SHELF-LIFE OF TOMATO

(Lycopersicon esculentum **Mill.***)*

By

BINU JOHN SAM

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

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Faculty of Agriculture
Kerala Agricultural University

Department of Processing Technology
COLLEGE OF HORTICULTURE
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Kerala, India

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DECLARATION

I hereby declare that this thesis entitled **Shelf-life of tomato (*Lycopersicon esculentum* Mill.)** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Vellanikkara

Binu John Sam

Dr. P. Jacob John
Associate Professor
Department of Processing Technology
College of Horticulture
Vellanikkara, Thrissur

October 1997

CERTIFICATE

Certified that this thesis entitled **Shelf-life of tomato (*Lycopersicon esculentum* Mill.)** is a bonafide work done independently by **Mr. Binu John Sam** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

(P. Jacob John)

Chairman, Advisory Committee

CERTIFICATE

We, the undersigned members of the Advisory Committee of Mr. Binu John Sam, a candidate for the degree of Master of Science in Horticulture with Major in Processing Technology, agree that the thesis entitled **Shelf-life of tomato (*Lycopersicon esculentum* Mill.)** may be submitted by Mr. Binu John Sam in partial fulfilment of the requirement for the degree.

Dr. P. Jacob John
Associate Professor and Head i/c
Department of Processing Technology
College of Horticulture
Vellanikkara, Thrissur.
(Chairman)

Dr. S. Rajan
Associate Professor and Head i/c
Department of Olericulture
(Member)

Dr. Augustine Antony
Assistant Professor
AICRP on M&AP
(Member)

Smt. P.B. Pushpalatha
Assistant Professor
Department of Processing Technology
(Member)

External Examiner

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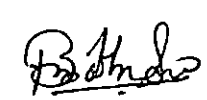

Binu John Sam

To my beloved parents

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ABBREVIATIONS

Br	-	Breaker
CA	-	Controlled Atmosphere
CF	-	Cling Film
CFB	-	Corrugated Fibre Board
CMSD	-	Coarse Moistened Saw
CONT	-	Control
CRD	-	Completely Randomised Design
Cv.	-	Cultivar
d	-	Days
dia	-	Diameter
ESD	-	Equilibrated Saw Dust
FMSD	-	Fine Moistened Saw Dust
FR	-	Fully Ripe
g	-	Grams
h	-	Hour
IM	-	Inherent Moisture
IU	-	International Units
kg	-	Kilogram
LDPE	-	Low Density Polyethylene
M	-	Moistened
MAP	-	Modified Atmosphere Package
MG	-	Mature Green
NS	-	Non Significant at 5% level
OPP	-	o - phenyl phenol
PLW	-	Physiological Loss in Weight
ppm	-	parts per million
PVC	-	Poly Vinyl Chloride
RH	-	Relative Humidity
SD	-	Saw Dust
SOPP	-	Sodium Ortho Phenyl Phenate
TSS	-	Total Soluble Solids
viz.	-	namely
wt	-	Weight

Introduction

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.), an important vegetable crop next to potato, is grown throughout the world under field and greenhouse conditions. It is also known in different names as 'Gold Apple', 'Love Apple', 'Apple of Peru', 'Edible Wolf Peach' etc. It is highly nutritive, a known source for vitamin A (320 IU), vitamin B (Thiamine - 0.07 mg) and vitamin C (31 mg).

Tomato is grown mainly in countries like USA, Russia, Netherlands, China, Italy, Egypt, Turkey and India with a world production of 78,025 thousand tonnes under an area of 2,876 thousand ha (FAO, 1996). In India, tomato is grown in almost all parts of the country, covering about 320 thousand ha, with an annual production of over 4,800 thousand tonnes. However, the area under tomato cultivation in Kerala is meagre due to the high incidence of bacterial wilt, and the lack of commercial cultivars suitable to this region.

Considering its multifarious uses, tomatoes are always in high demand, both at industrial and at household levels. However, tomato is categorised under commodities having poor shelf-life, resulting in a post-harvest loss of about 25 to 40%.

Tomatoes are stored normally under open conditions, resulting in heavy loss due to rotting and weight loss. Under tropical room storage conditions, (28±5°C and 65±20% RH), the shelf life of tomato fruits ranges between 7-14 days.

Therefore, it is imperative that any storage technique to increase the shelf-life of tomatoes will benefit both the producer and the consumer.

Technologies are either inadequate or unreachable to the producer in preventing this loss after harvest. The cost of tomatoes often ranges from Rs. 4/kg to Rs. 20/kg depending upon the season. Development of a simple and cheaper storage technique other than the traditional low temperature storage, would enable the retail vendors or even the producer himself to store his harvested produce temporarily for a reasonable period, especially when the prices are high.

Storage techniques hitherto are low temperature storage or modified atmosphere storage, which are mainly targeted on reducing the respiration rate of the fruits, thereby extending the self-life. But not much work has been carried out targeting to reduce the physiological loss in weight (PLW), of the fruits during storage. Since the low cost technologies for storage of tomatoes have not been adequately developed, the local market vendors often incur heavy losses due to weight loss or rotting.

Hence the present study was taken up with the following specific objectives.

1. To evaluate the existing methods of storage under ambient conditions
2. To develop a simple and cheap storage technique to extend the shelf-life of freshly harvested tomatoes under ambient conditions

Review of literature

2. REVIEW OF LITERATURE

Vegetables are highly perishable commodities and tomatoes are no exception to this, with a normal shelf-life ranging between 7 and 14 days. The main factors attributed to the spoilage are high temperature, humidity, oxygen, atmospheric pressure and fruit firmness. By controlling these factors, the storage life can be extended.

The major packaging and storage techniques adopted for these perishables are refrigerated storage, modified atmosphere storage (MAP), controlled atmosphere storage (CA), chemical treatments etc.

The literature on related works done so far, in different places is reviewed and presented here in the following titles.

2.1 Effect of stage of maturity at harvest on shelf-life of tomatoes

2.2 Effect of pre-treatments

2.3 Effect of skin coatings

2.4 Effect of chemicals

2.5 Effect of different packaging and storage conditions

2.1 Effect of stage of maturity at harvest on shelf-life of tomatoes

Stage of maturity at the time of harvest plays an important role in determining the shelf-life of tomatoes thereby both the producer and the consumer will be benefited. Therefore harvesting tomatoes at the proper stage becomes inevitable.

Fruits harvested at the immature green or mature green stage are normally poor in quality. But such fruits have the advantage of being stored for a longer duration than those harvested at turning stage or fully ripe stage. Fruits after the turning stage are preferred suitable for marketing compared to green fruits even after 17 days of its storage (Elnabawy, 1965).

In a study conducted by Favorov *et al.* (1973), it was revealed that tomatoes harvested at varying stages viz., green, pink and ripened; pink stage showed the least shrivelling during and after ripening. Kaur *et al.* (1977) have suggested that the turning pink stage is the best stage of harvest for storage and subsequent marketing. The spoilage of the fruit was more in the case of red stage followed by turning pink and green ripe stage. A similar study was conducted by Al-Shaibani and Greig (1979) with fruits of tomato cv. Jet star and Floramerica harvested at different stages of maturity and ripened at 20°C and 80% RH. Fruits harvested at the breaker stage was found to retain the highest total sugar content during storage.

Similarly, the thickness of the outer pericarp of tomatoes also vary with stage of maturity. Thickness increases with maturity (Hall *et al.*, 1979). Fruits, when harvested at green immature stage will have thinner pericarp resulting in an increased water loss during storage and in turn causes shrivelling.

According to Gaur and Bajpai (1982), tomato fruits of cv. Kuber, during its 12 days of storage at ambient temperature showed maximum shrivelling. Although, shrinkage measured at the fruit diameter during storage has been recorded in all the three stages of harvesting viz., turning stage, pink stage and red-ripe stage, the rate of shrinkage was slower in the turning stage, followed by pink stage. A similar pattern in respect of weight and moisture has also been recorded.

Shewfelt *et al.* (1987), studied the quality characteristics of fresh tomatoes (cv. Flora-Dale) at various stages of harvest and subsequent storage. It was observed that tomatoes harvested at earlier stages of maturity tend to maintain firmness for longer period and remained less intense in colour as the fruit changed from pink to red, than those harvested at later stages.

Two varieties of tomato viz., Punjab Chuhara and Punjab Kesri were evaluated at red, turning red and green stages by Kaur and Bajaj (1987), for storage changes over a period of 9 days. Red fruits of both the varieties were spoiled after nine days of storage, whereas `turning red' still remained marketable. Chemical analysis on carotenoids, lycopene and acidity also confirmed `turning red' to the optimum stage of harvest.

As far as ambient storage of tomatoes was concerned, Satwadhar *et al.* (1988), recommended pink stage to be the ideal stage to get maximum shelf-life. They got three times more life in pink stage than that of ripe fruits when stored. Similar studies on ambient temperature storage were carried out by Subburamu *et al.* (1990), with fruits of cultivars PKM-1, Marutham, Pusa Ruby and Palyur-1, harvested at 4 maturity stages viz., mature green, breaker, half-ripe and red ripe. Although the shelf-life was longer (11.0-12.5 days) in fruits picked at the mature-green stage, their quality after storage was poor than fruits picked at the breaker stage, which had an acceptable shelf-life of 8.3-10.5 days. Cultivar PKM-1 had the best keeping quality with the other cultivars being similar to one another.

Abnormal surface colouring was observed when fruits of cv. Momotaro at pinkish white and mature green stage were ripened at temperatures above 25°C. Though no significant changes in the sugar or malic acid content were noticed in fruits harvested at any maturity index, it was suggested that the fruits of cv. Momotaro may be harvested at pink stage which ripened normally (Maezawa *et al.*, 1993). Patchy colour development on storage of tomato fruits of cultivars Roma, Pusa Ruby, Sioux and Solan Gola, when harvested at mature green stage, was also reported by Anjukumari *et al.* (1993). However, the shelf-life was maximum when harvested at mature green stage (10.9 - 13.5 days).

The shelf-life of tomato fruits was indirectly correlated with the stage of harvest (Joshi and Khandekar, 1993) and fruits harvested at the breaker and half-ripe stage exhibited good shelf-life, with better quality (Mallik and Bhattacharya, 1996)

2.2 Effect of pre-treatments on the shelf-life of tomatoes

2.2.1 Precooling

Inorder to remove the field heat, tomatoes could be cooled immediately after harvest at 13°C, which would increase the total life of the fruits. This could be due to the reduction in the rate of respiration, weight loss and slowed down some of the physiological processes which influence ripening (Esch, 1981).

Precooling of tomatoes could be done by hydrocooling in tap water or cold water or by top icing with crushed ice for a period of 20 minutes. Minimum PLW was recorded in the case of tomatoes precooled by contact icing and subsequently stored under ambient conditions (Kumar, 1994).

However, some of the researchers noted negative effects too. Lingaiah *et al.* (1983), observed that pre cooling has no beneficial effect on the shelf-life of tomatoes packed in polythene bags held at ambient temperature.

Inaba and Crandall (1987), noted that colour development was significantly delayed and shelf-life extended without increasing decay or chilling injury, by resorting to cold shock treatment. Keeping the fruits at 0°C for 60 minutes delayed colour development by 4-5 days and at -2°C for 120 minutes, extended the shelf-life by 2-3 weeks.

2.2 Heat shock treatment

Mitcham and McDonald (1992), tested a novel idea of giving heat shock treatment to tomato fruits (cv. Sunny) harvested at mature green stage. It was observed that red colour development and softening were inhibited when the fruits were exposed to 40°C for 4 days and subsequently stored at 21°C. Fourteen days after the treatment, heat - stressed fruits were twice as firm as the controls.

A similar study was conducted by Atta - Aly and Brecht (1994), with cv. Sunny harvested at breaker stage. Fruits were pre-treated at 20-40°C for 1-4 days in an air flow system with saturated relative humidity. It was found that fruits pre-treated at 40°C for 4 days failed to ripen normally at 20°C and showed symptoms of high temperature treatment delayed subsequent fruit ripening and the degree of delay increased as temperature and exposure time increased. High temperature treatment had no residual effect on fruit softness, PLW, TSS, titratable acidity or panel taste. The data strongly suggest that exposing tomato fruits to a short period of high temperature delayed subsequent fruit ripening without affecting the quality.

Lurie *et al.* (1994), have reported that mature green tomatoes (cv. F. 144) warmed for 3 days at 38°C ripened at 20°C more slowly than unwarmed tomatoes. Their colour development and softening were delayed, though ethylene production was enhanced. After storage at 2°C for 3 weeks, it was observed that warmed tomatoes ripened normally while unwarmed tomatoes developed chilling injury. Pre-storage short term heat treatment (immersion in water at 42°C for 1 hr) and

long term heat treatment (holding in air at 38°C for 48 hr.) could allow storage of mature green tomatoes at 2°C for 14 days, with little loss of their ability to ripen normally at 20°C (McDonald *et al.*, 1996).

2.3 Effect of skin coatings on the shelf-life of tomatoes

2.3.1 Waxing

The response of tomatoes to wax emulsion coating has been reported in India first by Agnihotri and Ram (1970). It was observed that freshly harvested tomatoes treated with sodium orthophenyl phenate (SOPPS) and then dipped in 6% or 9% wax emulsion stayed longer at room temperature than untreated tomatoes. They were also characterised by reduced respiration rate, less weight loss and increased retention of acidity and ascorbic acid.

Domenico *et al.* (1972), evaluated the efficacy of 10 fungicides in combination with hot water and wax on the shelf-life of tomato fruits. Captan, Thiram, SOPP and Dithane M-45 showed promising results for extending the shelf-life. Application of these fungicides with wax emulsion proved to be effective. The storage life was 8 weeks at 50-55°F.

Waxing tomatoes by foam immersion process delayed ripening by 12 days for mature green tomatoes stored at 10°C, 4 days for semi-ripe tomatoes at the same temperature and 3 days for semi-ripe and green tomatoes kept at 7-19°C. (Castro and Valencia, 1973). Maneb and Imazalil at 0.1% and 0.2% respectively were found to be effective, along with wax emulsion, for extending the storage life

of tomatoes and protecting them from post harvest diseases (Fuchs and Barkai-Golan, 1979).

In another study conducted by Lingaiah *et al.* (1983), the shelf-life at ambient temperature was the longest (7 days) in waxed unpacked `Karnataka' hybrid tomatoes. Removing the peduncle from mature green tomatoes (cv. Caribe) and sealing the point of attachment with liquid paraffin wax was found to increase the storage life of the fruits, to 25 days at 27°C (Anon, 1984).

The major area of gas exchange of the fruit is the stem scar. A small amount of gas, particularly CO_2 is diffused out through the skin also. Coating is normally given to the whole fruit or only at the stem scars; as a single or double coating. It has been observed that, waxing the stem scar area of mature green tomato fruits reduces the CO_2 output, which is an indication of reduced respiration rate. But, waxing the other areas without waxing the stem scar has little effect, and complete waxing of the fruit shows blistering and minute eruption effects. Complete waxing of the fruit shows an enhanced rate of respiration at the initial stage followed by a steep decline. Therefore, sealing of the stem scar restricts the gas exchange and the respiration rate (Kalloo, 1986).

Hall (1989), compared the effects of plain wax coating and fungicidal wax coating on the shelf-life of tomatoes. It was observed that light pink tomatoes treated with plain wax exhibited 35.2% decay and those treated with fungicidal wax containing 2.5% O-phenyl phenol (OPP) exhibited only 20.2% decay, in a period

of 3 weeks storage. Whereas, light green tomatoes after 4 weeks had 23.5% and 7.3% decay respectively when treated with plain or fungicidal wax. Residual levels also indicated that only low OPP concentrations were necessary to achieve the desired effect.

The practical benefit from wax coating is the reduction in evaporation and respiration, (Sethi and Maini, 1989) and thus increase the shelf-life of fresh fruits.

Similar studies have also been conducted in banana (Vijayaraju *et al.*, 1992) and in mango (Rangavalli, *et al.*, 1993) with promising results.

2.3.2 Edible coatings

Edible materials like sucrose fatty esters, Pro-Long™, chitosan, corn-zein etc. can be used to provide a coating on tomato fruits, other than wax emulsions, to extend the storage life. These coatings form a semipermeable film, and modify the internal atmosphere of the tissue, consequently delaying the ripening process (Bai *et al.*, 1988).

The use of Durex 500™ and TAL Pro-Long™ at 20% w/v was evaluated by Nisperos and Baldwin (1989). Ripening was markedly delayed by Durex 500™, especially when an emulsifier was added; but colour development was uneven and most fruits developed a blotchy appearance. Ripening was delayed slightly by TAL Pro- Long™, but colour development was more uniform. These treatments enhanced the storage life of tomatoes upto 20 days.

Chitosan, a by-product from the sea-food industry, appears to be a safe material to be used as skin coatings, as indicated by toxicological studies (Hirano *et al.*, 1990). The effects of chitosan on respiration, ethylene production and quality attributes of tomato fruits stored at 20°C were investigated by El Ghaouoth *et al.* (1992). Coating the fruits with chitosan solution reduced the respiration rate and ethylene production at 2% concentration. Coating increased the internal CO_2 and decreased the internal O_2 levels of the fruits. Chitosan coated tomatoes were firmer, higher in titratable acidity, less decayed and exhibited less red pigmentation than the control fruits at the end of 4 weeks storage.

Park *et al.* (1994), studied the effect of corn-zein film coating on tomato fruits (cv. Mountain pride) at breaker and pink stages. It was observed that corn-zein film delayed colour change and loss of firmness and weight during storage and the shelf-life was extended by 6 days as determined by sensory evaluation.

Semperfresh™ (a fatty acid - sucrose ester mixture) is an improved formulation of edible coating, which can be used on tomatoes to improve its shelf-life. The treated fruits showed less weight loss in storage, and had a storage life of 3-5 days longer than untreated fruits, when treated with semperfresh at 0.8% or 1.2% concentration (Yoltas *et al.*, 1994). A similar study was conducted by Kabir *et al.* (1995), to evaluate the effects of Semperfresh at 0.2 to 0.4% concentration on breaker stage tomato fruits (cv. Pusa Early Dwarf). Results showed that treatments with Semperfresh at 0.2% to 0.4% were effective in increasing the storage life of tomato under ambient conditions (24-31.5°C and 77-90% RH).

2.4 Effect of chemicals on the shelf-life of tomatoes

2.4.1 Growth regulators

Growth regulators have shown to improve the post-harvest storage life of tomatoes. Kumar *et al.* (1987), reported that the tomato fruits treated with GA_3 at 10 ppm or BA at 25 ppm, and kept at ambient temperature showed minimum PLW and incidence of decay. These fruits were marketable even after 6 days of storage. The quality parameters such as TSS, acidity and ascorbic acid contents were not affected by these treatments.

Jana and Chattopadhyay (1989), studied the effects of 2,4-D, B-9 (Daminozide), GA_3, NAA and MH, each at 5-1000 ppm, on the shelf-life of tomatoes held at room temperature. It was concluded that ripening was delayed considerably by GA_3 at 200 ppm or 2,4-D at 100 and 200 ppm. The minimum weight loss occurred in fruits treated with NAA at 5 ppm.

The effects of growth regulators, fungicidal wax emulsion and low temperature storage and their combinations on the shelf-life of Kagzi lime were compared by Naik *et al.* (1993). It was observed that addition of growth regulators (BA 15-30 ppm and GA at 20 ppm) to the fungicide treated fruits and keeping them in polythene bag showed less PLW than wax emulsion treatment alone.

2.4.2 Effect of ethanol and acetaldehyde

The use of ethanol vapour or acetaldehyde to retard fruit ripening may be a viable technique to extend the market life of tomato fruits. Ethanol produced by plant tissues under anaerobic atmosphere, reversibly inhibits the ripening of mature - green tomatoes (Saltveit and Mencarelli, 1988).

In an experiment conducted by Savarese and Mencarelli (1989), treatment of tomato fruits of several cultivars with 10% ethanol, was found to delay maturation (ie. prolonged shelf-life) by 3-4 days, without affecting the quality. treatments with 20% ethanol caused a greater delay, but developed tissue lesions.

Tomato fruits were pre-treated in 70% ethanol, packed in low density polyethylene bags and stored upto 16 days. It was observed that spoilage was higher (53.1%) in ethanol treated fruits (Efiuvwevwere and Uwanogho, 1990).

Saltveit and Sharaf (1992), observed that, exposure of tomato fruits at breaker stage with ethanol @ 2 ml/kg at 20°C prolonged the delay in ripening during subsequent storage at 20, 15 and 12°C by 5, 6 and 7 days respectively compared with untreated control, without any reduction in quality or flavour, when compared between red ripe control and ethanol treated fruits.

Exposure of tomato fruits to 0.2-04% acetaldehyde vapours for 24 h, prior to storage caused inhibition of fruit ripening as expressed by less colour development. The endogenous levels of acetaldehyde and ethanol found in the

juice were positively correlated with the acetaldehyde concentration applied. Application of 0.6% acetaldehyde vapours for durations of 6 to 24 h also caused significant delay in colour development with fruits harvested at the breaker or turning pink stage (Pesis and Marinansky, 1993).

They further observed that exposure of tomato fruits to N_2 or CO_2 atmospheres at different concentrations (50-90%) for 48 h resulted in production of endogenous acetaldehyde and ethanol. Inhibition of ripening was maximum after treatment with 98% N_2 or 90% CO_2. Endogenous levels of acetaldehyde and ethanol was also found to be maximum in the same treatments. Polygalacturonase (a pectolytic enzyme) activity, which is one of the factors governing the firmness of the fruit was also inhibited by acetaldehyde as well as by CO_2 or N_2 pretreatment.

Hong *et al.* (1995), studied the effects of ethanol exposure and infiltration of ethanol on tomato fruits (cv. Recento) of mature green and breaker stages. It was noticed that the red colour development was inhibited in both the treatments in the two stages of ripeness. It took 32 and 22 days for tomato fruits exposed to ethanol vapours to become red ripe from mature green and breaker stages respectively. Effects of exposure to ethanol vapours on inhibition of ripening was more than that of infiltration with ethanol in both the stages.

In a recent study by Hong and Lee (1996), it was found that ethanol @ 5 mg/kg of tomato fruits suppressed ethylene and lycopene production and inhibited the softening of mature green stage fruits. The softening of breaker stage fruits was slightly retarded by ethanol treatment.

2.4.3 Ethylene absorbent

Potassium permanganate ($KMnO_4$) is found to be an effective impackage ethylene absorbent. In sealed plastic bags, when tomato fruits were kept @ 1g $KMnO_4$ for every 700g fruits, their storage life was increased (Giraldo *et al.*, 1977).

Sandooja *et al.* (1987), studied the effects of $KMnO_4$, when applied on the paper lining which was used as the cushioning material in boxes of tomato fruits harvested at mature green and pink stages. It was found that this treatment decreased weight loss and decay during storage and maintained various quality parameters such as TSS, acidity and ascorbic acid content of the fruits.

A similar work was carried out by Kumar *et al.* (1988). They found out that, when newspaper treated with 500 ppm $KMnO_4$ was used as cushioning material, in wooden boxes filled with tomatoes harvested at pink stage, the PLW was the least, during a storage period of 6 days under low temperature.

2.5 Effect of different packaging and storage techniques on the shelf-life of tomatoes

2.5.1 Individual film wrapping

The textural quality of fresh fruits and vegetables is influenced by moisture content and the biochemical constituents of the cell wall (Wasserman *et al.*, 1986). The loss of moisture can be minimised by individually packaging the produce with heat - shrinkable perforated films and stored at 21°C and 55% RH. Films with less

than 2% perforation drastically reduced weight loss and tissue softening, resulting in keeping tomatoes in good eating quality and bright red colours (Floros *et al.*, 1987).

Hulbert and Bhowmik (1987), have observed that shrink-wrapped mature green tomatoes stored at 18°C showed delayed colour development and shelf-life was increased by 10 days. These fruits were also firmer than controls.

Mature green tomatoes washed with 120 ppm chlorine water, dried and individually double wrapped with a heat shrinkable plastic film delayed the onset of climacteric respiration and increased the shelf-life by 10 days, when stored at 85-90% RH, (Bhowmik and Hulbert, 1989).

A similar study has been conducted successfully in chayote fruit (*Sechium edule*) by wrapping the fruit in a commercial grade polyvinyl chloride (PVC) film. There was a significant reduction in the weight loss (Aung *et al.*, 1996).

2.5.2 Modified atmosphere storage

The term modified atmosphere refers to the composition of the atmosphere within a film package, where there is no precise monitoring of the gas composition. When fresh fruits are packaged within a polythene bag, the actively respiring and metabolising produce reduces the O_2 and increases the CO_2 in the ambient air within the package thereby modifying the atmosphere within the package. The package act as a barrier for the exchange of gas to the external atmosphere.

The effectiveness of polythene as a packaging material for slowing down the ripening process, reducing weight loss and extension of shelf-life of fresh produce has been reported by Okubo *et al.* (1971). Retardation of ripening is also influenced by increase in film thickness, number of fruits in the package and fruit size (Kitagawa *et al.*, 1978).

The build-up of modified atmosphere when breaker stage tomato fruits were enclosed in polyethylene bags kept below ambient temperature extended the ripening time and improved firmness and quality. Short term storage at a moderately low temperature (10°C) combined with restricted gas exchange, could form the basis of an effective low cost system (Hobson, 1981).

Hobson (1982), has further reported that sealing tomato fruits (cv. Sonatine) at breaker stage in polyethylene bags, and holding at 20°C for 48 h before keeping at 2°C for 7 days, followed by unsealing and holding at 20°C extended the ripening time to 15.5 days compared to 6.1 days for control.

A storage life of 8 weeks at 13°C in modified atmosphere (LDPE) was reported, by Anderson and Poapst (1983). Weight loss was found to be less, but rotting by *Alternaria alternata* and *Fusarium* spp was noticed after this period. The lower rate of PLW in MA stored fruits is clearly due to the high humidity in the micro-atmosphere provided in the packages by the respiring fruits and to the low water vapour transmission rate of the packaging material used (Geeson *et al.*, 1985).

Ramana *et al.* (1987), found that packing tomatoes in polyethylene bags with no ventilation had markedly reduced PLW (2%). But spoilage due to fungal growth was a limitation to their storage life.

Use of polyethylene film for prepackaging of tomatoes can reduce the PLW and increase shelf-life considerably (Satwadhar *et al.*, 1988). The same packages can also retain maximum acidity and ascorbic acid content at the end of the storage period. Enhanced decay loss during the storage period was reported by Bhatnagar, (1989).

Nakhasi *et al.* (1991) studied the storage potential of tomatoes harvested at the breaker stage using modified atmosphere package (MAP). It was observed that after 23 days of MA storage at 15°C; fruits ripened normally under ambient conditions. A steady state of about 3.5 - 4.0 % O_2 and CO_2 was established within the package. No evidence of anaerobic conditions was observed. In a similar study, Marangoni and Stanley (1991), have concluded that greenhouse grown tomatoes could be stored for at least 30 days in the mature green stage at 12°C in MA with no detectable changes in quality. But field-grown mature green tomatoes (cv. Heinz 91-29) could be stored for only 10-30 days at 12°C in MA owing to heavy fungal infection.

Fungal infection within the MA containers can be minimised by controlling the RH within the pouch. The storage life of packaged red-ripe tomato fruits at 20°C was extended to 15-17 days, with a pouch containing NaCl, when compared

to 5 days storage without any pouch, mainly by retarding surface mould development (Shirazi and Cameron, 1992).

Naik *et al.* (1993), reported that the shelf-life of tomatoes harvested at breaker stage can be increased to almost four times compared with control, by packaging in 300 gauge polyethylene bags with 3 vents. Studies conducted by Hooda *et al.* (1994), has shown that, the least PLW for stored mature green tomatoes was in MA. but decay loss was more under the same conditions.

According to Onwuzulu *et al.* (1993) MA storage delayed the ripening process. Colour development was significantly retarded upto 12th day of storage in MA and thereafter it proceeded normally, when the fruits were removed from the packages and approached the colour of control fruits by the 16th day of storage.

2.5.3 Controlled atmosphere storage

Controlled atmosphere means an atmosphere in which the concentration of O_2, CO_2 and N_2 are maintained precisely at a specific level and the temperature as well is maintained below the ambient temperature. Ethylene and excess CO_2 produced by the metabolic activities of the fruit kept within the package are removed by scrubbers. The potentiality of controlled atmosphere storage for tomatoes has been investigated by many workers.

According to Eaves and Lockhart (1961), the best storage atmosphere is the mixture of 2.5% O_2 and 5% CO_2 at 12.7°C; however 2.5% O_2 and 2.5% CO_2 can also be used. Later Lockhart and Eaves (1967), have reported that oxygen in combination with nitrogen can extend the storage life. Low O_2 level or 100% N_2 at 10°C and 69-70% RH could store the fruits for 3 weeks. With respect to the stage of harvest for controlled atmospheric condition, Murata *et al.* (1968), have extended the storage life of mature green as well as pink fruits at CA of 5% CO_2/10% O_2, 10% CO_2/10% O_2 and 25% CO_2/10% O_2 to the extent of 6 weeks. It can also be ascertained that the important factors for extending the shelf-life are high CO_2 content and low oxygen content (Parsons *et al.*, 1970).

Salunke and Wu (1973), have reported 87 days as the maximum shelf-life at 1% O_2 and 99% N_2. Low O_2 level was found to inhibit fruit chlorophyll and starch degradation and also lycopene, β-carotene and soluble sugar synthesis. However, Li *et al.* (1973), have contradicted that the critical content of oxygen for effective inhibition of ripening during storage was 7% at 13-27°C and that for prolonged storage at 12-13°C was 2-4% but stored tomatoes showed physiological injury.

The great amount of CA testing of tomatoes is indicative of a pre-conceived potential for this practice, but the lack of commercial usage also is an indicative of many obstacles; one of which undoubtedly is the wide range of recommendations by different investigators for the proper CA gaseous combination (Isenberg, 1979).

Dennis *et al.* (1979), showed that approximately 95% and 90% of the fruits of cv. Sonatine remained green in a 5% CO_2, 3% O_2, 92% N_2 atmosphere and 5% CO_2, 5% O_2, 90% N_2 atmosphere respectively. The remainder of the fruits were at the breaker stage. About 3-4% of the fruits showed rot symptoms caused by *Botrytis cinerea*.

A storage life of 58 days in CA at 6-7°C was recorded by Afanas'er and Dogotar' (1982), with fruits of cvs. Fakel and Birunta at mature green and breaker stages. The percentage of marketable fruits ranged between 56.6 and 61.9%, whereas under normal atmospheric storage, it was only 21.8% during the same period.

Daesung *et al.*(1985), has reported that tomato fruits could be stored for 4 weeks in CA containing 2% O_2 alone and free of CO_2 having an RH of 80-90% with little change in quality. Based on the studies conducted by Goodenough and Thomas (1990), it was concluded that CA storage decreased breakdown of chlorophyll and also reduced or totally inhibited the synthesis of lycopene, carotenoids and xanthophyll in tomato.

2.5.4 Refrigerated storage

The ripening processes in tomato fruits can be delayed by optimum low temperatures, but temperatures below 45°F (7°C) though delays the ripening process substantially, leads to poor fruit quality and reduced shelf-life. However,

storage at 54°F (12°C) with an RH of 72 to 80% is found to be suitable for tomato storage (Stenvers, 1972; Salter, 1973).

Nandpuri *et al.* (1978), reported that fruits of cv. Punjab Chuhara and S-12 at green ripe stage were marketable for 22 and 28 days respectively, when stored at 33°F (0.5°C). But Isenberg (1979), has suggested that tomatoes could be successfully stored at 7.5-8°C for 10 days. Whereas at temperatures below 7°C symptoms of chilling injury were observed either in storage or subsequent ripening at ambient temperatures. Temperatures which cause chilling injury enhance decay (Risse *et al.*, 1981).

In some other studies, chilling injury was developed on tomatoes stored at 8-10°C where the colour development was also retarded and those stored at 12 and 14°C were softened more than those at 8 and 10°C (Kapitsimadi, 1989).

The colour change of mature green tomatoes of cv. Dombito stored at 15°C was significantly higher than the rates for those stored at 5 or 10°C. However there was no significant difference between the rates at 10° and 5°C (Pai and Sastry, 1990).

Joshi and Khandekar (1993), have concluded that the PLW of fruits at cold storage was minimum than either cool chamber or ambient temperature storage irrespective of varieties. The fruits stored at cold storage exhibited maximum shelf-life followed by those stored in cool chamber and ambient temperature.

2.5.4 Hypobaric storage

Subatmospheric pressure storage inhibited the ripening of tomatoes and thus extended the shelf-life. Inhibition was proportionate to the reduction in pressure. Physiological changes associated with ripening were also delayed. Tomatoes could be stored at 102 mm Hg for 100 days and then ripened at 646 mm Hg in 7 days (Wu *et al.*, 1972).

Storage life is influenced by atmospheric pressure. At low pressures storage life is often extended (Bangerth, 1974). A reduced partial O_2 pressure retards the onset and the rate of ripening of tomato fruits, irrespective of the total atmospheric pressure and the absorption of endogenously evolved ethylene. The reduction of the partial pressure is therefore a main factor in retarding senescence in low pressure storage (Stenvers, 1975; Streif and Bangerth, 1976; Stenvers, 1977).

The use of fungicides under reduced atmospheric pressure helps in the extension of storage life by protecting the fruits from rotting (Stenvers and Stork, 1977). However, subatmospheric pressure at 102 mm Hg retarded the growth and sporulation of storage fungi viz. *Rhizopus nigricans, Aspergillus niger* and *Alternaria* spp. It is apparent that lower the pressure, the more the inhibition of growth and sporulation of fungi (Ramana, 1993).

2.5.6 Equilibrated saw dust

One among the problems in storage of fresh fruits and vegetables is the weight loss and the rate of weight loss depends upon the temperature and relative humidity (RH). At low temperature and high RH, weight loss can be reduced considerably. Excess weight loss results in the shrivelling of the commodity thereby reducing its marketability (Kalloo, 1986).

Methods attempted in prolonging shelf-life involves optimization of handling and storage conditions; minimizing mechanical damage and slowing down the ripening process as well as regulating the temperature and humidity of the storage environment. The best RH for storage is between 60 and 90% (Oladiran and Iwu, 1993).

Studies on the use of moistened sawdust for storage of tomatoes gave positive results, with minimum post harvest losses and maintaining acceptable quality (Onwuzulu *et al.*, 1993).

Babar *et al.* (1994), found that storage of tomatoes in coarse moistened saw-dust (CMSD) significantly reduced overall fruit rotting percentage and weight loss percentage. It was also suggested that on-farm low cost primary storage of tomatoes can be adopted by the farmers with the use of CMSD to regulate their market supply through delaying the ripening of tomatoes.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation on the shelf-life of freshly harvested tomatoes, was carried out at the department of Processing Technology, College of Horticulture, Vellanikkara, Thrissur, Kerala during 1996-97. Vellanikkara enjoys a typical warm humid climate throughout the year.

Tomatoes are stored normally under open conditions resulting in heavy losses due to rotting and drying. In the present study an attempt has been made to develop a simple and cheap storage technique to extend the shelf-life of freshly harvested tomatoes under ambient conditions by controlling the physiological loss in weight (PLW).

The whole programme was divided into three major experiments for better execution.

3.1 Evaluation of the existing methods of packaging and storage techniques of tomato fruits with three stages of maturity viz. mature green, breaker and fully ripe stages

3.2 Standardization of packing medium (saw dust), its proportion to tomatoes by weight and the extend of moistening of sawdust to achieve equilibrium relative humidity (ERH).

3.3 Standardization of the stage of harvest for the best storage technique evolved by experiment 3.2.

3.1 Evaluation of the existing methods of packaging and storage techniques of tomato fruits with three stages of maturity viz. mature green, breaker and fully ripe stages

This experiment was carried out to evaluate the efficiency of some of the existing package and storage techniques available, with three stages of maturity viz. mature green, breaker and fully ripe stages under ambient conditions.

3.1.1 Source of tomato fruits for the study

The experiment was carried out with tomato fruits of two varieties.

a. Sakthi - A slow ripening, non-uniform, green shoulder variety.

b. PKM - 1 - A fast ripening variety

Tomato fruits of both the cultivars were obtained from potted plants grown in the Vegetable Research Farm of the Department of Olericulture, College of Horticulture, following the cultural practices recommended in the Package of Practices Recommendations `Crops 1993' of the Kerala Agricultural University [Plate 1 and 2]. The stage of harvest of fruits was determined visually based on the extent of colour breakdown as described by Grierson and Kader (1986), [Plate 3 and 4].

Plate 1 & 2 - Potted tomato plants grown for the study


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Plate 3 - Plants bearing fruits of different stages of maturity

Plate 4 - Tomatoes of cvs. Sakthi and PKM-1 harvested at different stages of maturity


SAKTHI


MATURE GREEN STAGE
BREAKER STAGE
FULLY RIPE STAGE
SAKTHI
PKM-1

a. Mature green - Entirely light to dark green but mature.

b. Breaker - First appearance of external pink, red or tannish - yellow colour, not more than 10%.

c. Fully ripe - Over 90% red; desirable table ripeness.

3.1.2 Preparation of fruits

Harvesting was done in the morning hours preferably before 10 am to minimise transpiration loss. They were taken to the laboratory for further treatments.

Fruits were sorted out for any spoilage, insect damage or cracking; such fruits were discarded. Weight of each fruit was taken using an electronic balance (OHAUS 200 portable standard) with 100 mg accuracy, and labelled individually.

3.1.3 Treatments - The following were the treatments.

T_1 - Mature green Sakthi fruits individually wrapped with cling film

T_2 - Mature green Sakthi fruits, packed in 150 gauge ventilated (2%) polythene bags, with impackage ethylene absorbent.

T_3 - Mature green Sakthi fruits treated with ethanol @ 2 ml/kg and packed in unventilated polythene bags with impackage desiccant (fused $CaCl_2$).

T_4 - Mature green Sakthi fruits kept open without any treatment (control)

T_5 - T_8 - All the above treatments were repeated sequentially, but with fruits at breaker stage.

T_9 - T_{12} - Treatments T_1 to T_4 were repeated sequentially, but with fully ripened Sakthi fruits.

T_{13} - T_{24} - All the treatments were carried out sequentially but, with fruits of cv. PKM-1, with three stages of maturity making the total number of treatments to 24.

3.1.4 Layout

All the experiments were laid out in a Completely Randomised Design (CRD) with two replications each.

3.1.4.1 Experiments with cling films

Tomato fruits at the three different maturity stages were taken in three lots, each consisting of 10 fruits. The fruits were washed and wiped dry with a clean dry muslin cloth. They were then individually wrapped with cling film (INTACT L 100™ of Flexo film wraps (India) Ltd., Aurangabad) and weighed individually. The initial weights were noted as described under 3.1.2. [Plate 5]

Plate 5 - (3) Tomatoes packaged under 2% ventilated 150 gauge polyethylene bags with impackage ethylene absorbent

(4) Tomatoes wrapped individually with cling film


3
4

3.1.4.2 Experiments with ventilated polythene bags with impackage ethylene absorbent

Twelve fruits each of different maturity stages, viz. mature green, breaker and fully ripe were selected as under 3.1.2 and packed separately in polythene bags of 150 gauge thickness having a size of 20 x 18 cm with 114 vents of 4 mm dia to make 2% ventilation. The bags were then heat sealed using a heat sealing machine [Quickseal™ of Sevana (India) Ltd], and stored under ambient conditions. [Plate 5]

3.1.4.2.1 Preparation of ethylene absorbent

Cakes of size 7 x 3 x 1 cm were made with `Plaster of Paris'. They were dried in a hot air oven and soaked in saturated $KMnO_4$ solution for about 30 minutes and again dried in the hot air oven. Each of these $KMnO_4$ impregnated cakes were packed in polythene bags of size 9 x 5 cm, having pin holes. Such six bags were prepared with impackage ethylene absorbent for the treatments T_2, T_6, T_{10}, T_{14}, T_{18} and T_{22}.

3.1.4.3 Treatments with ethanol

Fruits were exposed to ethanol vapours @ 2 ml/kg fruits for a period of 2 hrs. Each lot comprising of 1 kg fruits were treated at a time. Two ml ethanol was

pipetted out to a petridish of 10 cm dia and the same was kept in the centre with fruits spread around it. The whole set up was closed by a bell jar smeared with petroleum jelly at its bottom to make the enclosure air tight. It was kept undisturbed for about 2 hrs, till all the ethanol in the petridish got evaporated. Fruits were taken out after 2 hrs and packed in unventilated polythene bags with impackage desiccant (fused $CaCl_2$ @ 5 g/kg fruits) taken in a muslin cloth sachet.

3.1.5 Observations

Observations on both physical and chemical changes during storage were taken at weekly intervals as detailed below.

3.1.5.1 Physical observations

3.1.5.1.1 Physiological loss in weight (PLW)

The physiological loss in weight (PLW) was calculated on the initial weight basis as suggested by Srivastava and Tandon (1968), and expressed as percentage.

$$PLW\% = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

3.1.5.1.2 Decay percentage

The decay percentage was calculated as per the formula given by Bhatnagar *et al.* (1980).

$$\text{Percentage of fruit decayed} = \frac{\text{Wt. of the fruit decayed in the pack}}{\text{Total Wt. of the fruits in the pack}} \times 100$$

3.1.5.1.3 Marketability

Marketability was calculated based on cumulative spoilage and PLW (Onwuzulu *et al.*, 1995).

$$\% \text{ marketable fruits} = 100 - (\% \text{ spoilage} + \text{PLW}).$$

3.1.5.1.4 Firmness

Firmness of the fruits was measured by penetrometer method using Effegi Fruit Pressure Tester [Model F7.001 (0-5 kg)]. Fruits were held firmly with the left hand, leaning it on the table; and the fruit tester kept between the thumb and the forefinger of the right hand. The plunger was placed against the fruit and pressed with increasing strength till the plunger tip has penetrated into the pulp upto the notch. Slow penetration of the plunger was ensured, as sharp movements and sudden pressure application could impair measurements. Readings were noted from the pressure gauge as kg per square cm. Two readings, at opposite sides

were taken for each fruit from the composite sample of 5 fruits taken for weekly chemical observations.

3.1.5.1.5 Termination of the observations

During each evaluation the decayed fruits were discarded. Observations were terminated when 50% or more of the original sample was discarded as suggested by Kapitsimadi, (1989).

3.1.5.2 Chemical analyses

Composite samples comprising of five fruits selected at random in respect of each treatment were drawn at an interval of seven days for the estimation of pH, TSS, acidity, sugars, ascorbic acid, pectin and lycopene.

The samples were washed and wiped dry with a clean dry muslin cloth. They were then pulped using a mixer grinder. From this, the required amount of pulp for each estimation was weighed out. The pulped samples were stored in a deep freezer without delay, to avoid further degradation and used for the remaining analyses.

Clear juice was extracted by squeezing the pulp through a clean dry muslin cloth and used for the estimation of TSS, pH and sugars. Analytical grade chemicals of standard companies were used for this purpose.

3.1.5.2.1 Total soluble solids (TSS)

TSS was determined with the help of Erma hand refractometer (range 0-32° brix) and expressed in degree brix.

3.1.5.2.2 pH

pH was directly read from the juice extracted using a digital pH meter (model pH 5652 A of Electronics Corporation of India Ltd.).

3.1.6.2.3 Acidity

Titratable acidity was estimated as perthe A.O.A.C. (1975) method, and expressed as percentage of anhydrous citric acid (mg/100 g juice).

3.1.6.2.4 Sugars

Total sugars and reducing sugars were determined by Lane and Eynon method (Ranganna, 1986).

3.1.5.2.5 Ascorbic acid

Ascorbic acid content of the fruit during the storage period was determined by 2, 6 - dichlorophenol indophenol dye method as suggested by Ranganna, (1986).

3.1.5.2.6 Lycopene

The colour changes occurring to the tomato fruits during storage was authenticated by quantifying the amount of lycopene colorimetrically by the procedure suggested by Sadasivam and Manickam (1992).

3.1.5.2.7 Pectin

The pectin content was estimated as calcium pectate (Ranganna, 1986) and expressed as percentage.

3.2 Standardization of packing medium

This experiment was formulated with the objective of evolving a packing medium for the storage of tomatoes under conditions of equilibrium relative humidity (ERH). This would restrict the loss in weight of the fruits by reducing the respiration loss and evaporation losses, thereby extending the shelf-life.

3.2.1 Procurement of essential materials

3.2.1.1 Tomatoes

The required amount of tomatoes are procured as explained in 3.1.1.

3.2.1.2 Sawdust

Fresh sawdust was procured from the Paulson Wood Industries, Thrissur. It was ensured that the sawdust was free from teak wood saw-dust, inorder to eliminate any possibility of interference by tannin from teak wood on the experiment material.

3.2.1.3 Corrugated fibre board boxes (CFB boxes)

CFB boxes of uniform size (30 x 30 x 25 cm) of 4 kg capacity were utilized for holding the sawdust and fruits.

3.2.2 Estimation of moisture content in sawdust

Moisture content in saw dust was estimated as per the procedure laid out by Ranganna (1986), for the estimation of moisture in fruits and vegetables.

3.2.3 Treatments

The following were the treatments

T_1 - Tomato fruits and fresh sawdust in 1:0.5 proportion packed in CFB boxes

T_2 - Tomato fruits and fresh sawdust in 1:1 proportion packed in CFB boxes

T_3 - Tomato fruits and fresh sawdust in 1:1.5 proportion packed in CFB boxes

T_4 - T_6 - Treatments T_1 to T_3 repeated with dried sawdust (20% moisture)

T_7 - T_9 - Treatments T_1 to T_3 repeated with moistened sawdust (60% moisture) in that order

T_{10} - Control - Tomato fruits of cv. Sakthi kept open

T_{11} - T_{20} - All the treatments were repeated with fruits of cv. PKM - 1 making the total number of treatments to 20.

3.2.4 Layout of the experiment

All the experiments were laid out in a Completely Randomised Design (CRD) with two replications. For treatments T_1 - T_3 and T_{11} - T_{13}, fresh sawdust with an inherent moisture content of 35-40% by weight was used. If the sawdust was found to have a lower moisture content, the same was made up by moistening the dust by sprinkling the required quantity of water.

For treatments T_4 - T_6 and T_{14} - T_{16} the sawdust was dried under shade for 2-3 days till the moisture content was reduced below 20%.

In the case of treatments T_7 - T_9 and T_{17} - T_{19}, the sawdust was moistened to 60% level. The required quantity of water by weight was sprinkled on the sawdust and thoroughly mixed to make it uniformly spread and kept for nearly an hour for stabilization.

The procured tomatoes were prepared for the experiment as described in 3.1.2. Fruits were packed with sawdust as layer over layer alternating sawdust with fruits till the box was filled. [Plate 6]. Approximately 4 kg of fruits can be packed in a box of size 30 x 30 x 25 cm.

3.2.5 Observations

All the observations detailed under 3.1.5.1 were carried out.

3.3 Standardization of stage of harvest

This experiment was mainly meant to standardize the stage of harvest of tomatoes for the best treatment under 3.2.

3.3.1 Procurement of essential materials

Tomatoes were procured as in 3.1.1 and made ready for the experiment as described under 3.1.2.

3.3.2 Treatments

T_1 - The best treatment in experiment No.2 with mature green tomato fruits of cv. Sakthi.

T_2 - Control - mature green fruits of cv. Sakthi kept open without any package.

T_3 - The best treatment in experiment No.2 with breaker stage of tomato fruits of cv. Sakthi.

Plate 6 - Tomatoes packaged with ESD


5
6

T_4 - Control - Breaker stage fruits of cv. Sakthi kept open without any package.

T_5 - The best treatment in experiment No.2 with fully ripened fruits of cv. Sakthi.

T_6 - Control - Fully ripened fruits of cv. Sakthi kept open without any package.

T_7 - T_{12} - All the treatments (T_1 - T_6) are repeated with fruits of cv. PKM - 1 in the same order.

3.3.3 Layout of the experiment

The design and layout of the experiment was as under 3.2.3 for the best treatment under experiment No.2

3.3.4 Observations

All the observations described under 3.1.5 were carried out in this experiment also.

3.4 Sensory evaluation

Sensory evaluation was carried out with the help of a trained panel consisting of 15 members who were asked to evaluate the samples for its overall appearance, fruit colour, firmness, internal colour, sweetness, sourness and flavour, in comparison with freshly harvested on a 10 point hedonic scale. The ratings were as follows

0 - 2 - Poor

3 - 5 - Satisfactory

6 - 8 - Good

9 - 10 - Excellent

3.5 Tabulation and statistical analysis

Observations under each experiment were tabulated and analysed statistically in a Completely Randomised Design (CRD) as proposed by Panse and Suhatme (1976). The treatments were ranked according to Duncan's Multiple Range Test and the scores of organoleptic evaluation were analysed by the `t test'.

Results

4. RESULTS

The results of the studies conducted in the Department of Processing Technology, College of Horticulture, Vellanikkara during 1996-97 on the shelf-life of tomatoes under ambient conditions; with two varieties viz. Sakthi and PKM-1 are presented in this chapter.

4.1 Evaluation of the existing methods of packaging and storage for tomato fruits

The effect of different packaging and storage techniques adopted for tomato fruits cv. Sakthi and PKM-1 under ambient conditions with three stages of maturity, viz. mature green (MG), breaker (Br) and fully ripe (FR) were evaluated. The results are tabulated under tables 1 to 6.

4.1.1 Physiological loss in weight (PLW), decay percentage and marketability of tomato fruits

Changes in PLW, percentage decay and marketability recorded at weekly intervals for tomato fruits or Sakthi and PKM-1 are presented in tables 1a and 1b respectively.

Table no. 1a PLW, decay percentage and marketability of tomato friuts cv. Sakthi under different storage techniques

		PLW (%)				DECAY (%)				MARKETABILITY (%)			
	Days	7	14	21	28	7	14	21	28	7	14	21	28
T1	MG - Cling film	1.71^{d}	3.89^{f}	5.39^{ef}	6.67^{b}	0.0^{c}	0.0^{c}	0.0^{d}	24.94^{b}	98.29^{a}	96.11^{a}	94.61^{a}	$68_{i}39$
T2	MG - 2% Ventilation	3.31^{c}	4.83^{e}	6.76^{de}	8.73^{b}	0.0^{c}	0.0^{c}	21.87^{c}	45.61^{ab}	96.69^{ab}	95.17^{a}	71.37^{bc}	$45_{ab}67$
T4	MG - Open (Control.)	4.34^{b}	8.56^{b}	12.19^{b}	-	0.0^{c}	20.65^{bc}	52.42^{ab}	-	95.66^{ab}	70.79^{b}	35.38^{de}	-
T5	Br - Cling film	3.66^{bc}	6.94^{c}	9.08^{c}	13.36^{a}	0.0^{c}	14.82^{bc}	37.47^{bc}	47.96^{ab}	96.34^{ab}	$78_{b}24^{a}$	53.45^{cd}	$38_{b}68$
T6	Br - 2% Ventilation	3.65^{bc}	7.00^{c}	10.15^{c}	12.77^{a}	0.0^{c}	24.55^{b}	38.28^{bc}	53.64^{a}	96.35^{ab}	68.45^{b}	51.57^{cd}	$33_{b}59$
T8	Br - Open (Control)	5.93^{a}	10.19^{a}	14.66^{a}	-	0.0^{c}	27.93^{b}	59.58^{ab}	-	94.07^{ab}	61.88^{b}	25.76^{e}	-
T9	FR - Cling film	3.33^{c}	4.90^{e}	-	-	26.11^{a}	63.32^{a}	-	-	70.56^{cd}	31.78^{c}	-	-
T10	FR - 2% Ventilation	3.56^{bc}	5.85^{d}	8.23^{cd}	-	14.36^{bc}	36.90^{b}	62.03^{a}	-	$85_{i}08^{bc}$	57.24^{b}	29.74^{e}	-
T12	FR - Open (Control)	5.71^{a}	10.27^{a}	-	-	35.97^{a}	77.33^{a}	-	-	58.31^{d}	12.39^{c}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 1b PLW, decay percentage and marketability of tomato fruits cv. PKM - 1 fruits under different storage techniques

		PLW (%)				DECAY (%)				MARKETABILITY (%)			
	Days	7	14	21	28	7	14	21	28	7	14	21	28
T13	MG - Cling film	1.81^{d}	3.91^{de}	5.20^{c}	5.79	0.0^{c}	21.49^{d}	31.08^{c}	59.03	98.19^{a}	74.61^{a}	63.72^{ab}	35.17
T14	MG - 2% Ventilation	2.27^{cd}	3.14^{de}	5.14^{c}	5.91	0.0^{c}	16.89^{d}	32.92^{bc}	57.69	97.74^{a}	79.97^{a}	61.94^{ab}	36.4
T16	MG - Open (Control)	2.31^{cd}	5.34^{cd}	10.36^{a}	-	0.0^{c}	22.83^{d}	64.42^{ab}	-	97.69^{a}	71.83^{a}	24.92^{d}	-
T17	Br - Cling film	2.26^{cd}	5.03^{cd}	8.51^{ab}	11.66	0.0^{c}	20.51^{d}	37.40^{bc}	50.97	97.74^{a}	74.46^{a}	54.08^{bc}	37.38
T18	Br - 2% Ventilation	2.22^{cd}	4.22^{cde}	6.37^{bc}	-	0.0^{c}	31.31^{cd}	52.95^{ab}	-	97.79^{a}	64.47^{b}	40.68^{cd}	-
T20	Br - Open (Control)	4.61^{a}	10.78^{a}	-	-	13.76^{b}	50.48^{ab}	-	-	81.63^{b}	38.74^{c}	-	-
T21	FR - Cling film	3.11^{bc}	7.17^{bc}	-	-	34.07^{a}	51.58^{ab}	-	-	62.84^{c}	41.25^{c}	-	-
T22	FR - 2% Ventilation	3.43^{b}	5.91^{cd}	-	-	-	45.28^{bc}	-	-	96.57^{a}	48.82^{b}	-	-
T24	FR - Open (Control)	5.31^{a}	8.95^{ab}	-	-	35.76^{a}	63.14^{a}	-	-	58.93^{c}	27.91^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

4.1.1.1 Physiological loss in weight (PLW)

The minimum PLW of fruits of cv. Sakthi, on the 7th day was recorded in MG fruits when wrapped individually with cling films (1.71%). The trend was same till the termination of the experiment (28 days) with a cumulative PLW of 6.67%. This was found to be comparable with the cumulative PLW of MG fruits under 2% ventilation, for the same period, (8.73%). The maximum PLW was recorded in control samples of Br stage (14.60%) even after 21 days.

The trend was almost similar for cv. PKM-1, where the least cumulative PLW (5.79%) was recorded when the MG fruits were individually packed in cling films and was comparable with T_{14} (2% ventilation) at the end of 28 days of storage (5.91%). In T_{17} (Br CF) a high PLW of 11.66% was recorded during the same period of storage. The control fruits showed a PLW of 10.78% (T_{20}) even by 14 days of storage.

4.1.1.2 Percentage decay

Treatments [T_3, T_7, T_{11}, T_{15}, T_{19} and T_{23}] involving exposure to ethanol vapours and packaging in unventilated polythene bags with impackage desiccant (fused $CaCl_2$) had to be terminated during the first week itself due to the high incidence of rotting.

The percentage decay was practically nil for Sakthi fruits till 21 days in T_1 (MG cling film) but by 28 days, it recorded a low decay percentage of 24.94%. Treatments T_2 and T_5 recorded less than 50% decay even after 28 days of storage. But in treatments T_9, T_{10} and T_{12}, spoilage was observed by the first week of

storage itself. This was very high (35.97) for fully ripened fruits without any treatment on the very first week of storage.

In the case of cv. PKM-1, decay was observed in all the treatments during the second week of storage; the maximum was (63.14%) observed for T_{24} (FR-control) whereas T_{13} recorded the minimum spoilage even after 21 days of storage (31.08%) which was also on par with T_{14} (32.92%).

4.1.1.3 Marketability

Percentage marketability was more in case of T_1 (68.39%) for cv. Sakthi. FR fruits became unmarketable even before seven days of storage. All the treatments involving FR fruits showed significantly lesser marketability by one week of storage, whereas treatments T_5 and T_6 (Br - CF and 2% ventilation) during its entire storage period did not show any significant difference in marketability.

A similar trend was also observed in the case of PKM-1. MG fruits packed in cling films and 2% ventilation remained marketable (above 50%) till three weeks of storage. Marketability of Br stage fruits was increased when wrapped in cling film (T_{17}) and it was comparable to that of T_{13} and T_{14}. Fully ripened fruits of cv. PKM-1 had a shelf-life of maximum 2 weeks.

4.1.2 Total soluble solids (TSS) and acidity

Changes in TSS and acidity of tomato fruits cv. Sakthi and PKM-1 at three maturity stages as effected by the different storage treatments are given in Tables 2a and 2b.

Table no. 2a TSS and acidity of tomato fruits cv. Sakthi under different storage techniques

		TSS (°brix)					Acidity (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - Cling film	4.40^{c}	4.50^{b}	4.50^{cd}	4.05^{e}	4.00	0.4224^{c}	0.4288^{b}	0.4416^{c}	0.4736^{ab}	0.384
T2	MG - 2% ventilation	4.40^{c}	4.50^{b}	4.40^{d}	4.30^{d}	4.00	0.4224^{c}	0.4416^{b}	0.4864^{b}	0.5120^{a}	0.4096
T4	MG - Open (Control)	4.40^{c}	4.55^{b}	4.95^{b}	4.75^{ab}	-	0.4224^{c}	0.4480^{b}	0.3072^{e}	0.2816^{d}	-
T5	Br - Cling film	4.65^{b}	4.65^{b}	4.95^{b}	4.70^{b}	4.65	0.5248^{a}	0.4288^{b}	0.5376^{a}	0.4224^{bc}	0.3456
T6	Br - 2% Ventilation	4.65^{b}	4.65^{b}	4.95^{b}	4.70^{b}	4.60	0.5248^{a}	0.5568^{a}	0.5504^{a}	0.4608^{ab}	0.3968
T8	Br - Open (Control)	4.65^{b}	4.65^{b}	5.55^{a}	4.85^{a}	-	0.5248^{a}	0.5504^{a}	0.4224^{c}	0.3584^{c}	-
T9	FR - Cling film	5.00^{a}	4.80^{b}	4.60^{cd}	-	-	0.4736^{b}	0.3968^{c}	0.3200^{e}	-	-
T10	FR - 2% Ventilation	5.00^{a}	4.80^{b}	4.70^{bc}	4.55^{c}	-	0.4736^{b}	0.4032^{c}	0.3584^{d}	0.2688^{d}	-
T12	FR - Open (Control)	5.00^{a}	5.65^{a}	4.90^{b}	-	-	0.4736^{b}	0.3840^{c}	0.2688^{f}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 2b TSS and acidity of tomato fruits cv. PKM-1 under different storage techniques

		TSS (°brix)					Acidity (%)				
	Days	0	7	14	21	28	0	7	14	21	28
T13	MG - Cling film	4.00^{c}	4.25^{fg}	4.50^{c}	4.65^{ab}	4.6	0.5056^{b}	0.6016^{b}	0.7424^{a}	0.4992^{ab}	0.4608
T14	MG - 2% ventilation	4.00^{c}	4.10^{g}	4.35	4.55^{b}	4.5	0.5056^{b}	0.5760^{c}	0.7040^{ab}	0.4992^{ab}	0.4342
T16	MG - Open (Control)	4.00^{c}	4.35^{ef}	4.65^{c}	4.70^{a}	-	0.5056^{b}	0.5504^{d}	0.4992^{d}	0.4544^{bc}	-
T17	Br - Cling film	4.40^{b}	4.95^{c}	4.50^{d}	4.60^{ab}	4.65	0.5952^{a}	0.6016^{b}	0.6640^{bc}	0.4480^{bc}	0.4224
T18	Br - 2% Ventilation	4.40^{b}	4.45^{de}	4.65^{c}	4.70^{a}	-	0.5952^{a}	0.5952^{bc}	0.5120^{d}	0.4196^{c}	-
T20	Br - Open (Control)	4.40^{b}	5.25^{b}	4.85^{b}	-	-	0.5952^{a}	0.6912^{a}	0.6272^{c}	-	-
T21	FR - Cling film	4.75^{a}	4.55^{d}	4.20^{f}	-	-	0.5952^{a}	0.3840^{e}	0.3456^{e}	-	-
T22	FR - 2% Ventilation	4.75^{a}	4.55^{d}	4.05^{g}	-	-	0.5952^{a}	0.3904^{e}	0.3264^{e}	-	-
T24	FR - Open (Control)	4.75^{a}	6.05^{a}	5.05^{a}	-	-	0.5952^{a}	0.3840^{e}	0.3136^{e}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

4.1.2.1 Total soluble solids

Sakthi recorded an initial TSS of 4.4, 4.65 and 5.0 at different maturity stages viz. MG, Br and FR respectively. TSS has not changed significantly after 7 days of storage irrespective of the maturity, with a maximum in open storage of FR fruits (5.65). An increasing trend in TSS was seen in both MG and Br stage fruits till 14th day of storage and then showed a decline till the end of its shelf-life irrespective of the storage technique. For FR fruits, TSS steadily declined in T_9 and T_{10}, but for those under control, TSS increased till 7th day and then decreased. The minimum TSS (4.00) was observed in T_1 and T_2 after 28 days of storage.

The influence of storage techniques on TSS of fruits of cv. PKM-1 also showed similar results. An initial TSS of 4.0, 4.4 and 4.75 were recorded at MG, Br and FR stages of maturity respectively. The maximum increase in TSS during storage was recorded in FR fruits after one weeks of storage. The TSS of fruits under T_{13}, T_{14} and T_{17} were comparable (4.60, 4.50 and 4.65 respectively after 28 days of storage. The TSS of MG fruits increased till 21 days and later decreased, whereas in Br and FR control fruits, the increase was upto seven days and later decreased till the end of its storage period.

4.1.2.2 Acidity

Initial acidity at different stages of maturity significantly differed with lowest (0.4224) in MG fruits and maximum in Br stage fruits (0.5248). Acidity increased

with the advancement of storage in the case of treated MG fruits upto 21 days and later decreased; whereas in Br stage, the increase was only upto 14 days and then decreased in the treated samples but the corresponding controls showed an increase only upto seven days and then decreased. FR fruits recorded a steady decrease in acidity throughout the storage upto 14 days.

Similarly for PKM-1, the lowest acidity was reached for MG fruits (0.5056) which was significantly lower to Br and FR fruits. An increase in acidity upto 14th day was noticed for treatments T_{13}, T_{14} and T_{17}, whereas the increase was only upto 7 days in T_{16}, T_{18} and T_{20}.

4.1.3 pH and ascorbic acid

Data on pH and ascorbic acid of fruits of cv. Sakthi and PKM-1 are presented in tables 3a and 3b respectively.

4.1.3.1 pH

pH of both the varieties showed a declining trend during its normal ripening as indicated by its initial pH values. In the case of cv. Sakthi, it declined from 4.15 at MG stage to 4.00 at FR stage, whereas for cv. PKM-1, it declined from 4.29 at MG stage to 4.16 at FR stage.

Table no. 3b pH and ascorbic acid of tomato fruits cv. PKM-1 under different storage techniques

		pH					Ascorbic acid (mg/100g)				
	Days →	0	7	14	21	28	0	7	14	21	28
T13	MG - Cling film	4.29^{a}	4.25^{a}	4.08^{bc}	4.05^{a}	3.85	16.08^{c}	16.00^{f}	16.06^{c}	15.14^{d}	14.02
T14	MG - 2% ventilation	4.29^{a}	4.18^{a}	4.18^{ab}	4.03^{a}	3.95	16.08^{c}	16.42^{c}	16.60^{d}	16.09^{c}	15.88
T16	MG - Open (Control)	4.29^{a}	4.25^{a}	4.25^{a}	4.10^{a}	-	16.08^{c}	16.10^{ef}	15.12^{f}	15.02^{d}	-
T17	Br - Cling film	4.22^{ab}	4.15^{a}	3.20^{d}	3.88^{b}	3.73	21.68^{a}	21.55^{b}	19.42^{b}	19.24^{b}	19.08
T18	Br - 2% Ventilation	4.22^{ab}	4.20^{a}	4.20^{ab}	4.08^{a}	-	21.68^{a}	21.94^{a}	21.61^{a}	20.73^{a}	-
T20	Br - Open (Control)	4.22^{ab}	4.20^{a}	4.20^{ab}	-	-	21.68^{a}	18.64^{c}	17.51^{c}	-	-
T21	FR - Cling film	4.16^{b}	4.15^{a}	4.21^{ab}	-	-	18.49^{b}	17.04^{d}	16.74^{d}	-	-
T22	FR - 2% Ventilation	4.16^{b}	4.15^{a}	4.21^{ab}	-	-	18.49^{b}	17.08^{d}	16.83^{d}	-	-
T24	FR - Open (Control)	4.16^{b}	4.11^{a}	4.03^{cd}	-	-	18.49^{b}	16.38^{ef}	15.98	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 3a pH and ascorbic acid of tomato fruits cv. Sakthi under different storage techniques

		pH					Ascorbic acid (mg/100g)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - Cling film	4.15	4.20^{cd}	4.20^{de}	4.20^{d}	4.28	28.95^{c}	30.53^{cd}	27.74^{c}	26.03^{c}	24.06
T2	MG - 2% ventilation	4.15	4.16^{de}	4.20^{de}	4.28^{c}	4.35	28.95^{c}	30.42^{d}	27.01^{d}	25.49^{c}	23.88
T4	MG - Open (Control)	4.15	4.20^{d}	4.21^{de}	4.56^{a}	-	28.95^{c}	29.26^{e}	28.39^{c}	25.42^{c}	-
T5	Br - Cling film	4.08	4.10^{e}	4.15^{e}	4.25^{cd}	4.25	30.83^{b}	31.49^{ab}	31.85^{b}	31.39^{a}	29.08
T6	Br - 2% Ventilation	4.08	4.17^{d}	4.18^{e}	4.25^{cd}	4.28	30.83^{b}	31.17^{bc}	31.19^{b}	31.08^{a}	27.49
T8	Br - Open (Control)	4.08	4.16^{de}	4.29^{c}	4.37^{b}	-	30.83^{b}	31.92^{a}	32.61^{a}	30.46^{b}	-
T9	FR - Cling film	4.00	4.31^{ab}	4.53^{a}	-	-	31.38^{a}	26.98^{g}	22.73^{e}	-	-
T10	FR - 2% Ventilation	4.00	4.27^{bc}	4.53^{a}	4.53^{a}	-	31.38^{a}	25.80^{h}	21.47^{f}	20.36^{d}	-
T12	FR - Open (Control)	4.00	4.38^{a}	4.40^{b}	-	-	31.38^{a}	28.52^{f}	23.39^{e}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

In general, fruits of cv. Sakthi showed an increasing trend in pH during storage irrespective of stage of harvest and storage treatments. However, a slight increase in pH is seen on the 28th day of storage in the case of T_1 and T_2 (4.28 and 4.35). Maximum pH (4.53) was observed in FR fruits of Sakthi on 21st day of storage under 2% ventilation. Whereas in control samples of both MG and Br the value of pH was higher than the respective treated samples after 21 days of storage. After 7 days, a slightly higher pH of 4.38 was observed in FR fruits kept open when compared to other treatments. Br fruits when wrapped individually with cling film showed the lowest pH (4.25) after 28 days of storage.

On the other hand, pH of cv. PKM-1 showed a declining trend towards the end of its storage period irrespective of the stage of harvest or storage treatment. pH was significantly low (3.88) after 21 days of storage in Br fruits wrapped individually in cling film.

4.1.3.2 Ascorbic acid

The ascorbic acid content of fruits of cv. Sakthi ranged between 20.36 and 31.85 mg/100g and that of PKM-1, between 14.02 and 21.94 mg/100g.

The initial values ranged significantly with the stage of maturity in both the cultivars. In all the treatments the ascorbic acid content varied significantly upto 7 days of storage. Thereafter it increased in treatments T_5 and T_6 upto 14 days and

subsequently decreased. FR fruits showed a steep decline throughout the storage period regardless of the storage technique adopted.

The trend was similar for cv. PKM-1 also.

4.1.4 Influence of different storage techniques on the sugar content of tomato fruits

Changes in sugar content (total and reducing sugars) of fruits of cv Sakthi and PKM-1 as influenced by different storage techniques are presented in tables 4a and 4b.

4.1.4.1 Total sugars

A significantly increasing trend was evident from the initial values of total sugars of both the cultivars, when the stage advanced from MG to FR. Excepting T_9, T_{10} and T_{12}, all other treatments were on par with respect to total sugar on the 7th day of its storage. The maximum value (3.196) was recorded in the case of Br stage fruits under 2% ventilation on 14th day. There was no significant difference between the values on the 21st day, irrespective of the storage treatments. The total sugar content of those treatments, which lasted for 28 days was found to be less than their corresponding initial values.

Table no. 4a Total sugars and reducing sugars of tomato fruits cv. Sakthi under different storage techniques

		TOTAL SUGARS (%)					REDUCING SUGARS (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - Cling film	2.743	2.929^{ab}	3.195^{ab}	2.406^{a}	1.751^{b}	2.549	2.651	3.022^{ab}	2.173^{b}	1.539
T2	MG - 2% ventilation	2.743	2.828^{ab}	2.946^{b}	2.455^{a}	2.190^{a}	2.549	2.693	2.835^{b}	2.262^{ab}	1.818
T4	MG - Open (Control)	2.743	2.732^{b}	2.214^{cd}	1.562^{b}	-	2.549	2.577	2.109^{c}	1.430^{d}	-
T5	Br - Cling film	2.899	2.967^{a}	3.369^{a}	2.364^{a}	2.054^{a}	2.592	2.744	3.216^{a}	2.277^{ab}	1.896
T6	Br - 2% Ventilation	2.899	2.999^{a}	3.196^{ab}	2.602^{a}	2.041^{a}	2.592	2.902^{a}	2.985^{ab}	2.407^{a}	1.614
T8	Br - Open (Control)	2.899	3.027^{a}	2.471^{c}	2.021^{ab}	-	2.592	2.671	2.312^{c}	1.747^{c}	-
T9	FR - Cling film	3.158	2.621^{b}	2.038^{de}	-	-	2.470	2.649	1.304^{d}	-	-
T10	FR - 2% Ventilation	3.158	2.286^{c}	1.847^{e}	1.615^{b}	-	2.470	2.194^{bc}	1.460^{d}	1.342^{d}	-
T12	FR - Open (Control)	3.158	2.261^{c}	1.831^{e}	-	-	2.470	2.120^{c}	1.355^{d}	-	-

2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

Table no. 4b Total sugars and reducing sugars of tomato fruits cv. PKM-1 under different storage techniques

		TOTAL SUGARS (%)					REDUCING SUGARS (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T13	MG - Cling film	2.45	3.061^{ab}	2.116^{d}	2.100^{a}	1.406	2.267^{b}	2.737^{ab}	1.879^{c}	1.731^{ab}	1.243
T14	MG - 2% ventilation	2.45	3.170^{a}	3.240^{a}	2.220^{a}	1.79	2.267^{b}	2.882^{a}	2.619^{a}	1.864^{a}	1.429
T16	MG - Open (Control)	2.45	2.758^{bc}	2.647^{b}	2.109^{a}	-	2.267^{b}	2.570^{bc}	2.192^{b}	1.857^{a}	-
T17	Br - Cling film	2.826	2.813^{b}	2.413^{bc}	2.166^{a}	1.886	2.322^{b}	2.643^{bc}	2.099^{bc}	1.931^{a}	1.65
T18	Br - 2% Ventilation	2.826	2.952^{ab}	2.223^{cd}	2.060^{a}	-	2.322^{b}	2.671^{abc}	1.133^{d}	1.575^{b}	-
T20	Br - Open (Control)	2.826	3.167^{a}	2.238^{cd}	-	-	2.322^{b}	2.972^{a}	2.033^{bc}	-	-
T21	FR - Cling film	2.991	1.524	1.330^{e}	-	-	3.091^{a}	1.466^{d}	1.182^{d}	-	-
T22	FR - 2% Ventilation	2.991	2.226^{d}	1.829		-	3.091^{a}	1.812^{d}	1.405^{d}	-	-
T24	FR - Open (Control)	2.991	2.450^{cd}	1.488^{e}	-	-	3.091^{a}	2.325^{c}	1.222^{d}	-	-

2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

There was a significant difference in the initial values of total sugars for cv. PKM-1 during the different stages of maturity; the values showing an increasing trend with maturity stage (2.450% for MG and 2.991% for FR fruits). The maximum sugar content was attained in MG fruits after 14 days of storage under 2% ventilation (3.240%) whereas after 28 days the sugar content got reduced to 1.790% for the same treatment. FR fruits showed a continuous declining trend towards the end of storage period irrespective of the storage technique adopted, and the lowest value (1.330%) was recorded to by FR fruits wrapped with cling films (T_{21}) after 14 days of storage.

4.1.4.2 Reducing sugars

Reducing sugar content of fruits of cv. Sakthi also showed a similar trend to that of total sugars. Initial reducing sugar was maximum in Br stage fruits (2.592%) and least in FR fruits (2.470%). In MG and Br stage control fruits, the values showed an increasing trend till 7 days of storage, whereas there was an increase till 14 days in the corresponding treatments. FR control fruits showed a continuously declining trend till the end of the storage period. However between treatments there was no significant difference in reducing sugars till 7 days. Maximum reducing sugar content after 14 days of storage was observed in Br stage (3.216%) wrapped with cling film. Whereas the lowest value was recorded in FR fruits irrespective of the treatments after the same period of storage.

Though there was no significant difference in the initial values of reducing sugars of PKM-1 between MG and Br stages, FR values differed significantly from the rest. After 14 days of storage, MG fruits under 2% ventilation showed a maximum reducing sugar content of 2.619% and least value in FR fruits irrespective of treatments.

After 21 days of storage, Br fruits under 2% ventilation (T_{18}) showed the least reducing sugar content (1.575%) which was significantly different from other treatments. The final value of reducing sugars were much lesser than their initial values regardless of the storage treatments.

4.1.5 Effect of different storage techniques on the firmness and pectin content

Data on the changes in firmness and pectin content of tomato fruits cv. Sakthi and PKM-1 under the three maturity stages are given in tables 5a and 5b.

4.1.5.1 Firmness

It is evident from the data that MG fruits of cv. Sakthi were distinctly firmer than either Br stage or FR fruits. There was significant difference between the treatments involving all the three maturity stages after 7 days of storage.

It was observed that the same treatments involving different maturity stages varied significantly in firmness on the 14th day of storage, whereas no significant

Table no. 5a Firmness and pectin content of tomato fruits cv. Sakthi under different storage techniques

		FIRMNESS (Pressure kg/cm^2)					PECTIN (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - Cling film	4.5	3.70^{a}	2.40^{b}	2.15^{b}	1.9	0.045	0.040^{a}	0.035^{a}	0.030^{a}	0.01
T2	MG - 2% ventilation	4.5	3.90^{a}	3.25^{a}	2.50^{a}	1.9	0.045	0.040^{a}	0.035^{a}	0.030^{a}	0.01
T4	MG - Open (Control)	4.5	3.55^{a}	1.90^{bcd}	1.65^{c}	-	0.045	0.035^{a}	0.020^{ab}	0.010^{ab}	-
T5	Br - Cling film	3.05	2.90^{b}	1.85^{cde}	1.60^{c}	1.4	0.035	0.035^{a}	0.020^{ab}	0.015^{ab}	0.01
T6	Br - 2% Ventilation	3.05	2.78^{b}	2.30^{bc}	1.45^{cd}	1.3	0.035	0.025^{a}	0.020^{ab}	0.010^{ab}	Traces^{b}
T8	Br - Open (Control)	3.05	2.65^{b}	1.65^{def}	1.48^{cd}	-	0.035	0.020^{ab}	0.010^{b}	Traces^{b}	-
T9	FR - Cling film	2.63	1.65^{c}	1.38^{f}	-	-	0.01	Traces^{b}	Traces^{b}	-	-
T10	FR - 2% Ventilation	2.63	1.95^{c}	1.40^{ef}	1.25^{d}	-	0.01	Traces^{b}	Traces^{b}	Traces^{b}	-
T12	FR - Open (Control)	2.63	1.70^{c}	1.44^{ef}	-	-	0.01	Traces^{b}	Traces^{b}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 5b Firmness and pectin content of tomato fruits cv. PKM-1 under different storage techniques

		FIRMNESS (Pressure kg/cm^2)					PECTIN (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T13	MG - Cling film	4.03	3.20^{a}	2.15^{b}	1.90^{a}	1.77	0.050	0.040^{a}	0.035^{a}	0.030^{a}	0.2
T14	MG - 2% ventilation	4.03	3.05^{a}	2.55^{a}	2.00^{a}	1.70	0.050	0.035^{ab}	0.025^{ab}	0.015^{ab}	0.01
T16	MG - Open (Control)	4.03	3.20^{a}	2.05^{bc}	1.70^{b}	-	0.050	0.040^{a}	0.025^{ab}	0.020^{ab}	-
T17	Br - Cling film	2.80	2.25^{c}	1.95^{bc}	1.65^{b}	1.50	0.030	0.030^{abc}	0.020^{abc}	0.015^{ab}	0.01
T18	Br - 2% Ventilation	2.80	2.65^{b}	2.10^{bc}	1.55^{b}	-	0.030	0.020^{abc}	0.010^{bc}	Traces^{b}	-
T20	Br - Open (Control)	2.80	2.15^{c}	1.80^{c}	-	-	0.030	0.025^{abc}	0.020^{abc}	-	-
T21	FR - Cling film	2.30	2.00^{cd}	1.45^{d}	-	-	0.015	0.015^{bc}	0.010^{bc}	-	-
T22	FR - 2% Ventilation	2.30	2.05^{c}	1.40^{d}	-	-	0.015	0.015^{bc}	Traces^{c}	-	-
T24	FR - Open (Control)	2.30	1.65^{d}	1.28^{d}	-	-	0.015	0.010^{c}	Traces^{c}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

difference was observed in the firmness of Br stage and FR fruits even after 21 days, under different treatments. However, all the three treatments involving MG fruits were found to differ significantly in their firmness, with least value recorded for control and maximum firmness when stored under 2% ventilation.

The trend was similar in cv. PKM-1 with maximum initial firmness in MG fruits (4.03) and minimum initial values for FR fruits (2.30). No significant difference in firmness was observed on the 7th day, between treatments involving MG fruits, but fruits of Br stage and FR stage under 2% ventilation were distinctly different from the other two treatments with the corresponding maturity stages. After 21 days of storage, MG fruits under 2% ventilation recorded maximum firmness (2.00).

4.1.5.2 Pectin

The data presented in table 9 showed that there was a progressive decrease in pectin content of Sakthi fruits (from 0.045% to 0.010%) with the advancement in ripening regardless of the stage of harvest. There was no significant difference between the initial pectin content of MG and Br stage fruits, but differed significantly with that of FR fruits. Same trend was observed even after 7 days of storage. During the later stages of storage, the control fruits had lesser pectin content than their corresponding treated samples.

Between the stages of harvest, the pectin content of cv. PKM-1 reduced from 0.050% in MG fruits to 0.015%. During storage also, the pectin content of the fruits decreased progressively towards the final stage of storage irrespective of the

treatments. There was no significant difference between the pectin contents among the treatments involving fruits of same maturity on the 7th and 14th day.

4.1.6 Changes in lycopene content

Data on the changes in lycopene content of tomato fruits cv. Sakthi and PKM-1 as effected by different storage techniques is presented in table 6.

It was observed that as the maturity of the fruits of both the varieties advanced from MG to FR, there was considerable increase in lycopene content. The lycopene content of fruits under each treatment on the 7th and 14th day irrespective of the variety differed significantly. In the case of cv. Sakthi, lycopene development on 7th day was least in MG fruits (0.2350), kept under 2% ventilation + ethylene absorbent and maximum for FR control fruits. MG fruits kept under the same treatment showed the least colour development as the end of the storage period in both the varieties.

4.2 Standardisation of packing medium

The results of the experiment using sawdust as a packing medium, its proportion by weight to tomatoes and the extent of moistening required, to extent the shelf-life of tomatoes cv. Sakthi and PKM-1 are presented in tables 7a and 7b respectively.

Table no. 6 Lycopene content of tomato fruits under different storage techniques

		SAKTHI					PKM-1				
	Days→	0	7	14	21	28	0	7	14	21	28
T1/T13	MG - Cling film	0.1237^{c}	0.2603^{h}	0.3730^{i}	0.8885^{g}	1.782^{b}	0.1291^{c}	0.9908^{h}	1.6880^{g}	1.8970^{c}	2.9620^{b}
T2/T14	MG - 2% ventilation	1.1237^{c}	0.2350^{i}	0.4610^{g}	0.9571^{f}	1.427^{c}	0.1291^{c}	0.3260^{i}	0.8921^{i}	1.6580^{d}	2.3440^{d}
T4/T16	MG - Open (Control)	0.1237^{c}	0.2908^{g}	0.4368^{h}	1.6380^{c}	-	0.1291^{c}	1.5380^{f}	2.3930^{f}	3.8260^{a}	-
T5/T17	Br - Cling film	0.2724^{b}	0.6288^{f}	1.2610^{e}	1.5440^{e}	2.057^{a}	0.6054^{b}	2.1330^{e}	2.9750^{e}	3.7990^{a}	3.9560^{a}
T6/T18	Br - 2% Ventilation	0.2724^{b}	0.6615^{e}	1.1420^{f}	1.5910^{d}	2.1280^{a}	0.6054^{b}	1.2270^{g}	1.9290^{g}	2.5920^{b}	-
T8/T20	Br - Open (Control)	0.2724^{b}	0.8319^{d}	1.8580^{d}	2.1200^{b}	-	0.6054^{b}	2.5380^{d}	3.8750^{b}	-	-
T9/T21	FR - Cling film	2.1380^{a}	2.1940^{c}	2.7190^{b}	-	-	4.0180^{a}	3.8620^{c}	3.6260^{d}	-	-
T10/ T22	FR - 2% Ventilation	2.1380^{a}	2.2610^{b}	2.6610^{c}	2.5860^{a}	-	4.0180^{a}	4.0920^{a}	3.7670^{c}	-	-
T12/ T24	FR - Open (Control)	2.1380^{a}	2.2870^{a}	2.8590^{a}	-	-	4.0180^{a}	4.0540^{b}	3.9320^{a}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 7a PLW, decay percentage and marketability of tomato fruits cv. Sakthi stored under saw dust

		PLW (%)				DECAY (%)				MARKETABILITY (%)			
	Days →	7	14	21	28	7	14	21	28	7	14	21	28
T1	IM - 1:0.5 T:SD	0.58^{e}	1.20^{c}	1.74^{d}	3.81	0.0	0.0	24.12^{c}	57.29	99.43^{a}	98.80^{a}	74.15^{a}	38.91
T2	IM - 1:1 T:SD	0.81^{d}	1.30^{c}	1.89^{d}	-	0.0	34.56^{b}	77.07^{a}	-	99.19^{a}	64.15^{b}	21.04^{b}	-
T3	IM - 1:1.5 T:SD	1.52^{d}	2.43^{c}	3.21^{c}	-	15.99^{b}	38.87^{b}	70.60^{ab}	-	82.49^{a}	58.71^{b}	26.19^{b}	-
T4	Dry 1:0.5 T:SD	4.17^{c}	8.23^{b}	10.81^{b}	12.64	0.0	0.0	12.77^{c}	45.14	95.83^{a}	91.77^{a}	76.42^{a}	42.23
T5	Dry 1:1 T:SD	8.45^{a}	12.32^{a}	18.69^{a}	-	0.0	26.83^{c}	53.02^{b}	-	91.55^{a}	60.86^{b}	28.29^{b}	-
T6	Dry 1:1.5 T:SD	7.14^{b}	13.74^{a}	-	-	0.0	52.75^{a}	-	-	92.86^{a}	33.51^{d}	-	-
T7	M 1:0.5 T:SD	0.53^{e}	-	-	-	23.86^{b}	-	-	-	75.62^{a}	-	-	-
T8	M 1:1 T:SD	0.51^{e}	-	-	-	46.94^{a}	-	-	-	52.56^{b}	-	-	-
T9	M 1:1.5 T:SD	0.41^{e}	-	-	-	63.99^{a}	-	-	-	35.60^{b}	-	-	-
T10	Control	3.49^{c}	7.75^{b}	-	-	0.0	47.01^{a}	-	-	96.54^{a}	45.39^{c}	-	-

1. IM - Inherent moisture (35 - 40%)
   Dry - Moisture content <20%
   M - Moistened (60%)

2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

Table no. 7b PLW, decay percentage and marketability of tomato fruits cv. PKM-1 stored under saw dust

		PLW (%)				DECAY (%)				MARKETABILITY (%)			
Days →		7	14	21	28	7	14	21	28	7	14	21	28
T11	IM - 1:0.5 T:SD	0.86	1.55^{c}	2.24	3.05	0.0	0.0	29.83	61.33	99.14^{a}	98.46^{a}	67.93	35.62
T12	IM - 1:1 T:SD	2.49^{d}	4.92^{b}	7.08	-	0.0	21.75^{d}	56.61	-	97.51^{a}	73.33^{b}	36.32	-
T13	IM - 1:1.5 T:SD	2.07^{d}	4.72^{b}	-	-	0	55.60^{ab}	-	-	97.93^{a}	39.69^{d}	-	-
T14	Dry 1:0.5 T:SD	3.34^{c}	6.59^{b}	-	11.05	0.0	30.19^{cd}	33.77	60.25	96.67^{a}	63.22^{b}	56.64	28.71
T15	Dry 1:1 T:SD	6.24^{a}	10.10^{a}	9.59	-	0.0	43.49^{bc}	-	-	93.76^{ab}	46.40^{c}	-	-
T16	Dry 1:1.5 T:SD	6.55^{a}	10.93^{a}	-	-	11.06^{de}	44.71^{bc}	-	-	82.40^{b}	44.36^{c}	-	-
T17	M 1:0.5 T:SD	0.91^{c}	2.07^{c}	-	-	36.15^{c}	71.13^{a}	-	-	62.94^{c}	26.81^{d}	-	-
T18	M 1:1 T:SD	0.69^{c}	-	-	-	58.63^{b}	-	-	-	40.68^{d}	-	-	-
T19	M 1:1.5 T:SD	0.62^{c}	-	-	-	73.19^{a}	-	-	-	26.19^{e}	-	-	-
T20	Control	4.61^{b}	10.79^{a}	-	-	13.76^{d}	58.43^{ab}	-	-	81.63^{b}	38.74^{d}	-	-

1. IM - Inherent moisture (35 - 40%)
   Dry - Moisture content <20%
   M - Moistened (60%)

2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

4.2.1 Physiological loss in weight (PLW)

The PLW after 7 days of storage was minimum for Sakthi fruits in T_9 (1:1.5 tomato : moistened SD) and it was statistically on par with the PLW of T_1, T_7 and T_8. Tomatoes stored under sawdust with inherent moisture of 35.40% also showed less PLW than control, but was significantly higher than that of T_1, T_7, T_8 and T_9 whereas maximum PLW (8.45) during the same period was in T_5 (1:1 tomato : dried SD). Fruits stored under sawdust with inherent moisture (T_1, T_2 and T_3) showed less PLW after 14 days of storage regardless of the ratio, when compared with other treatments. The least cumulative PLW (3.81) at the end of the storage period (28 days) was recorded in the case of T_1 (1:0.5 tomato : SD with inherent moisture).

A similar trend was observed in the case of cv. PKM-1 also. The least PLW during the 4 weeks of storage was observed in fruits stored under treatment 1:0.5 tomato : SD with inherent moisture.

4.2.1 Decay percentage

Conspicuous decay after 7 days of storage was observed only in those samples where SD was moistened (T_8 and T_9) which were above 50%. After the second week of storage, almost all the treatments other than T_1 and T_4 showed decay. Those treatments remained till 28 days with decay percentage less than 50%. Whereas, when sawdust was moistened, the decay percentage also increased proportionately (T_7, T_8 and T_9).

Similarly, in PKM-1 also, all the treatments involving moistened sawdust had to be terminated after 14 days of storage due to high rate of decay, whereas T_1 (1:0.5) with inherent moisture did not show any decay till 14 days of storage. In general, it was observed that in both the varieties, as the tomato : SD ratio is increased from 1:0.5 to 1:1.5, the decay percentage was also found to be on the increase regardless of the moisture content in the sawdust.

4.2.3 Marketability

Tomatoes of both the cultivars remained superior in their marketability values, when stored under 1:0.5 tomato : SD ratio with inherent moisture and with a moisture level below 20% (dry), during the 4 weeks of storage. Fruits stored under moistened sawdust were rendered unmarketable even during the first week of storage since their marketability values fell below 50% level.

4.3 Standardisation of stages of harvest for the best treatment of experiment no.2

The response of tomato fruits cv. Sakthi and PKM-1 to the best treatment in experiment 2 (storage under 1:0.5 tomato : SD with inherent moisture of 35-40%) with 3 stages of maturity viz., MG, Br and FR are presented in tables 8 to 14.

4.3.1 Physiological loss in weight, decay percentage and marketability

The changes in PLW, decay percentage and marketability of fruits of different maturity stages when stored under equilibrated sawdust (ESD) ie., 1:0.5 tomato : SD with inherent moisture of 35-40% are presented in tables 8a and 8b.

Table no. 8a Effect of stage of maturity on PLW, decay percentage and marketability of tomato fruits cv. Sakthi stored under ESD

	Days	PLW (%)				DECAY (%)				MARKETABILITY (%)			
		7	14	21	28	7	14	21	28	7	14	21	28
T1	MG - 1:0.5 T:SD	0.64^{d}	1.40^{e}	2.40^{e}	4.77	0.0^{b}	0.0^{c}	7.03^{c}	49.68	99.36^{a}	97.60^{a}	90.57^{a}	45.54
T2	MG - Control	4.34^{b}	8.56^{b}	12.19^{b}	-	0.0^{b}	20.65^{bc}	52.42^{a}	-	95.66^{ab}	70.79^{b}	35.38^{cd}	-
T3	Br - 1:0.5 T:SD	1.82^{c}	3.32^{d}	4.63^{d}	6.16	0.0^{b}	0.0^{c}	28.10^{bc}	47.67	98.18^{a}	96.68^{a}	67.27^{b}	46.17
T4	Br - Control	5.93^{a}	10.19^{a}	14.66^{a}	-	0.0^{b}	27.93^{b}	59.58^{a}	-	94.07^{ab}	61.88^{b}	25.76^{d}	-
T5	FR - 1:0.5 T:SD	3.92^{b}	7.24^{c}	8.82^{c}	-	5.41^{b}	30.86^{b}	57.68^{a}	-	90.68^{ab}	61.90^{b}	33.49^{cd}	-
T6	FR - Control	5.71^{a}	10.27^{a}	-	-	30.97^{a}	77.33^{a}	-	-	58.31^{c}	12.39^{c}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 8b Effect of stage of maturity on PLW, decay percentage and marketability of tomato fruits cv. PKM-1 stored under ESD

		PLW (%)				DECAY (%)				MARKETABILITY (%)			
	Days →	7	14	21	28	7	14	21	28	7	14	21	28
T7	MG - 1:0.5 T:SD	0.75^{c}	1.82^{d}	2.91^{c}	4.17^{a}	0.0^{c}	0.0^{c}	13.65^{d}	39.57	99.25^{a}	98.18^{a}	83.45^{a}	56.26
T8	MG - Control	2.31^{cd}	5.34^{b}	10.36^{a}	-	0.0^{c}	22.83^{bc}	64.89^{a}	-	97.69^{a}	71.83^{b}	24.92^{c}	-
T9	Br - 1:0.5 T:SD	2.74^{bcd}	5.28^{b}	7.88^{ab}	12.65^{a}	0.0^{c}	0.0^{c}	21.67^{bc}	49.08	97.26^{a}	94.72^{a}	70.46^{b}	38.27
T10	Br - Control	4.61^{a}	10.78^{a}	-	-	13.76^{b}	50.48^{a}	-	-	81.63^{b}	38.74^{c}	-	-
T11	FR - 1:0.5 T:SD	1.84^{d}	3.98^{cd}	8.33^{ab}	-	0.0^{c}	26.39^{b}	54.08^{a}	-	98.16^{a}	69.63^{b}	37.59^{bc}	-
T12	FR - Control	5.31^{a}	8.95^{a}	-	-	35.76^{a}	63.14^{a}	-	-	58.93^{c}	27.91^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

4.3.1.1 Physiological loss in weight (PLW)

It was observed that as the maturity of the fruits advanced from MG to FR, there was a significant increase in PLW for Sakthi fruits stored under ESD even within 7 days of its storage. The same trend was followed till 28 days, with least cumulative PLW recorded in MG fruits (4.77) followed by Br stage (6.16).

The trend was same for PKM-1 fruits also. In this case, the cumulative PLW of Br stage fruits (12.65) was much higher than that of MG fruits (4.17).

4.3.1.2 Decay percentage

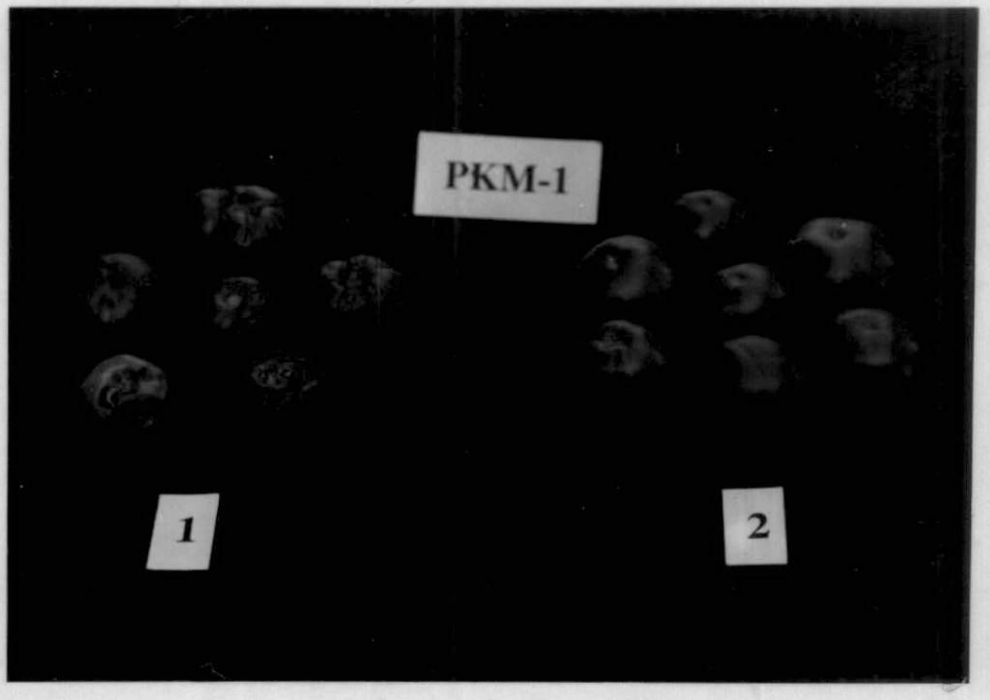
Spoilage was not observed in both the varieties of MG and Br fruits till 14 days of storage under ESD. For fruits of cv. Sakthi, the maximum spoilage was observed in FR control fruits whereas Br fruits showed the least spoilage(47.67%) under ESD followed by stage MG fruits (49.68%) after 28 days of storage. In both the cases, the spoilage was below 50%. [Plate 7]

The same trend was shown by PKM-1 also. [Plate 8]

Plate 7 - Tomatoes of cv. Sakthi after three weeks of ESD storage (2) in comparison with their control (1)

Plate 8 - Tomatoes of cv. PKM-1 after three weeks of ESD storage (2) in comparison with their control (1)


SAKTHI
1
2


PKM-1
1
2

4.3.1.3 Marketability

Marketability values for fruits of Sakthi under three maturity stages on the 7th day were comparable except for the FR control fruits. During the third week of storage, MG fruits under T_1 exhibited a significantly greater value of marketability (90.57%) than Br stage fruits (67.27%) with the same treatment. However, it was on par by the fourth week of storage with less than 50% value.

For fruits of PKM-1, the difference in marketability were insignificant between T_7 and T_9 during the first two weeks of storage; but by the third week, T_7 retained a superior value of 83.45%, followed by T_9 (70.46%).

4.3.2 Stage of maturity on TSS and acidity

Changes in TSS and acidity of tomato fruits cv. Sakthi and PKM-1 under three maturity stages as effected by storage under ESD are presented in tables 9a and 9b.

4.3.2.1 Total soluble solids (TSS)

TSS of MG fruits of cv. Sakthi were found to increase, till the 7th day and thereafter it showed a declining trend and reached a value (3.85) much below the initial TSS of 4.40. But in breaker stage treated fruits, the TSS was on the

Table no. 9a Effect of stage of maturity on TSS and acidity of tomato fruits cv. Sakthi stored under ESD

		TSS (° brix)					ACIDITY (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - 1:0.5 T:SD	4.40^{c}	4.45^{c}	4.00^{d}	3.95^{b}	3.85^{b}	0.4224^{c}	0.4288^{b}	0.4352^{b}	0.5120^{a}	0.3904^{a}
T2	MG - Control	4.40^{c}	4.55^{bc}	4.95^{c}	4.75^{a}	-	0.4224^{c}	0.4480^{b}	0.3072^{d}	0.2816^{c}	-
T3	Br - 1:0.5 T:SD	4.65^{b}	4.55^{bc}	5.20^{b}	4.75^{a}	4.65^{a}	0.5248^{a}	0.5376^{a}	0.5440^{a}	0.4480^{a}	0.3968^{a}
T4	Br - Control	4.65^{b}	4.65^{bc}	5.55^{a}	4.85^{a}	-	0.5248^{a}	0.5504^{a}	0.4224^{b}	0.3584^{b}	-
T5	FR - 1:0.5 T:SD	5.00^{a}	4.50^{bc}	4.05^{d}	4.00^{b}	-	0.4736^{b}	0.4416^{b}	0.3968^{c}	0.2434^{d}	-
T6	FR - Control	5.00^{a}	5.65^{a}	4.90^{c}	-	-	0.4736^{b}	0.3840^{c}	0.2688^{e}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 9b Effect of stage of maturity on TSS and acidity of tomato fruits cv. PKM-1 stored under ESD

		TSS (° brix)					ACIDITY (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T7	MG - 1:0.5 T:SD	4.00^{c}	4.20^{d}	4.35^{d}	4.05^{b}	4.10^{b}	0.5056^{b}	0.6144^{b}	0.7744^{a}	0.5376^{a}	0.4096^{a}
T8	MG - Control	4.00^{c}	4.35^{d}	4.65^{c}	4.70^{a}	-	0.5056^{b}	0.5504^{c}	0.4992^{c}	0.4544^{b}	-
T9	Br - 1:0.5 T:SD	4.40^{b}	5.10^{b}	4.70^{c}	4.65^{a}	4.40^{a}	0.5952^{a}	0.5952^{b}	0.7680^{a}	0.5037^{ab}	0.4608^{a}
T10	Br - Control	4.40^{b}	5.25^{b}	4.85^{b}	-	-	0.5952^{a}	0.6912^{a}	0.6272^{b}	-	-
T11	FR - 1:0.5 T:SD	4.75^{a}	4.85^{c}	4.75^{c}	4.10^{b}	-	0.5952^{a}	0.3072^{c}	0.6144^{b}	0.5120^{ab}	-
T12	FR - Control	4.75^{a}	6.05^{a}	5.05^{a}	-	-	0.5952^{a}	0.3840^{d}	0.3136^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

increase and reached a maximum of 5.20 on the 14th day and then decreased to 4.65 which was equivalent to its initial TSS. FR fruits showed a progressive decline in TSS till the end of storage period. There was significant difference between the TSS values of MG and Br stage fruits stored under ESD throughout the storage period.

On the contrary, MG fruits of cv. PKM-1 stored under ESD showed an increase in TSS till 14th day and thereafter decreased towards the end of the storage period. But the final TSS was slightly higher than the initial TSS. Br stage fruits under the same treatment showed an increase in TSS till 7th day and thereafter decreased to initial value of 4.40 at 28 days of storage. FR fruits also showed an increase in TSS till 7th day under the same treatment, but decreased to a much lesser value (4.10) than its initial TSS of 4.75. There was significant difference between the TSS of all the 3 maturity stages in all the treatments.

4.3.2.2 Acidity

Significant difference was observed between acidity of MG and Br stage fruits of cv. Sakthi stored under ESD during the first 2 weeks of storage. There was no significant difference after the 3rd and 4th week of storage. The acidity values of MG fruits stored under ESD increased till 3rd week, while Br stage fruits under the same treatment showed an increase only upto 2nd week of storage. The final acidity values were less than the initial values.

Acidity between MG and Br stage fruits of PKM-1 stored under ESD did not show any significant difference. However, there was an increasing trend within each stage with the advancement of storage period.

4.3.3 pH and ascorbic acid

Data on pH and ascorbic acid influenced by the stage of maturity of fruits cv. Sakthi and PKM-1 stored under ESD is given in tables 10a and 10b.

4.3.3.1 pH

Even though there was no significant difference in pH between the MG and Br stage of fruits of cv. Sakthi when stored under ESD throughout the storage, the values in pH of FR fruits showed distinctly higher values with that of MG and Br. The pH was found to increase steadily throughout the storage period, irrespective of the stage of maturity and storage treatment.

On the contrary, the pH of PKM-1 fruits was found to decrease with increase in storage period. However a slight increase in pH was observed during the 4^{th} week of storage in both MG and Br fruits and after 3^{rd} week for FR fruits. Control fruits showed a steadily declining trend. Barring the pH value of Br stage fruits after 21 days of storage under ESD, all other pH values under the same treatment did not differ significantly on any particular day of observation.

Table no. 10a **Effect of stage of maturity on** pH and ascorbic acid of tomato fruits cv. Sakthi stored under ESD

		pH					ASCORBIC ACID (mg/100g)				
	Days →	0	7	14	21	28	0	7	14	21	28
T7	MG - 1:0.5 T:SD	4.15^{a}	4.18^{cd}	4.22^{cd}	4.24^{c}	4.24^{a}	28.95^{c}	30.31^{b}	28.38^{b}	26.85^{c}	25.29^{b}
T8	MG - Control	4.15^{a}	4.20^{c}	4.21^{d}	4.56^{a}	-	28.95^{c}	29.26^{c}	28.39^{b}	25.42^{d}	-
T9	Br - 1:0.5 T:SD	4.08^{ab}	4.11^{d}	4.27^{cd}	4.29^{c}	4.30^{a}	30.83^{b}	31.94^{a}	32.87^{a}	32.06^{a}	30.01^{a}
T10	Br - Control	4.08^{ab}	4.16^{cd}	4.29^{c}	4.37^{b}	-	30.83^{b}	31.92^{a}	32.61^{a}	30.46^{b}	-
T11	FR - 1:0.5 T:SD	4.00^{b}	4.29^{b}	4.53^{a}	4.58^{a}	-	31.38^{a}	28.26^{d}	25.79^{c}	24.19^{e}	-
T12	FR - Control	4.00^{b}	4.38^{a}	4.39^{b}	-	-	31.38^{a}	28.52^{d}	23.39^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 10b **Effect of stage of maturity on** pH and ascorbic acid of tomato fruits cv. PKM-1 stored under ESD

		pH					ASCORBIC ACID (mg/100g)				
-	Days →	0	7	14	21	28	0	7	14	21	28
T7	MG - 1:0.5 T:SD	4.29^{a}	4.05^{bc}	3.79^{d}	3.96^{b}	4.04^{a}	16.08^{e}	16.19^{d}	16.26^{d}	15.39^{e}	15.07^{b}
T8	MG - Control	4.29^{a}	4.25^{a}	4.25^{a}	4.10^{a}	-	16.08^{e}	16.10^{d}	15.12	15.02^{e}	-
T9	Br - 1:0.5 T:SD	4.22^{ab}	3.98^{e}	3.85^{cd}	3.80^{c}	3.81^{a}	21.68^{a}	21.51^{a}	20.85^{a}	20.18^{a}	19.40^{a}
T10	Br - Control	4.22^{ab}	4.20^{ab}	4.20^{a}	-	-	21.68^{a}	18.64^{b}	17.51^{c}	-	-
T11	FR - 1:0.5 T:SD	4.16^{b}	4.10^{abc}	3.99^{b}	4.05^{ab}	-	18.49^{b}	18.10^{c}	18.06^{b}	17.89^{b}	-
T12	FR - Control	4.16^{b}	4.11^{abc}	4.03^{b}	-	-	18.49^{b}	16.38^{d}	15.98^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

4.3.3.2 Ascorbic acid

Ascorbic acid contents showed significant difference between the maturity stages of fruits of both the varieties throughout the storage period. The values showed a declining trend throughout and the ascorbic acid of Br stage fruits stored under ESD was significantly more than that of MG or FR fruits under the same conditions.

4.3.4 Total sugar and reducing sugar

Data on total sugars and reducing sugars of fruits of MG, Br and FR stages of cv. Sakthi and PKM-1 stored under ESD is presented in table 11a and 11b respectively.

4.3.4.1 Total sugar

The total sugar content of Sakthi fruits showed an increasing trend till 14th day in MG and Br stage fruits stored under ESD. The final total sugar content of both these treatments were less than their initial values. Br stage fruits stored under ESD exhibited a significantly higher total sugar content than MG fruits stored under the same condition. Excepting the total sugar content of Br stage fruits stored open, other controls showed a continuously declining trend towards the end of the storage period.

Table no. 11a **Effect of stage of maturity on** total sugars and reducing sugars of tomato fruits cv. Sakthi fruits stored under ESD

		Total sugar (%)					Reducing sugar (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - 1:0.5 T:SD	2.743^{a}	3.044^{a}	3.317^{a}	2.474^{a}	1.893^{b}	2.549^{a}	2.835^{a}	2.178^{b}	1.691^{c}	1.374^{a}
T2	MG - Control	2.743^{a}	2.732^{a}	2.214^{c}	1.562^{b}	-	2.549^{a}	2.577^{ab}	2.109^{bc}	1.430^{d}	-
T3	Br - 1:0.5 T:SD	2.899^{a}	3.033^{a}	3.43^{a}	2.364^{a}	2.202^{a}	2.592^{a}	2.605^{ab}	2.773^{a}	2.332^{a}	1.536^{a}
T4	Br - Control	2.899^{a}	3.027^{a}	2.471^{c}	2.021^{ab}	-	2.592^{a}	2.671^{ab}	2.312^{b}	1.747^{bc}	-
T5	FR - 1:0.5 T:SD	3.158^{a}	2.805^{a}	2.858^{b}	2.076^{ab}	-	2.470^{a}	2.711^{ab}	1.893^{c}	1.908^{b}	-
T6	FR - Control	3.158^{a}	2.261^{b}	1.831^{d}	-	-	2.470^{a}	2.120^{b}	1.355^{d}	-	-
		NS									

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level
3. Nonsignificant at 5%level

Table no. 11b Effect of stage of maturity on total sugars and reducing sugars of tomato fruits cv. PKM-1 stored under ESD

		Total sugar (%)					Reducing sugar (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T7	MG - 1:0.5 T:SD	2.450^{a}	3.210^{a}	2.186^{de}	2.168^{a}	1.776^{a}	2.267^{a}	3.091^{a}	2.214^{a}	1.984^{a}	1.483^{a}
T8	MG - Control	2.450^{a}	2.758^{bc}	2.647^{a}	2.109^{a}	-	2.267^{a}	2.570^{bcd}	2.192^{a}	1.857^{a}	-
T9	Br - 1:0.5 T:SD	2.826^{a}	2.971^{ab}	2.490^{bc}	2.110^{a}	1.921^{a}	2.322^{a}	2.737^{abc}	2.046^{b}	1.754^{ab}	1.645^{a}
T10	Br - Control	2.826^{a}	3.167^{a}	2.238^{cd}	-	-	2.322^{a}	2.972^{ab}	2.033^{b}	-	-
T11	FR - 1:0.5 T:SD	2.991^{a}	2.760^{bc}	2.085^{e}	1.695^{b}	-	3.091^{a}	2.293^{d}	1.790^{c}	1.565^{b}	-
T12	FR - Control	2.991^{a}	2.450^{c}	1.488^{f}	-	-	3.091^{a}	2.325^{cd}	1.222^{d}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

In the case of cv. PKM-1, both MG and Br stage fruits stored under ESD exhibited an increase in total sugar content till 7th day and thereafter declined. However, the total sugars of Br stage fruits under ESD was marginally higher than its corresponding value for MG fruits at the end of the storage period. Significant difference in total sugar was observed between MG and Br stage fruits under ESD only during 2nd week of storage.

4.3.4.2 Reducing sugars

Reducing sugars in Sakthi fruits differed significantly between MG, Br and FR fruits kept under ESD during the second week of storage. Both MG and FR fruits showed an increase in reducing sugars till 7th day whereas Br stage fruits showed an increase till 14th day when stored under ESD. The final reducing sugar values of Br stage fruits (1.536) was higher than that of MG stage (1.374). Control fruits showed a lower reducing sugar than those stored under ESD irrespective of the maturity stage, throughout the storage period.

In cv. PKM-1, MG and Br stage fruits showed an increase in reducing sugar content till 7 days of storage, and FR fruits showed a continuous decline. Significant difference was observed between the reducing sugars of all the maturity stages from the first week of storage itself. Reducing sugars were slightly higher in the case of MG fruits stored under ESD till 21st day and later showed a marginal decrease over the value of Br stage fruits after 28 days of storage.

4.3.5 Firmness and pectin

Data on firmness and pectin content of fruits of cv. Sakthi and PKM-1 under 3 maturity stages as influenced by ESD storage is presented in tables 12a and 12b respectively.

4.3.5.1 Firmness

Firmness of both the cultivars steadily decreased during the storage period irrespective of the treatments. Difference was significant between the firmness of MG and Br stage fruits stored under ESD throughout the storage period; with the fruits of MG being distinctly firmer than the Br stage fruits. FR fruits stored under ESD also was firmer than its corresponding control, but was less firm than the fruits of MG and Br stages.

4.3.5.2 Pectin

The difference in pectin content of MG and Br stage fruits of cv. Sakthi was significant after 14 days of storage. Whereas final pectin content of MG and Br stage fruits stored under ESD were on par.

Pectin content of MG and Br stage fruits of cv. PKM-1 significantly differed only during the first two weeks of storage. MG fruits had a significantly higher amount of pectin than the other two stages irrespective of the storage

Table no. 12a **Effect of stage of maturity** on firmness and pectin content of tomato fruits cv. Sakthi stored under ESD

		FIRMNESS (Pressure kg/cm^2)					PECTIN (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T1	MG - 1:0.5 T:SD	4.50^{a}	3.65^{a}	2.28^{a}	2.10^{a}	2.05^{a}	0.045^{a}	0.040^{a}	0.040^{a}	0.025^{a}	0.015^{a}
T2	MG - Control	4.50^{a}	3.55^{a}	1.90^{abcd}	1.65^{b}	-	0.045^{a}	0.035^{a}	0.020^{bc}	0.010^{ab}	-
T3	Br - 1:0.5 T:SD	3.05^{b}	2.65^{bc}	1.93^{abc}	1.70^{b}	1.45^{b}	0.035^{a}	0.030^{a}	0.015^{bc}	0.010^{ab}	0.015^{a}
T4	Br - Control	3.05^{b}	2.65^{bc}	1.65^{cd}	1.48^{b}	-	0.035^{a}	0.020^{ab}	0.010^{c}	Tr^{b}	-
T5	FR - 1:0.5 T:SD	2.63^{c}	2.33^{c}	2.10^{ab}	1.45^{b}	-	0.010^{b}	Tr^{b}	Tr^{c}	Tr^{b}	-
T6	FR - Control	2.63^{c}	1.70^{d}	1.44^{d}	-	-	0.010^{b}	Tr^{b}	Tr^{c}	-	-

1. Tr - Traces
2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

Table no. 12b **Effect of stage of maturity on** firmness and pectin content of tomato fruits cv. PKM-1 stored under ESD

		FIRMNESS (Pressure kg/cm^2)					PECTIN (%)				
	Days →	0	7	14	21	28	0	7	14	21	28
T7	MG - 1:0.5 T:SD	4.03^{a}	3.13^{a}	2.50^{a}	2.14^{a}	1.65^{a}	0.050^{a}	0.045^{a}	0.040^{a}	0.025^{a}	0.020^{a}
T8	MG - Control	4.03^{a}	3.20^{a}	2.05^{bc}	1.70^{b}	-	0.050^{a}	0.040^{ab}	0.025^{abc}	0.020^{a}	-
T9	Br - 1:0.5 T:SD	2.80^{b}	2.25^{b}	1.95^{bc}	1.65^{b}	1.50^{a}	0.030^{ab}	0.020^{bcd}	0.015^{bcd}	0.010^{a}	0.010^{a}
T10	Br - Control	2.80^{b}	2.15^{b}	1.80^{c}	-	-	0.030^{ab}	0.025^{abcd}	0.020^{abc}	-	-
T11	FR - 1:0.5 T:SD	2.30^{c}	2.18^{b}	1.90^{bc}	1.50^{b}	-	0.015^{b}	0.015^{cd}	0.010^{cd}	0.010^{a}	-
T12	FR - Control	2.30^{c}	1.65^{c}	1.28^{d}	-	-	0.015^{b}	0.010^{d}	Tr^{d}	-	-

1. Tr - Traces
2. Values represent mean of 2 replicates
3. Mean values with different superscripts differ significantly at 5% level

period and storage technique. The pectin content of MG fruits stored under ESD was marginally higher than the corresponding value of Br stage fruits at the end of the storage period, but they were statistically at par.

4.3.6 Effect of storage under ESD on lycopene

Data on lycopene content of fruits of cv. Sakthi and PKM-1 with three maturity stages, on storage under ESD is presented in table no. 13.

There was a significant difference in the lycopene content in all the treatments throughout the storage period irrespective of the stage of maturity and storage treatment. MG fruits of both the varieties stored under ESD had a slightly lesser lycopene content than its corresponding value for Br stage fruits throughout the storage period.

The lycopene content of MG fruits of Sakthi, on 28th day (0.3885) was equal to that of Br stage fruits on 7th day when stored under ESD. But the final lycopene content of breaker stage Sakthi fruits when stored under ESD (2.092) was comparable to the initial value (2.138) for FR fruits.

Though the lycopene content of MG fruits of cv. PKM-1 stored under ESD (T_7) on the 28th day was less than that of Br stage (T_9) fruits on the same day, it was higher than the lycopene content of Br stage fruits kept open on the 7th day.

Table no. 13 Effect of stage of maturity on lycopene content of tomato fruits cvs. Sakthi and PKM-1 stored under ESD (mg/100g)

		SAKTHI					PKM-1				
Days →		0	7	14	21	28	0	7	14	21	28
T1/T7	MG - 1:0.5 T:SD	0.1237^{c}	0.1306^{f}	0.1940^{f}	0.2626^{e}	0.3885^{b}	0.1291^{c}	0.8902^{f}	1.0310^{f}	1.5740^{c}	2.9360^{b}
T2/T8	MG - Control	0.1237^{c}	0.2908^{e}	0.4368^{e}	1.6380^{c}	-	0.1291^{c}	1.5380^{e}	2.3930^{d}	3.8260^{a}	-
T3/T9	Br - 1:0.5 T:SD	0.2724^{b}	0.3885^{d}	0.9728^{d}	1.4880^{d}	2.0920^{a}	0.6054^{b}	1.7700^{d}	2.3800^{e}	3.6030^{b}	3.8610^{a}
T4/T10	Br - Control	0.2724^{b}	0.8319^{c}	1.8580^{c}	2.1200^{a}	-	0.6054^{b}	2.5380^{c}	3.8750^{b}	-	-
T5/T11	Fr - 1:0.5 T:SD	2.1380^{a}	2.2610^{b}	2.142^{b}	2.0610^{b}	-	4.0180^{a}	4.2160^{a}	3.7610^{c}	3.7280^{ab}	-
T6/T12	FR - Control	2.1380^{a}	2.2870^{a}	2.859^{a}	-	-	4.0180^{a}	4.0540^{b}	3.9320^{a}	-	-

1. Values represent mean of 2 replicates
2. Mean values with different superscripts differ significantly at 5% level

Table no. 14 Organoleptic evaluation of fruit samples

		Whole fruit			Cut fruit		Taste		
		Overall appearance	Fruit colour	Fruit firmness	Overall appearance	Internal colour	Sweetness	Sourness	Flavour
Sakthi	Stored sample	7.37	7.07	7.10	7.17	7.20	5.93	5.00	5.67
	Fresh sample	7.57	6.80	7.63	7.23	5.87	5.33	5.73	5.87
	't' value	-0.3550	0.4781	-0.9950	-0.1065	1.8581	0.6826	-0.5181	-0.1808
	Significance (5%)	NS	NS	NS	NS	NS	NS	NS	NS
PKM-1	Stored sample	6.43	7.03	6.87	6.73	6.97	3.53	6.07	4.80
	Fresh sample	5.93	6.47	7.60	6.60	5.93	3.87	5.53	5.33
	't' value	0.7343	-0.9961	1.1784	-0.2009	-1.3775	0.3899	-0.5156	0.6193
	Significance (5%)	NS	NS	NS	NS	NS	NS	NS	NS

Values represent mean score of 15 values
NS - Non-significant at 5% level

4.4 Organoleptic evaluation

The results of the organoleptic evaluation carried out on 25th day, for the fruits of both the cultivars stored under ESD in comparison with the corresponding fresh plant ripe samples are presented in table no.14.

The results clearly indicate that there was no significant difference between the fruits stored under ESD and fresh plant ripe samples for any of the parameters evaluated organoleptically even after 25 days of ambient storage with ESD.

Discussion

5. DISCUSSION

Harvested fruits and vegetables are living entities and continue to perform all the life activities as it was with the mother plant. This causes wilting and shrivelling, leading to an ultimate reduction in quality of the saleable produce. Though these post-harvest losses can be minimised, employing refrigeration or controlled atmosphere storage, they are quite unreachable for an average Indian farmer or vegetable vendor. By evolving a simple and low cost energy saving technique for proper storage of these perishables, the present wastage can be reduced, giving more remunerative returns to the growers and reasonable price to the consumers. The results of the studies conducted under three experiments to evolve a simple and cheap storage technique for extending the shelf-life of tomatoes, under ambient conditions are discussed in this chapter.

5.1 Evaluation of existing methods of packaging and storage of tomatoes under ambient conditions

Storage of fruits under ambient conditions necessitates the use of certain materials which would reduce the respiration and transpiration rates of the produce thereby maintaining its fresh appeal. The methods of storage evaluated are storage under 2% ventilation with impackage ethylene absorbent, individually wrapping with cling film and in unventilated polythene bags with impackage desiccant.

Loss of water from the fruit as a result of respiration and transpiration reduces the fresh appeal. Fruits under cling films showed low PLW throughout the storage period compared to the fruits under 2% ventilation or control irrespective of the maturity stage. Cling film being less permeable to gases creates a modified atmosphere within the fresh fruit. This increases the internal CO_2 concentration and reduces the respiration rate, thereby preventing or delaying the senescence (Kabir *et al.*, 1995). Similar results on reduced PLW were reported by Drake *et al.* (1987) and El-Ghaouth *et al.* (1992).

The results of Risch and Watson (1980) also suggests that wrapping individual tomatoes in polymeric films resulted in reduced weight loss. This further authenticates the present results.

The PLW of fruits kept under 2% ventilation was also less than their corresponding controls, throughout the storage period. Kumar (1994), has suggested that storage of tomatoes in 100 gauge polyethylene (PE) film with or without ventilation can be recommended as a suitable package for MG fruits. In such packages, utilization of O_2 for respiration produces respiratory heat and water, resulting in high humidity around the fruits (Onwuzulu *et al.*, 1995).

Polyethylene act as a controlled condition and it reduces the weight loss and extends the shelf-life of the fruits. When fruits are packed in plastic bags, there is an evolution of CO_2 through the process of respiration and this is helpful in prolonging the shelf-life of the fruits (Kalloo, 1986). The low rate of PLW in fruits kept under 2% ventilation is clearly due to the high humidity storage atmosphere

created within the packages by the respiring fruits and the low Water Vapour Transmission Rate (WVTR) of the packaging material used. Observations by Geeson *et al.* (1985), also supports our findings.

When unventilated PE bags were used, there was condensation of moisture inside the package which lead to the spoilage due to fungal growth. To counteract this, an impackage desiccant (fused $CaCl_2$) was introduced in the package. But on absorption of moisture within the package, $CaCl_2$ got melted and subsequent contact on the fruit lead to early spoilage. This high humidity effect on fruits is made less pronounced by providing ventilation to the package. Alternatively, the packages may be opened at 2 or 4 days interval as suggested by Saguy and Mannhelm (1975), but has practical limitations.

The lesser PLW coupled with low decay percentage of MG and Br stage tomato fruits of both the cultivars under cling film and 2% ventilation rendered it marketable till 3 weeks.

The general increase in TSS found in fruits of both the cultivars under 2% ventilation and cling film may be due to the conversion of insoluble carbohydrates to soluble fractions. This is in conformity with the results of Siddiqui *et al.,* (1986). The titratable acidity of the fruit is based on the citric and malic acids which occur in more or less equal amounts in tomato. Production of malic or citric acid increases the net titratable acidity during storage (Davies, 1964) and later citrate catabolism reduces the acidity levels (Sakiyama, 1966).

pH is related to titratable acidity. But there can be both positive and negative correlations between them, (Kalloo, 1986). The positive correlation between pH and acidity observed in Sakthi fruits may be due to the differential buffering by the phosphate content of the fruit (Stevens, 1972).

The ascorbic acid content of PKM-1 was maximum at Br stage and the loss during storage was high in the fruits harvested at MG stage. This is in conformity with the results obtained by Subburamu *et al.* (1990) with the same variety. The slight increase in ascorbic acid may be due to the fresh synthesis or the reduction of dehydro-ascorbic acid (oxidised ascorbic acid) into ascorbic acid (Mapson, 1970). However, towards the end of the storage period, degradation was found to be higher in control fruits. This may be due to the influence of a comparatively higher oxygen content in the atmosphere (Singh *et al.*, 1970), coupled with cellular disorganisation (Harris and Karmas, 1977) which disintegrates the ascorbic acid.

During ripening, the reserve sugars get degraded into simple sugars causing an increase in TSS (Naik *et al.,* 1993). The comparatively less degradation of sugars in the case of treated samples suggests the reduction in the ripening processes due to treatment effect. Similar changes in TSS and sugars have been reported by Luis *et al.* (1977) and Wilberg (1977) which confirm the present findings.

Firmness decreased with the advancement of ripening, due to the conversion of pectic substances into soluble pectin (Singh, 1980). Reduction in

firmness may also be attributed to the hydrolysis of storage material for the production of energy needed for respiration (Mattoo *et al.*, 1975).

Almost normal colour development was observed in fruits wrapped with cling films but the colour development was restricted when kept under 2% ventilation with $KMnO_4$ impregnated cakes as ethylene absorbent. $KMnO_4$ absorbs ethylene, rendering it unavailable for the normal ripening process.

Sakthi fruits have a normal shelf-life of 16 days (Kumar, 1995) and PKM-1 fruits kept well for 12.5 days (Subburamu *et al.*, 1990). But the present findings suggests a shelf-life of about 21 days for both the cultivars, when wrapped individually with cling films or packed in 2% ventilated PE bags with impackage ethylene absorbent.

5.2 Standardisation of packing medium

The shelf-life of fruits and vegetables especially tomatoes can be improved, if it is cold stored or stored under controlled atmospheres (CA). But such sophisticated, expensive and energy intensive technology would be acceptable only in developed countries, who can afford it. Keeping in view of the various constraints involved in such systems an alternate, economical storage technique has to be developed (Kumar, *et al.*, 1988).

During the process of respiration and transpiration, the produce loses water, which is not replenished after harvest. Loss of moisture is the most obvious way in which freshness is lost and it affects the appearance, texture and saleability under open conditions (Naik *et al.*, 1993).

PLW is a loss of saleable weight and hence it has to be minimised. Minimising water losses from the produce involve lowering the capacity of the surrounding air to take up additional water ie: the vapour pressure difference between the produce and the air surrounding it should be reduced. This is the principle behind the use of equilibrated sawdust as a packing medium for the storage of tomatoes.

The observations on PLW has clearly indicated that the packing medium (sawdust) should have a moisture content between 35-40%. This may form the equilibrated condition of RH within the packing medium. The higher rate of PLW observed in fruits kept under dried sawdust (<20% moisture) is probably due to the desiccating effect of the sawdust, which creates a higher vapour pressure difference between the produce and the micro-environment surrounding it. This leads to early incidence of shrivelling and loss in marketability.

Increasing the moisture content of sawdust to 50-60% has a definite influence in reducing the PLW due to the much reduced vapour pressure difference. But the high incidence of decay even by the first week of storage limits its feasibility. A high rate of decay was reported by Lockhart and Eaves (1967) on

tomatoes stored under 89% RH. They have also reported that the rotting was significantly reduced by lowering the RH from 89% to 76%. RH of more than 85% is also reported to cause grey mould on the calyx end of tomatoes (Anon, 1979).

The increased rate of decay with increase in tomato : sawdust (SD) ratio suggests the creation of the anaerobic condition within the package which causes suffocation to the produce kept within. This, coupled with the increased moisture content aggravates the problem of decay.

Studies by Babar *et al.* (1994), on storage of $CaCl_2$ treated tomatoes in coarse moistened sawdust (CMSD) and fine moistened sawdust (FMSD), showed CMSD to be a better packing medium than FMSD. This further authenticates the present findings.

The combined effects of PLW and spoilage determine the ultimate marketability of the produce. Hence, based on the results obtained from the experiments on standardisation of packing medium, it was concluded that storage of tomatoes under 1:0.5 proportion using sawdust with a moisture content of 35-40% was ideal in reducing the PLW and spoilage under ambient conditions.

5.3 Standardisation of stage of harvest for storage under ESD

Port-harvest life of fruits and vegetables depends on stage of harvest, regulation of the biochemical changes in the fruit during ripening and protection

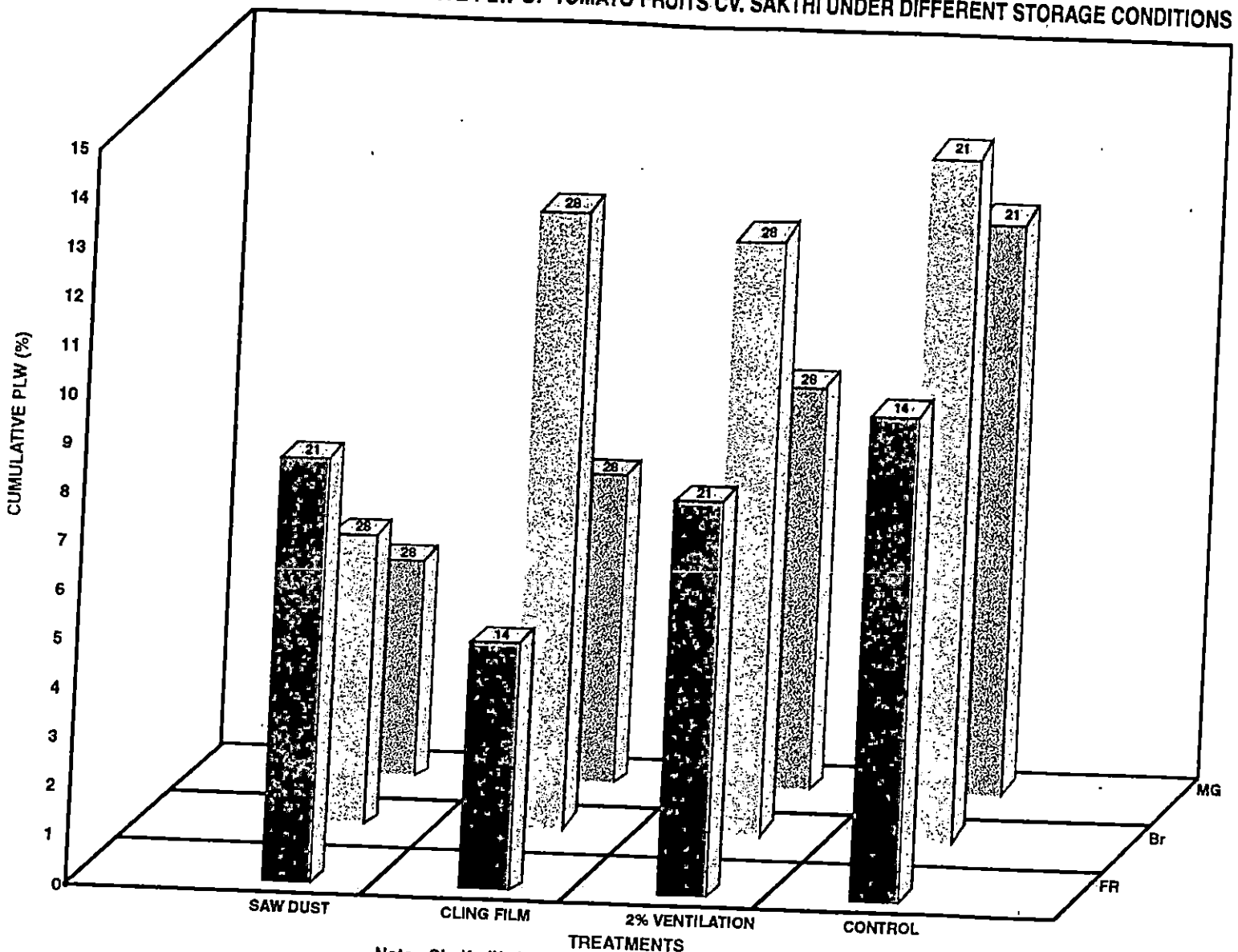
from microbial infections (Singh, 1980). The shelf-life of tomatoes was indirectly correlated with the stage of harvest (Joshi and Khandekar, 1993).

The results obtained from the experiments clearly indicates a low PLW for MG fruits after 4 weeks of storage under ESD. The same fruits of both varieties were firmer also. But PLW was found to increase with maturity stage, [fig. 1 and 2]. According to Bhatnagar *et al.* (1980), these differences between the PLW at different stages are due to the variability in skin texture of the fruit, especially the thickness of the pericarp. This can also be due to the low ethylene production during the early stages of maturity which in turn reduces the rate of respiration, transpiration and degradative processes (Hooda *et al.,* 1994).

Spoilage of fruits was also found to be correlated with the stage of maturity at harvest. Decay percentage was found to increase with maturity. Incidence of decay was comparatively less for MG fruits stored under ESD than Br stage fruits. This is in conformity with the results of Gaur and Bajpai (1982), with respect to stage of harvest. However, decay percentage was found to increase with storage period as reported by Kumar *et al.,* (1988).

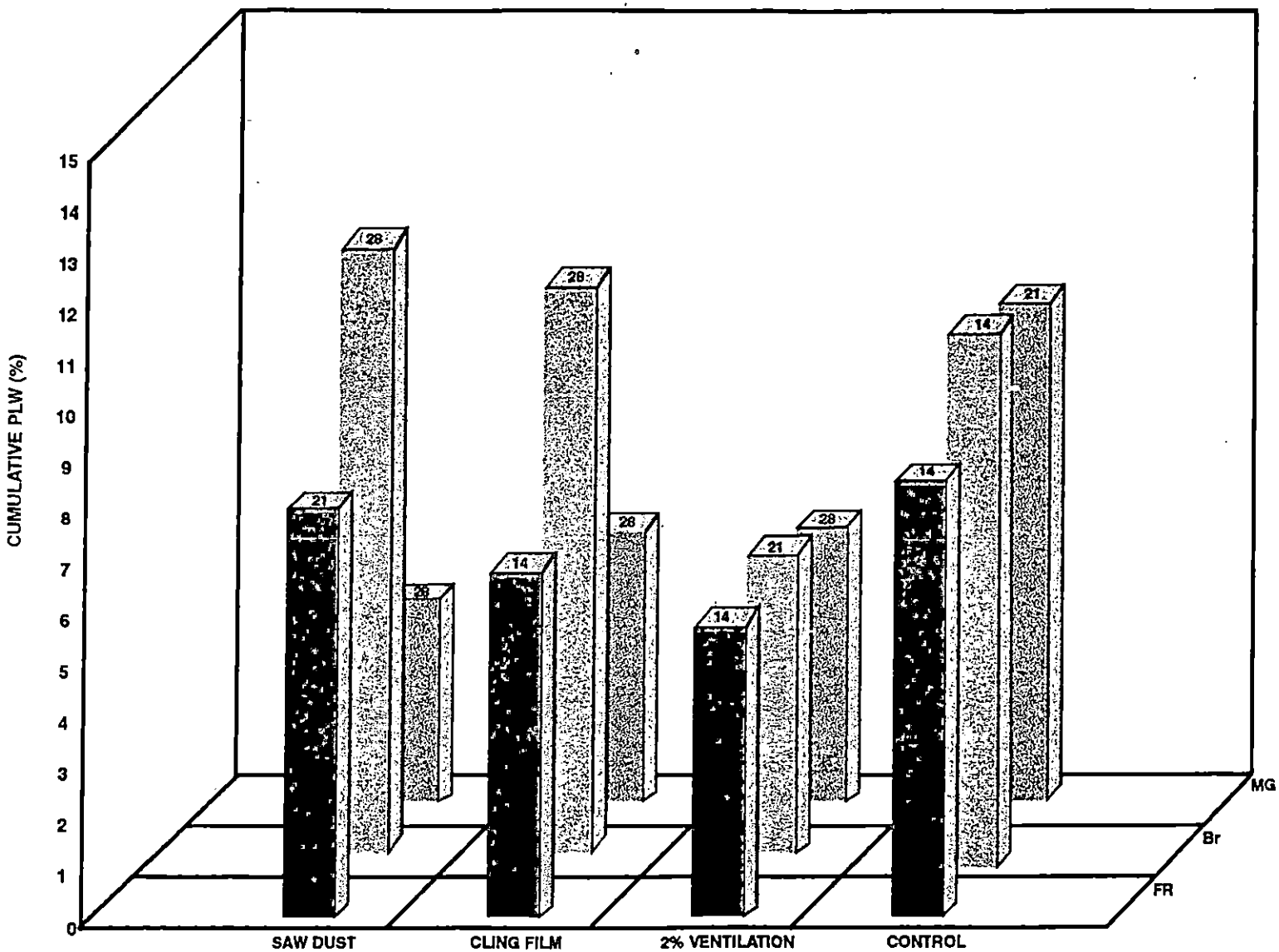
Stage of maturity has a definite role in the TSS content of tomato fruits. The TSS content was low at MG stage and high at FR stage. TSS tend to increase with storage, reach a maximum value and later decreased. The rise in TSS may be due to the degradation of polysaccharides to simple sugars by enzymatic reactions (Naik, *et al.,* 1993).

FIG. No.1 CUMULATIVE PLW OF TOMATO FRUITS CV. SAKTHI UNDER DIFFERENT STORAGE CONDITIONS



Note : Shelf - life in days is marked at the top end of the bars

FIG. No.2 CUMULATIVE PLW OF TOMATO FRUITS CV. PKM - 1 UNDER DIFFERENT STORAGE CONDITIONS



Note : Shelf - life in days is marked at the top end of the bars

The final TSS of MG and FR fruits were much below the initial value but the TSS at Br stage fruits at the end of the storage period under ESD was found to be equal to that of its initial value in both the cultivars, which suggests Br stage fruits to be ideal for storage under ESD. This is in conformity with the results obtained by Siddiqui *et al.* (1986) and Kumar *et al.* (1988).

The acidity of Sakthi fruits was low in MG stage and high in Br stage. In PKM-1 it was low in MG stage and high in FR stage. This is in conformity with the results of Subburamu *et al.,* (1990). The increase in acidity was due to the production of malic acid and citric acid (Davies, 1964), and the decrease in acidity levels is reported to be due to the catabolism of citrate which reduces the level of citric acid (Sakiyama, 1966). Similar results of Naik *et al.* (1993), confirm the present findings. The marginally higher values of acidity on storage under ESD suggests Br stage fruits to be the optimum stage of harvest.

Titratable acidity is associated with pH and citrate is largely responsible for it (Kalloo, 1986). In both the cultivars, FR fruits showed the least pH while MG fruits had the highest. However, the change in pH during storage was different in both the cultivars. The final pH of Br stage fruits of Sakthi was higher than the corresponding value for MG fruits, whereas Br stage fruits of PKM-1 showed a lesser pH than the corresponding value of MG fruits at the end of its storage period. There can also be a positive correlation between pH and titratable acidity as reported by Kalloo (1986). The positive correlation may be due to the differential buffering by the phosphate content of the fruit (Stevens, 1972). Low pH of the fruits was found to improve the colour, flavour, texture and ascorbic acid content (Leonard *et al.*, 1959).

Breaker stage and FR stage fruits of both the varieties showed higher initial values of ascorbic acid content than the corresponding value for MG stage. Tomato fruits are observed to accumulate ascorbic acid during ripening and hence higher values are recorded at Br and FR stages (Betancourt *et al.*, 1977). In both the cultivars, the ascorbic acid content showed a steep decline in the fruits harvested at MG stage than that of Br stage. Further, the ascorbic acid content of PKM-1 was maximum at Br stage. This is in conformity with the results of Subburamu *et al.* (1990), with the same variety.

Ascorbic acid in fruits, is sensitive to degradation, as plant tissues contain 4 enzymes viz. cytochrome oxidase, peroxidase, ascorbic acid oxidase and phenolase, which are responsible for its oxidative degradation (White and Salvey, 1974). In intact fruits these enzymatic systems are controlled. When cellular disorganisation occur due to mechanical damage, rotting or senescence, these oxidative activities become operative and leads to vitamin loss (Harris and Karmas, 1977).

Fruits kept open are more susceptible to disintegration of ascorbic acid, due to the high oxygen content in the air (Singh *et al.*, 1970). Also the degradation of ascorbic acid is pH dependent, being slow in acid pH, rapid at neutral pH and extremely rapid at alkaline pH (Burton, 1982).

The rise and fall in sugars is due to the degradation of polysaccharides into simple sugars during the ripening process (Naik *et al.*, 1993). In tomato, almost

whole of the sugar content consist of glucose and fructose (Burton, 1982). There is a marked increase in sugar content throughout the normal ripening of tomatoes especially during the changes from MG to Br stage, but during storage of FR fruits, the sugar content decreases (Winsor *et al.,* 1962). This is in conformity with the present results. The loss of sugars during storage is presumably due to the consumption during respiration (Burton, 1982).

There was a marked reduction in firmness of the fruit on ripening, which is attributed to the hydrolytic conversion of storage material in the fruit for providing energy for respiration (Mattoo *et al.*, 1975 and Singh, 1980). MG fruits were firmer than Br stage fruits in both the cultivars throughout the storage period. The fruits harvested at Br stage were more soft than those of MG stage at the end of the storage period. This might have been due to the greater initial softness at the time of harvest and its enhancement during the ripening process in comparison with the fruits of MG stage (Hooda *et al.*, 1994).

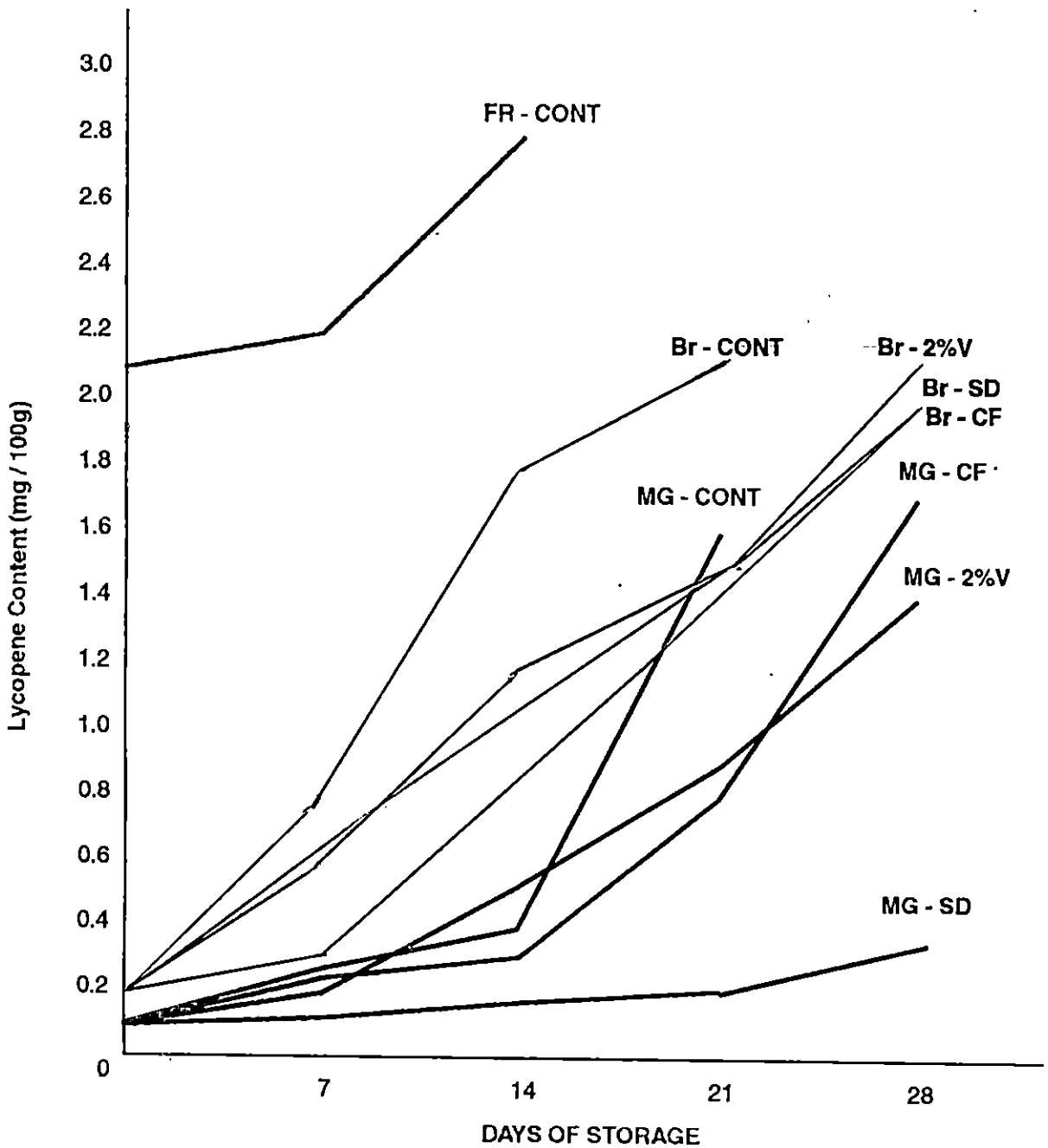
Firmness is also related to the pectin content of the fruit. Solubilization of pectic substances, cementing the cell well also is associated with softening of the fruit during ripening (Singh, 1980). During ripening, depolymerisation or shortening of chain length and de-esterification or removal of methyl esters occur to the polymer of pectic substances, leading to a decreased amount of pectin content during ripening. These processes occur more intensely in Br stage fruits than in MG fruits (Spencer, 1965).

Colour development showed significant variation between the different stages of maturity, when stored under ESD, [fig. 3 and 4]. Colour development of MG fruits was more or less hampered with storage under ESD. Colour development by Br stage fruits was more uniform and had better consumer acceptance as compared to MG fruits. According to Subburamu *et al.* (1990), the lycopene content of MG fruits was poor and was yellow or yellowish with red tinge without any market appeal, even when stored open. This confirms the present results on MG fruits stored under ESD. After 3 weeks of storage, Br stage fruits kept under ESD were found to be more glossy in appearance as compared to fresh samples. The red region of the spectrum accelerates ripening by increasing the lycopene synthesis in fruits (Worthington *et al.,* 1969). This can be correlated to the poor development of colour of MG fruits kept in ESD, which was totally shut off from light.

Further it may be also inferred that, the CO_2 evolved by the ripening fruits kept under ESD might have been trapped by the medium, thereby increasing the net CO_2 concentration. This can also lead to the decrease in O_2 levels, effecting the delayed ripening process. These results do not provide evidence as to whether the observed delay in ripening under sawdust is also attributed from the increased levels of CO_2 within the package. Nonetheless, this possibility should not be disregarded, since high CO_2 has been reported to reduce ethylene production and delay lycopene development in tomatoes by Buescher, (1979).

FIG. No. 3

LYCOPENE CONTENT OF TOMATO FRUITS CV. SAKTHI UNDER DIFFERENT STORAGE CONDITIONS



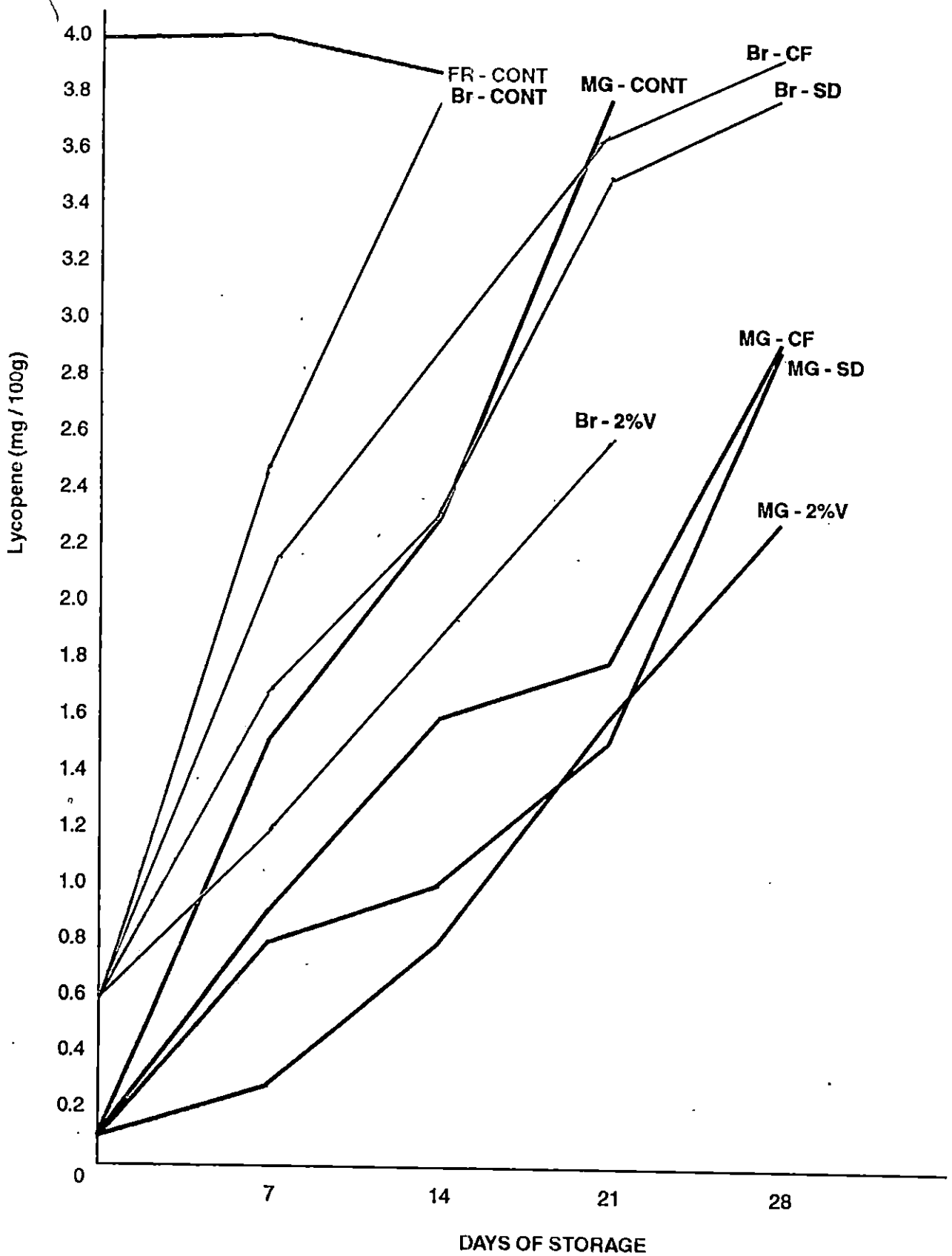
CF - Cling Film

SD - Saw Dust

2%V - 2% Ventilation + ethylene absorbant

CONT - Control

LYCOPENE CONTENT OF TOMATO FRUITS CV. PKM - 1 UNDER DIFFERENT STORAGE CONDITIONS



CF - Cling film
SD - Saw Dust
2% V - 2% Ventilation + ethylene absorbant
CONT - Control

Breaker stage fruits of both varieties stored under ESD were organoleptically evaluated on the 25th day of storage in comparison with plant ripened fresh samples of each variety. All the parameters of treated fruits of each variety (viz., overall appearance, colour and firmness of whole fruit; overall appearance and internal colour of cut fruit, sweetness, sourness and flavour) were rated statistically on par with those of corresponding fresh samples, indicating total consumer acceptability of the treated fruits.

Based on all the results *vide supra*, it may be concluded that tomato fruits harvested at Br stage and kept under ESD, can keep well for over three weeks for both the varieties (25 to 27 days for Cv. Sakthi and 21 to 25 days for cv. PKM-1) with minimal degradation in quality attributes.

Summary

SUMMARY

Studies on the shelf-life of tomato (*Lycopersicon esculentum* Mill.) were carried out in the Department of Processing Technology, College of Horticulture, Vellanikkara, during 1996-'97. The main objective was to develop a simple and cheap storage technique to extend the shelf-life of tomato fruits of two varieties viz. Sakthi and PKM-1 under ambient conditions. The salient findings are summarised here.

The PLW of tomato fruits under both 2% ventilation + ethylene absorbent and cling films were lesser than their corresponding controls. The spoilage of fruits under 2% ventilation + ethylene absorbent was found to be less followed by wrapping with cling film. The rate of spoilage was high in the case of fruits stored in unventilated polyethylene bags and hence terminated during the first week itself. The other two storage techniques were found to be equally good with respect to all the parameters evaluated, viz., TSS, acidity, pH, ascorbic acid, pectin, firmness, sugars and lycopene.

Though the existing ambient storage techniques can guaranty a shelf-life of about 3 weeks, compared to 10 to 12 days in open storage, the cost involved is high with respect to the packaging material and the labour involved. So a simple and cheaper storage technique had to be evolved.

It was observed that the PLW and spoilage were least, when tomato fruits were stored under the ratio of 1:0.5 (tomato : saw dust), with the saw dust having a moisture content of 35-40%, to provide an equilibrated condition (ESD).

Among the three maturity stages tried under ESD, mature green (MG) stage showed least PLW and spoilage for a period of over 25 days. But the colour development was hampered in this case. Breaker (Br) stage fruits had a comparable PLW and spoilage to that of MG stage and exhibited better colour development when stored under ESD. Other parameters like TSS, acidity, sugars, firmness, ascorbic acid etc. for Br fruits were also favourable with storage under ESD.

Br stage fruits stored under ESD for 25 days were organoleptically rated on par with that of fresh, plant ripened samples. Further, the cost involved in setting up the package is also negligible due to the low cost of saw dust and container (used CFB boxes), and also due to the reusability of the same. Tomato fruits harvested at breaker stage could be stored under ESD for more than 25 days with least deteriorative changes and full colour development.

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SHELF-LIFE OF TOMATO

(Lycopersicon esculentum Mill.*)*

By

BINU JOHN SAM

ABSTRACT OF A THESIS

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Faculty of Agriculture
Kerala Agricultural University

Department of Processing Technology
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 654
Kerala, India

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ABSTRACT

An experiment was conducted at the Department of Processing Technology, College of Horticulture, Vellanikkara, during 1996-97 to evolve a simple and cheap storage technique for tomatoes under ambient conditions.

Results revealed that some of the existing packaging and storage techniques viz., storage under 2% ventilation + ethylene absorbent and individual wrapping with cling films under ambient conditions, were effective in storing the fruits for about three weeks. But the cost involved in these methods were comparatively high. An alternative low cost storage technique was evolved using equilibrated saw dust as the packing medium.

Two varieties of tomatoes, viz. Sakthi and PKM-1 were stored under saw dust having a moisture content of 35-40% with a proportion of 1:0.5 (tomato : saw dust). A shelf-life of more than 25 days was obtained for both the varieties with least deteriorative changes and with the same sensory qualities as that of plant ripened tomatoes.

Optimum stage of harvest for storage under ESD was breaker stage which possessed all the quality attributes like TSS, acidity and well developed colour at the end of the storage. Organoleptic quality of stored breaker stage fruits was on par with fresh plant ripe fruits. The cost involved in this method is negligible, with zero energy requirement and without any complicated technology.