remained constant (Figure 6.8). At 20°C titratable acidity levels decreased rapidly during first 10 days and then continued to decrease slightly between 10 and 60 days of storage (Figure 6.8). There was no correlation between either the O_2 or CO_2 concentrations inside the films and the acidity levels of fruits during storage. But the titratable acidity values of pink tomatoes sealed in PE50 were found to be significantly (P=0.05) higher than those for other treatments.

Tomatoes harvested at both the mature green and pink stages of maturity and stored at 20°C became less acid than fruits stored at 13°C, while the lowest acid value of unwrapped mature green tomatoes was 0.25 % after 60 days of storage at 13°C. The acidity values of mature green tomatoes packed in the same films became less than 0.25 % even after 30 days storage at 20°C (Figure 6.7). After 20 days storage acidity levels of pink tomatoes stored at 20°C became lower than those stored at 13°C.



Control:unwrapped, *PE20*:Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*:Sealed with 50μ polyethylene, *PVC*:Sealed with 10μ polyvinyl chloride, *PP*:Sealed with 25μ polypropylene

Figure 6.7. Changes of titratable acidity values of tomatoes harvested at mature green stage of maturity and sealed in various thicknesses of various packaging films and stored at 13°C and 20°C.



Control:unwrapped, *PE20*:Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*:Sealed with 50μ polyethylene, *PVC*:Sealed with 10μ polyvinyl chloride, *PP*:Sealed with 25μ polypropylene

Figure 6.8. Changes of titratable acidity values of tomatoes harvested at pink stage of maturity and sealed in various thickness of various packaging films and stored at 13°C and 20°C.

6.3.1.7. Total Soluble Solids (TSS)

Table 6.7. Mean squares from the analysis of variance of tomatoes during 60 days modified atmosphere packaging storage (for TSS).

Source of Variation	df	Mature Green	Pink
Temperature (T)	1	0.29**	0.21**
Treatments (TR)	5	3.81***	3.13***
Storage (S)	5	0.06***	0.04***
TxTR	5	0.03***	0.02***
TxS	5	0.06***	0.04***
TRxS	25	0.02***	0.02***
TxTRxS	25	0.05***	0.04***
Residual	350	0.11	0.05
Total	421		

*** Fpr < 0.001 ** Fpr < 0.01

The effects of the interaction of storage temperature and packaging treatment on the softening of tomato fruits was highly significant (P=0.001) (Table 6.7). The TSS content of mature green tomatoes increased significantly (P=0.05) during the first 30 days of storage at both 13°C and 20°C, and the titratable acidity values of mature green tomatoes sealed in PE50 were found to be significantly (P=0.05) higher than the other treatments at 30 days storage (Figure 6.9 and 6.10). Although the TSS values of tomatoes stored at 20°C became slightly less than those at 13°C after 30 days of storage, there was a general similarity between 13°C and 20°C. Sugars are one of the major constituents of TSS. The sugar content (therefore TSS) increases progressively throughout maturation because of pectin degradation and there is a particularly pronounced rise which occurs with the appearance of yellow pigmentation (Hobson and Davies, 1971). In this experiment all the mature green tomatoes had shown some evidenceof begining to ripen by 30 days storage (Figure 6.1), and their TSS values had increased up to maximum point by this time. There were also similar

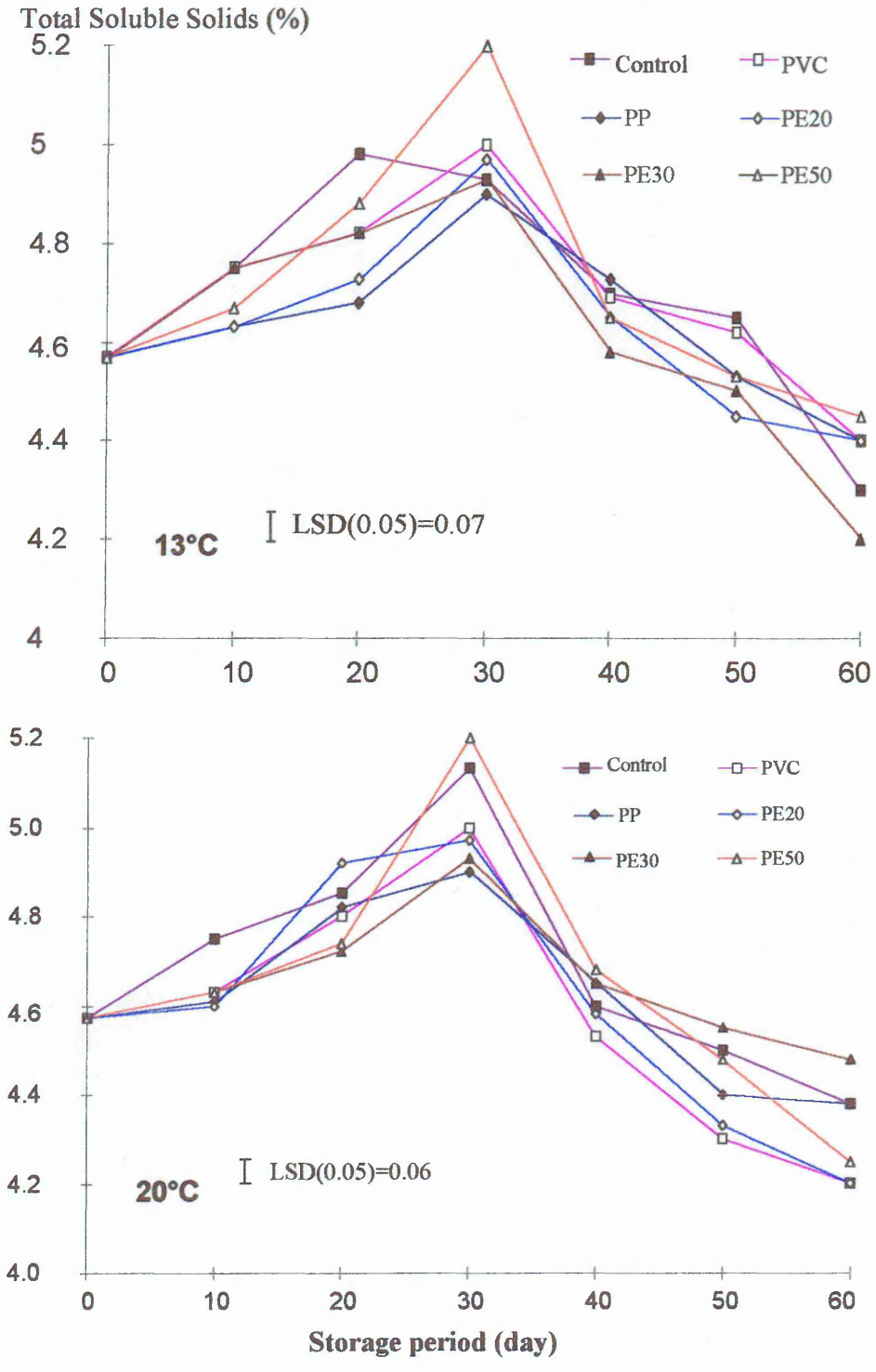
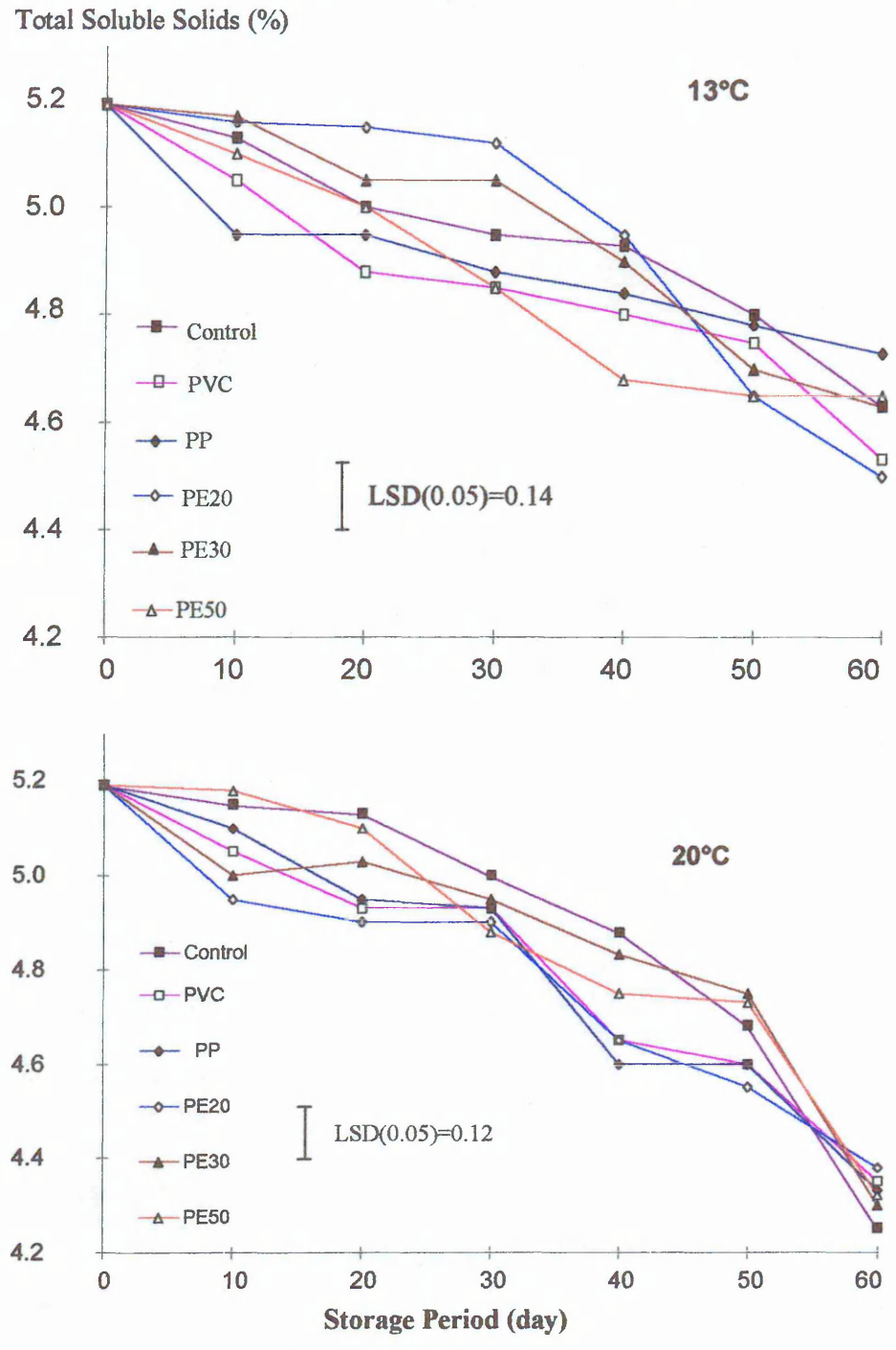


Figure 6.9. The changes of total soluble solids of tomatoes harvested at the mature green stage and sealed in various thicknesses of various packaging films and stored at 13°C and 20°C.



Control:unwrapped, *PE20*:Sealed with 20μ polyethylene, *PE30*:Sealed with 30μ polyethylene, *PE50*:Sealed with 50μ polyethylene, *PVC*:Sealed with 10μ polyvinyl chloride, *PP*:Sealed with 25μ polypropylene

Figure 6.10. The changes of total soluble solids values of tomatoes harvested at pink stage of maturity and sealed in various thickness of various packaging films and stored at 13°C and 20°C.

TSS values for pink tomatoes stored at both temperatures decreased progressively during 60 days storage and reduction was more extreme at 20°C. TSS values for pink tomatoes stored at 13°C were slightly higher than the TSS values of fruits stored at 20°C (Figure 6.10). Although the TSS tended to decrease during storage, there was no apparent correlation between this and the identify of plastic film wraps used.

6.3.1.8. Decay

Decay was not found until 40 days of storage at 13°C for all tomatoes stored in films (Table 6.3). During storage, the number of fruits showing decay increased progressively after 40 days. It was observed 10 days earlier at 20°C than at 13°C. All treatments showed some rotting (8 %) after 50 days storage which increased again after 60 days ranging between 8 % and 33 % dependent on packaging films. 8 % of the pink tomatoes sealed within polyethylene films had decayed at 20°C by the 40th day (Table 6.3). Unwrapped pink tomatoes started to decay after 30 and 40 days at 20°C and 13°C respectively. At the end of the 60 days storage 16 % or 25 % of the unwrapped fruits harvested at pink stage of maturity were decayed at 13°C and 20°C respectively. It was 0 % and 16 % for tomatoes harvested at mature green stage of maturity at the same temperatures respectively, mentioned above, but 25 % of those sealed in PE20 decayed after 60 days storage. Decay percentages of tomatoes sealed with PE30 were 16 % at both 13°C and 20°C but when they were sealed in PE50 and PP it was 8 % after 60 days of storage at 13°C and 16 % at 20°C.

Mature green fruits which had been packaged did not decay during 40 days storage at 13°C and 20°C. Even after 60 days storage the percentages of

decayed tomatoes sealed in whole films had the lowest at 13°C (8 %). Rotting did not appear in unwrapped tomatoes at 13°C but these tomatoes were very soft at the end of the storage period and there was slight senescence: fruits became softer and had some small twists or wrinkles in the fruit skin. There was no significant difference between storage temperatures of 13°C and 20°C until 30 days of storage but after that more rotted tomatoes were recorded at 20°C. Pink tomatoes had more decayed fruits than mature green ones.

Table 6.8. The percentages of decayed mature green pink tomatoes packed in different films and stored at 13°C and 20°C during the storage periods.

Period (days)	Tempe-rature	Unwrapped		PE20		PE30		PE50		PVC		PP	
		Green	Pink	Green	Pink	Green	Pink	Green	Pink	Green	Pink	Green	Pink
10	13	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
20	13	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
30	13	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	8	0	0	0	0	0	0	0	0	0	0
40	13	0	8	0	0	0	0	0	0	0	0	0	0
	20	0	8	0	8	0	8	0	8	0	0	0	0
50	13	0	8	8	8	0	8	8	8	0	8	8	0
	20	16	16	8	16	0	16	8	16	8	16	8	8
60	13	0	16	8	25	8	16	8	8	8	8	8	8
	20	16	25	16	25	16	16	8	16	16	33	8	16

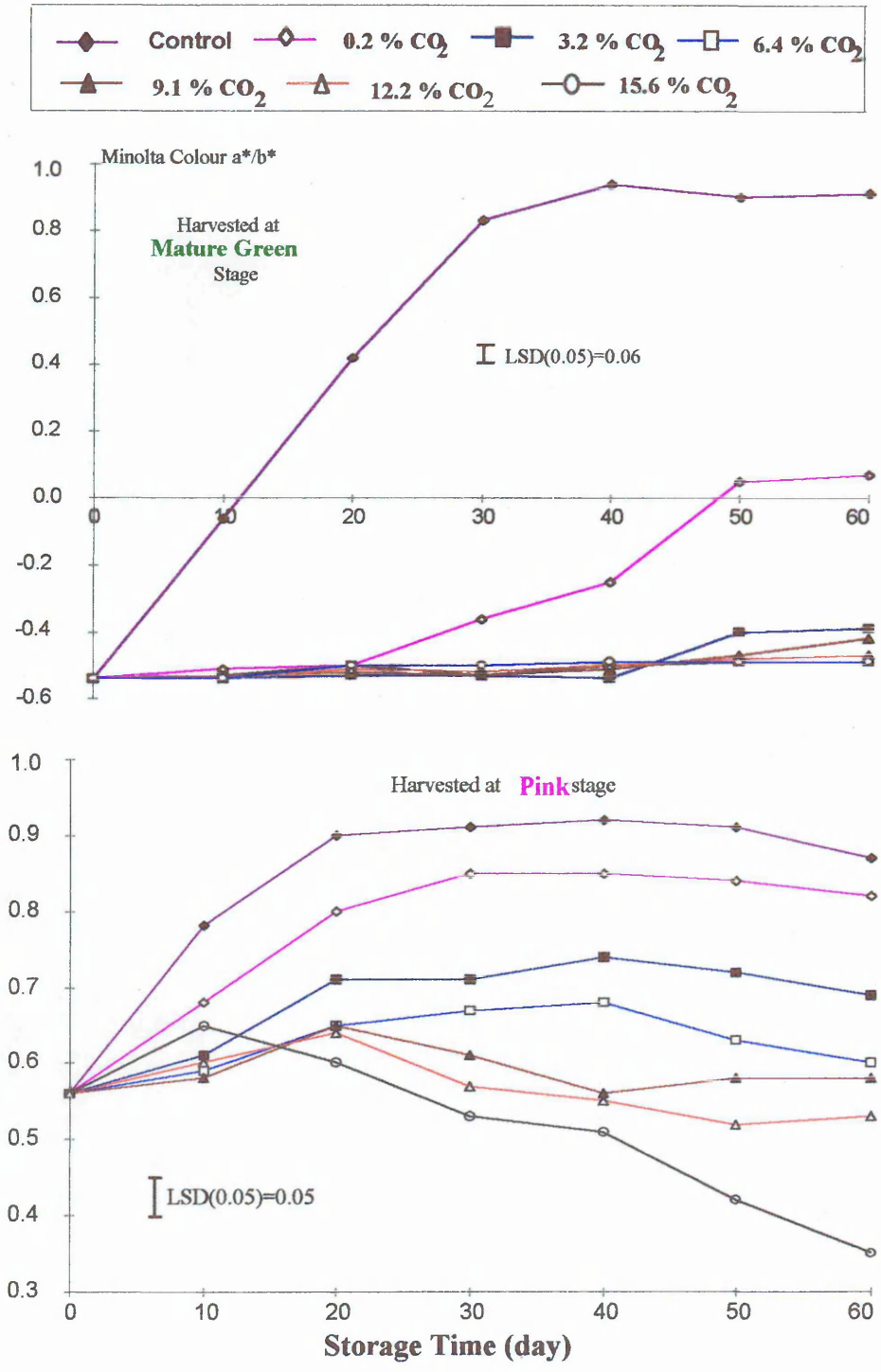
There was no difference between the packaging films in terms of rotting of green tomatoes at 13°C. Fruit in PVC and PE20 had a higher percentages of rotted fruits for pink tomatoes at 20°C.

6.3.2. Controlled Atmosphere Storage of Tomatoes

6.3.2.1. Colours

In tomatoes harvested at the pink stage of maturity considerable variation was observed and there were significant differences (P=0.05) between the treatments during storage period. The colour of control (20.9 % O_2 and 0.3 % CO_2) tomatoes generally showed a rapid increased in redness over the first 30 days storage, reached its reddest point by the 40th day and then remained constant. There was no significant (P=0.05) difference in the colour values of fruits in any of the treatments before 20 days storage. After 20 days storage the colour of the fruits stored in 0.2 % CO_2 with 5.5 % O_2 increased steadily and reached a light pink colour (between turning and pink maturation stages) at the end of 60 days storage. No significant (P=0.05) change occurred in the other treatments throughout the storage period.

Control fruit stored in 20.9 % O_2 and 0.3 % CO_2 changed colour more quickly than all the fruits in the CAS treatments. Fruit stored in 0.2 % CO_2 with 5.5 % O_2 generally changed colour more quickly than the other CA levels (Figure 6.11). Tomatoes stored as control and tomatoes stored at 0.2 % CO_2 and 3.2 % CO_2 reached their reddest colour after the first 20 and 30 days of storage respectively, then remained approximately the same colour. The colour of tomatoes stored in 3.2 % and 6.4 % CO_2 also increased during the first 20 days of storage but levels were significantly lower than control and fruits stored in 0.2



Green: -0.62-(-0.49), ***Breaker***: -0.48-(-0.26), ***Turning***: -0.25-0.06, ***Pink:*** 0.08-0.56, ***Light red:*** 0.61-0.95, ***Red:*** 0.95-1.22

Figure 6.11. Changes of Minolta colour (a*/b*) values of mature green and Pink tomatoes stored in various controlled atmosphere environments (all with 5.5 % O_2) during storage time at 13°C.

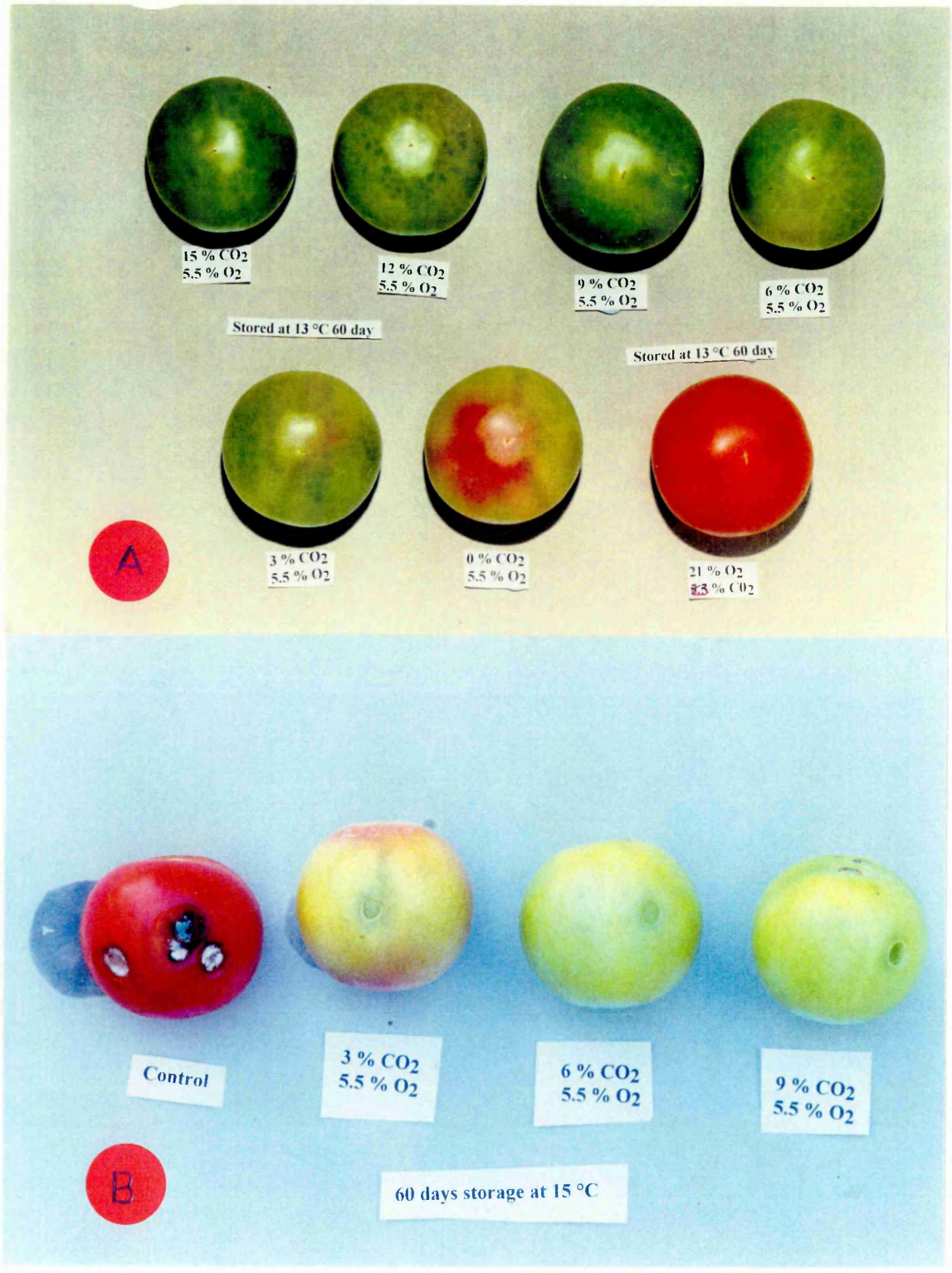


Plate 6.2. Some tomatoes stored in CAS in various CO_2 levels with 5.5 % O_2 at (A) 13°C and (B) 15°C.

for fruits stored in 12.2 % CO_2 with 5.5 % O_2 and 15.6 % CO_2 with 5.5 % O_2 actually decreased during the 60 days of storage. Colour values of fruits stored in 15.6 % CO_2 with 5.5 % O_2 decreased more than those in 12.2 % CO_2 with 5.5 % O_2. Although the colour values of tomatoes stored in 9.1 % CO_2 with 5.5 % O_2 increased slightly during the first 20 days of storage, after 20 days, they started to decrease. After 40 days storage fruit colour remained the same and was very similar to the initial fruit colour.

6.3.2.2. Firmness

Firmness (Nmm^{-1}) was defined as the amount of force (N) required to penetrate of 6 mm dia through the skin to fruit flesh dwided by the deformation (mm) of fruits during penetration (see Chapter 3.4.1.2). Firmness values of mature green tomatoes stored in CAS also decreased with increasing storage time. Decreases in firmness values were higher for control and tomatoes stored in 0.2 % CO_2 with 5.5 % O_2 than for other treatments. Instrumental measurement of firmness showed that all the fruits softened at the end of a 60 days storage period. Tomatoes stored as control and in 0.2 % CO_2 with 5.5 % O_2 were significantly (P=0.05) softer than others especially after 20 days. Although there were significant (P=0.05) differences among the treatments, whole mature green tomatoes stored (including fruits stored in 0.2 % CO_2) in CAS were very firm until that time, and their firmness values were higher than the MMV1 throughout the storage period (Figure 6.12).

In tomatoes harvested at the pink stage of maturity all fruit softened throughout the storage period but some of those stored in CAS (0.2 % CO_2, 3.2 % CO_2, 6.4 % CO_2 and 9.1 % CO_2 with 5.5 % O_2) softened significantly (P=0.05) more

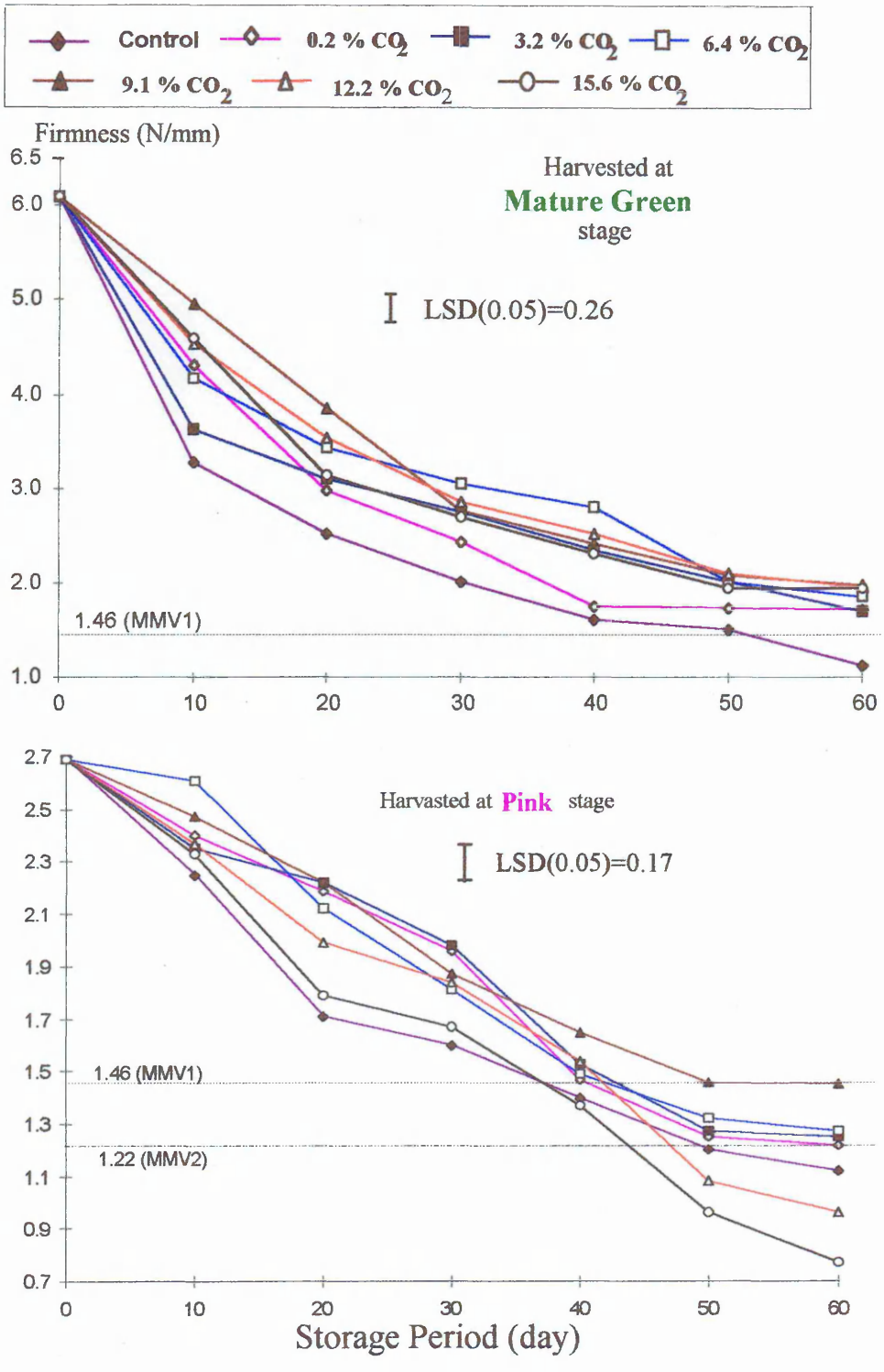


Figure 6.12. Changes of firmness values of mature green and pink tomatoes stored in various controlled atmosphere (all with 5.5 % O_2) environments during storage at 13 °C.

slowly than those stored as control, in 12.2 % CO_2 with 5.5 % O_2 and 15.6 % CO_2 with 5.5 % O_2. Slight CO_2 injuries were shown on those stored in 12.2 % and 15.6 % CO_2 with 5.5 % O_2. Therefore those tomatoes softened prematurely because of CO_2 injury. The primary symptoms of CO_2 injury are retarded and irregular ripening, premature softening and appearance of brown spots at the blossom-end (Grierson and Kader, 1993). Water soaked areas are also observed caused by CO_2 injury on tomatoes (Buescher, 1979b). There was no significant (P=0.05) difference in firmness values between tomatoes stored as control and those in 15.6 % CO_2 with 5.5 % O_2 until the 40th day storage. Also no significant (P=0.05) difference was observed in the firmness values of the rest of the treatments until 40 days storage. But after that time tomatoes stored in 15.6 % CO_2 with 5.5 % O_2 lost their firmness very rapidly (Figure 6.12). Tomatoes stored as controls and those stored in 15.6 % CO_2 with 5.5 % O_2 were shown to fall below the MMV1 (see Chapter 4) after 35 days storage while all those stored in between 0.2 % CO_2 and 12.2 % CO_2 with 5.5 % O_2 were above the MMV1 level even after 40 days storage. It was found that fruits stored in 9.1 % CO_2 with 5.5 % O_2 remained close to this MMV1 level and were still very firm after 60 days storage. Fruits stored in 3.2 % CO_2 and 6.2 % CO_2 with 5.5 % O_2 were considered to be still marketable even after 60 days storage.

6.3.2.3. Total Soluble Solid (TSS)

TSS values of all the fruits (except kept in 12.2 % CO_2 with 5.5 % O_2) harvested at the mature green stage increased significantly (P=0.05) during the first 20 days of storage, then these levels tended to decrease with the exception of 6.4 % and 9.1 % CO_2 with 5.5 % O_2. The acidity of fruits stored in 6.4 % CO_2 with

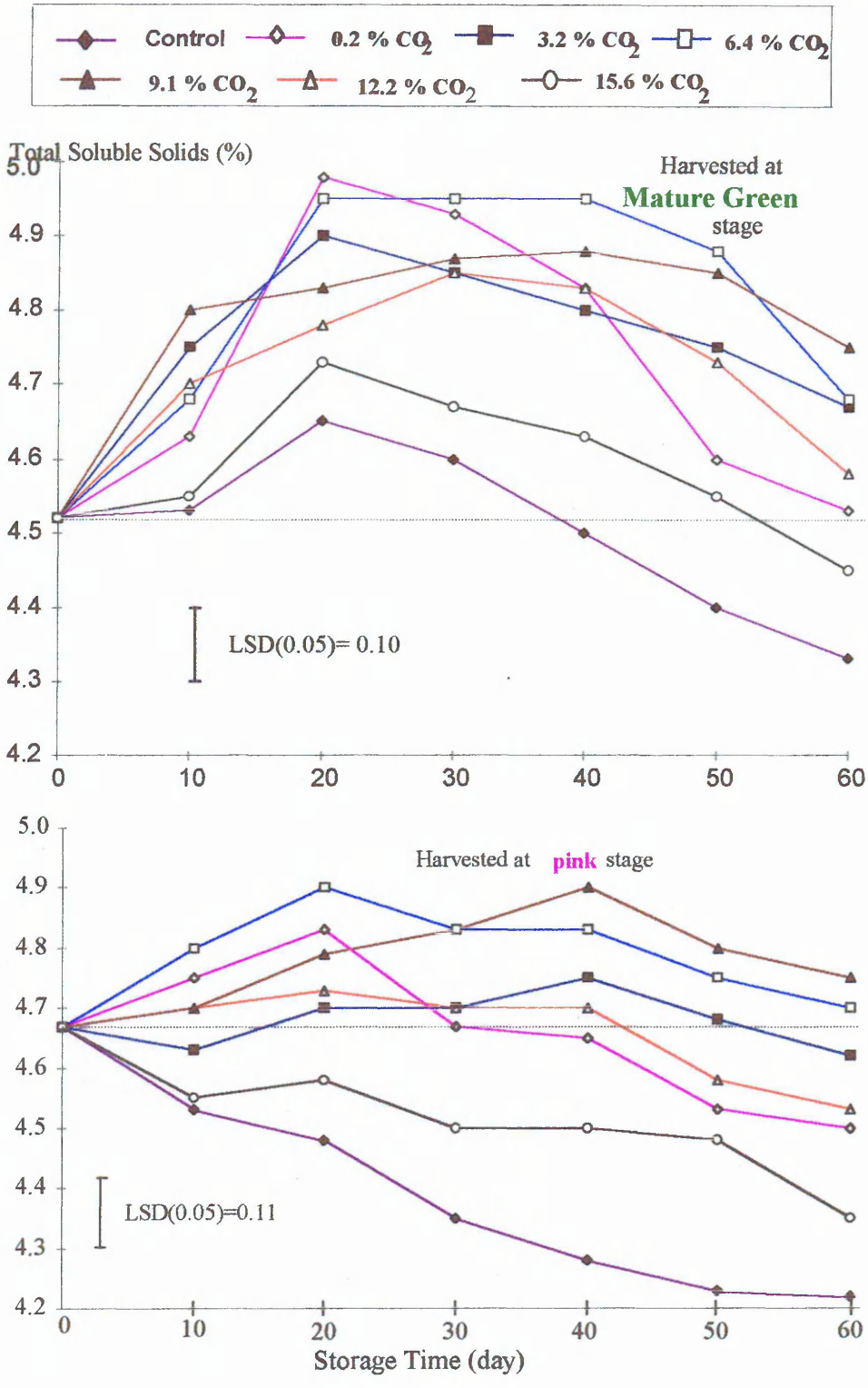


Figure 6.13. Changes of total soluble solids values of mature green and pink tomatoes stored in various controlled atmosphere (all with 5.5 % O_2) environments during storage time at 13 °C.

5.5 % O_2, 9.1 % CO_2 with 5.5 % O_2 and 12.2 % CO_2 with 5.5 % O_2, did not decrease between 20 and 40 days of storage. The fruits were stored in 6.4 % and 9.1 % CO_2 all with 5.5 % O_2 remained approximately the same between 20 and 40 days while it was slightly increasing in 9.1 % CO_2 with 5.5 % O_2 until 30 days. Although there was no clear correlation between the TSS values of fruits and their storage atmospheres, the TSS values of tomatoes stored as a control and in 15.6 % CO_2 with 5.5 % O_2 were significantly (P=0.05) lower than all other treatments. The TSS values of the fruits stored in 3.2 %, 6.4 % and 9.1 % CO_2 with 5.5 % O_2 for 60 days were significantly (P=0.05) higher than all other treatments. It was found that the TSS values of all tomatoes stored in CAS were higher than their initial TSS values after 60 days of storage except for the TSS values of the fruits stored in 15.6 % CO_2 (Figure 6.13. and 6.14).

TSS values of all the fruits harvested at the pink stage of maturity increased significantly (P=0.05) during the first 20 days of storage except the fruits stored as a control and in 15.6 % CO_2 levels with 5.5 % O_2. Their TSS values decreased continuously throughout storage. TSS values of tomatoes harvested at pink stages of maturity and stored in 0.2 % CO_2 and 6.4 % CO_2 all with 5.5 % O_2 increased significantly (P=0.05) during the first 20 days of storage whereas the TSS values of fruits stored in 9.1 % CO_2 with 5.5 % O_2 increased significantly (P=0.05) within the first 40 days of storage. TSS tended to decrease during storage after these days. TSS values of tomatoes stored in 6.4 % CO_2 with 5.5 % O_2 and 9.1 % CO_2 with 5.5 % O_2 were higher after 60 days of storage than their initial TSS values (Figure 6.13). At the end of 60 days storage the TSS values of tomatoes stored in 3.2 % CO_2 with 5.5 % O_2, 6.4 % CO_2 with 5.5 % O_2 were found to be approximately the same as their initial TSS values.

TSS values of tomatoes stored in 0.2 % CO_2, 12.2 % CO_2 and 15.6 % CO_2 all with 5.5 % O_2 and control treatment were found to be significantly (P=0.05) lower than their initial TSS levels (Figure 6.13).

6.3.2.4. Titratable Acidity

Titratable acidity of pink and mature green tomatoes in all treatments increased during the first 10 days of storage and then steadily decreased until 60 days of storage (Figure 6.14). Although there was a significant (P=0.05) difference in acidity of tomatoes between treatments, there was no direct correlation with the concentrations of CO_2 levels to which the fruit had been exposed during storage.

The acidity values of tomatoes harvested at the pink stage of maturity and stored in 12.2 % CO_2 with 5.5 % O_2 and 15.6 % CO_2 with 5.5 % O_2 were lower than the other treatments during all storage times, but after the 30th day of storage control fruit acidity values also fell (Figure 6.14). Tomatoes stored in 3.2 % CO_2 with 5.5 % O_2, 6.4 % CO_2 with 5.5 % O_2 and 9.1 % CO_2 with 5.5 % O_2 treatments had higher acid levels than the other treatments. The situation was slightly different for mature green tomatoes. Acidity values of both the control and fruits stored in 12.2 % CO_2 with 5.5 % O_2 levels were lower than other treatments.

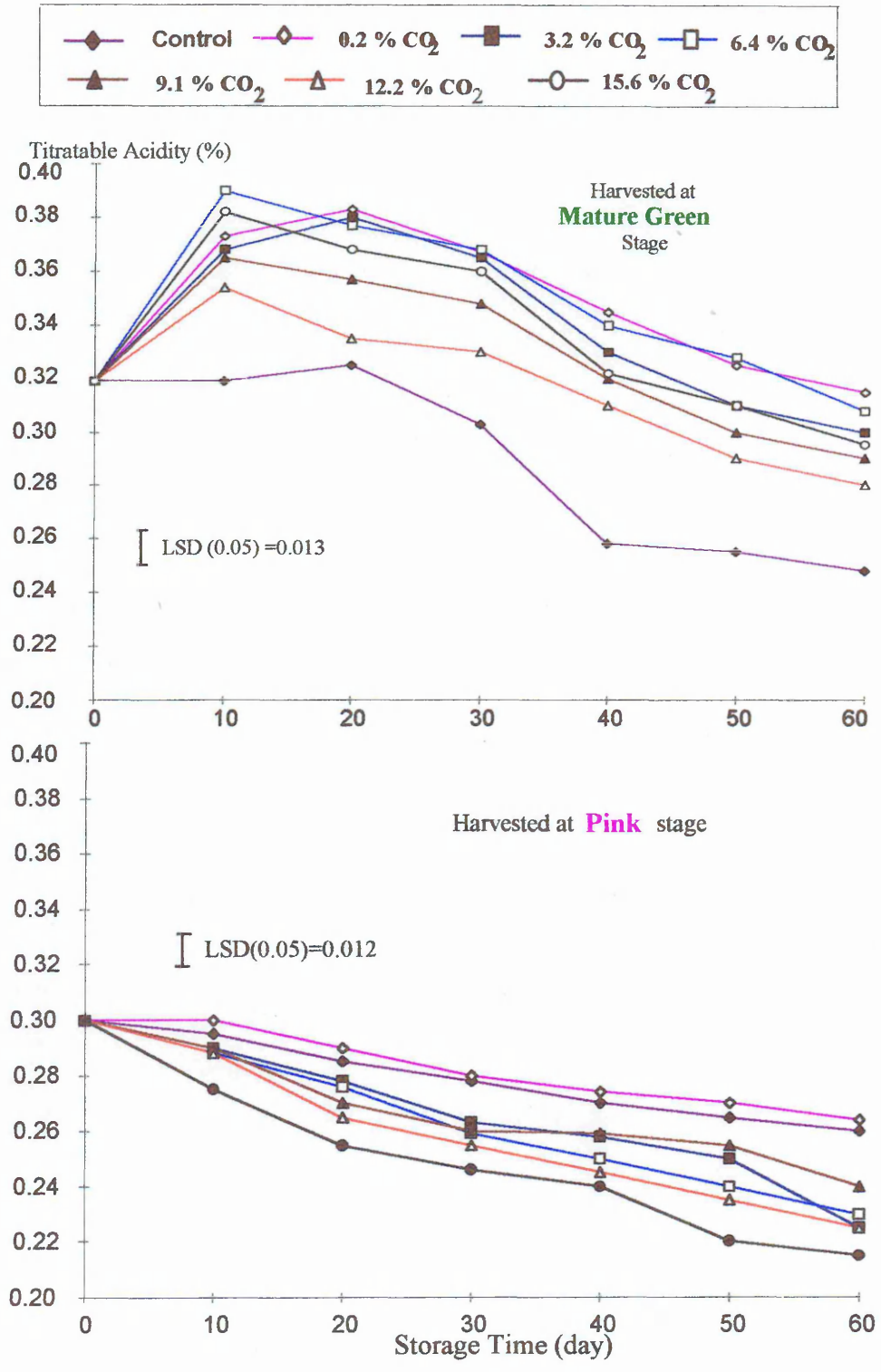


Figure 6.14. Changes of titratable acidity of tomatoes harvested at mature green and pink maturity stages and stored in various controlled atmosphere (all with 5.5 % O_2) environments at 13 °C.

6.3.2.5. Decay

Table 6.9. The percentages of decayed tomatoes harvested at the pink stage of maturity and kept in CAS using various CO_2 levels with combined with 5.5 % O_2 during storage time at 13°C

Treatments	Maturity Stage	Storage Periods (days)					
		10	20	30	40	50	60
Control	Green	0	0	0	0	8	20
20.9 % O_2+0.3 % CO_2	Pink	0	0	0	0	25	50
0.2 % CO_2	Green	0	0	0	0	8	20
+ 5.5 % O_2	Pink	0	0	0	0	10	30
3.2 % CO_2	Green	0	0	0	0	10	10
+ 5.5 % O_2	Pink	0	0	0	0	9	10
6.4 % CO_2	Green	0	0	0	0	10	15
+ 5.5 % O_2	Pink	0	0	0	10	18	40
9.1 % CO_2	Green	0	0	0	0	5	8
+ 5.5 % O_2	Pink	0	0	0	5	8	10
12.2 % CO_2	Green	0	0	0	0	10	15
+ 5.5 % O_2	Pink	0	0	0	33	55	65
15.6 % CO_2	Green	0	0	0	0	10	15
+ 5.5 % O_2	Pink	0	0	0	50	61	80

Decay was not detected until 30 days of storage and it was first observed in pink tomatoes stored in 6.4 % CO_2 with 5.5 % O_2 level and over after 40 days of storage (Table 6.4). While decay levels ranged between 5-8 % in 9.1 % CO_2 they were higher in 12.2 % CO_2 with 5.5 % O_2 and 15.6 % CO_2. All treatments showed some decay after 50 days storage and a further increase after 60 days. After 60 days storage the lowest number of decayed fruits were in 3.2 % CO_2 with 5.5 % O_2 and 9.1 % CO_2 with 5.5 % O_2 environments for both pink and mature green tomatoes. It was found that pink tomatoes had a higher decay ratio than mature green tomatoes and decay symptoms were observed 10 days earlier in pink tomatoes than mature green tomatoes.

6.4. Discussion

6.4.1. Permeability of packaging materials and internal atmospheres of packages

Previously published work on permeability of plastic films used the standard condition of 25°C and 75 % RH or 38°C and 90 % RH to test the films. This was in order to have the same conditions for the analysis of the permeability of the films to gas and water vapour. However, it has been shown that film permeability is proportional to temperature (Parry, 1993). Also, if humidity is too high moisture may condense on the film and may affect its permeability (Pascat, 1986). The same temperatures were used with permeability measurements and in the subsequent MAP and CAS experiments. The packages were also kept in temperature controlled rooms to limit temperature variation and to reduce the possibility of condensation on the inside of the packages.

The differences between permeability studies and the actual O_2 and CO_2 levels in the packed fruit are difficult to explain. As shown in previous works (Saguy and Mannheim, 1975; Geeson et al., 1985; Zagory and Kader, 1988) the films were less permeable to O_2, CO_2 and water vapour at the lower temperature. However there was little difference in the equilibrium O_2 and CO_2 levels inside the packaged fruit at the two temperatures used in the experiments. This could be due to the higher temperature giving the films a higher permeability (Varsanyl, 1986) or to the higher respiration rate of the fruits at the higher temperature. This is a very useful phenomenon and one that could be exploited commercially because it may be expected that fruits will spend periods of time at different temperatures in marketing. However, condensation may occur in the

packages when they are moved from lower to higher temperatures but, treatments are available to prevent condensation on plastic films (Zagory and Kader, 1988; Pascat, 1986). The effect of different packaging films, especially PE films in different thicknesses, on the O_2 and CO_2 concentration was predictable from the permeability data because there is a clear relationship between film thickness and gas permeability ratios of PE films.

The difference in equilibrium concentration of O_2 and CO_2 inside the packaging films related directly to the permeability ratios of the gases. Generally, permeability is dependent on the thickness and nature of the films. Comparing one film to another, the O_2 permeability of PP is approximately the same as PE50 whereas PVC is the same as PE30 film. In terms of CO_2 permeability PP is the least permeable film: it is approximately 2 times less permeable than PE50, 3 times than PE30 and 3.5-4 times than PE20. These results were in agreement with Greengrass (1993) who reported that PP film provides a five to ten times greater barrier to gases than the same thicknesses of polyethylene. Equilibrium concentration of both gases at both temperatures was approximately the same. This could be due to the permeability of packaging films (Parry, 1993) and the respiration rate of tomatoes (Day, 1993), both could be increased by increasing the storage temperature. This work shows that the effect of storage temperature increase is that the permeability of packaging films increases less than the respiration rate of tomatoes. Therefore tomatoes consumed more O_2 and produced more CO_2 than the films allowed to pass in and out of the packages. Consequently, O_2 fell more and CO_2 increased more at 20°C than at 13°C.

6.4.2. Colour

In these experiments, the eventual red colour of all the fruits, irrespective of harvest maturity and storage temperature, was similar. However, the reduction of the rate of development of the red colour in tomatoes during storage was affected by the level of CO_2 in the atmosphere around them in the MAP. These effects had previously been reported by Saguy and Mannheim (1975); Geeson et al., (1985) and Zagory and Kader (1988). The mechanism of the CO_2 action was reported to be that CO_2 successfully competes for binding sites with ethylene and thus impedes the effects of ethylene on the ripening process (Burg and Burg, 1969; Kubo et al., 1989). The development of red colour in tomatoes is due to chlorophyll destruction and the synthesis of carotenoids and lycopene (Grierson and Kader, 1986). Synthesis of lycopene and β-carotene is dependent on the availability of O_2 (Hobson and Davies, 1971; Salunkhe and Wu, 1973). This would account for the delayed development of the red colour in fruits in MAP (especially in less permeable films which are PP and PE50) as observed in my experiments. However, there were indication (not statistically significant) that the fruits harvested at the mature green stage of maturity, and stored in MAP which gave the highest CO_2 and lowest O_2, were slightly less red in colour than the fruit in the other treatments. Although CO_2 and O_2 concentrations were very similar in the packages at both 13°C and 20°C, ethylene production by tomatoes would be more inhibited or delayed at 13°C than at 20°C (Kubo et al., 1989). So, the ripening rate of the fruits was earlier at 20°C than at 13°C for both maturation stages. There was a clear correlation between the CO_2 levels and red colour development of tomatoes. Yang et al., (1987) and Salunkhe and Wu (1973) showed that there was also a clear correlation between red colour development and lycopene content of tomatoes. The slowing down or

decreasing of red colour development of tomatoes was directly dependent on the level of ethylene required to stimulate ripening. In this experiment a high level of CO_2 inhibited the production of ethylene. Therefore red colour values of tomatoes were decreased in 12.2 % and 15.6 % CO_2, ,both combined with 5.5 O_2. It could be due to the continuation of synthesis of β-carotene but not (or less) lycopene in high CO_2 as mentioned by Buescher (1979b). Another possibility was reported by Buescher (1979a) that the retardation of lycopene development in high CO_2 exposed fruits may be explained on the basis that ethylene synthesis declined faster in the presence of high CO_2.

The fruits in CAS behaved differently to the fruit in MAP. In fact the fruit in CAS behaved like the results of experiments reported in the literature (Kader, 1980; Dennis et al., 1979; Parsons et al., 1970 and Yang and Chinnan, 1988). The difference was that the fruit harvested at the mature green stage never became fully red in CAS whereas they were at marketable (light red) stage of ripening when they were in MAP. The difference may be due to the difference in O_2 and CO_2 levels. However this seems unlikely since the range of O_2 concentration in the less permeable films was 4 to 6 % (compared to 5.5 % O_2 in the CAS) and CO_2 concentrations were in the range of 3 to 14 % (compared to 0.2 % to 15.6 % in the CAS). The differences between MAP and CAS could also be due to ethylene accumulation in MAP since the CAS were continuously flushed. This is confirmed by the literature (Burg and Burg, 1969, Kubo et al., 1989) at the very high CO_2 levels. At higher temperatures O_2 consumption and ethylene production increases, causing ripening to hasten, so the colour of the fruits becomes redder by accumulating a higher level of lycopene at a higher

temperature. It has also been reported that lycopene synthesis slows down below 16°C (Goodwin and Goad, 1974).

6.4.3. Firmness

Delayed softening in MAP could also be due to higher water loss during storage, which might have contributed to lower flesh firmness. Firmness was related to packaging films. Fruits sealed in less gas and water vapour permeable films were firmer than fruits sealed in more permeable films at the same temperature and at both maturity stages. Tomatoes became softer in the higher O_2 and CO_2 permeable films. This could be related to higher ethylene production by fruits in that kind of storage environment. Lyons and Pratt (1964) confirmed that ethylene level encourages ripening in tomatoes, and ethylene production increased at breaker stage and was at its highest level at the light red stage of maturity. This shows that the ethylene level contributed to the softening of the fruits. It was reported that ethylene production in eggplants in low CO_2 concentration is higher than in high CO_2 concentration, which indicates that exposing fruit to ethylene causes abscission and softening (Reid, 1985), and therefore reduce storage life (Kader, 1985a). Lowering the temperature decreases ethylene production and the rate of response of the tissues to ethylene, since ripening and enzyme reactions are delayed and therefore fruits are firmer at the lower temperature.

Tomatoes harvested at the pink stage of maturity became softer than fruits harvested at the mature green stage of maturity during storage time. Cell wall degradation is very effective on the softening of fruits. Hobson and Grierson (1993) reported that swelling of middle lamella occurs in ripe fruit as the

structure disintegrates and allows cell movement, and that turgor pressure falls as the cell wall progressively weakens. Once fruit is fully ripe tissue disorganisation becomes increasingly dominant when the cell wall becomes very thin and the organised cytoplasmic units largely disintegrate (Ho and Hewitt, 1986). So firmness of the fruits harvested at further stage of ripeness becomes softer before fruits harvested at an earlier stage of ripening.

It was found that during MAP of the mature green tomatoes, TSS values were increased until 30 days of storage (Figure 6.7) while their firmness values were decreasing (Figure 6.3). When their TSS values tended to be decreased (Figure 6.7) firmness values remained approximately constant (Figure 6.3). The same situation was also observed on the tomatoes harvested at the pink stage of maturity. TSS values of some of those tomatoes did not decrease (or decreased slightly) within the first 20 days of storage (Figure 6.8). During that time, especially the first 10 days, their firmness values decreased dramatically. TSS values of fruits, especially, stored at 20°C decreased dramatically after the 30th days of storage (Figure 6.8), but their firmness values remained constant. Therefore it was thought that increasing TSS values clearly contributed to the softening of tomato texture.

Tucker and Grierson (1987) reported that there was a loss of neutral sugars and that these losses could be affective in the softening process of tomatoes. During ripening there is a loss of nautral sugars in most fruit this is predominantly galactose, but some loss in arabinose also occurs (Tucker and Grierson 1987). Hobson (1993) reported that it is commonplace for neutral sugars to be lost from the cell walls during the ripening and softening of many fruit species, but it is

difficult on present knowledge to ascribe the dramatic changes in texture just to the loss of selected sugars. But at least sugars may contribute slightly to these changes, since Tucker (1993) reported that galactose and arabinose are the major component of the wall's neutral pectin (Tucker, 1993).

Of the quality factors investigated the most marked response was the maintenance of texture under elevated CO_2 concentrations in CAS (including 3.2 %, 6.4 % and 9.1 % all combined with 5.5 % O_2), but fruits stored at 9.1 % CO_2 with 5.5 % O_2 were found to be firmer during CAS even when harvested at the pink stage of maturity. In this experiment, fruits became softer in the 0.2 % and 3.2 % CO_2 with 5.5 % O_2 because this amount of CO_2 was not enough to inhibit the production of ethylene in tomatoes harvested at the pink stage of maturity but it was enough to inhibit it in mature green tomatoes, at least for 20 days (Figure 6.9). This could be due to the ethylene production in tomatoes harvested at the pink stage of maturity being higher than at the mature green stage of maturity, since Yang et al., (1987) found that ethylene production of the tomatoes in MAP was 4-5 times higher in tomatoes harvested at the pink stage of maturity than the mature green stage of maturity. Ethylene promotes the action of polygalacturase (PG) which contributes towards in tomato softening (Grierson and Tucker, 1983). This is because the state of the cell walls has the strongest effect on fruit firmness (Goodenough, 1991). Burton (1982a) and Mutschler and Guttierri (1987) reported that those pectic materials could be broken down by pectinestarase (PE) and polygalacturanase (PG) by solubilizing the polygalacturonic acid in the pectin fraction in the walls (Themmen et al., 1982). Because ethylene encourages the synthesis of PG in a low CO_2 and high ethylene environment (Grierson and Tucker, 1983), high CO_2 levels help to

delay the ripening action of ethylene. In tomato fruits, CO_2 accumulation in the intercellular space functions as a natural ethylene antagonist (Yang, 1985). Grierson et al.,(1985) reported that natural production of ethylene precedes PG synthesis by at least 20 hours. In tomatoes, a rise in the internal ethylene concentration was shown to occur before the respiratory rise and the application of ethylene to mature green tomatoes stimulated ripening. It was reported that if mature green tomatoes were treated with ethylene in air they initiate the ripening and synthesis PG earlier than similar fruit held in ethylene free air.

In my experiment, increasing CO_2 concentration to 12.2 % and 15.6 % with 5.5 % O_2 gave fruits harvested at the pink stage of maturity a softer texture. This was not because ethylene levels were increased, since Buescher (1979a) found that ethylene production in ripe tomatoes in 10 % and 20 % CO_2 was significantly lower than fruits stored in 5 % CO_2 or in air. High CO2 can inhibit ethylene formation by limiting the formation of ACC and inhibiting the conversion of ACC into ethylene (Riquelme et al., 1994). But the phenomenon could be due to CO_2 injuries during long term storage. The effect on fruit softness could be detected until 30 days of storage of tomatoes harvested at the pink stage of maturity. There was no indication of softening even after 60 days of storage of tomatoes harvested at the mature green stage of ripening (Figure 6.10) even with some CO_2 injuries. Beneficial effects on texture with 5 % CO_2 have been reported by many authors (Herner, 1987 and Kader, 1986) and Larsen and Watkins (1995) showed that strawberries stored in 10 % CO_2 with 2 % O_2 at 20 °C had a firmer texture then those stored in air. Kader (1986), also reported that although elevated CO_2 atmospheres slowed the softening rate of tomatoes, the

mechanism of controlled or modified atmosphere effects on the texture of fresh fruits and vegetables is still not fully understood.

6.4.4. Weight Loss

Weight losses of tomatoes sealed in plastic films are consistent with the results of other works (Parsons et al, 1970 and Floros et al, 1987). The occurrence of the highest weight loss throughout storage in unwrapped tomatoes is in agreement with Ottosson and Wiberg, (1977). It may be due to loss of moisture from the produce to the surrounding environment. A small contribution may have come from the lower respiration rate of the tomatoes which would have occurred with the higher carbon dioxide and lower oxygen levels inside these films. For example PP and PE50 had the lowest gas permeability (Table 6.1) and also the lowest weight loss. Storage temperature has a considerable effect on weight loss during MAP. At a higher temperature, the permeability of the films and respiration rate of fruits will be affected. Films became more permeable (Parry, 1993) with increase in fruit respiration rate (Day, 1993). Fruits had less weight loss in lower storage temperature because of the lower respiration rate causes less water production from the fruit tissues. Fruit respiration involves many enzymatic reactions and these reactions increase with the increase in temperature. Higher temperature also causes a decrease in the RH in the storage environment. This shows that less humidity and higher temperature result in higher weight loss.

The rates of weight loss of tomatoes sealed in plastic films also correlated quite closely with the water vapour transmission rates (WVTR) of the packaging films. Higher relative humidity could be one of the most important factors which affect

weight loss in order to prevent water loss from the fruits. Riquelme et al., (1994) reported that weight loss in tomatoes was inversely related to the relative humidity inside the film and directly related film permeability to water vapour. If the loss of fresh weight is over 5 %, this level may cause wilting or shrivelling, thus reducing market values (Wills et al., 1989). All the fruits lost less than 5 % fresh weight value after 60 days storage except fruits harvested at the pink stage of maturity and sealed in PVC and PE20 during storage at 20°C.

6.4.5. Acidity

Major changes in titratable acidity were shown in tomatoes during storage. Change in titratable acidity during tomato ripening is also a major factor in the eating quality of fruit. The present results demonstrate the influence of storage temperature, maturity at harvest, and storage time. Titratable acidity was higher in tomatoes stored at 13°C than at 20°C whether harvested at the mature green or pink stages of maturity. This can probably be attributed to the good physical condition of the fruit. This means that less disease or injury occurred in tomatoes stored at 13°C. The decreases in acidity at 20°C are probably associated with faster ripening, and therefore these fruits had earlier senescence compared to those stored at 13°C. The present results also demonstrate that storage temperature and length of time affected acidity changes. These results are in agreement with Richardson and Hobson (1987) who reported that the acidity of tomatoes decreased with the increase in temperature. Goodenough and Thomas (1980) showed that in the Seaford Abundance variety malic and citric acid fell as well as titratable acidity during storage. In my experiment all treatments displayed decreasing acidity. This observation is in agreement with Hall (1966) and Hobson and Davies (1971). Titratable acidity was affected by MAP and CAS

treatments. This is also in agreement with Parsons et al., (1970), and Goodenough and Thomas (1981).

Although there was no correlation between the changes in acidity values of tomatoes and the thickness of packaging films, the acidity levels of tomatoes harvested at the pink stage of maturity and sealed in PE50 were higher at both temperatures than at the other treatments. This could be due to the higher RH which occurred inside the PE50 packages, because the PE50 film had the lowest permeability to water vapour (Table 6.1). Delay in the ripening of fruits could be due to a reduction in ethylene production in high humidity, because of saturation of intercellular space within the fruits could slow down the respiration rate (Wilkinson, 1970; Kader 1985a). Therefore, fruits harvested at the pink stage of maturity and sealed in the PE50 had a slower ripening rate than fruits sealed in PE20, PE30 and PVC during storage. So, in this case, the acidity of those tomatoes could be more affected by fruit ripeness, and they were more acidic. However, fruits sealed in PP were also less ripe, and were similar in ripeness to the fruit sealed in PE50. But their acidity values were lower than fruits sealed in PE50. This lower acidity could be due to higher CO_2 (13-14 %) or lower (4-5 %) O_2 levels (Table 6.2).

Retardation of ripening is at least partially attributable to a low O_2 atmosphere which slows down ethylene synthesis and action, and high CO_2 inhibiting ethylene action (Sherman, 1985). O_2 is necessary for ACC to be converted into ethylene. Low O_2 concentration can inhibit the action of EFE (ethylene forming enzyme), increase the levels of ACC, decrease the phenomenon of autocatalytic ethylene production and limit the increase in ACC synthesis activity (Riquelme et

al., 1994). CO_2 directly regulates the biosynthesis rate of ethylene (Horton, 1985). It was shown that a low level of CO_2 can affect ethylene synthesis, and high levels inhibit its formation and action by limiting the formation of ACC and inhibiting the conversion of ACC into ethylene (Riquelme et al., 1994). CO_2 can also influence the physiological effects of ethylene by acting to regulate the retention of ethylene within fruit tissues, and part of this 'retention' could be at 'action' sites within the cells (Horton, 1985).

Maturity at harvest obviously affects acidity levels in tomatoes. The acidity levels of tomatoes were highest when they were harvested at the pink stage of maturity (Figure 6.6 and 6.12), and then decreased throughout the storage period. The acidity values of tomatoes harvested at the mature green stage of ripening and kept in MAP (Figure 6.1) and CAS (Figure 6.9) increased during the first 10 days then tended to decrease. The colour values of those many tomatoes kept in MAP by that time were still mature green especially those stored at 13°C (Figure 6.1) and during CAS (Figure 6.9). Hall (1966) and Hobson and Davies (1971) state that the highest level of acidity was at the green yellow (breaker) stage. But my research shows that this is not the case when the fruits are harvested at the mature green stage of maturity and stored long term, because the fruits had the highest acidity in the first 10 days during long term storage, and all the fruits kept in CAS were still at the mature green stage by that time. Many of the fruits kept in MAP were also still at the mature green stage until 10 days storage, whereas some of them could have reached breaker stage of maturity by that time depending on their storage environments. The reason for the increased acidity in mature green tomatoes in the first 10 days packed in MAP and CAS could be due to CO_2 fixation before reaching an equilibrium concentration of CO_2. This is

because CO_2 concentration in the packs became higher in the first week after sealing depending on the permeability of packaging films then the desired equilibrium concentration of the CO_2 was reached within a couple more days.

It would seem logical that fruits stored in CAS with increased levels of CO_2 would be more acid because CO_2 is an acid gas which should be dissolved in the cell sap in proportion to its concentration in the surrounding atmosphere, but my results disagreed with this. Goodenough and Thomas (1981) reported that acids increased steadily throughout maturation and ripening, reaching a peak as the fruit changed colour and then declining somewhat. Hobson and Davies (1971) also reported that the highest level of acidity was at the green yellow stage mentioned earlier. However, it seems that this research was carried out during vine ripening of tomatoes in air. There is little information on acidity changes during CAS of tomatoes. Parsons et al., (1970) found that titratable acidity increased with increasing CO_2 concentration from zero to 5 % CO_2 during CAS, but there was no comment about consumer response to these levels of acidity, and there was also no information about comparison to control tomatoes at that time. It is difficult to find adequate information about the relationship between acidity changes and CO_2 concentration during CAS. But there are conflicting reports on some other fruits. In a recent review paper, Riquelme et al., (1994) reported that storage of strawberries in low O_2 and high CO_2 concentrations does not affect titratable acidity. It was also reported that in 60 % CO_2 there was no affect on titratable acidity in Valencia oranges, while storage of lemons under high CO_2 leads to accumulation of organic acids (Biale, 1960). Salunkhe and Wu (1974) reported that the titratable acidity of green beans increased during air storage, but decreased slightly in CAS. They also

reported that the titratable acidity of broccoli and asparagus decreased progressively with increasing concentration of CO_2 in the CAS. It was concluded that titratable acidity levels decreases firstly because the maturation and ripening rates of fruits increase when they are stored in air or in very low CO_2 environment during long term storage. Secondly, if the CO_2 level is higher than 9 % in the storage environment these CO_2 levels cause a decrease in the acidity levels of the tomatoes. It was more effective on ripe fruits (i.e. more effective on pink tomatoes than mature green ones).

6.4.6. Total Soluble Solids

It was found that in this study TSS values of mature green tomatoes kept in MAP increased until 30 days of storage then tended to decrease progressively (Figure 6.9). But their TSS values on 40 days storage were approximately the same as their initial TSS values. After 40 days they were less than their initial values. Goodenough and Thomas (1981) also found similar results during MAP with the fructose and glucose content of tomatoes which increased for the first four weeks of storage then tended to decrease. The sugar content of tomato fruits started to rise at the onset of ripening and ripeness was attained only during, or just after, the climacteric rise in respiration (Whiting, 1974). It was also reported that it increased progressively throughout maturation and ripening (Hobson and Davies, 1971; Davies and Kempton, 1975). There is, however, a particularly pronounced rise which occurred with the appearance of yellow pigmentation (Hobson and Davies, 1971). The TSS of tomatoes are made up largely of sugars with some organic acids and other chemicals (Hobson and Grierson, 1993). Acidity levels have been shown to decrease during storage which would account for some of the losses in TSS, but other losses would be accounted for by sugar consumption in the normal metabolism of the fruit. Generally TSS

values of tomatoes stored in higher CO_2 environments are lower compared to those stored in lower CO_2, because the ripening rate is inhibited by high CO_2 concentration. Therefore production of sugars, organic acids and other substance which contributes to TSS values of tomatoes were inhibited. Hobson and Davies (1971) reported that higher CO_2 prevented the production of sugars, organic acids and other chemicals which are the main substance of TSS. Herner (1987) also reported that the accumulation of reducing sugars in potato tubers is prevented by concentration of 5 % CO_2 or more. He also reported that the conversion of sugar in peas and sweet corn can be inhibited by high CO_2 levels.

TSS values of tomatoes harvested at mature green or pink stage of maturity and kept in 3.2 %, 6.4 % and 9.1 % CO_2 all with 5.5 % O_2, remained higher than other treatments after 60 days storage (Figure 6.13). Fruits stored in 6.4 % and 9.1 % CO_2 in 5.5 % O_2 were significantly ($P=0.05$) higher than other treatments' TSS values. In CAS ethylene production by tomatoes was negligible as mentioned earlier. In these storage environments with the contribution of a high level of CO_2 concentration the ripening of the fruits was inhibited. Thus some sugar and organic acid production was prevented and TSS values of these tomatoes (kept in CAS) were higher than the TSS values of the fruits kept in MAP.

In tomatoes the rate of total sugar accumulation is considerably reduced by storage in 10 % CO_2 compared to storage in air (Burton, 1982b). However, low O_2 (1 %) storage is shown to inhibit sugar accumulation. It is also reported that swelling and extensive hydration of cell walls accompany ripening and there is much evidence that insoluble pectin becomes solubilised. Hemicellulose also becomes degraded at this time (Hobson, 1993). The results of my experiment

confirm this latter trend, and may be related to the suppression of the fruit's metabolism affecting the degradation of pectins and hemicelluloses more than the respiration rate. There are some conflicting reports also about changes in TSS and sugar levels in the literature. These include no changes in TSS (Esquerra and Bautista, 1990) and an increase in reducing sugar (Goodenough and Thomas, 1981).

6.4.7. Decay

The atmospheres within the PP (5-6 % O_2 and 11-13 % CO_2) gave the best result for the Liberto variety (1993 results) without any physiological disorders and with less decay. This is contrary to the finding of Geeson et al., (1985) who reported that PP films caused severe physiological damage to the tomatoes, and that ripening was completely inhibited and did not resume when packs were perforated. This contradiction might be due to different thicknesses of packaging films, because there was no information about the thicknesses of film in this report, or it may be due to the effect of the variety of tomatoes, because they used a different variety to those used in this study. The Criterium variety was used in the 1994 experiments. Fruits sealed in PP (containing of 5-6 % O_2 and 11-13 % CO_2) had severe physiological damage, as reported by Geeson et al., (1985). There is also another finding which is contrary to Geeson et al (1985): they reported that the WVTR of sealed packs did not influence the development of fungal spoilage whereas it influenced my results.

Generally, at the end of 60 days storage tomatoes harvested at the pink stage of maturity had more decayed fruit than fruits harvested at the mature green stage of maturity. Those stored at 20°C had much more decay than those at 13°C. Tomatoes harvested at the pink stage and sealed in higher WVTR films (PVC

and PE20) had slightly more senescence, [meaning that fruits became softer and had some small twisted folds in the fruit skin] than those sealed in lower WVTR films (PP and PE50). Tomatoes sealed in higher WVTR film had more decayed fruits after long term storage because they were too weak in texture to resist microbial attack. Occurrence of more decayed fruit with PVC or PE20 than PP or PE50 could be due to more senescent tissue which could be easily affected by fungi penetrating fruits encouraged by humidity during long term storage. In his paper Thompson (1971) showed similar results in disease development in mangoes when they were stored in plastic film compared to those stored unsealed. He concluded that the effect was due either to the fruit being less ripe in the plastic film bags or because they were more turgid because of the plastic films. This fruit turgidity could have reduced the ability of the fungi to penetrate the cells of the fruit thus lowering the infection levels. In terms of the former explanation, Dennis (1987) showed that tomato fruit became more susceptible to disease as they ripen. Another possible explanation could be that reduced O_2 or increased CO_2 levels in the atmosphere have been shown to reduce the growth of fungi (Kader, 1986; McGlasson and Wills, 1972).

In CAS of tomatoes the results are similar to those of Parsons et al., (1970) who reported that mature green tomatoes held at 12.8°C for 6 weeks kept significantly better in 3 % O_2 and zero CO_2 plus 97 % N_2 than in air. However they showed that in air 66 % of the tomatoes decayed after 6 weeks at 12°C. No CO_2 injury was observed in the present experiment. CO_2 injuries were reported by Parsons et al., (1970) in low O_2 (0 to 3 %) in combination with 3-5 % CO_2 but Buescher (1969a) did not observe CO_2 injury at 4 % O_2 with 5 to 10 % CO_2.

Chapter 7. Temperature effects on MAP and CAS of tomatoes.

7.1. Introduction

Storage temperature is very important for the shelf life of tomatoes. Many researchers have investigated the relationship between temperature and the deterioration rate of tomatoes (see Chapter 2, section 2.5.4.1). It is concluded that the lower the storage temperature, the longer the shelf life (Shewfelt, 1986). But tomato fruits are susceptible to chilling injury at low temperature (Kader, 1986), so to save tomato fruits from injury there is general agreement on a minimum storage temperature for mature green tomatoes without causing any chilling injuries, namely 13°C (Kader et al., 1978b; Parsons et al., 1970; Risse and Miller, 1984 and Hobson, 1987).

The main reason for doing this experiment was that there were no chilling injury problems with the experiments done in 1993 for MAP treatments at 13°C. No problem was seen until 30 days of storage in 1994 at 13°C when I set up the same MAP experiment using the same storage conditions with the 'Criterium' variety before setting up the CAS experiment. However, such good results were not achieved with the 'Liberto' variety and some temperature injury occurred in the 1994 experiments after 30 days storage. The symptoms were mainly shown as local water accumulation and some discolouration on the fruits. It was therefore decided that another experiment should be set up at 15°C. In fact, comparison of storage temperature was not initially one of the main objectives of the work. However, as a result of chilling injury problems at 13°C at the beginning of 1994 using the 'Criterium' variety, comparison of the storage temperature became one of the objectives of the work.

7.2. Material and methods

This experiment was carried out in 1994 using the 'Criterium' variety. Tomato fruits were harvested at the mature green stage of maturity and stored in either MAP or CAS at 13°C and 15°C. The source of fruits, MAP and CAS methods, colour, acidity and TSS measurements are described in Chapter 3.

7.3. Results

7.3.1. Gas Composition of Internal Atmosphere.

Table 7.1. Times for concentration of CO_2 and O_2 to equilibrate and equilibrium concentrations (%) in experimental packages of pink and green tomatoes sealed with different packaging films at 13°C and 15°C.

		O_2		CO_2	
Pack. Materials	Storage Temperature	Equilibrium Time (days)	Equilibrium Concentration (%)	Equilibrium Time (days)	Equilibrium Concentration (%)
PP	13	1.8-2.6	4.6-5.8	2.8-4.2	11.0-12.0
	15	1.9-2.2	4.5-5.6	3.2-4.6	12.1-13.1
PE30	13	1.0-2.5	7.4-8.2	2.6-3.8	2.8-4.8
	15	1.2-2.4	8.2-9.5	1.4-2.3	5.0-5.3
PE50	13	1.8-3.2	4.6-5.8	3.4-3.6	4.6-6.0
	15	1.9-3.4	3.5-4.3	4.2-5.4	5.9-8.1

Generally, O_2 concentration decreased and CO_2 concentration increased in packages when they reached their equilibrium concentration at both temperatures (Table 7.1). Equilibrium rate of O_2 decreased and CO_2 concentration increased with increasing thicknesses of polyethylene film. It was found that CO_2 permeability of PP was approximately half of PE50 at both temperatures whereas the O_2 concentration was the same for PE50 at 13°C and was slightly higher at 15°C (Table 7.1). PE50 packages gave the lowest O_2 concentration and PP gave the highest CO_2 concentration in the packages at both temperatures. Although O_2 concentration was similar in PE30 at both

temperatures it was considerably lower in PE50 at 15°C than at 13°C. In comparison test at 15°C gave somewhat higher CO_2 concentrations than test at 13°C in all packages.

7.3.2. Colour

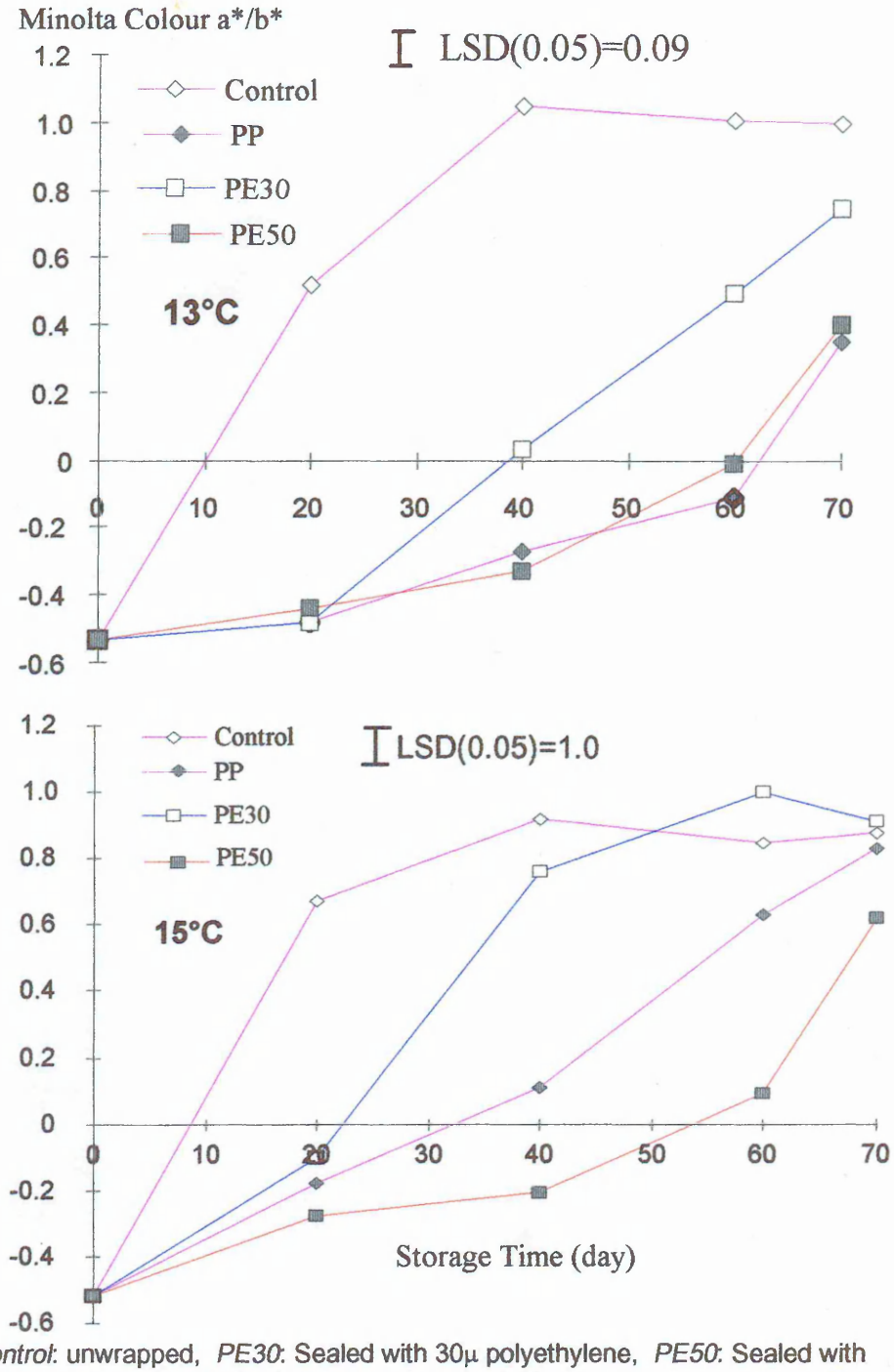
The effects of the interaction of storage temperatures and storage treatments on the colour development of tomato fruits during 70 days was highly significant (P=0.001) (Table 7.2).

Table 7.2. Mean squares from the analysis of variance of tomatoes during 70 days modified and controlled atmosphere packaging storage (for colour).

Source of Variation	df	MAP	CAS
Temperature (T)	1	0.36**	0.44***
Treatments (TR)	3	0.85***	0.50***
Storage (S)	2	15.68***	15.03***
SxT	2	0.03ns	0.01ns
SxTR	6	0.14***	0.04***
TxTR	3	0.05**	0.07***
SxTxTR	6	0.06***	0.09***
Residual	120	0.02	0.01
Total	143		

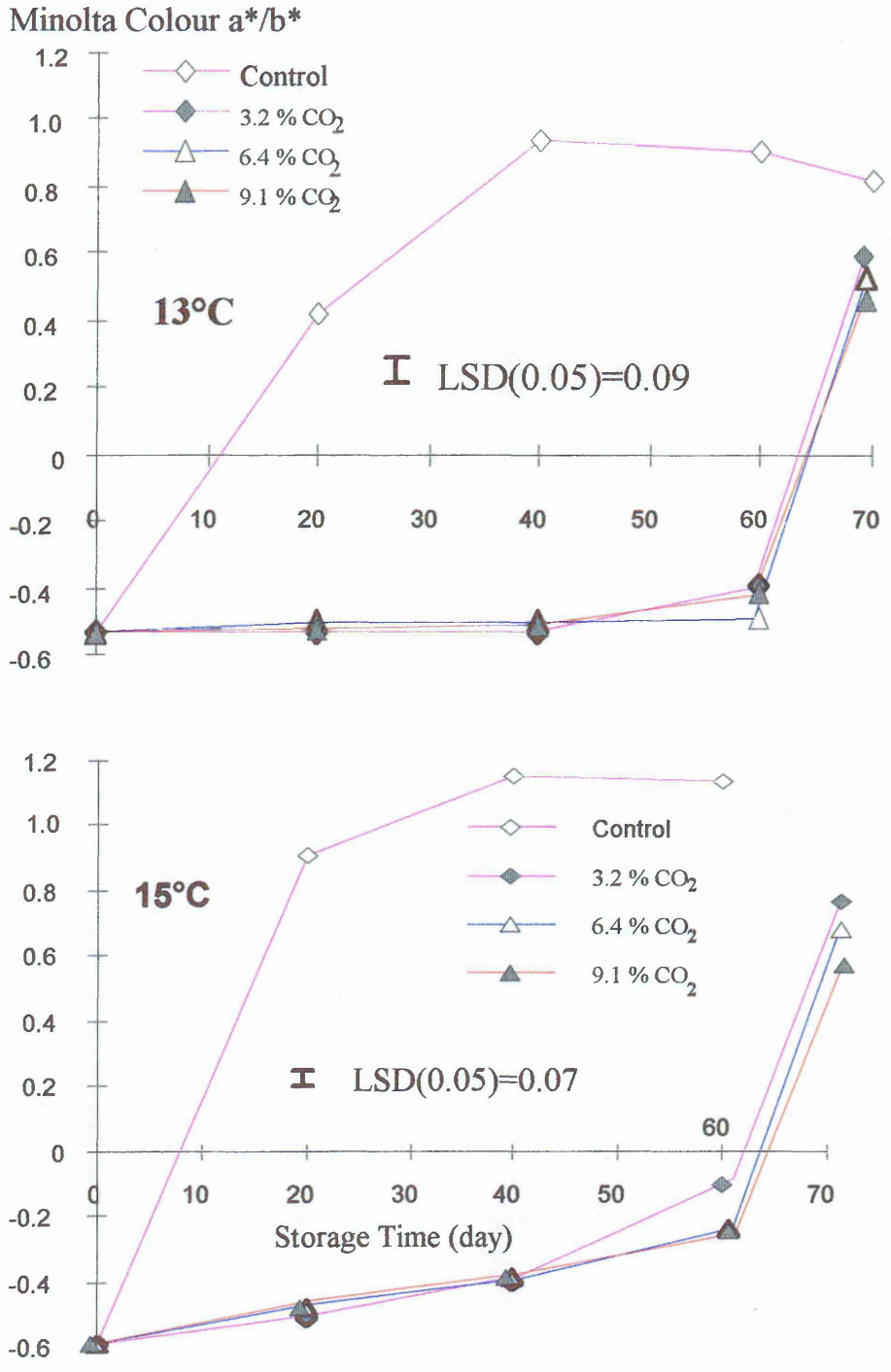
*** Fpr < 0.001 ** Fpr < 0.01 ns= No significant interaction

Red colour development of tomatoes increased significantly (P=0.05) throughout the storage time (Figure 7.1). Colour stability of unwrapped (control) fruits occurred after 40 days storage at both temperatures while there was no change in colour development of tomatoes sealed in PP and PE50 until 20 days of storage at 13°C. From 20 days onwards red colour increased steadily throughout the storage period (Figure 7.1). The red colour development of mature green tomatoes sealed with PE50 and PP was retarded, even after 60 days storage compared to PE30, and especially to the control. The colour of all



Control: unwrapped, *PE30*: Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PP*: Sealed with 25μ polypropylene

Figure 7.1. Changes of Minolta colour (a*/b*) values of tomatoes harvested at mature green stage of maturity and sealed in various MAP films for 60 days storage at 13°C and 15°C plus 10 days in air at 20°C.



Green: -0.62-(-0.49); *Breaker*: -0.48-(-0.27); *Turning*: -0.25-0,06; *Pink*: 0.08-0.57, *Light red*: 0.61-0,95 *Red*: 0.95-1.22

Figure 7.2. Changes of Minolta colour values of tomatoes harvested at mature green stage of maturity and kept in CAS (all with 5.5 % O_2) for 60 days storage at 13°C and 15°C plus 10 days in air at 20°C.

tomatoes sealed in PE50 and PP films steadily increased during 60 days, and did not reach a full red colour even after 60 days. Tomatoes sealed in PE30 just began to change in colour after 40 days of storage at 15°C. Colour development of tomatoes stored at 15°C increased faster than tomatoes stored at 13°C although the CO_2 level was higher and the O_2 level was lower inside packages stored at 15°C than at 13°C (Table 7.1). The colour of all fruits sealed in either PP or PE50 was still at the turning colour stage at 13°C after 60 days storage whereas the colour of the fruits in PP changed earlier than fruit colour in PE50 at 15°C and reached the pink stage. Tomatoes sealed in PP reached pink colour on the 40 th day, whereas the fruits stored in PE50 reached the same colour stage 20 days later than fruit sealed in PP. In both MAP or CAS development of red colour was slow at 13°C. It even stopped in CAS. It was found that the Criterium variety was more sensitive to low storage temperature (even 13°C) and O_2 levels with high CO_2 concentration in storage environment. Tomatoes stored at 13°C had some uneven ripening for 10 days following 60 days at 20°C storage.

The colour of tomatoes stored in 3.2 %, 6.4 % and 9.1 % CO_2 at 13°C did not change even after 60 days storage (Figure 7.5). But by that time (even after 30 days) some decay and local water accumulation occurred in tomatoes stored at 13°C (Table 7.5 and 7.6). The colour development of tomatoes in the same storage environments increased steadily and significantly (P=0.05) throughout the storage period at 15°C compared to 13°C. The colour values of tomatoes stored at 15°C were significantly (P=0.05) higher (especially after 20 days storage) than the colour values of fruit stored at 13°C. Water condensation did not occur and there was less decayed fruit at 15°C than at 13°C.

7.3.3. Titratable acidity

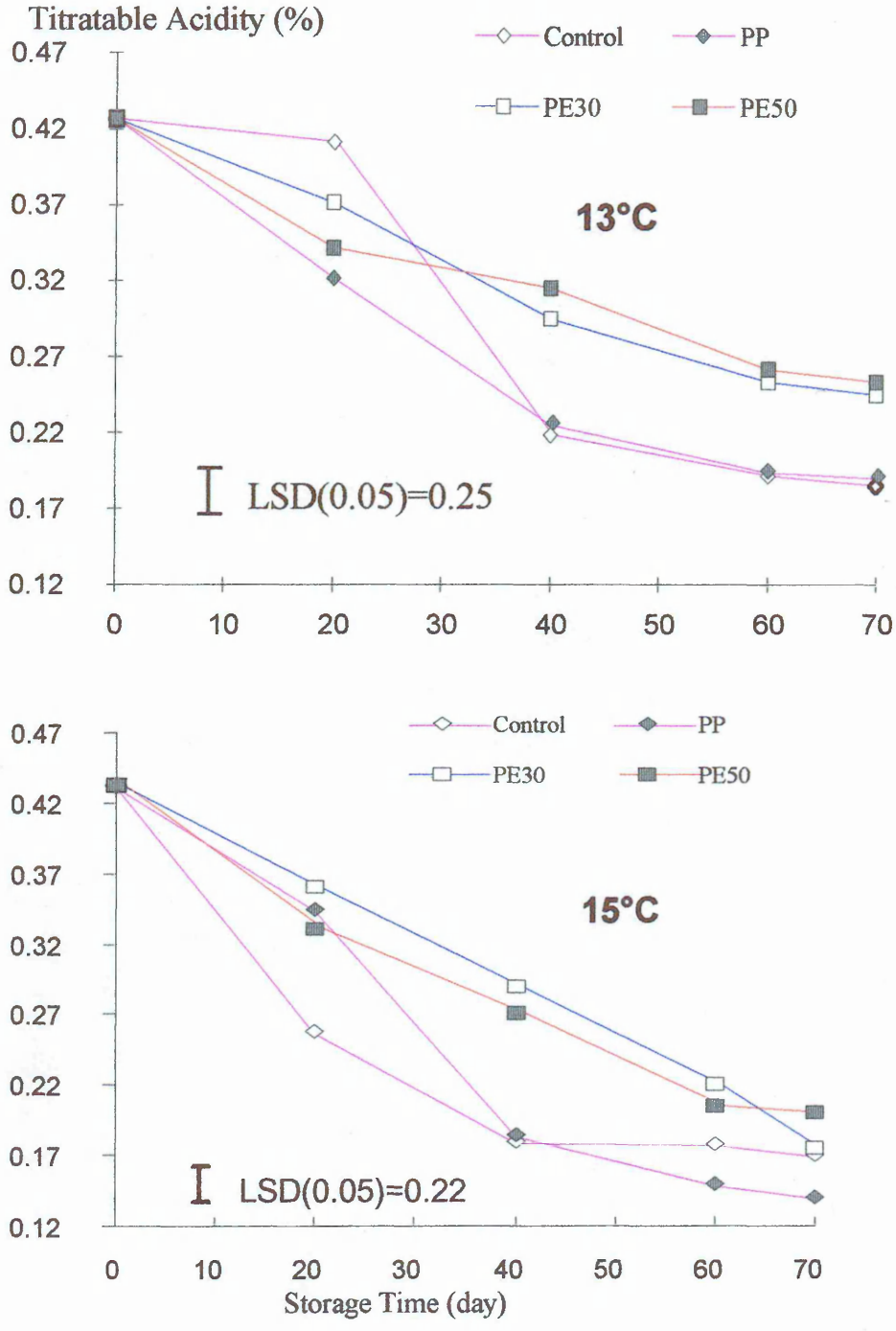
The effects of the interaction of storage temperatures and storage treatments on the titratable acidity changes of tomato fruits during 70 days was highly significant (P=0.001) (Table 7.3).

Table 7.3. Mean squares from the analysis of variance of tomatoes during 70 days modified and controlled atmosphere packaging storage (for titratable acidity).

Source of Variation	df	MAP	CAS
Temperature (T)	1	0.03**	0.01***
Treatments (TR)	3	0.05***	0.04***
Storage (S)	2	0.08***	0.03***
SxT	2	0.03***	0.01***
SxTR	6	0.04**	0.01***
TxTR	3	0.03***	0.01***
SxTxTR	6	0.02***	0.01***
Residual	120	0.00	0.00
Total	143		

*** Fpr < 0.001 ** Fpr < 0.01 ns= No significant interaction

The acidity of all sealed tomatoes decreased throughout the storage time. There was a similarity in the acidity values of tomatoes stored between 13°C and 15°C (Figure 7.3). The acidity of tomatoes stored long term in 11-13 % CO_2 and 4.5-8 % O_2 levels (in PP film) decreased significantly and faster than fruits in PE30 and PE50 throughout the storage time at both 13°C and 15°C, and control tomatoes also had a decrease in titratable acidity after 40 days storage at 13°C. So, the acidity values of fruits sealed in PP were similar to control fruit and both of them lower than the acidity of fruits sealed in PE30 and PE50 especially after 40 days storage at both 13°C and 20°C. There was no significant (P=0.05) difference on the acidity values between tomatoes sealed in PE30 and PE50.



Control: unwrapped, *PE30*: Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PP*: Sealed with 25μ polypropylene

Figure 7.3. Changes of titratable acidity of tomatoes harvested at mature green stage of maturity and stored in various MAP films for 60 days at 13°C and 15°C plus 10 days in air at 20°C.

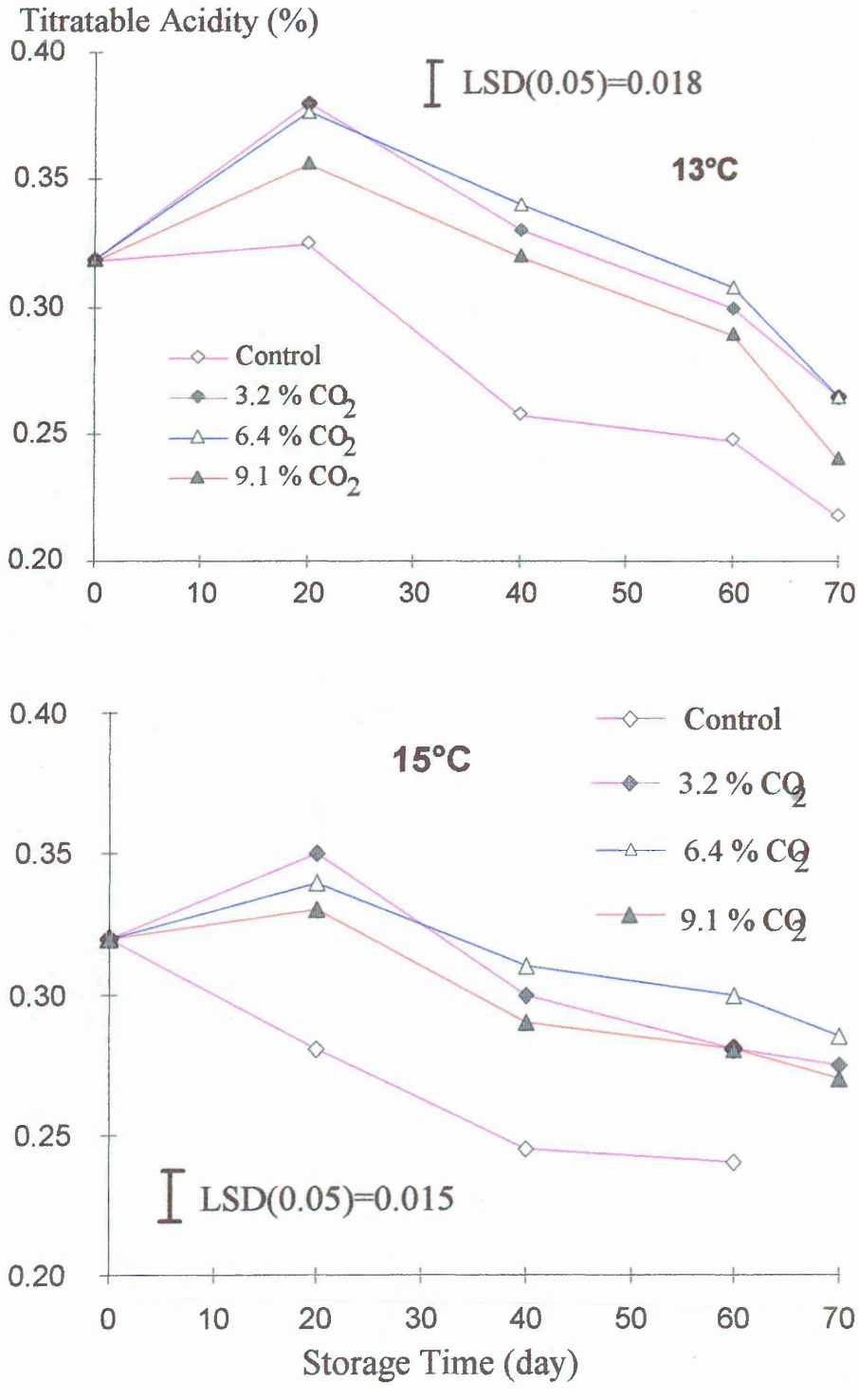


Figure 7.4. Changes of titratable acidity tomatoes harvested at mature green stage of maturity and kept in CAS (all with 5.5 % O_2) for 60 days storage time at 13°C and 15°C plus 10 days in air at 20°C.

Titratable acidity of tomatoes in CAS increased during the first 20 days at both 13°C and 15°C (Figure 7.4). After 20 days acidity levels tended to decrease until 70 days of storage. Although there was no correlation between the O_2 or CO_2 concentrations and acidity levels of fruits during CAS, the acidity values of tomatoes stored in 6.4 % CO_2 with 5.5 % O_2 were the highest among the treatments and the lowest was in 9.1 % CO_2 with 5.5 O_2. There was significant a (P=0.05) difference between the control fruits and fruits exposed to all levels of CO_2 during storage while no significant difference occurred among the tomatoes exposed to different levels of CO_2. The acidity values of tomatoes kept in CAS at 13°C were very similar to fruits stored at 15°C.

7.3.4. Total Soluble Solids (TSS)

The effects of the interaction of storage temperatures and storage treatments on the changes in TSS of tomato fruits during 70 days was highly significant (P=0.001) (Table 7.4).

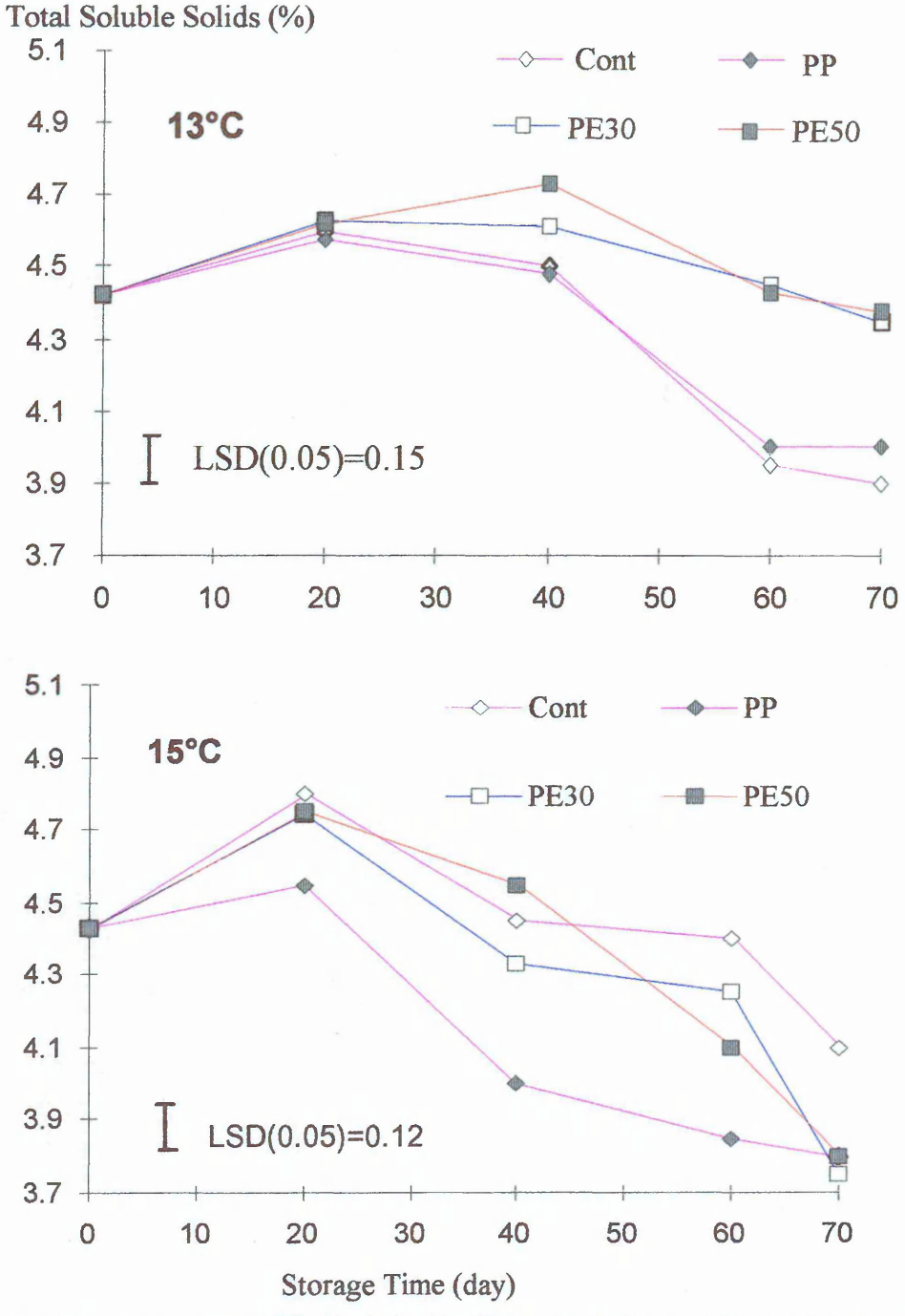
Table 7.4. Mean squares from the analysis of variance of tomatoes during 70 days modified and controlled atmosphere packaging storage (for TSS).

Source of Variation	df	MAP	CAS
Temperature (T)	1	4.36**	6.11***
Treatments (TR)	3	0.55***	0.42***
Storage (S)	2	1.68***	1.44***
SxT	2	0.53**	0.23***
SxTR	6	0.64**	0.44***
TxTR	3	0.04ns	0.01ns
SxTxTR	6	0.06***	0.06***
Residual	120	0.01	0.01
Total	143		

*** Fpr < 0.001 ** Fpr < 0.01 ns= No significant interaction

TSS contents of tomatoes increased more rapidly at 15°C than at 13°C during the first 20 days of storage (Figure 7.5). There was a trend towards decreasing TSS during storage after that, but no consistent relationship between different plastic films was observed at either 13°C or 15°C. There was a similarity in TSS values of fruits sealed in the same packaging materials at 13°C and 15°C whereas the acidity of control fruits was lower at 13°C than at 15°C.

Tomatoes kept in CAS also showed approximately the same TSS changes as with the MAP treatments (Figure 7.6). Except for control fruits, the TSS values of tomatoes kept in MAP were lower than fruit kept in CAS at both temperatures. Tomatoes stored at 13°C in CAS had slightly higher TSS than fruits stored at 15°C between 20 and 40 days storage. But when fruits were taken out of CAS to ripen for 10 days between 60 and 70 days storage the TSS values of fruits stored at 13°C continued to decrease while it increased for fruits stored at 15°C.



Control: unwrapped, *PE30*: Sealed with 30μ polyethylene, *PE50*: Sealed with 50μ polyethylene, *PP*: Sealed with 25μ polypropylene

Figure 7.5. The changes of total soluble solid contents of tomatoes harvested at mature green stage of maturity and stored in various MAP films for 60 days at 13°C and 15°C plus 10 days in air at 20°C.

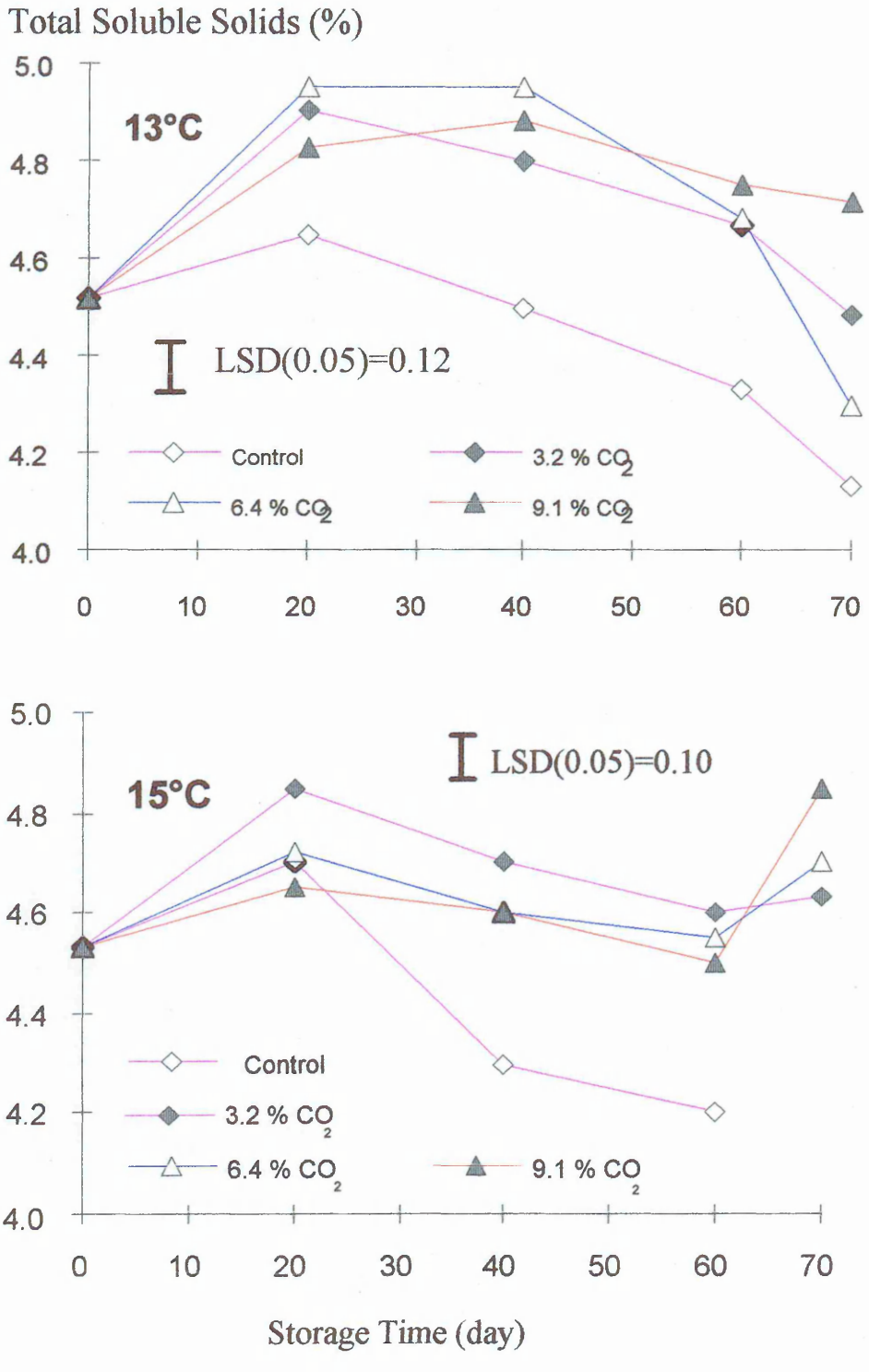


Figure 7.6. The changes of total soluble solid contents of tomatoes harvested at mature green stage of maturity and stored in various CAS (all with 5.5 % O_2) for 60 days at 13°C and 15°C plus 10 days in air at 20°C.

7.3.5. Effect of MAP on Decay

Table 7.5. The percentages of decayed tomatoes packed in different films and stored at 13°C and 15°C for 60 days followed by storage unwrapped at 20°C for 10 days.

Storage Period	Unwrapped		PP		PE30		PE50	
(day)	13°C	15°C	13°C	15°C	13°C	15°C	13°C	15°C
20	0	0	0	0	0	0	0	0
40	0	0	8	5	0	0	0	0
60	17	5	17	30	17	28	17	17
70	20	10	25	40	25	35	25	20

Table 7.6. The percentages of decayed tomatoes harvested at mature green stage of maturity and kept in CAS at 13°C and 15°C for 60 days and subsequent stage in air at 20°C for 10 days.

Storage Period	Unwrapped		3.2 % CO_2 + 5.5 % O_2		6.4 % CO_2 + 5.5 % O_2		9.1 % CO_2 + 5.5 % O_2	
(day)	13°C	15°C	13°C	15°C	13°C	15°C	13°C	15°C
20	0	0	0	0	0	0	0	0
40	10	20	0	0	0	10	0	8
60	20	35	10	15	15	20	8	10
70	40	75	15	20	20	25	12	15

Generally, the incidence of decay was higher in film wrapped fruits than in unwrapped fruit (Table 7.5). No decay was found until 40 days storage at 13°C and at 15°C for tomatoes sealed in plastic films except for fruits sealed in PP. Some infection was observed after 40 days storage in PP. All treatments showed some decay after 50 days storage, with a further increase until 60 days. Decay levels increased when packages were opened and left to ripen between 60-70 days storage at 20 °C. Decay levels were similar in fruits stored in CAS (Table 7.6) to those stored in MAP (Table 7.5) but they were generally lower. This is in spite of the CAS controls having more higher than the MAP controls.

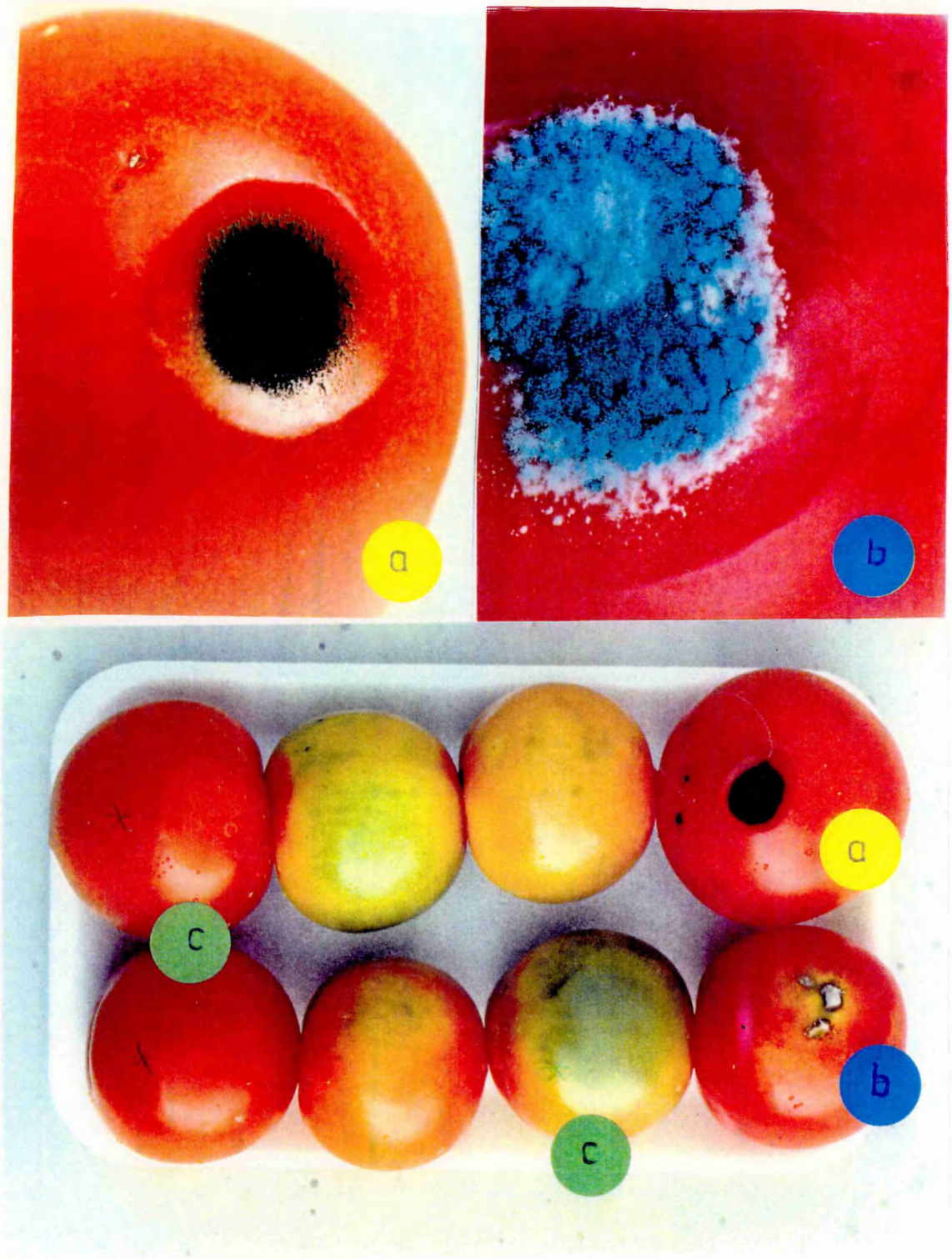


Plate 7.1. Some diseases occurred during storage 'Criterium' variety in 1994 at 13°C. Alterneria rot (a), blue mould rot (b) and cottony leak (c).

In comparison, there was a significant difference between storage temperatures especially after 50 days when more decayed tomatoes were recorded. More 'Alternaria rot' and 'blue mould rot' with 'Cottony leak' (local water accumulation) occurred at 13°C (Plate 7.1).

7.4. Discussion

The colour pigments of tomatoes and the relationship between pigments and effective gases in MAP were discussed in detail in Chapter 6. Furthermore, the formation of lycopene were highly dependent upon the presence of oxygen (Hobson and Davies, 1971). Delay in colour development (β-carotene and particularly lycopene formation) in this experiment is not only due to high CO_2 and low O_2 concentrations but also these differences in the behaviour of tomatoes stored at 13°C and 15°C could be due to the fruit at the lower temperature being subjected to chilling injury. Some chilling injury symptoms such as the pitting of the skin and some local discolouration with browning and yellowish colour (Wills et al., 1989) were observed in MAP and CAS at 13°C. But this contrasts with Parsons et al., (1970), and Risse and Miller (1984) who all reported that 12.8°C storage temperature was safe for long term storage of mature green tomatoes without causing chilling injury. Hobson (1987) found that a temperature of 10°C or less inhibits red pigment (probably lycopene) formation.

A change in the acid concentration during tomato ripening is a major factor in the flavour of the fruit. The present results also demonstrate that the influence of storage temperature and time on these acidity changes is considerable as previously shown by Richardson and Hobson (1987). Thorne and Efiuvwevwere, (1988) found that chilling temperatures affected citric and malic acids. They

reported that these acids increased with the decrease of storage temperature (19°C, 12°C, 7°C and 5°C). In the present work it was found that there was a considerable increase in titratable acidity occurred as temperature was reduced, especially in CAS. The acidity values of tomatoes decreased throughout storage in MAP but it did not decrease during the first 20 days in CAS. It could be due to ethylene accumulation in MAP, because this starts very early in MAP while in CAS it is only produced in limited amounts even towards the end of storage.

Increasing TSS levels in the first 20 days could be due to the ripening process because during normal ripening, pectic compounds degrade into sugar and acids (Malis-Arad et al., 1983) and contribute to increasing the amount of TSS. An increase in TSS values in fruits stored at 13°C is likely because of this, but it could also be also result of chilling injury. This causes the release of some amino acids, sugars, and mineral salts from cells, together with the degradation of cell structure (Wills et al., 1989), and also provides an excellent substrate for the growth of pathogenic organisms especially fungi (Buescher, 1974; Hatton and Cubbedge, 1982). Water condensation was visible in MAP while it was not visible in CAS fruit because of the flow through system and lower humidity. The higher level of decay could be due to the high relative humidity in the atmosphere of the sealed package tomatoes because many researchers agree about higher humidity levels in MAP increases and hastens fungal spoilage (Kader et al., 1989; Risse et al., 1985 and Geeson et al., 1985). The incidence of decay in the fruits in sealed bags was probably due to infection with Fusarium spp (Sommer et al., 1992) but definite identification has not been carried out. High humidity and accumulation of CO_2 can contribute to decay as indicated by the studies of Parsons et al., (1970) and Esquerra and Bautista (1990).

Hobson (1987) reported that translucent water soaked patches occurred when the red tomatoes were stored at 5°C or 7.5°C for 9 days in air. In tomatoes a soft, water-soaked lesion may occur on any part of the fruit and enlarge rapidly. This disease is sometimes called 'water rot' (Snowdon, 1991). But there is one contrary report which claims that water soaked appearance is associated with CO_2 toxicity (Buescher (1979a). Sommer et al., (1992) and Snowdon (1990 and 1991) reported that Alternaria rot and Blue Mould rot appears especially when the fruits have been weakened by chilling injury. Decayed tissue due to Alternaria rot is firm and dry (Sommer et al., 1992).

Unsealed treatments had less decayed fruits than sealed fruits but unsealed fruits were unmarketable because of a softer texture than those sealed in MAP. The decay differences between MAP and CAS were most probably due to differences of RH. RH was higher in MAP and resulted in more decayed fruits. These findings were in agreement with Parsons et al., (1970) who reported that the percentages of decayed tomatoes in CAS were significantly lower than for fruits stored in ambient atmosphere.

Chapter 8. Relationship between sensory attributes and objective measurements of postharvest quality of tomatoes stored in CAS and MAP

8.1. Introduction

Appearance and flavour are the main quality factors for fresh tomatoes (Kader et al., 1978a). To reach acceptable colour and hence flavour development, tomato fruit should be left to fully ripen on the plant. However, if this is done the fruit must be marketed locally without delay (Hobson, 1989). The problem arises when the tomatoes are transported to other regions or where an extension of the shelf life is required. Delaying ripening and extending the shelf life of tomatoes for long term storage could be achieved by CAS and MAP as shown in previous chapters. But there was no adequate information in the literature on sensory evaluation of tomatoes after long term MAP or CAS. In the present study, subjective and objective measurements of quality were made on random samples of tomatoes stored in CAS or MAP at different storage temperatures. In seeking ways to relate sensory assessment to objective measurements of quality, TSS, titratable acid TSS/acid ratio of tomatoes have been studied.

The objectives of this work were to determine the relationship between sensory and objective measurements of postharvest qualities of tomatoes stored in CAS and MAP and to determine the effect and contribution of storage treatments on those quality measurements.

8.2. Material and Methods

The source of fruits, MAP and CAS methods were described in Chapter 3.

Sensory evaluation: For sensory evaluation stored and reference (control) fruits were used. Tomatoes were harvested at either the pink or the mature green harvest maturity then stored for 60 days sealed within different modified atmosphere packaging films or various controlled atmosphere environments (see Chapter 3). After 60 days all modified atmosphere packages and controlled atmosphere containers were opened. Tomatoes which had been stored in CAS for 60 days were given a further 10 days for ripening in air at 20°C. Reference tomatoes were harvested at the pink stage 10 days earlier than taste panel and kept in store at 13°C. At the time of the taste panel, all the fruits were fully red. Ten semi-trained judges were selected from a pool of MSc and PhD students from different countries. Those panellists were trained to use the score sheet. Statistically, firstly, triangle testing was applied to differentiate the acceptable fruits concerning their firmness, colour and appearance after storage, then secondly a scoring test was applied to fruit from the rest of the treatments (Larmond, 1987). Three tomatoes from each of the different treatments, which had been stored for 60 days (for MAP) or 70 days (for CAS) together with three reference fruit, were sliced into 4 pieces. Each panellist tasted one piece of tomato from all the treatments. MAP samples were evaluated by using scales for three flavour attributes in 1993: fresh tomato flavour, sweetness and sourness. Additionally in 1994, acceptability levels also evaluated for tomatoes stored in CAS. The scale used was between 1 and 5. ***Flavour***: 1: poor flavour, 2: weak flavour, 3: moderate, 4: good enough, 5: Strong tomato flavour; ***Sweetness***: 1: not sweet, 2: slightly sweet, 3: moderate, 4: good enough, 5: very sweet;

Sourness: 1: not sour, 2: slightly sour, 3: moderate, 4: sour, 5: very sour; ***Acceptability***: 1: not acceptable, 2: less acceptable, 3: acceptable (moderate), 4: more acceptable, 5: perfect.

8.3. Results

8.3.1. Ripening of tomatoes

After 60 days storage the Minolta a*/b* colour values of tomatoes stored in MAP were between 0.92-0.95 in tomatoes assumed to be at the same stage of ripeness. The Minolta a*/b* colour values of tomatoes stored in CAS were between 0.58-0.69, therefore, on the basis of skin colour, the tomatoes were also assumed to be at the same stage of ripeness in CAS treatments.

8.3.2. Effects of MAP on sensory qualities of tomatoes

The flavour scores of the control tomatoes were significantly (P=0.05) higher than those stored in MAP for 60 days after being harvested both at the pink and mature green stages and stored at either 13°C or 20°C (Figure 8.1). Control tomatoes had similar sweetness scores to the whole tomatoes stored at 13°C and tomatoes harvested at pink stage of maturity stored at 20°C.

The flavour of fruits sealed in PP was significantly (P=0.05) higher than the fruits sealed in PE50 (Figure 8.1 and Table 8.1). Harvest maturity and storage temperature did not affect the flavour of fruits sealed in the same packaging material (Figure 8.1). There was an indication that fruit harvested at the mature green stage of maturity were sweeter than those harvested at the pink stage of maturity after storage at 13°C, but differences were not significant. Storage

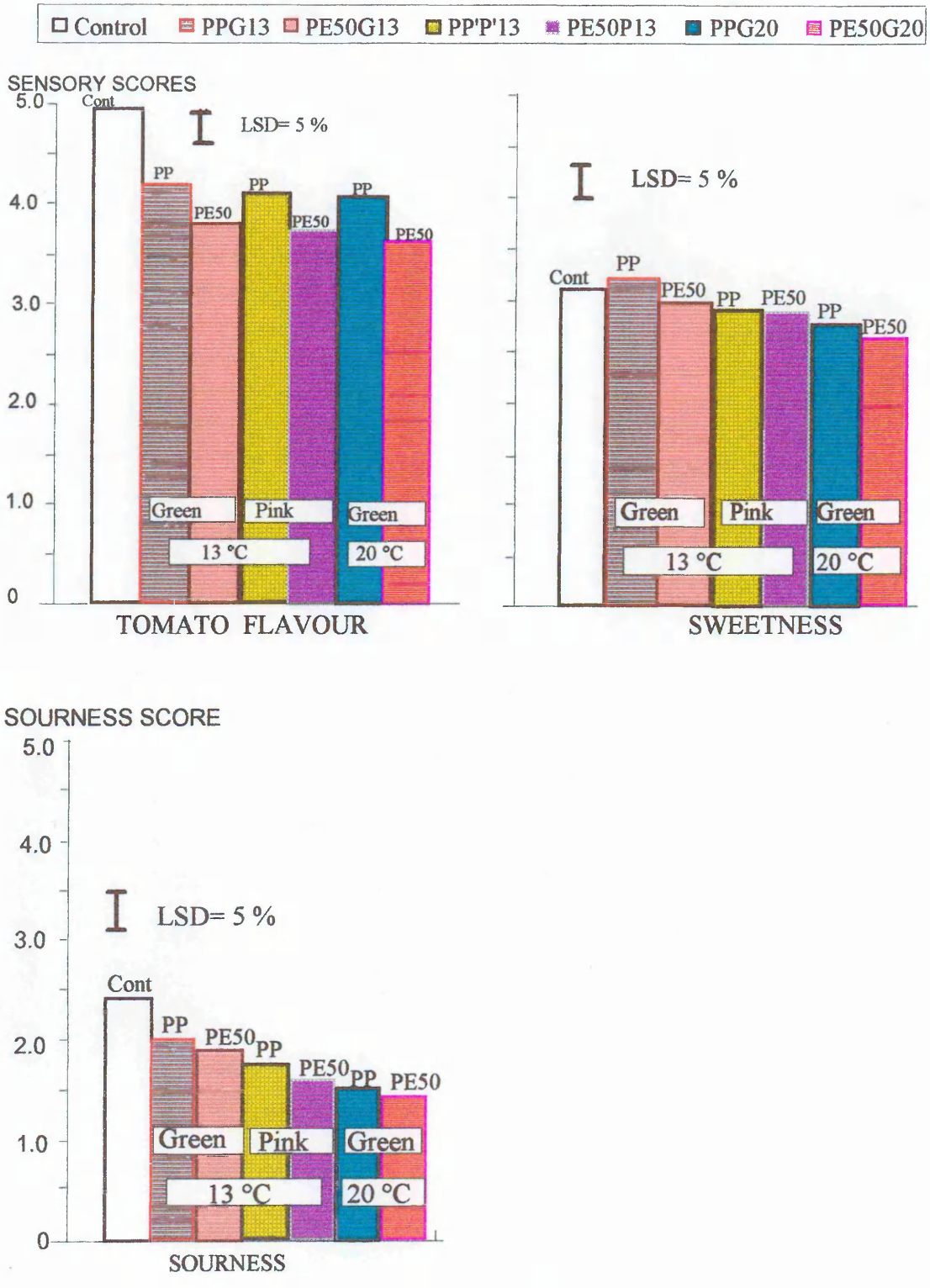


Figure 8.1 . Means of sensory evaluation scores of tomatoes harvested at mature green and pink stage of maturity and stored for 60 days within various modified atmosphere packaging films at 13°C and 20°C.

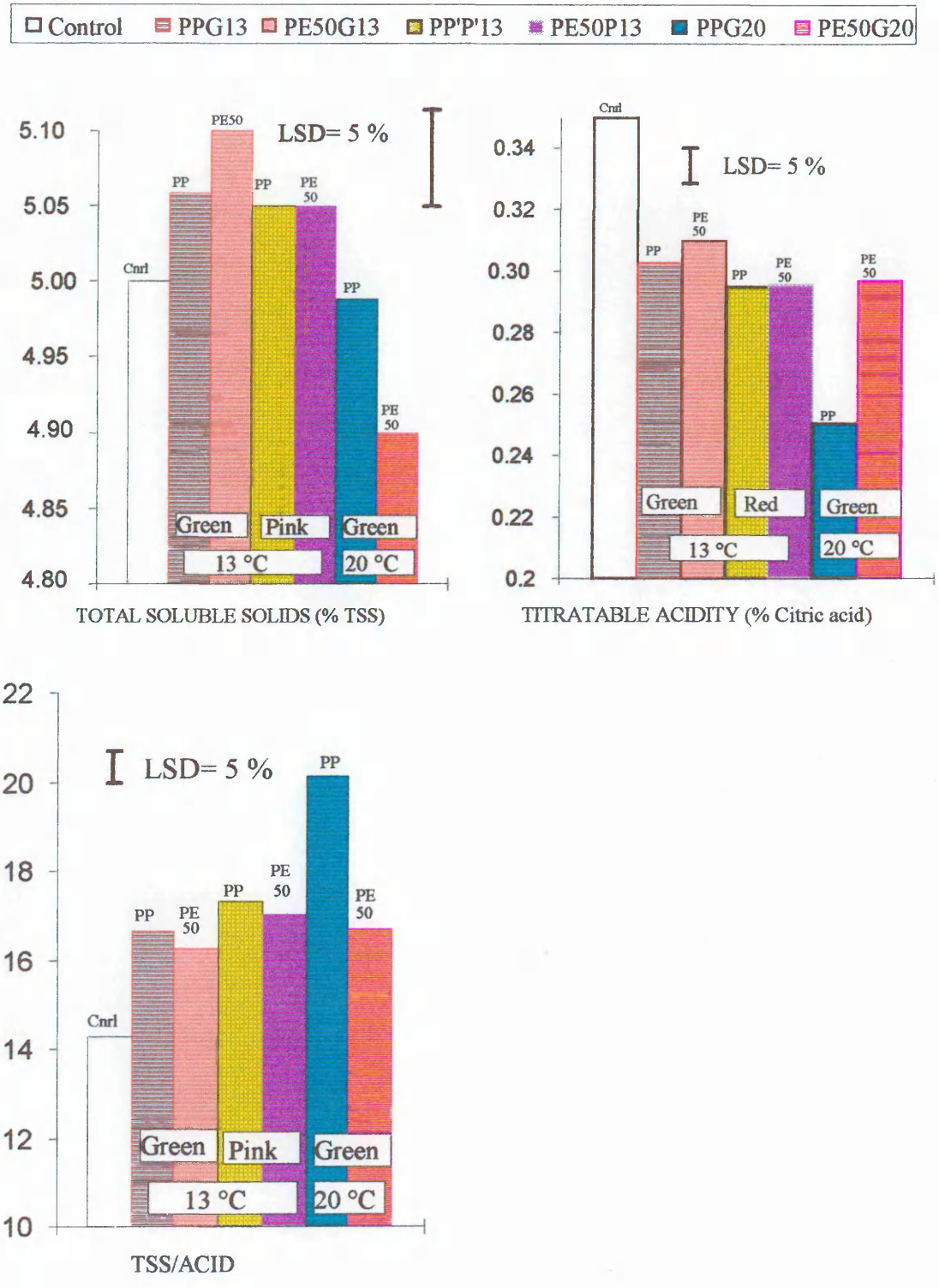


Figure 8.2. Means of objective measurements of tomatoes harvested at mature green and pink stage of maturity and stored for 60 days within various modified atmosphere packaging films at 13°C and 20°C.

Table 8.1. The effects of packaging materials, storage temperature and maturation stages on subjective and objective quality measurements of tomatoes

	Tomato Flavour	Sweetness	Sourness	Total Soluble Solids (TSS)	Titratable Acidity (TA)	TSS/TA
	Main effect wrapping (Figures are means of mature green stage of maturity, the two storage temperatures 13° and 20°C)					
PP	4.15 **	3.00	1.75	5.02	0.28	18.43 ***
PP50	3.70	2.85 ns	1.65 ns	5.00 ns	0.30 ***	16.62
	Main effects of temperature (Figures are means of wrapping and mature green stage of maturity)					
13°C	4.00	3.10 *	1.95 ***	5.08 ***	0.30 ***	16.68
20°C	3.85 ns	2.75	1.45	4.94	0.27	18.37***
	Main effects of harvest maturity (Figures are means of wrapping and storage temperature is 13°C)					
Pink	3.90	2.90	1.70	5.05	0.29	17.12
Green	4.00 ns	3.10 ns	2.00 ns	5.08 ns	0.30 ns	16.68 ns

ns= not significant, Significance levels are: *= 0.05, **= 0.01, ***= 0.001

temperature appeared to affect the sweetness of fruit harvested at the mature green stage of maturity: fruit stored at 13°C gave a higher sweetness than those stored at 20°C. Packaging films did not significantly (P=0.05) affect the sweetness score of tomatoes although there was some indication that fruit sealed in PP were slightly sweeter than those stored in PE50 (Table 8.1). There were no significant (p=0.05) differences in sourness between PP and PE50 or between pink and green harvest maturity. There was an indication that the fruits stored at 13°C were sourer than those stored at 20°C. There was generally a positive correlation between titratable acidity and sourness. Although titratable acidity values of mature green tomatoes sealed in PP and stored at 20°C was significantly (P=0.05) lower than the acidity values of other treatments, judges gave the normal scores them. The lower acidity level was not reflected by the panellists.

There was no significant relationship between packaging films and total soluble solids except for mature green fruits sealed in PE50 films, which were significantly (P=0.05) higher than control and mature green tomatoes stored at 20°C (Figure 8. 2). Those mature green fruits had a significantly (P=0.05) lower TSS value than all other treatments when they were stored at 20°C.

Although there were no significant differences in the acidity values among the majority of the treatments, it was found that the titratable acidity of the control fruit was significantly (P=0.05) higher than the fruit in all other treatments. It was also lower for green tomatoes sealed in PP and stored at 20°C. There were no significant (P=0.05) differences in TSS:acid ratio among the treatments except for two treatments whih were unwrapped (control) and fruits sealed in PP.

Table 8.2. Correlation coefficient (r) for sensory scores and objective measurements of tomatoes harvested at mature green stage of maturity and sealed within MAP films for 60 days (n=60)

	Tomato Flavour	Sweetness	Sourness
TSS	0.37**	0.42**	0.29*
Acid	0.39**	-0.64***	0.39**
TSS/Acid	-0.37**	0.63***	-0.35**

Results of correlation analysis for MAP are summarised in Table 8.2. Regression analyses show that there was a strong relationship between sensory scores and objective measurements (Table 8.2). Titratable acidity and TSS had the most effect on the sensory characteristics of the tomatoes. Generally, flavour had the highest correlation with sourness, sweetness, titratable acidity and TSS. According to sensory evaluation results there was a strong correlation between TSS and tomato flavour, TSS and both sweetness and sourness. Also, as expected,

acid concentration gave a negative correlation with sweetness but was positively correlated with sourness (Table 8.2).

8.3.3. Effects of CAS on the Sensory Qualities of Tomatoes

Control tomatoes had the highest score for tomato flavour and sweetness; their consumer acceptability (Figure 8.3 and 8.4) was significantly higher than tomatoes from the other treatments, and they were more acceptable than fruit stored in CAS for 60 days.

No significant differences occurred in the flavour, sweetness or acceptability scores between the three CAS treatments for the tomatoes harvested at the mature green and pink stages of maturity. These three CAS treatments are; 3.2 %, 6.4 % and 9.1 % CO_2 environments all with 5.5 % O_2. Except the sweetness scores of tomatoes harvested at the pink stage of maturity and stored in 6.4 % CO_2 (Figure 8.4), which were significantly higher than fruit stored in 3.2 % CO_2. Tomatoes harvested at pink stage of maturity and stored in 3.2 % CO_2 had the lowest scores of tomato flavour and sweetness and were less acceptable although their sourness was similar to the sourness of fruits stored in 6.4 % and 9.1 % CO_2 combined with 5.5 % O_2.

Tomatoes harvested at the pink stage of maturity and stored in 9.1 % CO_2 had medium sweetness, the lowest sourness and the highest tomato flavour and consumer acceptability among the CAS treatments. Their fruit sourness was found to be significantly lower than other treatments (Figure 8.4).

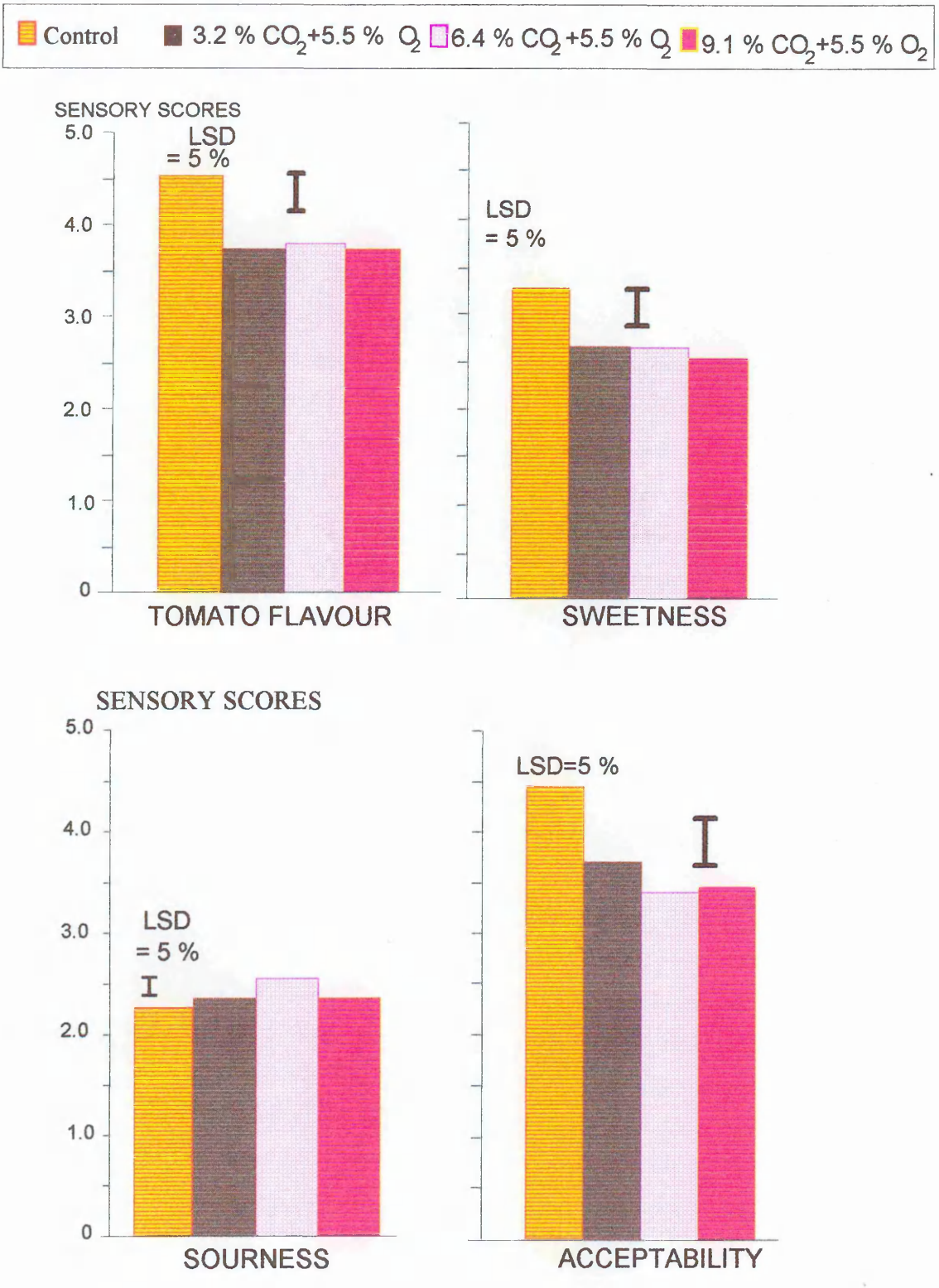


Figure 8.3. Means of sensory scores of tomatoes harvested at mature green stage of maturity and kept in CAS for 60 days at 15°C plus 10 days in air at 20°C.

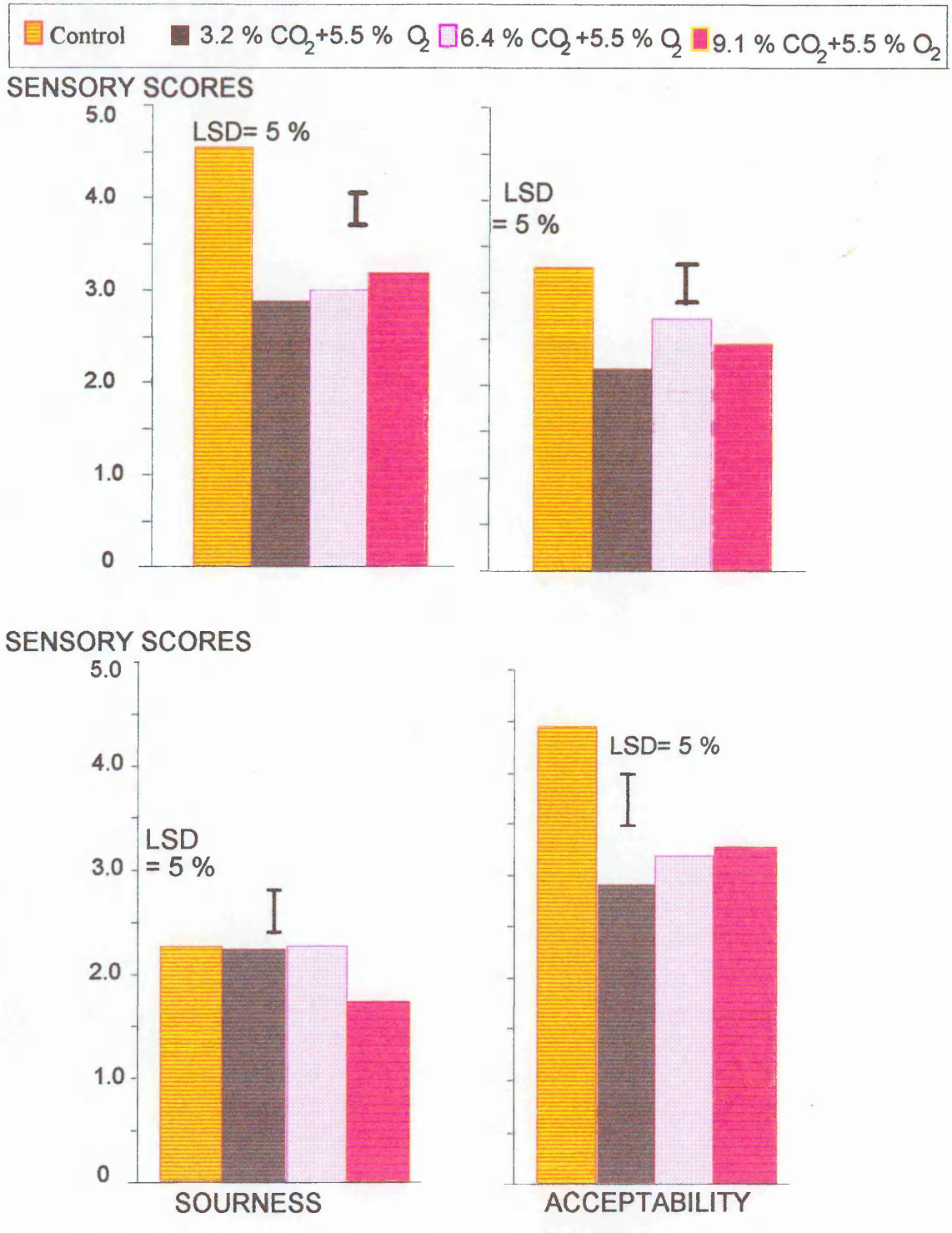


Figure 8.4. Means of sensory scores of tomatoes harvested at pink stage of maturity and kept in CAS storage for 60 days at 13°C plus 10 days in air at 20°C.

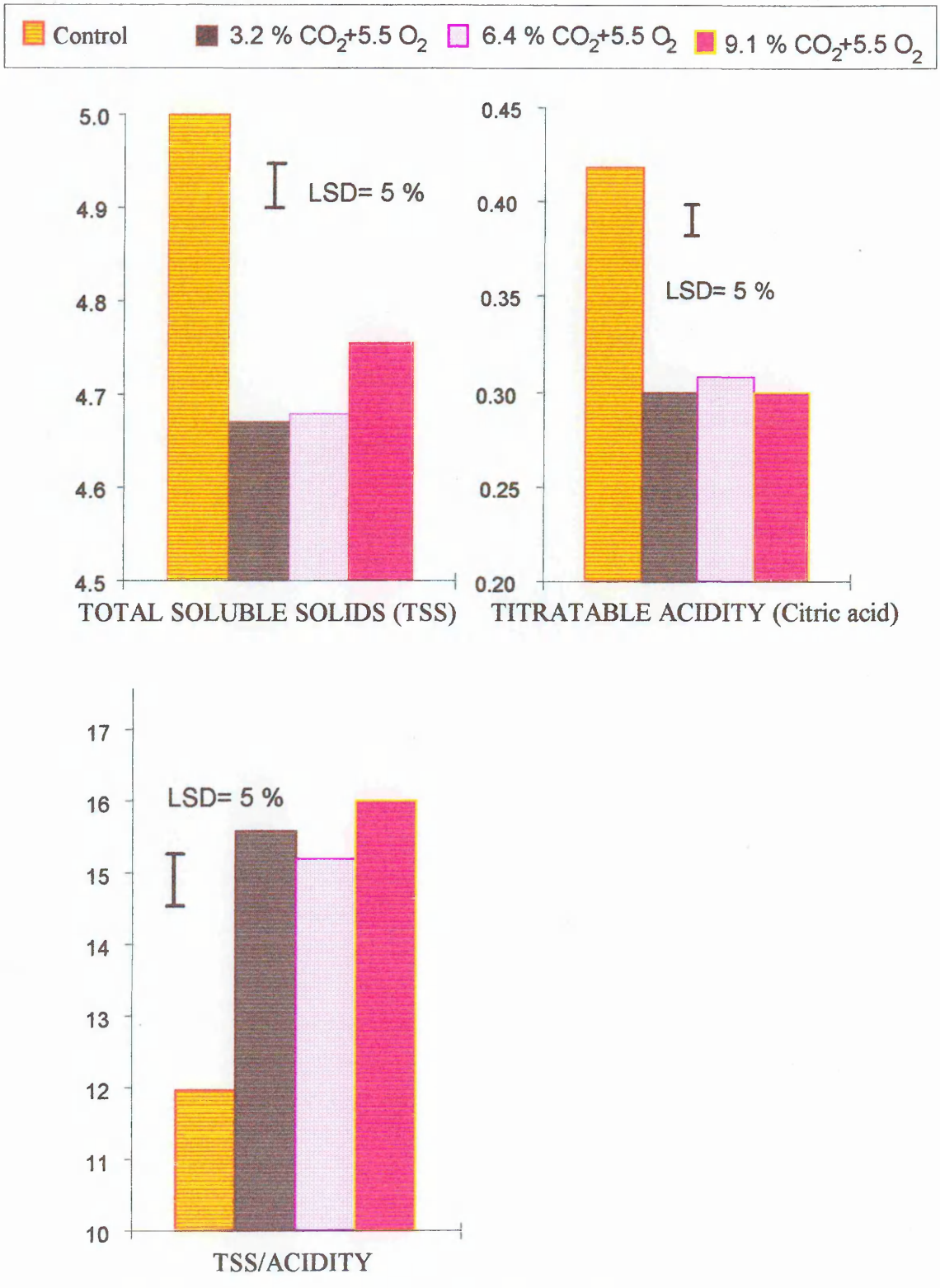


Figure 8.5. Means of objective measurements of tomatoes harvested at mature green stage of maturity and kept in CAS for 60 days at 15 °C plus 10 days in air at 20 °C.

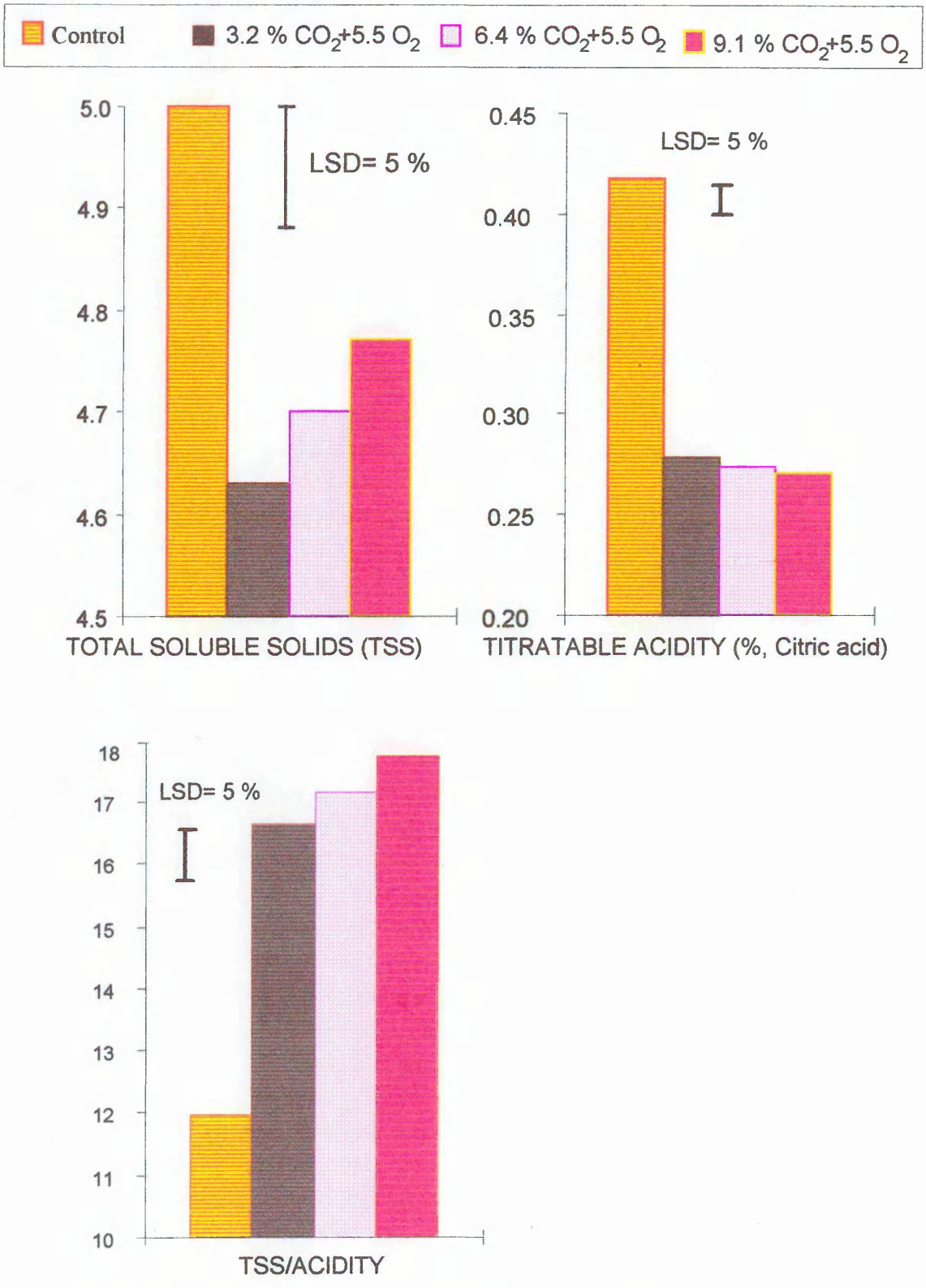


Figure 8.6. Means of objective measurements of pink tomatoes stored for 60 days in controlled atmosphere storage for 60 days in air at 13 °C.

Tomatoes harvested at the mature green stage of maturity and stored in 6.4 % CO_2 with 5.5 % O_2 had the lowest score for acceptability, although their tomato flavour and sweetness scores were very similar to other treatments in CAS. This might be due to the fact that fruits stored in 6.4 % CO_2 with 5.5 % O_2 had the highest sourness scores and these sourness score were significantly higher than the control fruit (Figure 8.3). There was no significant difference in sourness scores for the rest of the treatments. This higher sourness could be affected by decay, because of higher decayed levels in this treatment giving off-flavours which could be interpreted as sourness.

Control fruits had the highest scores for TSS and acidity and naturally the lowest TSS over acid ratio (Figure 8.5 and 8.6). There was a significant variation among the treatments on TSS values. Tomatoes harvested at the mature green stage of maturity and stored in 9.1 % CO_2 had significantly higher TSS at the end of 60 days of storage than fruits stored in 3.2 % and 6.4 % (Figure 8.5). TSS values were also higher for those tomatoes stored in 9.1 % CO_2 than for all other treatments for tomatoes harvested at the pink stage of maturity (Figure 8.6), with only the difference between 9.1 % CO_2 and 3.2 % CO_2 found to be significant (P=0.05). TSS values of tomatoes generally increased with increasing CO_2 levels. There were no differences in the titratable acidity of tomatoes either at the mature green or pink stage of maturity which are similar to the results of the taste panel.

Results of correlation analysis for CAS are summarised in Table 8.3. and 8.4. Regression analyses show that there was a strong relationship between sensory scores and objective measurements (Table 8.2). It was found that tomato flavour had a strong positive correlation with TSS and acidity levels of both the

mature green and pink stages of tomatoes after 60 days of storage. Sweetness had a strong positive correlation with TSS, whereas it had a strong negative correlation with acidity levels. It was also found that there was a negative correlation between the acidity and sourness values of tomatoes. Acceptability level of tomatoes had a strong correlation with sweetness, TSS and acid levels (Table 8.3 and 8.4).

Table 8.3. Correlation coefficient (r) for sensory scores and objective measurements of tomatoes harvested at mature green stage of maturity and kept in CAS for 60 days at 15°C plus 10 days in air at 20°C (n=40)

	Tomato Flavour	Sweetness	Sourness	Acceptability
TSS	0.43**	0.46**	0.13	-0.45**
Acid	0.54**	-0.42**	0.34*	0.39**
TSS/Acid	-0.54**	-0.21	-0.23	-0.29

Table 8.4. Correlation coefficient (r) for sensory scores and objective measurements of tomatoes harvested at pink stage of maturity and kept in CAS for 60 days at 13°C plus 10 days in air at 20°C (n=40)

	Tomato Flavour	Sweetness	Sourness	Acceptability
TSS	0.55**	0.36*	0.08	0.46**
Acid	0.53**	-0.39*	0.38*	-0.43**
TSS/Acid	0.39*	0.09	-0.41**	0.36*

8.4. Discussion

Both CAS and MAP gave considerable extension in storage life of tomatoes at 13°C or 20°C irrespective of maturity. This effect has been shown previously (Morris and Kader, 1974; Dennis et al., 1979; Grierson and Kader, 1986). However what was not known was the comparative effect of CAS or MAP on the eating quality of those fruit after long term storage. There is considerable difficulty in obtaining information on comparative eating quality of fruit stored in CAS or MAP because fruit which have been stored in air cannot be used as a control for comparison because their storage life is very much shorter. In all experiments the control fruit used for comparison were fruit that had been harvested (from the same sources for CAS and MAP of the fruit stored) and stored in a manner in which tomatoes would be treated in commercial practice. Although these may not be ideal in terms of eating quality, vine ripened fruit would have a better flavour, (Kader et al., 1978a), it was felt that they would give a more realistic comparison. The result confirms that the controls always gave higher scores than the CAS or MAP stored fruits.

The sugar and acids are more important and more quickly perceived by panellists. Long term storage of tomatoes always results in inferior sensory characteristics than those stored in short term. This is because tomatoes lose their flavour compounds, which are mainly based on the acid and sugar amounts, during long term storage. Hence it is particularly important that acid levels should be maintained in stored fruit to avoid a bland and uninteresting impression when the fruits are consumed. Several workers have shown that tomato fruit flavour reaches the best acceptable level when acidity and sugars are high (Kader et al., 1977; Grierson and Kader, 1986; Hobson and Grierson, 1993). High sugar and high acid are associated with high flavour intensity

(Stevens et al., 1977), high acid and low sugar give tart fruit while high sugars and low acid give bland, tasting fruit (Grierson and Kader, 1986).

Stevens (1986); Kader et al., (1978a) and Resurreccion and Shewfelt, (1986) have shown that variation in sugar and acids and the sugar/acid ratio are important to tomato flavour, but my research quantifies the contribution of long term MAP or CAS on tomatoes. Sugar and acid contents are not the only contributors to sweetness and sourness. Tomato flavour intensity is also affected by the organic volatile compounds produced by the fruit (Stevens et al., 1977). These were not measured in my experiment, but may have contributed to the flavour and acceptability scores from the taste panels.

The differences in tomato flavour shown between those packed in PP and PE50 films occurred because of their permeability to gas and water vapour. High CO_2 and low O_2 maintained better acidity levels than low CO_2 and high O_2. Kader (1980) and Kader (1987) reported that it is because high CO_2 delays the ripening of fruits acid and total sugar levels could be higher in less ripe fruits than in ripe or over ripe fruits. This is because acid and sugar contents of fruits decrease with the increasing ripening rate, especially after the pink stage of maturity (Grierson and Kader, 1986; Ho and Hewitt, 1986). Furthermore, a desirable humidity level was obtained in PP and PE50 packages. So the water vapour transmission rate in those films was more suitable to long term storage in MAP.

The effect of the combination of harvest maturity, packaging film and storage temperature on flavour was very important because of the inhibition of ripening.

Storage temperature differences could be explained by the affect of packaging films on respiration rates and permeability characteristics. Therefore the accumulation of some gases (high CO_2 and low O_2) in the packages affects the ripening rate by causing the inhibition of ethylene production in the storage environments (Kubo et al., 1989). The storage life and sensory quality of fruits at the end of the storage period could also be affected. Keeping less ripe fruit (i.e. mature green) in PP film at lower storage temperature (at 13°C) gave the best and most acceptable fruit quality.

At the end of this study the findings on the improvement in sensory quality after long term storage of tomatoes in MAP and CAS warrants future study as a basis of recommendations for improving consumer acceptance. Sensory results suggested that the use polyethylene film in 50 micron thickness or polypropylene 25 micron in thickness is good for packaging of tomatoes without any disease or disorders at least 40 days at 13°C. Tomatoes stored in 5.5 % O_2 combined with 3.2 to 9.1 % CO_2 had a lower ripening rate with higher tomato flavours and consumer acceptability.

Chapter 9. Conclusions and Further Recommendations

9.1. General Conclusion

The investigations described in this thesis were carried out in small scale storage room conditions and were conducted to evaluate possible storage treatments to extend the storage life as well as to retain high quality tomatoes harvested either at the mature green or pink stage of maturity. The changes in fruit colour and flesh firmness were inhibited in some storage temperatures and storage environments. Certain combinations of O_2 and CO_2 were also effective in reducing disease.

In general, from the results of the research showed that some of the packaging films showed potential in the control of fungal growth on the surface and fruits calyx. The application of MAP and CAS techniques was observed to reduce the rate of skin reddening and softening of tissues. Consequently the storage life of tomatoes was extended and the fruit's eating quality was maintained at acceptable levels. This was achieved by using suitable packaging films at 13°C and suitable storage atmospheres in CAS for the variety 'Liberto'. For the variety 'Criterum' storage at 13°C resulted in physiological disorders.

The conclusion of this work was that tomatoes can be stored for at least 60 days and still have acceptable colour, texture and flavour. There was some variability in disease development over this storage period with fruit in all treatments showing decay symptoms but, generally the ones kept in MAP or CAS at 9.1 % CO_2 with 5.5 % O_2 had less diseased fruit than with other treatments.

The major findings of this study are;

1) If the firmness values of tomatoes are above the 1.28 N mm^{-1}, although they are slightly soft, they are good enough to making a salad in the opinion of ten judges. If the firmness value is above 1.46 N mm^{-1} the tomatoes are firm and easily marketable.

2) Tomatoes harvested at the pink stage of maturation will change to a light red colour within 2-3 days at 20°C. From this work the optimum colour for marketing could be expressed as Minolta colour a*/b* within the range of 0.6 to 0.95.

3) On the contribution of the skin to firmness measurement of tomatoes: it can be concluded that damage to the skin of ripe tomatoes affected firmness significantly. This effect was less noticable with mature green tomatoes.

4) As expected, the relative humidity levels had a significant effect on the eating and marketing quality of tomato fruits. Storage of both pink and mature green tomatoes at a high (92-96 %) RH level was better than medium RH (76-80 %) and low RH (60-65 %) levels.

5) An increase in CO_2 concentration did not produce CO_2 injury even in 13-14 % for 'Liberto' variety of tomatoes (1993 results with MAP). But more than 10 % CO_2 was harmful for 'Criterium' variety (1994 results with CAS).

6) Tomatoes packaged in PE50 (6-7 % CO_2 and 4-5 % O_2) and PP (12-13 % CO_2 and 5-6 % O_2) were more firm than fruits within PE20 (3 % CO_2 and 11-13% O_2), PE30 (4-5 % CO_2 and 7-8 % O_2) and PVC (3-4 % CO_2 and 10-11 % O_2) at 13°C. Keeping quality of tomatoes improved when harvested at pink stage of maturity and packaged in PE50 or PP, and for mature green tomatoes packaged in PP, PE30 or PE50.

7) In terms of decay and growth of fungi, this was inhibited and the best results were achieved when mature green tomatoes were sealed within PVC and PE30 at 13°C. In these packages no decay was not observed after 50 days storage whereas 8 % of the fruit was decayed in PP and PE50. It was observed that PVC (especially 10 μ thick) is not suitable for long term MAP of tomatoes due to increasing water loss. After 60 days of storage only 8 % of the fruits were decayed in each packaging treatments at 13°C.

8) In CAS it was concluded that it would be possible to extend the storage life of tomatoes for at least 40 days with zero decay ratio and very good retention of firmness. For 60 days MAP (or 70 days CAS) the quality of a majority of tomatoes stored in 9.1 % CO_2 with 5.5 % O_2 was good with low decay (8 %) ratios. The fruits were the most acceptable to consumers on the basis of sensory evaluation.

9) For many years researchers have claimed that 12.8°C (or 12°C according to some) was safe for the storage of mature green tomatoes. However the results of this experiment using the 'Criterium' variety of tomatoes is that storage at 13°C (12.8°C-13.9°C) is not safe, and that some chilling injury symptoms are

observed during the storage period at 13°C. There is uneven colour development with unclear changes in titratable acidity and total soluble solids in the 'Criterium' variety during storage at 13°C. Furthermore the amount of decayed fruits is very high, especially after 50 days storage.

9.2. Conclusion

In CAS some treatments delayed softening and full colour development. CAS had much less effect on other biochemical processes so that, at the end of the 70 days storage, the fruits showed that greater biochemical similarities when they ripen to the fruits were stored short term (control) in air. When tomatoes are harvested at mature green stage of maturity and stored in CO_2 between 3.2 % and 9.1 % with 5.5 % O_2, it is possible to obtain shelf life of at least 40 days without any decayed fruits and 40-50 days with higher TSS at 13°C. Even after 70 days at 15°C fruits have acceptable acidity levels and very good tomato flavour, have a brighter red colour and their overall acceptability is very satisfactory.

9.3. Further Recommendation

This study recommends a number of new lines for research.

1) At the end of the 60 days storage period it was found that in the MAP and CAS experiments fruits in some of the treatments had very good sensory qualities concerning consumer acceptance within suitable packaging film or when using suitable concentrations of O_2 and CO_2. During sensory evaluation it could be better to determine the contribution of individual sugars and organic

acids to sensory qualities and consumer acceptability of the tomatoes after long term MAP or CAS.

2) The effects of high CO_2 and low O_2 levels on the development of tomato colour pigments during MAP or CAS could be undertaken.

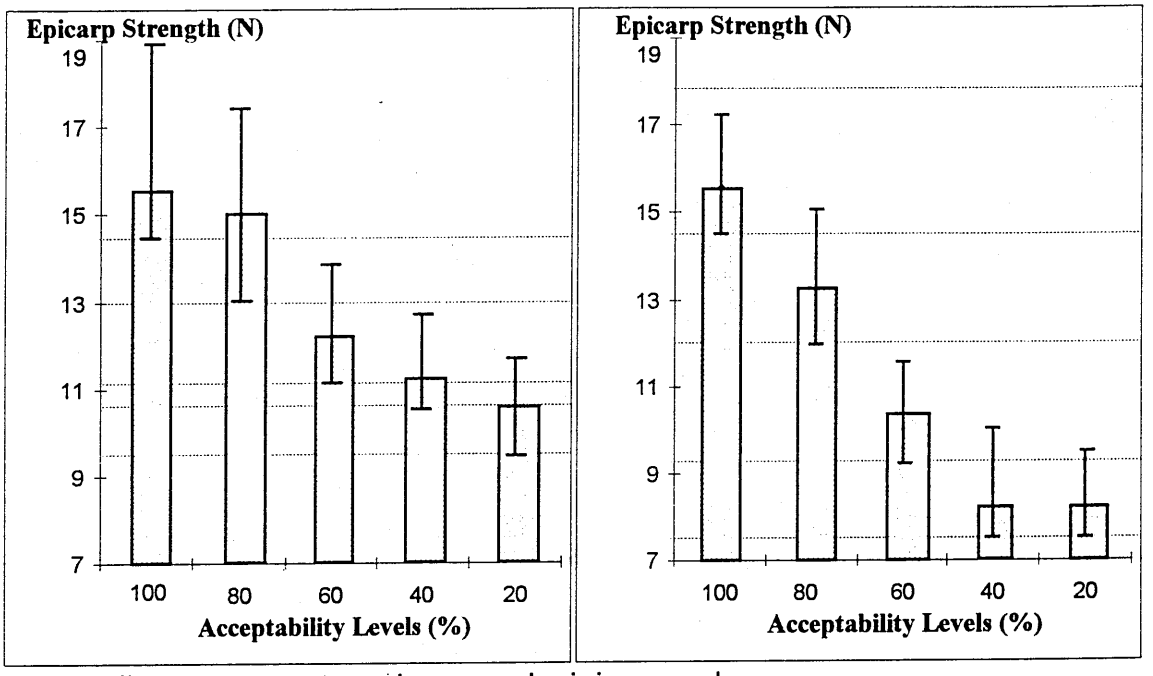
3) Work is needed to determine the effects of CO_2 and O_2 concentrations on inhibitation of ethylene production from in during CAS.

4) Work is needed to determine the effects of especially high CO_2 levels on the changes of organic acids in tomatoes during CAS.

5) In terms of CO_2 injury concern, 13 % CO_2 did not have a harmful affect on 'Liberto' variety of tomatoes but 'Criterium' variety had some CO_2 injurey at above 10 % levels. Therefore, development of decay increased above that CO_2 concentration combined with 5.5 % O_2. This level of CO_2 is not recommended especially for long term storage of 'Criterium' variety of tomatoes.

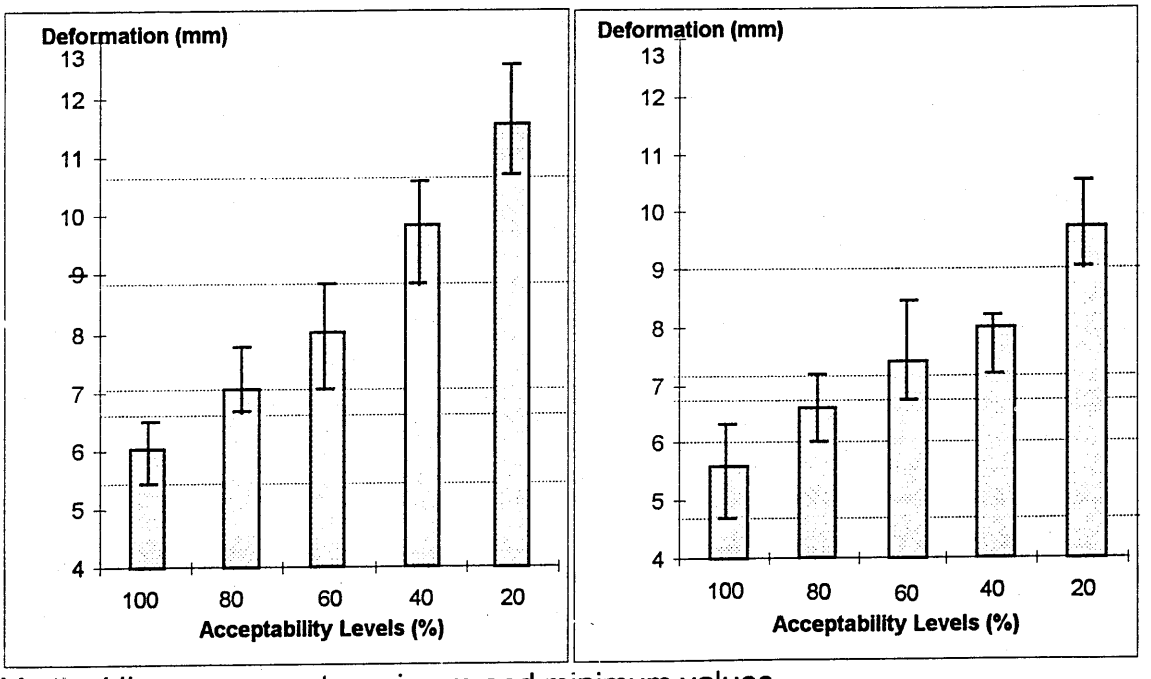
6) The response of various tomato varieties to chilling injury symptoms at 13°C and the development of colour in mature green tomatoes was not uniform. A more comprehensive examination of this aspect should be undertaken especially with the improved new varieties and available in UK.

Appendix 1. Relationship between epicarp strength values and acceptability levels of tomatoes



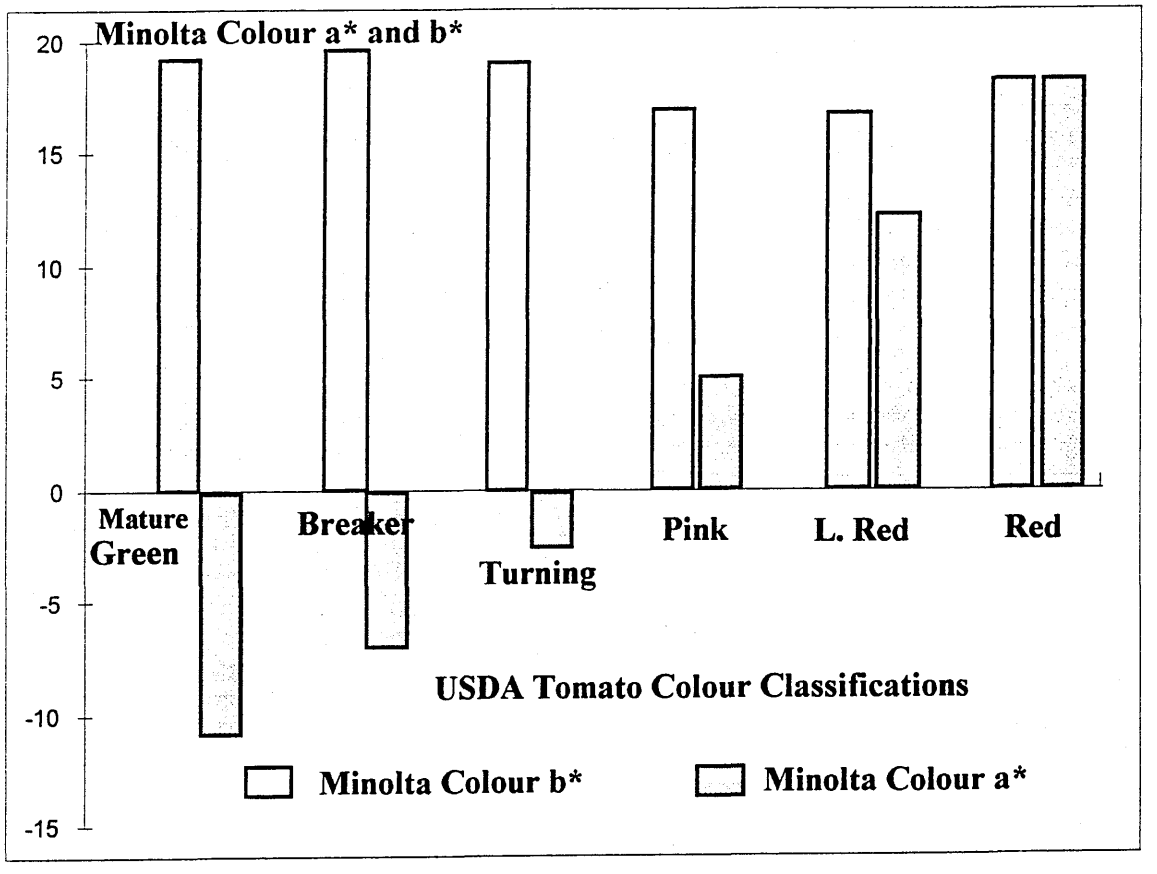
Vertical lines represent maximum and minimum values

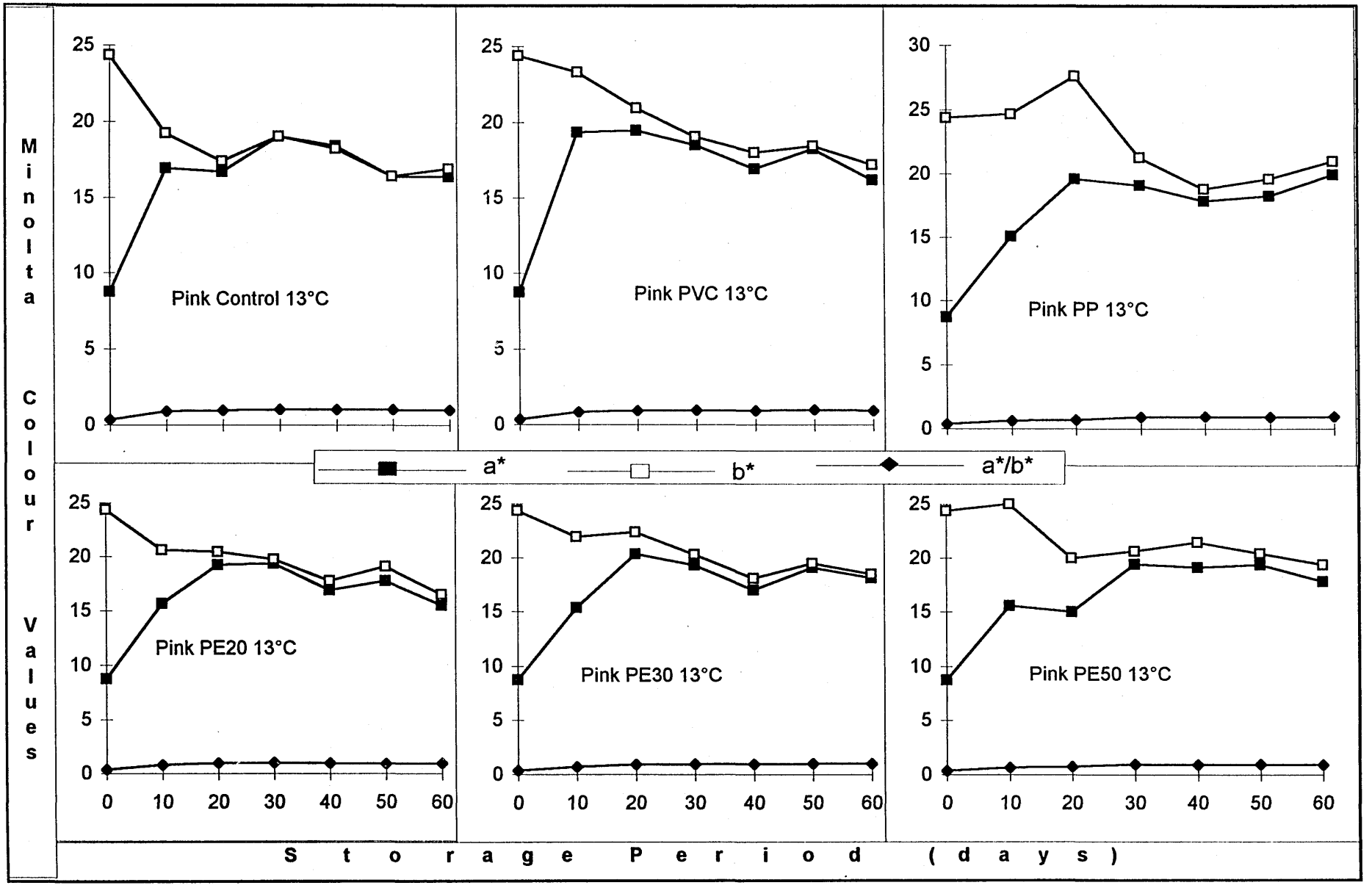
Appendix 2. Relationship between deformation values and acceptability levels of tomatoes



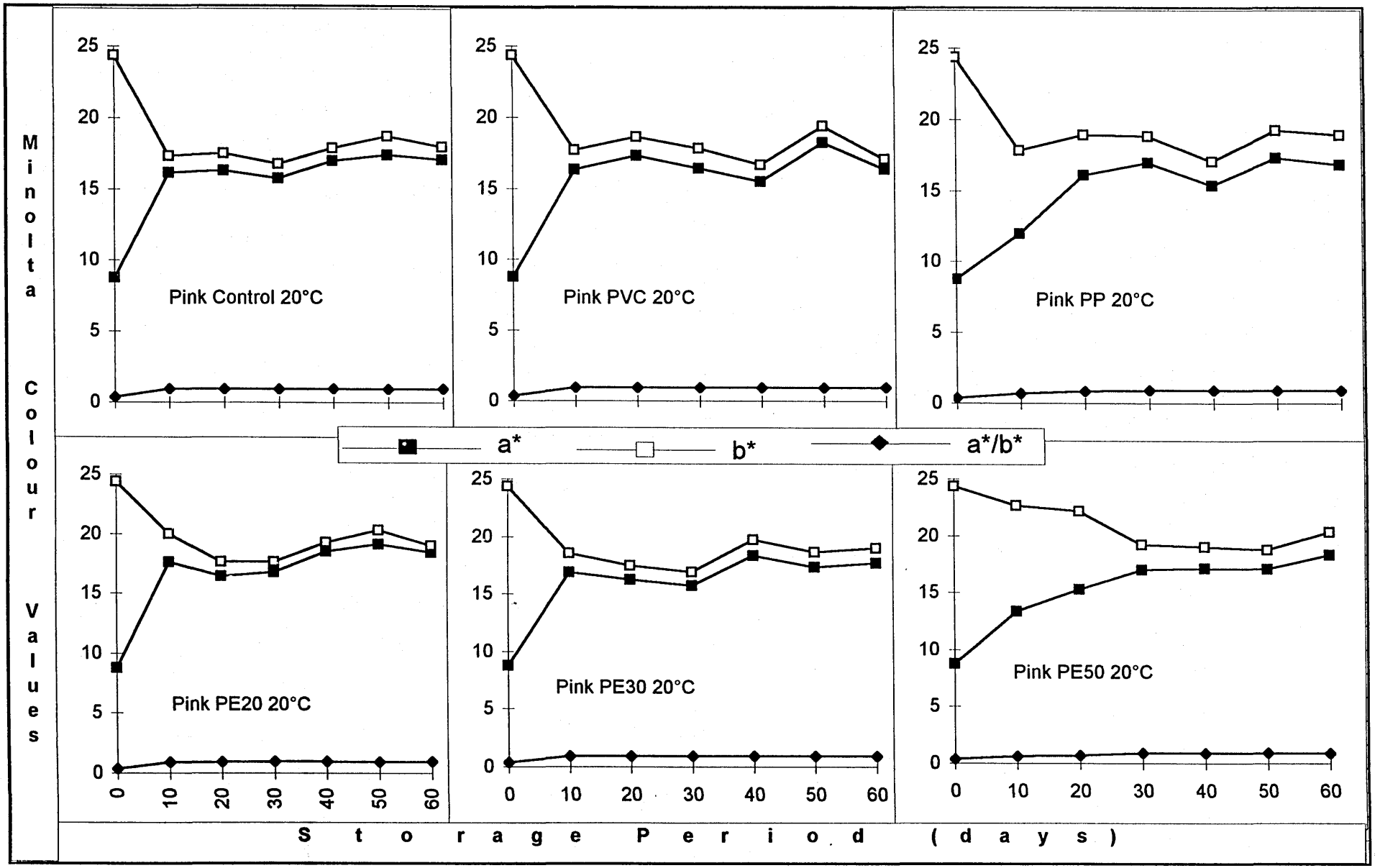
Vertical lines represent maximum and minimum values

Appendix 3. Minolta colour values of tomatoes during ripening according to USDA tomato colour classification

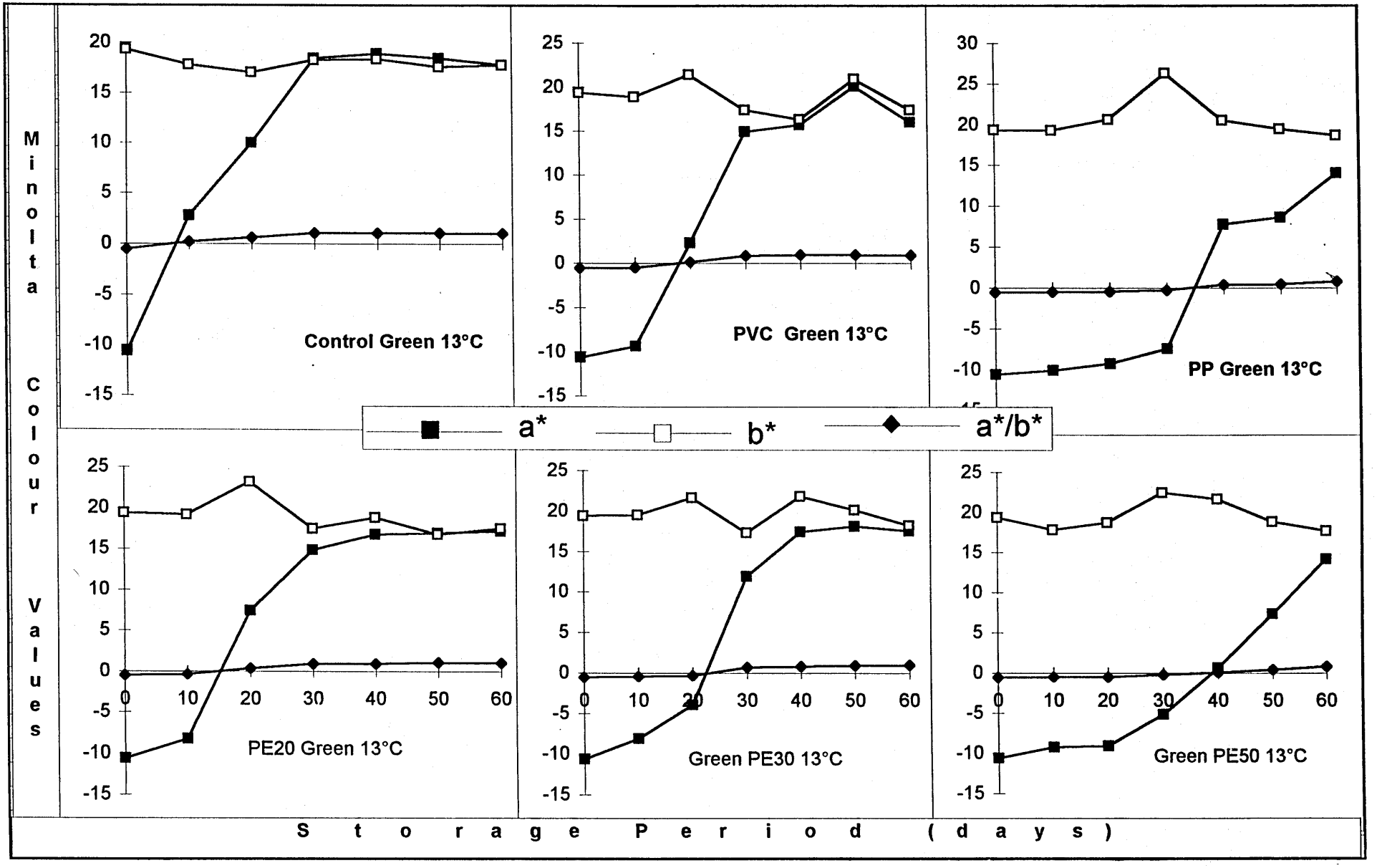




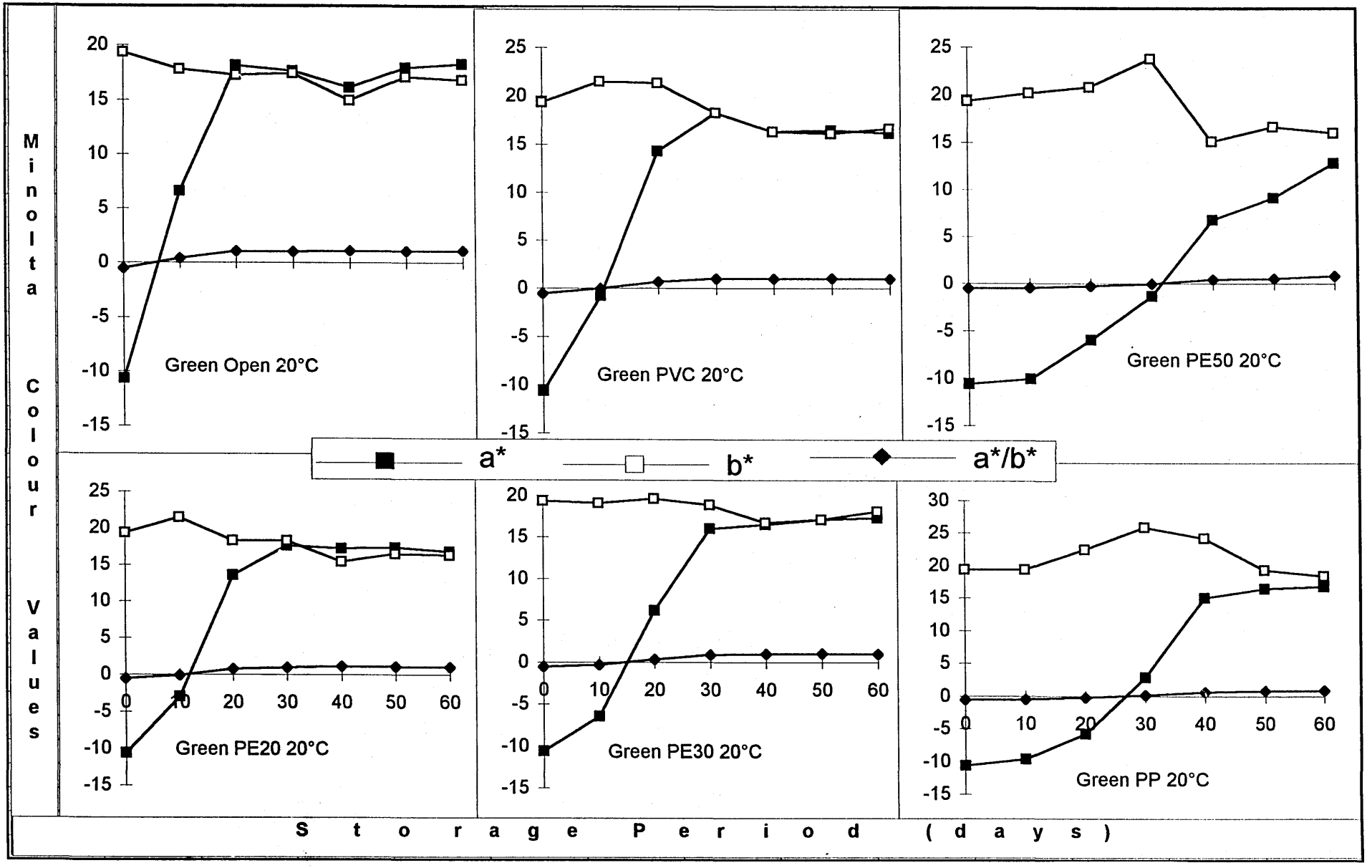
Appendix 4. The changes of minolta colour (a*, b*, a*/b*) values of tomatoes harvested at pink stage of maturity and sealed in various packaging filmsduring storage periods at 13°C



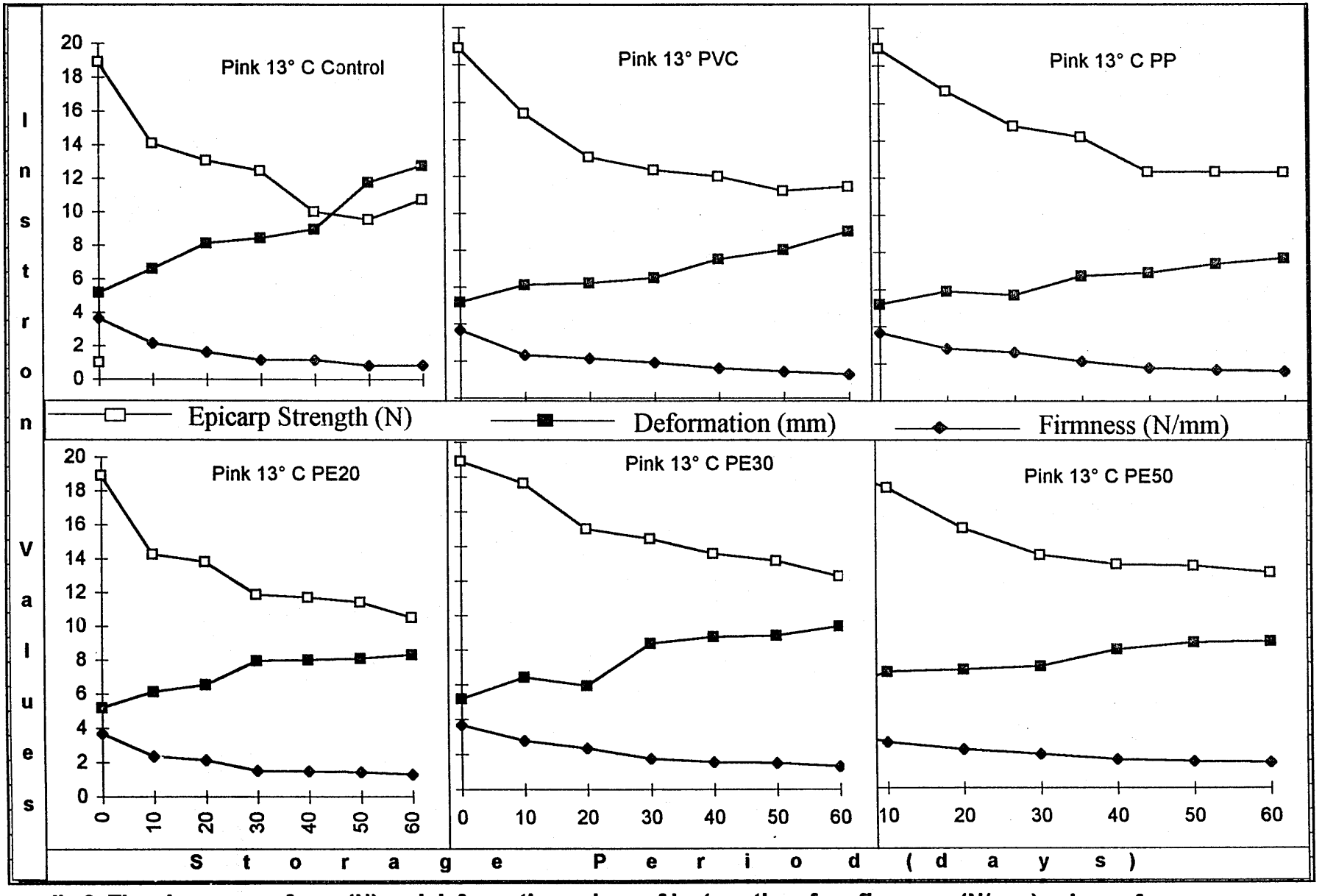
Appendix 5. The changes of minolta colour (a*, b*, a*/b*) values of tomatoes harvested at pink stage of maturity and sealed in various packaging filmsduring storage periods at 20°C



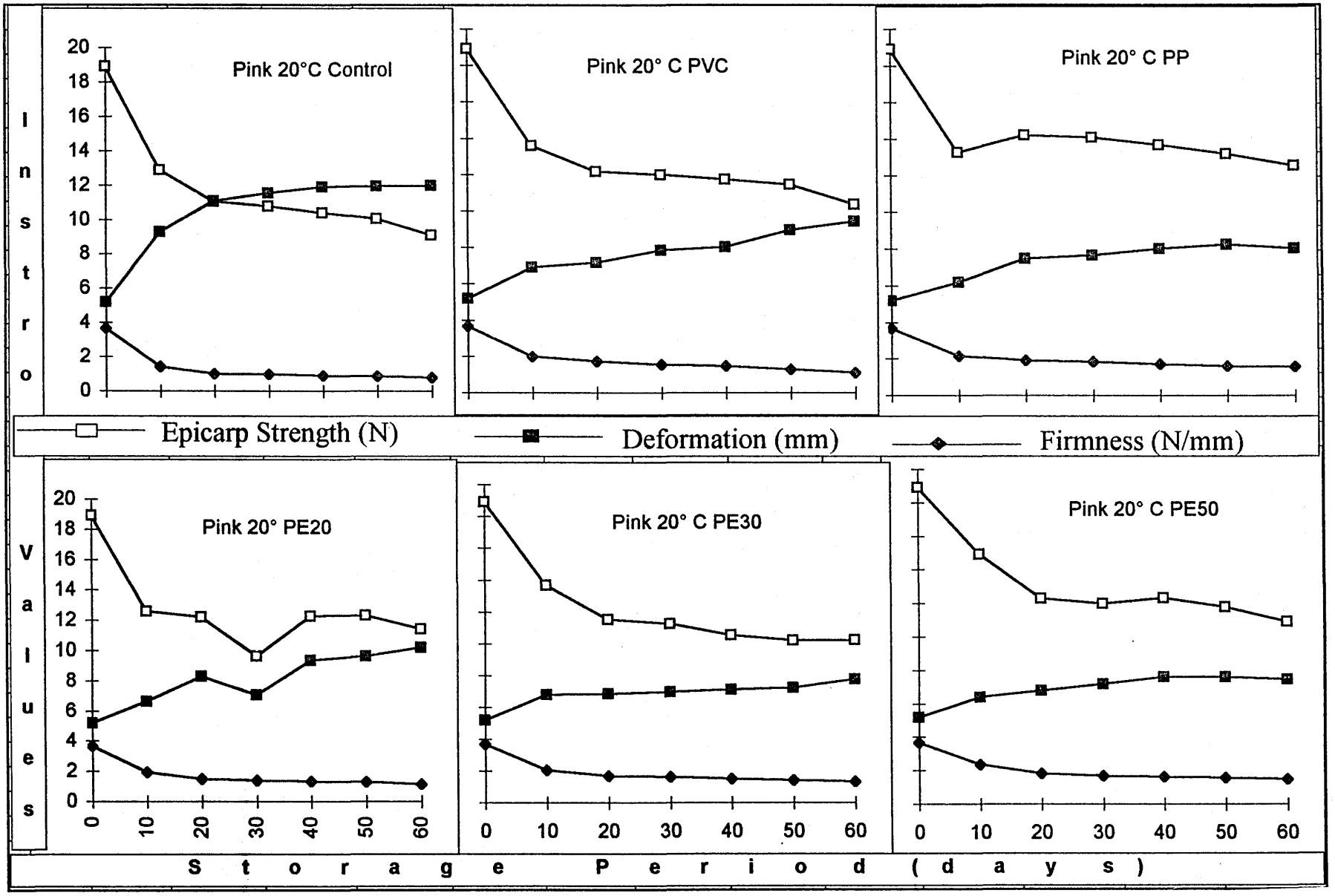
Appendix 6. The changes of minolta colour (a*, b*, a*/b*) values of tomatoes harvested at mature green stage of maturity and sealed in various packaging filmsduring storage periods at 13°C



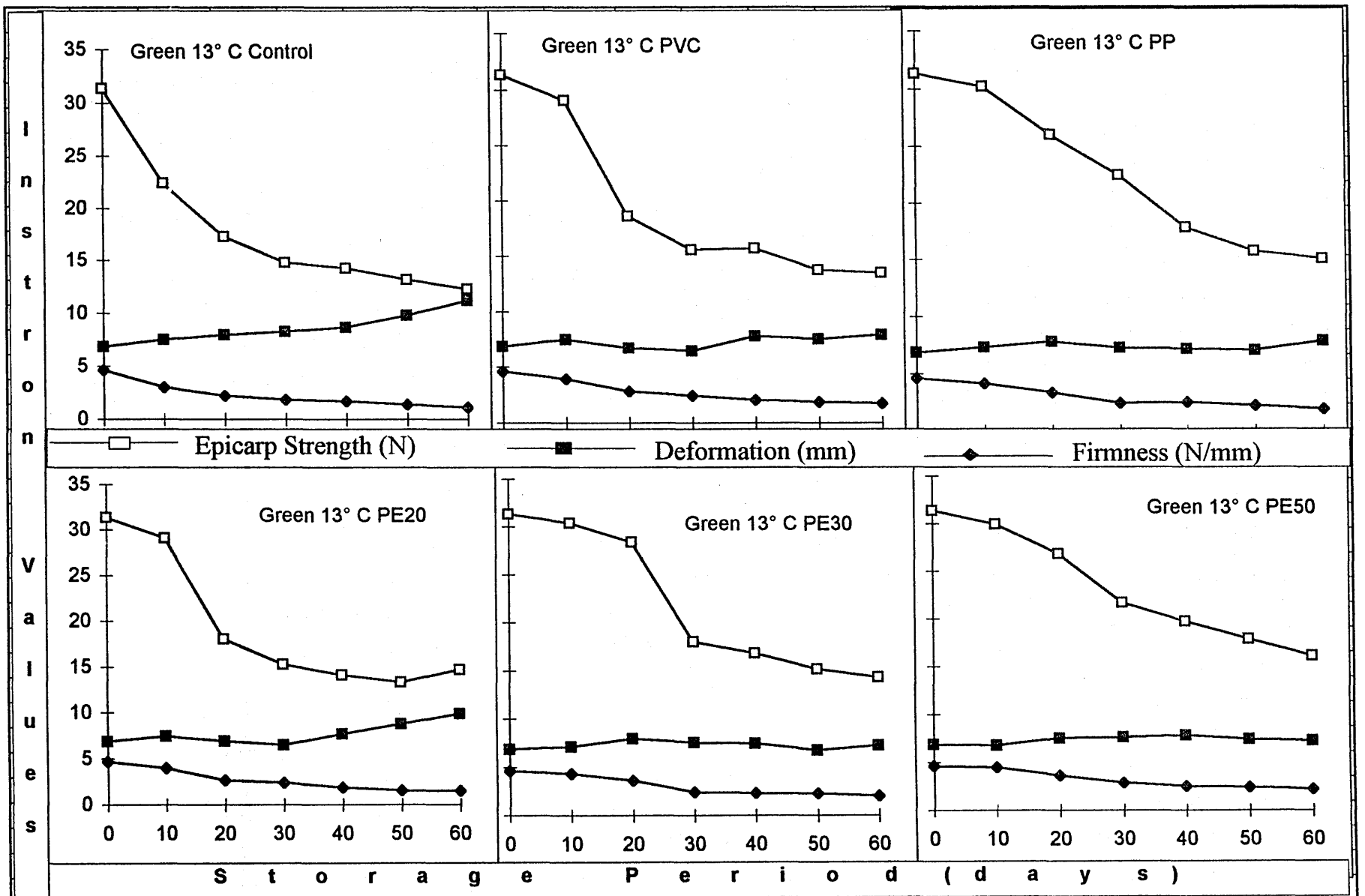
Appendix 7. The changes of minolta colour (a*, b*, a*/b*) values of tomatoes harvested at mature green stage of maturity and sealed in various packaging filmsduring storage periods at 20°C



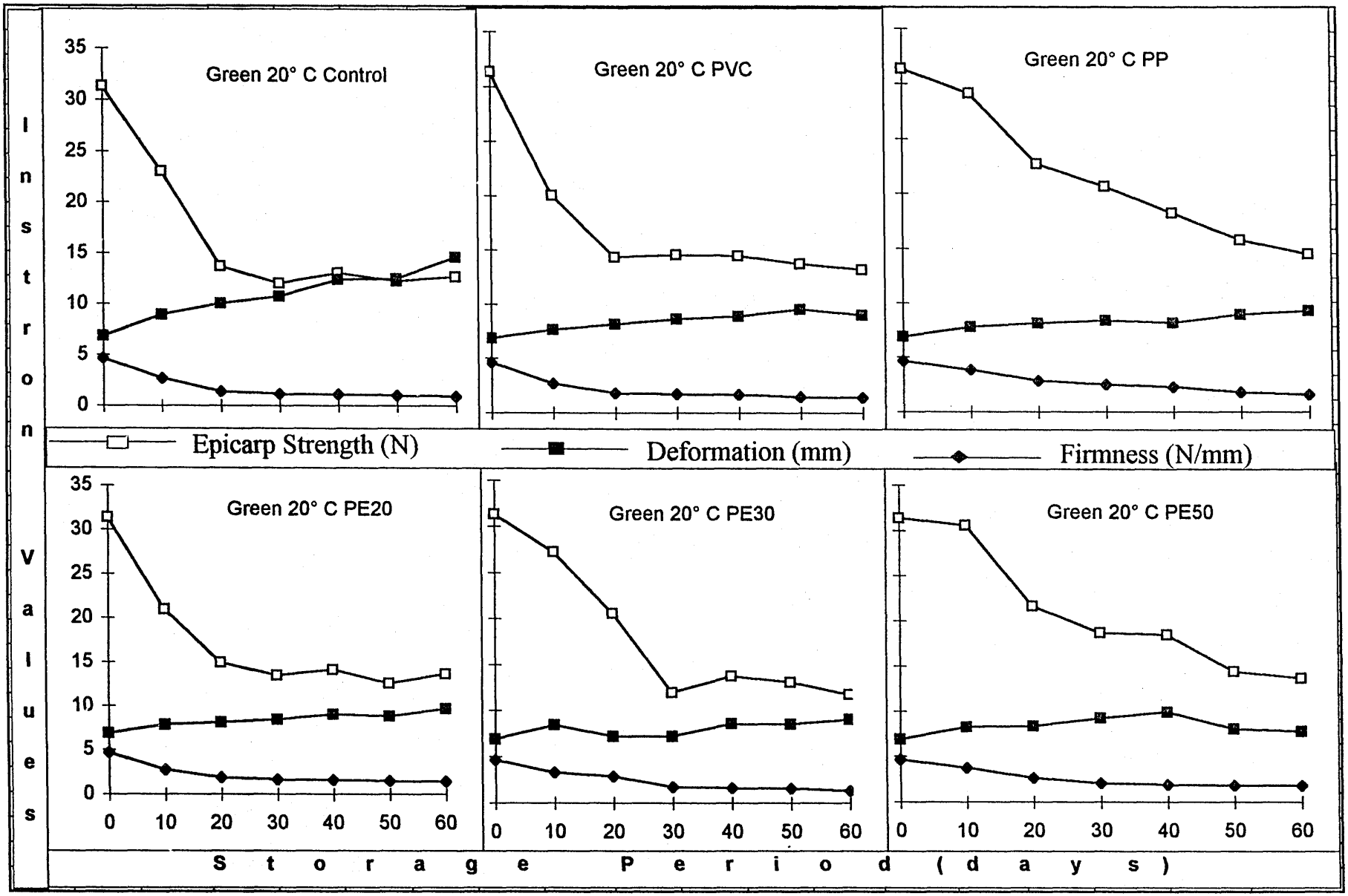
Appendix 8. The changes on force (N) and deformation values of Instron therefore firmness (N/mm) values of tomatoes harvested at pink stage of maturity and sealed in various packaging films during storage periods at 13°C



Appendix 9. The changes on force (N) and deformation values of Instron therefore firmness (N/mm) values of tomatoes harvested at pink stage of maturity and sealed in various packaging films during storage periods at 20°C



Appendix 10. The changes on force (N) and deformation values of Instron therefore firmness (N/mm) values of tomatoes harvested at the mature green stage of maturity and sealed in various packaging films during storage



Appendix 11. The changes on force (N) and deformation values of Instron therefore firmness (N/mm) values of tomatoes harvested at the mature green stage of maturity and sealed in various packaging films during storage

REFERENCES

Abou Aziz, A.B., M.M. Abdel Maksood, K.A. Abdel-Samie and A.S. Abdel-Kader. (1974). Effect of Picking Stage and Temperature on Quality and Ripening of Tomato Fruits. Gartenbauwissenschaft. 39, 74-75.

Adegoroye, A.S., P.A. Jolliffe and M.A. Tung. (1989). Texture Characteristics of Tomato Fruits (Lycopersion esculentium) Affected by Sunscald. Journal of Science Food Agriculture. 49, 95-102.

Anonymous. (1990). The Manual of Vegetable Storage. Farm Electric. The Electrical Council. EC5324. England.

Anonymous. (1991). International Standard (ISO:5524;1991(E)). Tomato Guide to Cold Storage and Refrigerated Transport. Second Edition.

Anonymous. (1992). Minolta, Precise Colour Communication. Colour Control From Feeling To Instrumentation. Hand Book . Printed by Minolta Camera Co. Ltd. Japan.

Bakker, J., P. Bridle and C. F. Timberlake. (1986). Tristimulus measurements (CIELAB76) of portwine colour. Vitis. 25, 67-78.

Barmore, C.R. (1987). Packaging Technology for Fresh and Minimally Processed Fruit and Vegetables. Journal of Food Quality. 10, 207-217.

Batu, A. and A.K. Thompson. (1993). Effects of Cross-head Speed and Probe Diameter on Instrumental Measurement of Tomato Firmness. Proceedings of the International Conference for Agricultural Machinery and Process Engineering October 19-22. pp:1340-1345. Seoul, Korea.

Baumann, H. (1989). Adsorption of Ethylene and Carbon Dioxide by Activated Carbon Scrubbers. Acta Horticulturae. 258, 125-129.

Bedrosian, K. and R.F. Schiffman. (1979). Controlled Atmosphere Tomato Package. British Patent No:1,558.324.

Ben-Yehoshua, S., A. Apelbaum and E. Cohen. (1981). Decay Control and Fungicide residues in citrus fruits seal-packaged in high density polyethylene film. Pestic Science. 12, 485-490.

Ben-Yeshoshua, S. (1985). Individual Seal-packaging of Fruit and Vegetables in Plastic Film. A new Postharvest Technique. HortScience. 20, 32-37.

Betancourt, L.A., M. A. Stevens and A.A. Kader. (1977). Accumulation and loss of sugars and reduced ascorbic acids in attached and detached tomato fruits. J. Am. Soc. Hort. Sci., 102, 721-723.

Biale, J.B. (1960). Respiration of Fruits. In Handbook Der Plantephysiologie. Encyclopedia of Plant Physiology (J. Wolf (ed)). pp: 536-592. Springer-Verleg. Berlin

Bishop, D. (1990). Controlled Atmosphere Storage. In Cold and Chilled Storage Technology. (C.V.J. Dellino (Ed)). pp: 66-98. Blackie and Son Ltd.

Brady, C., W.B. McGlasson and J. Speir. (1987). The Biochemistry of Fruit Ripening. In Tomato Biotechnology (D.J. Nevins and R.A. Jones (eds)). Plant Biology, Vol. 4, pp:279-288. Alan R. Liss inc., New York.

Brown, R.P. (1981). Permeability. In Handbook of Plastics Test Methods. Second edition. pp:378-394. George Godwin Limited. The Plastics and Rubber Inst.

Buescher, R.W. (1974). Quality Changes in Tomatoes as Affected by Low Temperature Storage of Unripe Fruit. Arkansas Farm Research. 23, 11.

Buescher, R.W. (1979a). Influence of CO_2 on Postharvest Ripening and deterioration of Tomato. J. Amer. Soc. Hort. Sci. 104, 545-547.

Buescher, R.W. (1979b). Influence of high temperature on physiological and compositional characteristics of tomato fruits. Lebensm. Wiss. Technol. 12,162-164.

Buescher, R.W. and E.C. Tigchelar. (1975). Pectinesterase, polygalacturonase, Cx-cellulose Activities and Softening of the Rin Tomato Mutant. Hort. Sci. 10, 624-625.

Burg, S.P. and E.A. Burg. (1967). Molecular Requirements for the Biological Activity of Ethylene. Plant Physiol. 42, 144-152.

Burg, S.P. and E.A. Burg. (1969). Interaction of Ethylene, Oxygen and Carbondioxide in the Control of Fruit Ripening. Qual. Plant Mater. Veg., 19, 185.

Burton, W.G. (1982a). Ripening and senescence of fruits. In Postharvest physiology of food crops. (W.G. Burton (ed)). p:181-198. Longman Group Ltd.

Burton, W.G. (1982b). Physiological Responses to Stress and Disease. In Postharvest Physiology of Food Crops. Chapter 9. pp: 199-217. Logman Group Ltd.

Cheng, T. S., J.D. Floros, R.L. Shewfelt and C.J. Chang. (1988). The Effect of High Temperature Stress on Ripening of Tomatoes. Plant Physiology. 132, 459-464.

Crawford, R.J. (1985). Polyethylenes. In General Description of Plastic and Rubbers. In Plastic and Rubber Engineering Design and Applications. pp:54-59. Netherwood Dalton and Co. Ltd. Netherlands.

Davies, J.N. and R.J. Kempton. (1975). Changes in the Individual Sugar of Tomato Fruit During Ripening. J. Sci. Food Agric. 26,1103-1110..

Day, B.P.F. (1988). Optimisation of Parameters For MAP of Fresh Fruit and Vegetables. CAP' 88. pp:147-170. Scotland Business Research Inc.

Day, B.P.F. (1993). Fruit and Vegetables. In Principles and Application of Modified Atmosphere Packaging of Food. (R.T. Parry (ed)). pp:114-133. Blackie Academic and Professional. UK.

De Bruyn, J.W., F. Garresten and L.E. Olson. (1971). Variation in Taste and Chemical Composition of the Tomato. Euphytica. 20, 214-227.

Dennis, C., K.M. Browne and E. Adamicki. (1979). Controlled Atmosphere Storage of Tomatoes. Acta Horticulturae. 93, 75-83. Quality of Vegetables.

Dennis, C. (1987). Salad Crops. In Postharvest Pathology of Fruits and Vegetables. p:157-164. Academic Press Inc.

Dover, C.S. (1989). The Principles of Effective Low Ethylene Storage. Acta Horticulturae. 258, 25-36.

Efiuvwevwere, B.J.O. and S.N. Thorne. (1988). Development of Chilling Injury Symptoms in Storage Tomato Fruit. J. Sci. Food Agric. 44, 215- 226.

El-Grooni, M.A. and N.F. Sommer. (1981). Effect of Modelling Atmospheres on Postharvest of Fruit and Vegetables. Hortic. Rev., 3, 412-461.

Esquerra, E.B. and D.K. Bautista. (1990). Modified Atmosphere Storage and Transport of 'Improved Pope' Tomatoes. ASEAN Food Journal. 5, 27-33.

Floros, J.D., M.S. Chinnan and H.Y. Wetztein. (1987). Extending The Shelf Life of Tomatoes by Individually Seal Packaging. For Presentation at the International Winter Meeting Of American Society of Agricultural Engineers. Hyatt Regency, Chicaco, IL. USA

Frith, J. (1991). The Transport of Preshable Foodstuffs. SRCRA Shipowners Refrigerated Cargo Research Association. Cambridge. UK.

Geeson, J.D., K. Maddison and K.M. Browne. (1981). Modified Atmosphere Packaging of Tomatoes. Associated of Applied Biologist. Packaging of Horticultures Produce. AAB/NCAE Residential Meeting. pp:8-15.

Geeson, J.D. and K.M. Browne. (1983). New Packaging Technology Aims to Extend Shelf Life. Grower. 14, 35-38.

Geeson, J.D. (1984). The Use of Controlled and Modified Atmospheres For the Storage and Distribution of Fruits and Vegetables. Proc. of the Inst. of Food Science and Technology. 17, 101-106.

Geeson, J.D., K.M. Browne, K. Maddison, J. Shepherd and F. Guaraldi. (1985). Modified Atmosphere Packaging to Extend the Shelf Life of Tomatoes. Journal of Food Technology. 20, 339-349.

Geeson, J.D., K.M. Browne and F. Guaraldi. (1986). The Effects of Ethylene Concentration in Controlled Atmosphere Storage of Tomatoes. Ann. Appl. Biol. 108, 605-610.

Geeson, J.D. (1989). Modified Atmosphere Packaging of Fruit and Vegetables. Acta Horticulture. 258, 143-150.

Goodenough, P.W. and T.H. Thomas. (1980). Comparative Physiology of Field-Grown Tomatoes During Ripening on the Plant or Retarded Ripening in Controlled Atmosphere. Ann. App. Biol. 94, 445-455.

Goodenough, P.W. and T.H. Thomas. (1981). Biochemical changes in Tomatoes Stored in Modified Gas Atmospheres. I. Sugars and Acids. Ann. App. Biol. 98, 507-515.

Goodenough, P.W. (1982). Tomato in Controlled Atmosphere Storage. Grower. 2, 17-18.

Goodenough, P.W. (1991). Tomato, Cucumber and Gherkin. In Food Flavours. Part C. The Flavour off Fruits. pp, 327-350. (I.D. Morton and A.J. Acleod (eds)). Elsevier Science Publishing B.V.

Goodwin, T.W. and L.J. Goad. (1974). Carotenoids and Triterpenoids. In The Biochemistry of Fruits and Their Products. (A.C. Hulme (ed)). 1, 305-368. Academic Press London and New York

Gormley, L. and S. Egan (1978). Firmness and Colour of Fruit at Some Tomato Cultivars From Various Sources During Storage. Journal of Science of Food and Agriculture. 29, 534-538

Gorris, L.G.M. and H.W. Peppelenbos. (1992). Modified Atmosphere and Vacuum Packaging to Extend the Self Life of Respiring Food Products. HortTechnology. 2, 303-309.

Gould, W.A. (1983a). Composition of Tomatoes. In Tomato Production and Quality. pp:344-361. Second edition. Avi publishing Company, Inc.

Gould, W.A. (1983b). Colour and Colour Measurement. In Tomato Production, Processing and Quality. (W. A. Gould (Ed)). pp:229-244. Avi publishing company.

Greengrass, J. (1993). Films For Modified Atmosphere of Foods. In Principles and Application of Modified Atmosphere Packaging of Food. (R.T. Parry (ed)). pp:114-133. Blackie Academic and Professional. UK.

Grierson, D. and G.A. Tucker. (1983). Timing of Ethylene and Polygalacturonase Synthesis in Relation to the Control of Tomato Fruit Ripening. Planta. 157, 174-179.

Grierson, A. and A.A. Kader. (1986). Fruit Ripening and Quality. In Tomato Crop. (J.G. Atherton and J. Rudich(eds)). pp,241-280. Chapman and Hall Ltd. USA.

Grierson, D., M.J. Maunders, M.J. Holdworth, J. Ray, C. Bird, P. Moureau, W. Schuch, A. Slater, J.E. Knapp and G.A. Tucker. (1987). Expression and Function of Ripening Genes. In Tomato Biotechnology. (D.J. Nevins and R.A. Jones (eds)). pp:309-323. Alan R. Liss, Inc.

Gross, K. C. and C. E. Sams. (1984). Changes in Cell Wall Neutral Sugar Composition During Fruit Ripening: a Cpecies Survey. Phytochemistry. 23, 3457-3461.

Hall, C.B. (1966). Quality Changes in Fruits of Some Tomato Varieties and Lines ripened at 68°F for various periods. Proc. Fla. State Hort. Soc. 79, 222-227.

Hardenburg, R.E., A.E. Watada and C.I. Wang. (1986). The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. US. Dept. of Agr. Handbook. 66.

Hatton, T.T. and R.H. Cubbedge. (1982). Reducing Chilling Injury in Grapefruit by pre-Storage Conditioning. USDA-ARS-Advances in Agr. Technology, Southem Service. No:25

Herner, R.C. (1987). High CO_2 effects on Plant organs. In Postharvest physiology of Vegetables. (J. Weichman (ed)). pp:239-253. Mackel Dekker. New York.

Ho, L.C. and J.D. Hewitt. (1986). Fruit Development. In The Tomato Crops (J.G. Atherson and J. Ruddic (eds)). pp:201-239. Chapman and Hall. London and New York

Hobson, G.E. (1965). The firmness of Tomato Fruit in Relation to Polygalacturonase Activity. Journal of Horticultural Science. 40, 66-72.

Hobson, G.E. and J.N. Davies. (1971). The Tomato. In The Biochemistry of Fruits and Their Products. (A.C. Hulme (ed)). 2, 437-482. Academic Press London and New York.

Hobson, G.E. (1981). The Short Term Storage of Tomato Fruits. Journal of Horticultural Science. 56, 363-368.

Hobson, G.E., P. Adams and T.J. Dixon. (1983). Assessing the Colour of Tomato Fruit During Ripening. J. Sci. Food Agric. 34, 286-292.

Hobson, G.E. (1987). Low-Temperature Injury and The Storage of Ripening Tomatoes. Journal of Horticultural Science. 62, 55-62.

Hobson, G. E. (1989). Manipulating the Ripening of Tomato Fruit-Low and High Technology. Acta Horticulturae. 258, 593-600.

Hobson, G.E. (1993). Factors in Texture Changes During Fruit Ripening. Australasian Postharvest Conference. pp:405-409.

Hobson, G. E. and D. Grierson. (1993). Tomato. In Biochemistry of Fruit Ripening. (G. Seymour, J. Taylor and G. Tucker (eds)). pp:405-442. Chapman and Hall, London.

Hobson, G.E. and A.J. Murrey. (1994). From Producer to Pantry-Using Biotechnology to Preserve Crop Quality. Aspect of Applied Biology. 39, 95-102.

Isenberg, F.M.R. (1979). Controlled Atmosphere Storage of Vegetables. Horticultural Rev. 1, 337-394.

Kader, A.A. (1966). Effect of Growth Regulating Substances on Ripening and Shelf life of Tomatoes. Hortic. Sci., 1, 90-93.

Kader, A.A., M.A. Stevens, M.A. Albright, L.L. Morris and M. Algazi. (1977). Effect of Fruit Ripeness When Picked on Flavour and Composition of Fresh Market Tomatoes. J. Amer. Soc. Hort. Sci., 102, 734-727.

Kader, A.A., L.L. Morris, M.M. Stevens and M.A. Holton. (1978a). Composition and Flavour Quality of Fresh market Tomatoes as Influenced by Some Postharvest Handling Procedures. J. Amer. Soc. Sci. 103, 6-13.

Kader, A.A., L.L. Morris and P. Chen. (1978b). Evaluation of Two Objective Methods and Subjective Rating Scale For Measuring Tomato Firmness. J. Amer. Soc. Hort. Sci. 103, 70-73.

Kader, A.A. (1980). Preventation of Ripening in Fruits by Using of Controlled Atmosphere Storage. Food Technology. May, 51-54.

Kader, A.A. (1985a). Ethylene-Induced Senescence and Physiological Disorders in Harvested Horticultural Crops. HortScience. 20, 54-57.

Kader, A.A. (1985b). Modified Atmosphere and low-pressure Systems During Transport and Storage. In Post Harvest Technology of Horticultural Crops. (Kader et al (Eds)). Univ. of California. Division of Agriculture and Natural Research.

Kader, A.A. (1986). Biochemical and Physiological Basis for Effects of Controlled and Modified Atmospheres on Fruits and Vegetables. Food Technology. 40, 99-100,102-104.

Kader, A.A. (1987). Respiration and Gas Exchange of Vegetables. In Postharvest Physiology of Vegetables. (J. Weichmann (Ed.)). pp:25-43. Marcel Dekkar, Inc. New York.

Kader, A.A., D. Zagory and E.L. Kerbel. (1989). Modified Atmosphere Packaging of Fruit and Vegetables. CRC Critical Reviews in Food Science and Nutrition. 28, 1-30.

Kader, A.A. (1992). Modified Atmospheres During Transport and Storage. In Postharvest Technology of Horticultural Crops. (A.A Kader (Ed)). pp:85-92. Agriculture and Natural Resources Publications. University of California. USA.

Kawada, K. and P.W. Hale. (1980). Effects of Individual Film Wrapping and Relative Humidity on Quality of Florida Grapefruit and Condition of Fibreboard Boxes in Simulated Export Tests. Pro. Fla. State. Hort. Soc., 93, 319-323.

Kopeliovitch, E., Y. Mizrahi, H.D. Rabinowitch and N. Kedar. (1982). Effect of the Fruit Ripening Mutant Genes Rin or Nor on the Flavour of Tomato Fruit. J. Amer. Soc. Hort. Sci. 107, 361-364.

Kubo, Y., A. Inaba and R. Nakamura. (1989). Effects of High CO_2 on Respiration in Various Horticultural Crops. J. Japan. Soc. Hort. Sci. 58, 731-736.

Larmond, E. (1987). Sensory Evaluation Can Be Objective. In Objective Methods in Food Quality Assessment (J.G. Kapsalis(ed)). pp:3-14. CRC Press Inc. Boca Raton, Florida.

Larsen, M. and C.B. Watkins. (1995). Firmness and Concentrations of Acetaldehyde, Ethylacetate and Ethanol in Strawberries Stored in Controlled and Modified Atmospheres. Postharvest Biology and Technology. 5,39-50.

Levy, S. and J.H. Dubois. (1977). Polymer Structure and Physical Properties. In Plastic Product Design Engineering Handbook. pp:1-30. Champton and Hall Ltd. London.

Lindsay, R.T. and M.A. Neale .(198). Cold Stores for Fresh Vegetable. In Quality in Stored Precessed Vegetable and Fruits. (Eds) P. W. Goodenough and R.K. Atkin. pp:315-327. Academic Press

Lurie, S. and J.D. Klein. (1992). Ripening Characteristics of Tomatoes Stored at 12°C and 20°C following a Prestorage Heat Treatment Scientia Horticulculturae. 51, 1-2, 55-64.

Lyons, J.M., J.K. Raison and P.L. Steponkus. (1979). The Plant Membrane on Response to Low Temperature. An Overview. In Low Temperature Stress In Crop Plants. The Role of The Membrane. (J.M. Lyons, D. Graham and J.K. Raison (eds)). pp:1-2. Academic Press. New York.

Lyons, J.M. and H.K. Pratt. (1964). Effect of Stage of Maturity and Ethylene Treatment on Respiration and Ripening of Tomato Fruits. Amer. Soc. for Hort. Sci., 84, 491-500

Malis-Arad, S., S. Didi and Y. Mizrahi. (1983). Pectic Substances: Changes in soft and Firm Tomato Cultivars and in non-Ripening Mutants. Journal of Horticultural Science, 58, 111-116.

McGlasson, W.B. and R.B.H. Wills. (1972). Effects of Oxygen and Carbon dioxide on Respiration, Storage Life, and Organic Acids of Green Bananas. Austral. J. Biol. Sci. 25, 35-42.

McGlasson, W.B. (1985). Ethylene and Fruit Ripening. HortScience. 20, 51-54.

McKeown, A.W. and E.C. Lougheed. (1980). Low pressure storage of some vegetables. Acta Horticulturae. 116, 83-99.

Morris, L.L. and A.A. Kader. (1974). Postharvest physiology of Tomato Fruits. In Fresh Market Tomato Research . Vegetable Corps Series; 171, 36-48. California, Davis.

Morris, L.L. (1982). Chilling Injury of Horticultural Crops. An Overview. Hort. Science. 17, 161.

Mutschler, M.A. and Guttieri, M. (1987). The Effect of The alc Mutant On Tomato Ripening. In Tomato Biotechnology. (D.J. Newins and R.A. Jones (eds)). pp: 289-297. Alan R. Liss, Inc.

Ottosson, L. and L. Wiberg. (1977). Postharvest Changes in Green Tomatoes Lycopersicon Esculentum L. ActaHorticulturae. 62, 267-274

Paine, F.A. and H.Y. Paine. (1992a). Notes on Packaging Materials. Handbook of Food Packaging. pp:53-96. Second edition. Blackie Academic and Professional. UK.

Paine , F.A. and H.Y. Paine. (1992b). Fresh Fruit and Vegetables. In Handbook of Food Packaging. pp:231-247. Second Edition. Blackie Academic and Professional. UK.

Parry, R.T. (1993). Introduction. In Principles and application of modified atmosphere packaging of food. (R.T. Parry (ed)). pp:1-18. Blackie. Academic and Professional. UK.

Parsons, C.S., R.E. Anderson and R.W. Penny. (1970). Storage of Mature Green Tomatoes in Controlled Atmospheres. J. Amer. Soc. Hort. Sci., 95, 791-796.

Pascat, B. (1986). Study of some Factors Affecting Permeability. In Food Packaging and Preservation. The Theory and Practice. (M. Mathlouthi (ed)). pp:7-24. Elsevier Applied Science Publishers.

Peleg, K. (1985). Storage and Preservation Techniques. In Produce Handling, Packaging and Distribution. p:29-51. Avi Publishing Company Inc. Westport, Connecticut.

Picha, D.H. (1986). Effect of Harvest Maturity on the Final Fruit Composition of Cherry and Large-fruited Cultivars. Jour. of the Amer. Socit. of Hortic. Sci. 111, 723-727.

Ramana, S.V., B.L. Mohan-Kumar and K.S. Jayaraman. (1987). Extension of Stored Life of Tomatoes Under Ambient Conditions by Continuous Flushing of Storage Atmosphere. Indian Food Packer. 41, 24-29.

Rangana, S. (1979). Manual of Analysis of Fruits and Vegetables Products. MC-Graw Hill Publ. Company.

Reid, M.S. (1985). Ethylene and Abscission. HortScience. 20, 45-50.

Resurreccion, A.V.A. and R.L. Shewfelt. (1985). Relationship Between Sensory Attributes and Objective Measurements of Postharvest Quality of Tomatoes. Journal of Food Science. 50, 1240-1245,1256.

Rhodes, M.J.C. (1980). Chilling Injury-Some Underlying Biochemical Mechanism. In Opportunities For Increasing Crop Yields. (R.G. Hurd, P.V. Biscoe and C. Dennis (eds)). pp: 377-393. Pitman Publishing Ltd. London.

Richardson, C. and G.E. Hobson. (1987). Compositional Changes in Normal and Mutant Tomato Fruits During Ripening and Storage. J. Sci. Food Agric., 40, 245-252.

Riquelme, F., M.T. Pretel, G. Martinez, M. Serrano, A. Amoros and F. Romajoro. (1994). Packaging of Fruits and Vegetables: Recent Results. In Food Packaging and Preservation. (M. Mathlouthi (ed)). p:141-158. Blackie Academic and Professional. London...

Risse, L.A. and W.R. Miller. (1984). Effects of Film Wrapping on Mature Green Tomatoes Before and After Ethylene Treatment. Proc. Fla. State Hort. Soc. 97, 112-114.

Risse, L.A., W.R. Miller and S. Ben-Yehoshua. (1985). Weight Loss, Firmness, Colour and Decay Development of Individual Film Wrapped Tomatoes. Tropical Science. 25, 117-121.

Risse, L.A. (1987). Status of Film Wrapping Fresh Produce. For Presentation at the 1987 Summer Meeting. American Society of Agricultural Engineers.

Risse, L.A. (1989). Individual Film Wrapping of Florida Fresh Fruit and Vegetables. Acta Horticulturae. 258, 263-270. Postharvest 88.

Roberts, R. (1990). An overview of Packaging Materials for MAP. International Conference on the Modified Atmosphere Packaging. 15th-17th October. Campden. Food and Drink Research Association. England.

Rouffignac, P.D.D. (1990). Packaging in the Marketing Mix. Butterworth-Heinemann Ltd. Oxford. UK.

Saguy, I. and C.H. Mannheim. (1975). The Effect of Selected Plastic Films and Chemical dips on the Shelf life of Marmande Tomatoes. Journal of Food Technology. 10, 547-556.

Sakiyama, R. and M.A. Stevens. (1976). Organic acid accumulation in atteched and detached tomato fruits. J. Am. Soc. Hort. Sci. 101,394-396.

Salunkhe, D.K. and M.T. Wu. (1973). Effects of Low Oxygen Atmosphere Storage on Ripening and Associated Biochemical Changes of Tomato Fruits. J. Amer. Soc. Hort. Sci. 98, 12-14.

Salunkhe, D.K. and M.T. Wu. (974) Development in Technology of Storage and Handling of Fresh Fruits and Vegetables. In Storage, Processing and Nutritional Quality of Fruits Vegetables. (K. Salunkhe (ed)). p:121-161. CRC Press.

Salunkhe, D.K., H.R. Bolin and N.R. Reddy. (1991). V. Packaging, Storage, Processing and Nutrition Quality of Fruit and Vegetables. In Processed Fruit and Vegetables. Second Edition. Vol. II. pp:18-21. CRC press.

Sherman, M. (1985). Control of Ethylene in the Postharvest Environment. HortScience. 20, 57-60.

Shewfelt, R.L. (1986). Postharvest Treatment for Extending the Shelf Life of Fruit and Vegetables. Food Technology. May, 70-80,89

Shirazi, A. and A.C. Cameron. (1992). Controlling Relative Humidity in Modified Atmosphere Packaging of Tomato Fruit. HortScience. 27, 336-339.

Smith, S.M., J.D. Geeson, K.M. Browne, P.M. Genge and H.P. Everson. (1987). Modified Atmosphere Retail Packaging of Discovery Apples. J. Sci. Food Agric. 40, 179-187.

Snowdon, A.L. (1990). A Colour Atlas of Postharvest Diseases and Disorders of Fruit and Vegetables. Volume 1: General Introduction and Fruits. pp:11-53. Wolfe Scientific Ltd.

Snowdon, A.L. (1991). A Colour Atlas of Postharvest Diseases and Disorders of Fruit and Vegetables. Volume 2. Solanaceous Fruit Vegetables. General. pp:53-93. Wolfe Scientific Ltd.

Sommer, N.F., R.J. Fortlage and D.C. Edvards. (1992). Postharvest Diseases of Selected Commodities. In Postharvest Technology of Horticultural Crops. (Kader et al., (eds)). Agriculture and Natural Resources. pp: 117-160. Publications 3311. University of California. USA.

Splittstoesser, W.E. (1984). Tomato. In Vegetable Growing Handbook. pp: 227-277. Avi Publishing Company, Inc.

Steal, R.G.D. and J.H. Torrie. (1987). Principle and procedures of Statistics. A Biometrical Approach. Second Edition. McGraw Hill Book Company.

Stevens, M.A., A.A. Kader, M.A. Holton and M. Algazi. (1977). Genotypic Variation for Flavour and Composion in Fresh Market Tomatoes. J. Amer. Soc. Hort. Sci. 102, 680-689.

Stevens, M.A., A.A. Kader and M. Albright. (1979). Potential for Increasing Tomato Flavour via Increasing Sugar and Acid Content. J. Amer. Soc. Hort. Sci., 104, 40-42.

Stevens, M.A. (1986). Inheritance of Tomato Fruit Quality Components. In Plant Breeding Reviews, (J. Janick (ed)). pp, 272-311. Avi Publishing Co., Inc., Westport, Conn., USA.

Stevens, M.A., C.M. Rick. (1986). Genetics and Breeding. In Tomato Crop. (J.G. Atherton and J. Rudich, (eds)). pp, 35-109. Chapman and Hall.

Themman ,A.P., G.A. Tucker and D. Grierson. (1982). Degradation of Isolated Tomato Cell Walls by Purified Polygalacturonase in vitro. Plant Physiol. 69:122-124

Thorne, S. and J. S. S. Alvarez. (1982). The Effect of Irregular Storage Temperatures on Firmness and Surface Colour in Tomatoes. Journal Science Food Agriculture. 33, 671-676.

Thorne, S.N. and B.J.D. Efiuvwevwere. (1988). Changes in Organic Acids in Chilled Tomato Fruit (Lycopersicon esculentum Mill). J. Sci. Food Agric., 44, 309-319.

Thomas, T.H., L.K. Drew and P.W. Goodenough.(1982). Determination of Firmness of Field-Grown Tomato During Storage in Controlled Atmosphere or Ripened at Different Temperatures. Ann. Appl. Biol., 100,197-202.

Thompson, A.K. (1971). The Storage of Mango Fruits. Trop. Agric. (Trinidad). 48, 63-69

Thompson, A.K., B.O. Been and C. Perkins. (1974). Effects of Humidity on Ripening of Plantain Bananas. Separatum Experentia, 30, 35-36.

Tijskens, L. M. M. and R. W. Evelo. (1994). Modelling Colour of Tomatoes During Postharvest Storage. Postharvest Biology and Technology. 4, 85-89.

Tong, C.B.S. and K.C. Gross. (1989). Ripening Characteristics of a Tomato Mutant, Dark Green. J. Amer. Soc. Hort. Sci., 114, 635-638.

Troller, J.A. and J. H. Christian. (1978). Water Activity and Food. pp:87-92, 146-147. Academic Press. New York.

Tucker, G.A. and D. Grierson. (1987). Fruit Ripening. In The Biochemistry of Plants-A Comprehensive Treatise. (D.D. Davies (ed)). Vol. 2. pp:265-318. Academic Press.

Tucker, G.A. (1993). Introduction. In Biochemistry of Fruit Ripening. (G. B. Seymour, J. E. Taylor and G. A. Tucker (eds)). pp:1-51. Chapman and Hall London.

Ulrich, R. (1975). Physiological and Partial Consideration. In Postharvest Physiology, Handling and Utilisation of Tropical and Subtropical Fruit and Vegetables. (E. B. Pantastico (ed)). p:186-200. The Avi Publishing Company, Inc.

USDA. (1976). United States Standards for Grade of Fresh Tomatoes. US. Dept. Agric., Mktg., Serv., Washington D.C. pp:10.

Varsanyl, I. (1986). Permeability of Polymers in Food Packaging. Food Packaging and Preservation. (M. Mathlouthi (ed)). pp:25-38. Elsevier Applied Science Publishing Co. Inc. London UK.

Van den Berg, L. and C.P. Lentz. (1977). High Humidity Storage of Vegetables. Acta Horticulturae. 62, 192-208.

Van Den Berg, L. (1987). Water Vapour Pressure. In Postharvest Physiology of Vegetables (J. Weichmann (ed)). pp: 203-230. Marcel Dekker Inc. New York.

Watada, A.E. (1986). Effects of Ethylene on the Quality of Fruits and Vegetables. Food Technology. May, p:82-85.

Weatherall, I.L.and W.G. Lee. (1991). Instrumental Evaluation of Some New Zealand Fruit Colours Using CIELAB Values. New Zealand Journal of Botany. 29, 197-205.

Weichmann, J. (1989). Low Oxygen Effects. In Postharvest Physiology of Vegetables. (J. Weichman (ed)). p:231-237. Markel Dekker Inc. New York

Whiting, G.C. (1974). Constituents of Fruits. 1. Sugars. In Biochemistry of Fruit and Vegetables. (A.C. Hulme (ed)). Vol. 1. pp:1-27. Academic Press. London.

Wilkinson, B.G. (1970). Physiological Disorders of Fruits After Harvest. In Biochemistry of Fruits and Their Products. (A.C. Hulme (ed)). pp: 537-554. Academic Press. London.

Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee and E.G. Hall. (1989). Postharvest and Introduction to the Physiology and Handling of Fruit and Vegetables. In Physiology and Biochemistry of fruit and Vegetable. pp:17-38. Blackwell Scientific Publication Ltd

Yang, S.F. (1985). Biosynthesis and Action of Ethylene. HortScience. 20, 41-45.

Yang, C.C., P. Brennan, M.S. Chinnan and R.L. Shewfelt. (1987). Characterisation of Tomato Ripening process As Influenced by Individual Seal-Packaging and Temperature. Journal of Food Quality. 10, 21-33.

Yang, C.C. & M.S. Chinnan. (1988a). Modelling The Effect of O_2 and CO_2 on Ripening and quality of Stored Tomatoes. Amer. Soc. of Agric. Eng. 31, 920-925.

Yang, C.C. and M.S. Chinnan. (1988b). Computer Modelling of Gas Composition and Colour Development of Tomatoes Stored in Polymeric Films. Journal of Food Science. 53,869-872.

Zagory, D. and A.A. Kader, (1988). Modified Atmosphere Packaging of Fresh Produce. Food Technology. 42, 70-77.