EFFECT OF EDIBLE WAX COATING AND MODIFIED ATMOSPHERIC PACKAGING ON SHELF LIFE OF SLICING CUCUMBER (*Cucumis sativus*)

By

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree

Bachelor of Technology
In
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Post-Harvest Technology and Agricultural Processing

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR- 679 573, MALAPPURAM

KERALA, INDIA

2013

DECLARATION

We hereby declare that this project report entitled **''EFFECT OF EDIBLE WAX COATING AND MODIFIED ATMOSPHERIC PACKAGING ON SHELF LIFE OF SLICING CUCUMBER (*Cucumis sativus*)"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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CERTIFICATE

Certified that this project work entitled **''EFFECT OF EDIBLE WAX COATING AND MODIFIED ATMOSPHERIC PACKAGING ON SHELF LIFE OF SLICING CUCUMBER (*Cucumis sativus*)''** is a record of project work done jointly by Ms. Chinchu Mohan and Ms. Hima John under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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Acknowledgement

ACKNOWLEDGMENT

We bow to the lotus feet of 'God the Almighty' whose grace had endowed us the inner strength and confidence and blessed us with a helping hand at each step during this work.

We feel fortunate to be associated with advisor **Dr. Sudheer K.P**, *Associate Professor, Dept. of Post-Harvest Technology and Agrl. Proceesing (PHT & AP), Kelapaji College of Agricultural Engineering and Technology (K.C.A.E.T), Tavanur*. He guided during the course of this research work with words of wisdom and training for patience. We are indebted for his sympathetic and kind co-operation provided for the accomplishment of this research work as a sympathetic and encouraging advisor.

It gives us an immense pleasure to thank **Dr. M. Sivaswami**, *Dean (Ag.Engg.), K.C.A.E.T, Tavanur* for providing us an opportunity to work on this project.

We express our thanks to **Dr. Santhi Mary Mathew**, *Prof. & Head, Dept. of PHT & AP, K.C.A.E.T, Tavanur* for her help and encouragement.

We are really thankful to **Er. Anu Varughese**, Assistant Professor, Department of IDE and **Dr. Beril Pathrose**, Assistant Professor, KVK, for their valuable suggestions that helped a lot in carrying out this project work.

We wish to acknowledge the assistance and encouragement from all PHT & AP staff, K.C.A.E.T, Tavanur, especially **Ms. Divyasree, P.S.,** Biochemist.

We express our whole hearted floral thanks to our seniors in K C A E T, **Pritty. S. Babu** and **Madhana Supriya** and also to our batch mates who helped us a lot in our work.

It is our pleasure and privilege to express my cordial thanks to our beloved **parents** for their moral support and constant encouragement, affectionate concern and prayers throughout this work.

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Dedicated to

Agricultural Engineering Profession

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SYMBOLS AND ABBREVIATIONS

APEDA	Agricultural and Processed Food Products Export Development Authority
^{o}Brix	Degree Brix
CO_2	Carbon di-oxide
C	Carbon
^{o}C	^{o}Celcius
cm	centimetre
CA	Controlled Atmosphere
CAS	Controlled Atmospheric Storage
EMA	Equillibrium modified atmosphere
et al.,	and others
etc.	et cetra
Fig.	figure
g	gram
Hrs	hour(s)
i.e.	that is
K.C.A.E.T	Kelappaji College of Agricultural Engineering and Technology

kg	kilogram
LDPE	Low density poly ethylene
MAP	Modified atmosphere packaging
MA	Modified atmosphere
M.C	Moisture Content
mg	milligram
mm	millimetre
ml	milliliter
MT	Million Tonnes
O_2	Oxygen
PAM	Passive Atmosphere Modification
PLW	Physiological loss in weight
TSS	Total Soluble Solids
UK	United Kingdom
USDA	United Nations Department of Agriculture
viz.	namely
w/w	weight by weight
wb	wet basis
%	per cent
/	per

$\approx$	approximately

Introduction

CHAPTER 1

INTRODUCTION

Fruits and vegetables are the foundation of nutrition. They provide low-calorie, high nutrient options for the daily diet. They are packed with vitamins, minerals and protective plant compounds. They have gained increasing interest among nutrition specialists, food scientists and consumers, since frequent consumption of fruits reduces the risk of certain cardiovascular diseases and cancer (Liu, 2003). In the recent years, demand for both fresh and processed fruits and vegetables have been substantial, and this trend is likely to continue in future. The increase in demand can be regulated by either increasing their production or by adopting suitable processing and packaging techniques for its preservation.

India, the world's second largest producer of fruits and vegetables after China and has an output of 775.25 lakh tons and 1496.07 lakh tons respectively, in 2011-12 which is about 3% higher than previous (The Economic Times, April 24, 2012). India is blessed with a large variety of fruits and vegetables and is known as fruit and vegetable basket of the world. And it is also the largest producer of ginger and okra amongst vegetables and ranks second in production of potatoes (10%), onions, cauliflowers, brinjal, cabbages, etc. Amongst fruits, the country ranks first in production of bananas (28%), papayas, mangoes (39%), lemons and limes. The vast production base offers India tremendous opportunities for export. During 2010-11, India exported fruits and vegetables worth Rs.3856 crores which comprised of fruits worth Rs.2635 crores and vegetables worth Rs.1221 crores. India is also a prominent exporter of fresh vegetables in the world (APEDA, 2008).

Though India is one of the largest producers of fruit and vegetables, it processes only less than 2.5% of the huge production as compared to 70 - 83% in advanced countries (Akhila and Sharina, 2009). According to Nanda *et al*. (2012), the post-harvest losses in India are estimated to be 5.8 - 18% of the total production which valued over Rs.27,500 crores annually. Fresh fruits and vegetables normally have an elaborate spoilage microflora, due to intensive contact with various types of microorganisms during growth and postharvest handling (Gorris, 1992). In addition to this, the highly perishable nature of fruits and vegetables due to their high water content, make them susceptible to desiccation, mechanical injury and pathological breakdown. This results in changes in texture, colour, flavour and nutritional value of the food. These changes can render food unpalatable and potentially unsafe for human consumption. If we reduce even 1% of the loss, that would save about Rs.900 crores. Though post-harvest management technology is available in certain sectors, the supply chain inefficiency and inadequate infrastructure are the main causes for such wastages.

India grows the largest number of vegetables from temperate to humid tropics and from sea-level to snow-line. Vegetables are excellent source of vitamins, particularly niacin, riboflavin, thiamin and vitamins A and C. They also supply minerals such as calcium and iron besides proteins and carbohydrates. Vegetables combat under nourishment and are known to be cheapest source of natural protective tools. Most of the vegetables, being short duration crops, fit very well in the intensive cropping system and are capable of giving very high yields and very high economic returns to the growers. Major vegetables grown in India are potato, onion, tomato, cauliflower, cabbage, bean, egg plants, cucumber and garkin, frozen peas, garlic and okra. (APEDA, 2008).

The cucumber (*Cucumis sativus*) is a creeping vine that roots in the ground and grows up trellises or other supporting frames, wrapping around supports with thin, spiraling tendrils. The plant has large leaves that form a canopy over the fruit. The fruit of the cucumber is roughly cylindrical, elongated with tapered ends, and may be as large as 60 cm long and 10 cm in diameter. Having an enclosed seed and developing from a flower, botanically speaking, cucumbers are classified as accessory fruits. However, much likes tomatoes and squash they are often perceived, prepared and eaten as vegetables. Cucumbers usually contain more than 90% water.

The origin of cucumber was from India. It has been cultivated for at least 3,000 years, and was probably introduced to other parts of Europe by the Greeks or Romans. Records of cucumber cultivation appear in France in the 9th century, England in the 14th century, and in North America by the mid-16th century. Although India is a traditional producer of cucumber, its export potential was discovered during the late 1980s. In the emerging trade scenario, cost and quality of a commodity determine the flow and dynamics of its trade in the world market. India with favourable agro-climatic conditions and surplus labour has the potential to produce high quality cucumber round the year and has the capacity to export it to the international market (Nalini *et al*., 2008).

Pre-harvest factors appear to be responsible for much of the variation in cucumber quality and shelf life. The ability to predict the post-harvest longevity of cucumbers would facilitate the commercial segregation of fruit with different storage potentials. Cucumber shelf life has been found to decline with increase in fruit age at harvest (Lin and Ehret, 1991). Although cucumbers have a limited shelf life, they offer high quality. The perishable nature of cucumbers prevents the economical storage of fresh fruits for longer than 1 month (Todd *et al*., 2000).

To reduce the post-harvest losses, proper packaging and storage is necessary. The selection of most suitable packaging method plays a significant role in increasing the shelf life of cucumber while maintaining its nutritional quality. The demand for fresh fruits and vegetables increases day by day. So various packaging techniques like modified atmospheric packaging (MAP), self-breathing bags, controlled atmospheric storage (CAS) etc., various post-harvest techniques like wax coating and temperature control can extend the shelf life and helps in maintaining the freshness and hence results in increasing consumer satisfaction (Madhana, 2012).

Fresh-pack processing of cucumbers has been widely accepted because of the high quality of the final product. Refrigerated products are also gaining in consumer popularity (Todd *et al*., 2000). With this background information we have taken up this study with the following objectives.

- To study the suitability of various packaging methods for extending the shelf life of cucumber.
- To study the effect of wax coating on shelf life extension.
- To analyse the post-harvest quality parameters of the stored cucumber.

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various research workers related to the present study that gives general information on cucumber, its physiochemical characteristics and its storage studies.

2.1 Cucumber (*Cucumis sativus*)

2.1.1 History and distribution

It is native to India, found wild in the Himalayas from Kumaun to Sikkim and cultivated throughout the country with different vernacular names viz. cucumber (English), *Kheera* (Hindi), *Trapusha* (Sanskrit), *Shashaa* (Bengali) and *Vellarikkay* (Tamil). Kirkbride (1993) has enlisted 70 species synonymous for *C. Sativus*. There is much evidence to suggest that the cucumber is indigenous to Himalayan origin of northern India and are domesticated in Asia. In China, it is cultivated for at least 2000 years and occupies 2nd largest area among vegetables after Chinese cabbage. In India, this species has been cultivated with two forms: creeping form, cultivated in the field during hot season; and climbing form, cultivated during the rainy season (Whitaker *et al*., 1996; Peter *et al*., 2007; Mukherjee *et al*., 2012).

2.1.2 Morphological characteristics

Cucumber fruits are classified as nonclimacteric (Biale and Young, 1981). It is an annually growing creeping vine. Its leaves are hispidly hairy trailing or climbing type. Leaves are simple alternate, deeply cordate 3 - 5 lobed in both surfaces with a hairy margin denticulate. Flowers are yellow in colour; male flowers are clustered, bearing anthers with cohering, connective crushed or elevated above the cells whereas females are solitary thick covered with very bulbous based hairs (Warrier, 1994). Fruits are compressed, elongated, ellipsoid, dorsiventrally convex and laterally ridged with variable size. Seeds are cream or white, testa hard and smooth. Cucumber has enclosed dicoyledonous seeds and it develops from a flower, and therefore it is classified as a fruit. Micropyle pointed, distinctly visible; outer most layer of testa is absent and each cotyledon shows five distinct patches of small, thin walled, polygonal cells (Anonymous, 2001).

2.1.3 Propagation

Most common method of propagation followed in cucumber is through seeds. They are usually seeded in single rows at a depth of 1.27 to 2.54 cm. Row spacing vary from 91.4 to 182.8 cm. Final plant spacing should be 22.86 to 30.48 cm in the row on irrigated land and 38.1 to 45.72 cm on dry land. Plants should be thinned before the four-leaf stage if the stand is too thick. Cucumber seed will not germinate at soil temperatures below 15.55^{0}C, and the most rapid germination occurs at 35^{0}C.

2.1.4 Harvesting

Duration from pollination to harvest in slicing cucumber is 15 - 18 days, and 5 - 10 days for pickling cucumber. Cucumber plants set fruit and develop over a long period of time; therefore marketable fruit are ready for harvest over an extended period of time. Size of marketable fruit for slicing cucumbers ranges from 15.24 - 25.4 cm in length and 3.81 - 6.35 cm in diameter. Slicing cucumbers should be fresh, crisp, of medium size, well formed, uniform and of a deep green colour. The fruit is picked before it has reached full diameter and while the seeds are still small and soft. A light green or yellow skin colour is an indication that the fruit is over mature for picking.

Cucumbers are picked manually. The fruit should be held near the stem and clipped or snapped with a slight twist motion and not be pulled off. The frequency of harvest is usually every other day or daily during the warm months, and 2 - 3 times per week during cooler weather or at higher elevations. Fruit quality is best controlled when fruit is picked daily especially during warm weather.

Daily harvest is recommended for the oriental slicing types. Cucumbers should be kept in the shade until taken to the packing house where they may be hydro-cooled, washed, sorted, graded, sized, and packed (Hector *et al.*, 1993).

2.1.5 Varieties

Varieties of cucumber are conventionally separated in to four categories: (i) the exotic group of European and American cultivars; (ii) cultivar from the western part of India that are xerophytic in nature; (iii) Chinese cultivars with long fruits and glossy skin; and (iv) Himalayan type, mostly with rusty skin (Peter & Abraham, 2007). National Seed Corporation is promoting the ‘Poinsett’ variety of cucumber which was introduced from the USA and now popular in northern India. It is highly resistant to downey mildew, powdery mildew, anthracnose and angular leaf spot. *Poona Khira* in Maharastra, *Balam Khira* in Uttar Predesh, *Khira 95* and *Khira 90* in Himachal Pradesh are the diverse varieties accepted by the cultivator at different regions in India. Indian Agricultural Research Institute (IARI), New Delhi developed some new varieties of cucumber such as DC-1 (Pusa Uday), DC-3 etc. (Anonymous, 2010; IARI, 2012).

In human cultivation, the varieties of cucumbers are classified into three main varieties: "slicing", "pickling", and "burpless".

2.1.5.1 Slicing cucumbers

Cucumbers which are grown to be eaten fresh are called slicing cucumbers. They are mainly eaten in the unripe green form, since the ripe yellow form normally becomes bitter and sour. Slicers grown commercially for the North American market are generally longer, smoother, more uniform in colour, and have a much tougher skin. Slicers in other countries are smaller and have a thinner, more delicate skin. Smaller slicing cucumbers can also be pickled.

2.1.5.2 Pickling cucumbers

Cucumbers can be pickled for flavour and longer shelf life. Although any cucumber can be pickled, commercial pickles are made from cucumbers specially bred for uniformity of length-to-diameter ratio and lack of voids in the flesh. Those cucumbers intended for pickling, called picklers, grow to about 7 cm to 10 cm long and 2.5 cm wide. As compared to slicers, picklers tend to be shorter, thicker, less regularly shaped, and have bumpy skin with tiny white or black-dotted spines. They are never waxed. Colour can vary from creamy yellow to pale or dark green. Pickling cucumbers are sometimes sold fresh as “Kirby” or “Liberty” cucumbers. The pickling process removes or degrades much of the nutrient content, especially that of vitamin C.

2.1.5.3 Burpless cucumbers

Burpless cucumbers are sweeter and have a thinner skin than other varieties of cucumber, and are reputed to be easy to digest and to have a pleasant taste. They can grow as long as 61 cm. They are nearly seedless, and have a delicate skin. Most commonly grown in greenhouses, these parthenocarpic cucumbers are often found in grocery markets, shrink-wrapped in plastic.

2.1.6 Nutrient composition

Fruits contain water (96.4%), protein (0.4%), fat (0.1%), carbohydrate (2.8%), mineral (0.3%), calcium (0.01%), phosphorus (0.03%), iron (1.5 mg/100 g) and vitamin B (30 IU/100 g). Enzyme crepsin, proteolytic enzyme, ascorbic acid, oxidase, succinic and malic dehydrogenase have also been reported in fruits (Kapoor, 1990; USDA, 1984). Fruits contain a high concentration of ascorbic acid (Chu, 2002) whereas pulp and peel extracts contain lactic acid (≈ 7 - 8% w/w), which showed antioxidant activity (Sotiroudis, 2010). Seeds are also rich by the number of constituents including crude proteins (42%) and fats (42.5%) (Kapoor, 1990).

2.1.7 Post harvest utility

Recommended storage for cucumbers includes temperatures between 10 - 13^{0}C and 90 - 95% relative humidity. Average storage life is 10 - 14 days. At storage temperatures above 13^{0}C the fruit will ripen and turn from deep green to yellow. Chilling injury occurs when fruit is held below 10^{0}C for two days or longer (Hector *et al.*, 1993). It is widely consumed fresh in salads or fermented (pickles) or as a cooked vegetable (Sotiroudis, 2010). Amongst 30 species of Cucumis, *C. sativus* has the most economic value (Kapoor, 1990; Peter *et al*., 2007). The medicinal properties of the cucumber had been described since ancient times. The fruits and seeds of cucumber are recommended globally to prepare cosmetic products for the treatment of various skin problems like wrinkles and sunburn (James, 1997).

2.2 Quality characteristics

In the emerging trade scenario, cost and quality of a commodity determine the flow and dynamics of its trade in the world market (Kumar *et al.*, 2008). Quality of the product is determined by its chemical and nutritional composition (Pritty, 2012).

2.2.1 Total soluble solids

Increase in total soluble solids (TSS) during storage may be due to acid hydrolysis of polysaccharides (Luh and Woodroof, 1975). The physiological maturity of the fruit at harvest is a major determinant of quality and TSS. Sugar import in vine-ripened fruit increases in the latter stages of ripening (Carrari *et al.*, 2006). Jamal and Chieri (2006) observed that TSS was not affected either by room temperature or low temperature storage in tomatoes. The TSS is a refractometric index that indicates the proportion (%) of dissolved solids in a solution. It is the sum of sugars, acids and other minor components in the fruit pulp (Balibrea *et al*., 2006; Kader, 2008). Fernando *et al.* (2012) had conducted a study for determining TSS of apples using nondestructive sensors. The greater weight loss in bulk cucumbers compared to packaged fruit was associated with accelerated chlorophyll degradation, lower acidity, and lower soluble solids content. (Nunes *et al*., 2011).

2.2.2 Ascorbic acid

Izumi *et al*. (1984) studied the effect of chilling temperatures on changes of ascorbic acid content of some chilling-sensitive crops. Contents of ascorbic acid in cucumber decreased continuously at 5^0C, but no decrease was observed at 20^0C.

Fruits and vegetables are important sources of ascorbic acid. The most satisfactory chemical methods of estimation were based on the reduction of 2, 6-dichlorophenol indophenols dye to a colourless leuco-base (Sadasivam and Manikkam, 1992).

The loss of vitamin C after harvest can be reduced by storing fruits and vegetables in reduced O_2 and/or up to 10% CO_2 atmospheres; higher CO_2 levels can accelerate vitamin C loss. Vitamin C of produce is also subject to degradation during processing and cooking (Lee and Kader, 2000).

Piga *et al*. (2003) investigated the effect of refrigerated storage on polyphenols and ascorbic acid content and in manually peeled whole cactus pear fruits packaged with a low gas barrier film and had found out that ascorbic acid showed no significant variations.

The temperature-dependence of vitamin C loss in the -3 to -20^0C range was adequately modeled for frozen green vegetables by Giannakourou and Taoukis (2003). Comparison among different green vegetables showed that the type of plant tissue significantly affects the rate of vitamin C loss.

Vitamin C is a water soluble vitamin that is widely considered as an appropriate marker for monitoring quality changes during processing, storage and at the end point of the frozen chain. This is a consequence of its concentration change due to irreversible oxidation mechanisms that are enhanced by temperature abuses (Serpen *et al*., 2007).

Studies were undertaken by Elsa *et al*. (2011) on vitamin C (ascorbic acid) alterations of frozen broccoli (*Brassica oleracea* L. *sp. Italica*) stored at isothermal (-7, -15 and -25^{0}C) and non-isothermal (accelerated life testing with step-stress methodology; temperature range from -30 to -5^{0}C) conditions and had found out that even after the blanching and freezing operations, broccoli had a vitamin C (ascorbic acid) content of which is higher than the values reported for other green fresh vegetables.

2.2.3 Texture

Texture can be defined as "that group of physical characteristics that arise from the structural elements of the food, are sensed primarily by the feeling of touch, are related to the deformation, disintegration and flow of the food under a force, and are measured objectively by functions of mass, time, and length".

Fleming *et al.* (1982) reported that penetration force was about five times greater for mesocarp than endocarp in cucumbers. Mesocarp and endocarp were firmer near the stem end than at the blossom end of cucumbers.

Thompson *et al.* (1985) had made a study on texture changes during storage of blanched cucumber slices and had found out that except for the 99^{0}C blanch, there was an increase of firmness as a result of blanch treatment.

Guzman and Barrett (1997) reported that calcium chloride or calcium lactate dips (2.5%, 1 minute) either alone or in combinations with heat treatments maintained or improved the firmness of fruits and vegetables at 5^{0}C. Gorni *et al.* (1998) reported that storing the products at low temperature will maintain the texture significantly.

Firmness is one of the components of texture which is a complex sensory attribute that also includes crispiness and juiciness (Konopacka and Plocharski,

2003) and is critical in determining the acceptability of horticultural commodities (Abbott and Harker, 2004).

Alfredo (2005) found out that cucumbers stored at 10^{o}C for 15 days had acceptable texture, although the peel was described as slightly tough or leathery while the mesocarp tasted slightly watery.

2.2.4 Colour

Colour characteristic of foods are an important quality attribute resulting from both pigmented and originally non pigmented compounds. The major causative factor of colour in most foods is due to the presence of a broad array of natural pigments. Visual perception of colour can be described by three variables namely, hue (a), value (L) and chroma (b) (Yeshajahu *et al.*, 1996).

A more useful criterion for classifying cucumbers would be assessment of expected keeping quality, defined as the time taken from the initial colour to a pre-defined colour limit (Tijskens and Polderdijk, 1996).

Cucumber fruit with more intense green colour at harvest have longer storage potential, perhaps reflecting either optimal harvest maturity (Kanellis *et al.*, 1986; Mattsson and Nilsson, 1996).

Schouten *et al*. (1997) reported that the initial cucumber colour is related to the growing conditions of the cucumber plant. By applying the concept of correction for biological age, colour development can be described independent of maturity of the cucumber. The correction for biological age could be assessed by combining an accurate initial colour measurement and three photosynthetic parameter measurements making predictions on the colour development possible. By defining the keeping quality of a cucumber as the time to reach a colour limit, predictions on keeping quality could be made. The batch keeping quality was defined as the time it takes until 5% of all cucumbers in a batch reach the colour limit (Schouten and Kooten, 1998).

Schouten *et al*. (2002) had made a physiological model of the chlorophyll metabolism for cucumbers and using colour data from cucumbers stored at 12, 20 and 28^{0}C, the parameters of the model were estimated with time and temperature simultaneously as explaining variables. And had found out that that 95% of all cucumbers in a batch had an acceptable colour, was obtained at 20^{0}C.

Hertog (2002) outlined a mathematical approach to interpret batch behaviour for shriveling of apples and colour change of avocados that is based on the underlying processes occurring at the individual level.

Schouten *et al*. (2002) had developed a colour model describing the change in concentration of the compounds with green colour (chlorophyll (CHL) and chlorophyllide (chl)) and their precursor (protochlorophyllide (Pchl)) over time and temperature. It was assumed that no precursor would be synthesised after harvest. Colour is defined as the sum of CHL and chl.

Schouten *et al*. (2004) had conducted a study on batch variability and cultivar keeping quality of cucumber. The batch model is tested and validated using colour data of two sets of cucumber batches. Applying a previously developed cucumber colour model, the precursor concentration determining the keeping quality at harvest was estimated. The amount of colour precursor at maximal maturity could be estimated in common for batches of the same cultivar and was defined as cultivar keeping quality.

Nilsson (2005) had found out that in seedless cucumber the declining hue angle due to development of a spotted green colour was not related to the endogenous ethylene production.

Dermesonlouoglou *et al*. (2008) reported that dehydrofrozen samples exhibited significantly improved stability, with the rates of colour change being reduced up to 36.7% for osmotically pre-treated cucumbers, compared to the untreated samples. Colour measurements indicated that colour change of untreated and blanched frozen cucumber samples was more intense than the change of colour of pre-treated samples.

The feasibility of minimal processing and MAP (5% O_2 + 5% CO_2) to preserve colour attributes and bioactive compounds of fresh-cut tomato from different cultivars was evaluated through storage under refrigeration was studied by Serrano *et al*. (2008). They found that the fresh-cut tomatoes maintained the main antioxidant compounds and colour parameters for 21 days at 4^0C. Moreover, some health-related compounds such as phenolics increased after 14 days of storage at 4^0C irrespective of the studied cultivar.

Hurr *et al*. (2009) had reported that cucumber that had green surface colour at harvest displayed a precipitous drop in chlorophyll content during storage in air that was greatly accelerated by ethylene treatment.

2.2.5 Titrable acidity

Acids are one of the energy reserves of the fruit; therefore these are used in the respiration process and converted to more simple molecules such as CO_2 and water (Wills *et al*., 1998). As a result of respiration, acids decrease, but water loss in the fruit increases its concentration.

Marupadi *et al*., (2011) studied the enhancement of storage life and quality maintenance of papaya fruits using Aloe Vera based antimicrobial coating. The results showed that the titrable acidity in the fruit samples decreased with storage time in both control and treated fruits. However, the difference was to a lesser extent in coated fruit compared to control.

Nunes *et al.* (2011) had conducted a study on distribution center and retail conditions affect the sensory and compositional quality of bulk and packaged slicing cucumbers. And had reported that acidity of cucumber significantly decreased compared to initial values, regardless of the treatment. On average, packaged cucumbers had significantly higher acidity than bulk cucumbers. In addition, the acidity of cucumbers stored at optimum temperature was higher than that of cucumbers stored at low or high temperatures.

2.2.6 Moisture content

Banks *et al*. (1997) stated that surface coatings can reduce moisture loss and retard ripening of avocados without adversely affecting the other aspects of fruit quality. The avocados can lose 1% of its moisture each day at 20^{0}C, 60% RH. Surface coatings like wax act as a good barriers to water vapour. This reduces the rate at which water evaporates from the fruit surface and thereby slows loss of saleable weight. Thus, he found that waxing reduced moisture loss by up to 50%.

George (1972) had conducted a study on waxed and unwaxed cucumbers stored at 12.8^{0}C and 70 - 80% RH, and at 23.9^{0}C and 40 - 50% RH, for up to 21 days. And had reported that moisture loss was least at 12.8^{0}C in waxed cucumbers and varied between 9.7 and 15.2%, compared with up to 22.6% in the control.

Experiments were conducted during the 1994 spring harvest season to determine the effectiveness of 5 types of fruit and vegetable wax in retarding moisture loss from and chilling injury of cucumber fruits stored at 5^{0}C and 15^{0}C. Vapour pressure deficits were approximately the same at these storage temperatures. The effectiveness of the waxes in retarding moisture loss and reducing chilling injury decreased with increasing wax dilution except for the surfactant-based waxes which increased moisture loss and chilling injury at the lowest dilution. At low temperatures cracks may occur in some of the waxes which enhance moisture loss from the fruit (Purvis, 1994).

2.3 Waxing

Edible coatings can provide an additional protective coating for fresh products and can also give the same effect as MAP in modifying internal gas composition. Wax was the first edible coating used on fruits. The Chinese applied wax coatings to oranges and lemons in the 12th and 13th centuries. Although the

Chinese did not realize that the full function of edible coatings was to slow down respiratory gas exchange, they found that wax coated fruits could be stored longer than non-waxed fruits (Park, 1999).

Films and coatings have received much attention in recent years because they extend shelf life and improve food quality by providing a barrier to mass transfer, carry food ingredients and improve mechanical integrity or handling characteristics of a food. Waxing is one of the coating technologies suitable for preservation of fruits and vegetables. By this method we can increase the shelf life of agro-produce by more than 2 weeks. This gives breathing time for marketing. This will also increase the market (Krochta, 1997; Anonymous, 2004). Some of the benefits of waxing include improved appearance, less moisture loss, less economic loss, reduced postharvest decay, longer postharvest life and less susceptibility to chilling injury. Victor *et al.* (2011) had summarized the main compounds used as edible films and edible coatings (Table 2.1).

Polysaccharides and proteins are great materials for the formation of edible coating and edible film, as they show excellent mechanical and structural properties, but they have a poor barrier capacity against moisture transfer. This problem is not found in lipids due to their hydrophobic properties, especially those with high melting points such as bee-wax and carnauba wax (Morillon *et al*., 2002).

Sindu *et al*. (2009) reported that waxed pear fruits could be cold stored for 75 days and non-waxed fruits for 60 days in corrugated fiber board cartons with minimum weight loss, spoilage, excellent appearance and better fruit quality.

Barman *et al.* (2011) had studied enhancement of shelf life and preservation of fruit quality of pomegranate coated with putrescine and carnauba wax during cold storage. The combinational impact of putrescine and carnauba wax was found much effective over putrescine, carnauba wax and control.

Highest percentage of water loss (≈17%) was recorded in control fruits and lowest (≈10%) with putrescine + carnauba wax at 60th day of cold storage.

Table 2.1 Summary of different compounds used in edible film and edible coating

(Vıctor *et al*., 2011)

Compounds	Reference
Carboxymethylcellulose, casein	Ponce *et al*. (2008)
Casein derivates with beeswaxand fatty acids	Fabra *et al*. (2009)
Locust bean gum, guar gum,ethyl cellulose	Shrestha *et al*. (2003)
Mesquite gum	Bosquez *et al*. (2010)
Gelatin with glycerol, sorbitol and sucrose	Arvanitoyannis *et al*. (1997) Sobral *et al*. (2001)
Gelatin-casein cross-linked with transglutaminase	Chambi and Grosso (2006)
Pectin	Maftoonazad *et al*. (2007)
Cassava starch	Kechichian *et al.* (2010)
Pre-gelatinized maize starch	Pagella *et al*. (2002)
Wheat gluten	Tanada and Grosso (2005)
Sodium alginate and pectin cross-linked with $CaCl_2$	Altenhofen *et al*. (2009)
HPMC with fatty acids	Jimenez *et al*. (2010)
Beeswax	Morillon *et al*. (2002)
Carnauba wax	Shellhammer and Krochta (1997)
Chitosan	Romanazzi *et al*. (2002); Devlieghere *et al*. (2004); Martınez *et al*. (2010); Aider (2010)

Chitosan-gelatin	Arvanitoyannis *et al*. (1997)
Maize starch-chitosan-glycerin	Liu *et al*. (2009)
HPMC-tea tree essential oil	Sanchez *et al*. (2010)
Cashew gum	Carneiro *et al*. (2009); Souza *et al*. (2010)
Galactomannans	Cerqueira *et al*. (2009)

Fahad *et al.* (2012) had studied the effect of application of gum Arabic edible coating on weight loss, firmness and sensory characteristics of cucumber fruits. Cucumber was coated with gum Arabic at different concentration (5, 10, 15 and 20%) and stored at 10 and 25^{0}C for up to 16 days. Gum coating significantly reduced weight loss of the fruits at both storage temperatures. The application of gum edible coating delayed softening of cucumber fruit during 16 days of storage at 10 and 25^{0}C. Sensory characteristics of cucumber such as colour, taste, tenderness, appearance and overall acceptability of coated (5 - 20%) cucumbers were much better preserved while storing.

2.4 Modified atmospheric packaging

MAP of fresh fruits and vegetables refers to the technique of sealing actively respiring produce in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere (Jobling, 2001). In addition to atmosphere modification, MAP vastly improves moisture retention, which can have a greater influence on preserving quality than O_2 and CO_2 levels. Furthermore, packaging isolates the product from the external environment and helps to ensure conditions that, if not sterile, at least reduce exposure to pathogens and contaminants (Mir and Beaudry, 2000).

Gorris and Peppelenbos (1992) reported that MAP slow down the metabolic activity of a product and of the microorganisms present, both spoilage and pathogenic, limiting the O_2 supply and applying an elevated level of CO_2.

Wang and Qi (1997) reported that cucumbers packaged in perforated or sealed LDPE bags were found to have less severe chilling injury than non-wrapped fruit in storage at 5^0C and 90 - 95% relative humidity. The onset of chilling injury was also delayed by the LDPE packaging compared to the non-packaged control. The concentrations of CO_2 increased to 3% while O_2 levels decreased to 16% in the sealed bags. Fruit in the sealed bags had the least decay. The O_2 and CO_2 concentrations inside the perforated bags changed very little from the ambient atmosphere. The weight loss of non-wrapped fruit reached 9% in 18 days while perforated and sealed samples lost less than 1% during the same period.

Sanz *et al*. (1999) used perforated polypropylene packages to study the effects of perforation on gas concentration and strawberry quality. Strawberry packages with perforations, and treated by simulating transport and shelf life conditions, developed an internal atmosphere with composition close to that recommended for this fruit. This controlled decay and reduced deterioration, thus extending strawberry postharvest life. Moreover, fruit ripeness degree and nutritional value were better preserved, although this MAP seemed to reduce fruit colour and lead to off-flavour development.

Prasad *et al*. (2001) had undertook an investigation on pumpkin in minimally processed form, packed in different polymeric film bags of varying permeabilities, creating an active EMA within the package for the extension of storage life. It was observed that minimally processed pumpkin, which has a high respiratory rate at room temperature could be stored for a period of 25 days at 5 ± 2^0C under modified atmosphere packaging conditions with a minimum PLW of 0.06% and marginally low changes in biochemical constituents, such as vitamin C, TSS, moisture, carotenoids and titrable acidity, enabling the retention of near-fresh quality.

The six primary environmental variables usually controlled in CAS and MAP are storage duration, temperature, relative humidity, and the concentrations of O_2, CO_2, and ethylene. The ‘optimum’ storage environment for each commodity is designed to maintain these variables within a set of limits that produces the maximum storage life for most of the individual members of the commodity (Saltveit, 2003).

Equilibrium modified atmosphere (EMA) packaging is used primarily for the packaging of fresh fruit and vegetables. Either the pack is flushed with the required gas mix or the produce is sealed within the pack with no modification to the atmosphere. Subsequent respiration of the produce and the gas permeability of the packaging allow an equilibrium-modified atmosphere to be reached. EMA is also called passive atmosphere modification (PAM). The passive MAP is also called commodity generated modified atmosphere. In this there is matching of the commodity respiratory characteristic with gas permeability of the packaging system so that a suitable equilibrium micro atmosphere can be evolved. This is through the consumption of O_2 and evolution of CO_2 in respiration process (Irtwange, 2006).

A mathematical model was developed for chopped carrot packaged in simulated MAP 100 gauge LDPE bags to evaluate the effect of perforation level on the concentrations of O_2 and CO_2 and levels of relative humidity inside the package. Perforations resulted in reducing the steady state times of O_2 and CO_2 and the effect was more pronounced on O_2. The increase in number of perforations and decrease in ambient relative humidity predicted a little decrease in relative humidity within the package but it remained above 98%. (Sharma and Chand, 2008).

2.5 Storage studies

Morris and Platenius (1939) suggested that the severity of pitting in cucumber is inversely related to the relative humidity of the storage atmosphere and also reported that the reduced transpiration rate, rather than the high humidity itself, is the effective factor in minimizing injury caused by low temperatures.

Eaks and Morris (1956) reported that the increasing rate of respiration for cucumber fruits held at chilling temperature was correlated with the time of onset and development of chilling injury as measured by the degree of surface pitting and deterioration rate of fruit when transferred to 25^0C after various exposures to low temperatures.

Parkin and Kuo (1989) reported that chilling at 4^0C in the dark induced lipid degradation in cucumber fruit upon rewarming at 14^0C. Rates of ethane evolution by fruits rewarmed after 3 days of chilling were up to four-fold higher than those evolved by unchilled (14^0C) fruits.

Mercer *et al*. (1992) had conducted a study on cell wall polysaccharide changes associated with chilling injury of cucumber and to examine the influence of storage atmospheres on development of chilling injury. They found that the chilling injury symptoms increased with storage at 5 and 6^0C. Chilling injury was slight after 2 days, slight to severe after 4 days, and severe to very severe after 6 days of storage at 5 and 6^0C followed by 2 days at 25^0C. Chilling injury symptoms were more severe after 4 days than after 2 days at 25^0C.

Cucumbers, like many warm-season horticultural crops, are injured when they are exposed to temperatures just above freezing. The harvested fruit are injured when they are stored at low temperatures (below 4^0C) for a few days (Cabrera *et al*., 1992; Mercer and Smittle, 1992; and Purvis, 1995).

Paull, (1998) reported that low temperature has been used to extend the shelf life of temperate fruits and vegetables while the negative effect of low temperature ($<10^0$C) on the shelf life of tropical plants and commodities. Low temperature storage has the additional benefit of protecting non-appearance quality attributes: texture, nutrition, aroma and flavour. In addition, delays in cooling after harvest can reduce commodity shelf life and quality.

Hakim, *et al*. (1999) reported that respiration rates were higher for fruit which had been stored at 1^0C than for fruit which had been stored at 4^0C, indicating greater chilling injury at 1^0C than at 4^0C. Respiration rates were also correlated with pyruvate levels in cucumber fruit stored at 1^0C but not at 4^0C.

Tano, *et al*. (2007) found out that temperature fluctuations had a major impact on the composition of the package atmospheres and on product quality, The quality of the product stored under the temperature fluctuating regime was severely affected as indicated by extensive browning, loss of firmness, weight loss increase, the level of ethanol in the plant tissue, and infection due to physiological damage and excessive condensation, compared to products stored at constant temperature. It was clear that temperature fluctuation, even if it should occur only once, can seriously compromise the benefits of MAP and safety of the packaged produce.

Tsuchida *et al.* (2010) had undertook a study to determine the difference between chilled and non-chilled cucumbers in the incorporation of acetate-1,2-^{14}C into the tricarboxylic acid cycle as a measure of pyruvate utilization, and whether this difference is reflected in the activity of citrate synthase in healthy and chilled cucumber tissues and had found out that increased synthesis of alanine and pyruvic acid and reduced activity of citrate synthase could serve as biomarkers of stress-induced changes during storage of chilled cucumbers.

Materials and Methods

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the methodology adopted for satisfying the objectives of this study.

3.1 Cucumber sample collection

Cucumbers (*Cucumis sativus*), which belong to the *AUC2* variety were procured from the K.C.A.E.T instructionnal farm and Precision farm development centre rain shelter and *Nikerson* variety from a farmer at Vettam, Thavanur, Malappuram district. They were harvested 12 to 15 days after opening of the flower. The fruits collected were cleaned and some of them were coated with bee wax formulation, some with commercial wax (semperfresh) and remaining were kept without coating. These samples were packed in 260 ± 1 gauge LDPE bags (0% perforations and 0.25% perforations) and 200 gauge self-breathing bags and was stored at 11 ± 2^0C and 95% RH.

3.2 Physio-chemical characteristics estimation

3.2.1 Moisture content

The moisture content of cucumber was determined by gravimetric method. The known weight of the samples ($W_{initial}$) was kept inside a hot oven at a temperature of 100^0C. The samples were weighed in every 24 hrs until the weight become constant and this weight is taken as final weights (W_{final}) of the samples. The moisture content was expressed as the percentage change in weight (Ranganna, 1995).

$$\text{Moisture content (\%)} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \quad \text{.................................} (3.1)$$

3.2.2 Total soluble solids

TSS was measured using a hand refractometer. Samples were crushed and made into juice. One or two drops of juice were placed on the hand refractometer for TSS measurement. It was expressed in degree Brix (Ranganna, 1995).

3.2.3 Ascorbic acid

Ascorbic acid otherwise known as vitamin C was determined by dye method (Sadasivam and Manickam, 1992). The reagents used were 4% oxalic acid, standard ascorbic acid solution in 4% oxalic acid and dye solution (42 mg of sodium bicarbonate and 52 mg of 2,6, dichloro phenol indophenol dye in 200 ml of distilled water). About 100 mg of pure dry crystalline ascorbic acid was taken and made up to 100 ml using 4% oxalic acid to get the stock solution. The working standard solution (100 ml) was prepared by diluting 10 ml stock solution using 4% oxalic acid. About 5 ml each of working standard solution and 4% oxalic acid were pipetted into a conical flask and titrated against the dye solution. End point was the appearance of pale pink colour which persisted for a few minutes. The titration was repeated for 3 times to get the concordant value. The amount of dye consumed (V_1) was determined which was equal to the amount of ascorbic acid present in the working standard solution. Then the sample was made into pulp and 10 ml of the homogenized pulp (V_s) was taken and made up to 100 ml with 4% oxalic acid solution. Then 5 ml of the made up solution was pipetted out into a conical flask and titrated against the dye (V_2). The quantity of ascorbic acid (mg) present in 100 gm of sample was calculated as follows.

$$\text{Ascorbic acid (mg/100g)} = \frac{0.5}{V_1} \times \frac{V_2}{5} \times \frac{100}{V_s} \times 100 \quad \text{................................ (3.2)}$$

3.2.4 Titrable acidity

The cucumber slices were crushed and filtered through a muslin cloth. About 10 g of fresh filtered homogenized pulp were made up to 100 ml with distilled water. About 10 ml of the prepared solution was titrated against 0.1 N

NaOH solution using phenolphthalein as indicator. The appearance of a light pink colour was the end-point that quantifies the NaOH required to neutralize the juice. Then the titrable acidity was calculated and expressed as per cent citric acid (Ranganna, 1986). Amount of titrable acidity (N_s) present in 100 g of sample was calculated as follows

$$N_s\,(\%) = \frac{\text{Normality of alkali} \times \text{Titre value} \times \text{Equallent weight of acid} \times 100}{\text{Volume of sample taken} \times 100} \quad \text{.................} \ (3.3)$$

3.2.5 Texture Analysis

This important quality parameter which affects the consumer acceptability of cucumber was determined using Texture Analyser (Stable Micro Systems, UK; Plate 3.1). The instrument had a micro-processor regulated texture analysis system interfaced to a personal computer. The instrument consists of two separate modules; the test-bed and the control console (keyboard). Both are linked by a cable which route low voltage signal and power through it. The texture analyser measures force, distance and time and hence provide a three-dimensional product analysis. Forces may be measured to achieve set distances and distances may be measured to achieve set forces.

The sample was kept on the flat platform of the instrument and was subjected to double compression by a cylindrical probe with 5 mm diameter. The test was conducted at a speed of 2 mm/s using 50 kg load cell. The sample was allowed for a double compression of 75% with trigger force of 0.025 kg during which various textural parameters were determined. From the force deformation curve, the firmness or hardness (peak force), stiffness (slope of the curve) and toughness (area under the curve) were determined.

Plate 3.1 Texture analyser (Stable Micro Systems)

3.2.6 Colour

Hunter lab colourimeter (Mini Scan XE Plus) was used for the colour measurement involved in the study (Plate 3.2). It works on the principle of collecting the light and measures energy from the sample reflected across the entire visible spectrum. The meter uses filters and mathematical models which rely on “standard observer curves” that defines the amount of green, red and blue primary lights required to match a series of colours across the visible spectrum and the mathematical model used is Hunter model.

This system uses three values viz. ‘L’, ‘a’ and ‘b’ to describe the precise location of a colour inside a three-dimensional visible colour space. Measurements displayed in L, a and b values represents light - dark spectrum with a range from 0 (black) to 100 (white), the green - red spectrum with a range from - 60 (green) to + 60 (red) and the blue - yellow spectrum with a range from - 60 (blue) to + 60 (yellow) dimensions respectively (Ali *et al*., 2008).

The colorimeter was calibrated against standard white and black tiles before each actual colour measurement. For each sample at least three replications were performed at different positions and the mean values were taken. The sample colour was measured by filling the cut samples of cucumber in the transparent cup without any void space. The deviation of colour of samples from the standard were observed and recorded in the computer interface and the average value of 'L', 'a' and 'b' were determined.

Plate 3.2 Experimental set up of Hunter lab colour flex meter

3.2.7 Physiological loss in weight

The PLW in cucumber was calculated according to the method of Thakur *et al.* (2002). For determining the PLW, fruits were weighed after imposing the treatment which served as the initial fruit weight. The loss in weight was recorded at regular interval until the product was spoiled, which served as the final weight. The PLW was determined by the following formula and expressed as percentage.

$$\text{PLW (\%)} = \frac{A - B}{A} \times 100 \quad \text{...} \; (3.4)$$

Where, A – Original fruit weight (g).

B – Final fruit weight in the day of observation (g).

3.3 Wax coating

The edible formulation was designed to create a MA inside the fruit, reducing its physiological activity through restricted gaseous exchange between the interior of the crop and the environment. Wax coatings create an invisible, edible protective film around the fruit. They are effective in delaying ripening and reducing spoilage of a wide range of fresh produce. In addition, commercial wax fruit coatings function by modifying the rate of respiration of the produce. Also, wax treatment can help to maintain the freshness and firmness of fruits by minimising weight loss (dehydration).

3.3.1 Bee wax

Bee wax, a natural wax of animal origin was used. It has a melting point of 62 to 64^{0}C. It was never subjected to a temperature more than 64^{0}C, so as to avoid a chance of discolouration at an extreme of 85^{0}C. Bee wax maintains the quality and freshness of the fruit. Also, it prevents evaporation of water, inhibits respiration rate and polishes the skin to increase the attractiveness of fruit for consumers.

The bee wax cannot be used as such. A vegetable oil was required as a base to prepare the wax emulsion. Hence, a formulation of bee wax with rice bran oil was made. Various concentrations of bee wax in rice bran oil were tested to obtain a solution which remained at room temperature without solidification. Of the trails conducted, the best result was obtained when the wax to oil ratio was taken as 1:100 (Alfiya *et al.*, 2010). This standardized wax was applied over cucumbers.

3.3.2 Commercial wax

Commercial wax used in the present investigation was Semperfresh collected from M/s. Agri Coat Industries, UK. This was a powder formulation of sucrose esters, sodium carboxy methyl cellulose and a mixture of mono- and di-glycerides of fatty acids, all of which are derived from plant sources.

The experiment was carried out using 2% solution (1% active commercial wax) i.e. 20 g/litre of water. This was prepared as follows: Liquid commercial wax concentrate is poured slowly into the water flow while filling the container with water to the correct volume. In order to minimise foaming during this procedure the water inlet should be kept below the water level. The resulting dispersion should be left for 30 minutes with occasional stirring to use.

3.4 Modified-atmosphere packaging of cucumbers

Cucumbers coated with bee wax formulation and commercial wax and non- coated fruits were stored in different MAP conditions.

3.4.1 Self-breathing bags

In this study we had done EMA Packaging using LDPE bags with a nano composite incorporated window (Techno Fresh) which helps to attain the EMA at a faster rate.

Techno Fresh is a unique polymer based technology, which is capable of providing different package permeability, in order to create specific oxygen and carbon dioxide levels in a package and maintain this optimum atmosphere. As the product consumes oxygen and gives off carbon dioxide, an equilibrium gas concentration is established in the package. This process is a function of the membrane permeability and its carbon dioxide to oxygen selectivity ratio. Thus the created atmosphere is able to extend shelf life, maintain high quality and preserve nutrients of fresh produce/flowers by naturally regulating respiration of said items.

Cucumbers coated with bee wax, commercial wax and non-coated cucumbers were packed using Techno Fresh and stored at various conditions. The different treatments were represented as follows,

TC1: Sample coated with bee wax and stored at 11 ± 2^{0}C and 95% RH

TC2: Sample coated with commercial wax and stored at 11 ± 2^{0}C and 95% RH

TC3: Sample without wax coating and stored at 11 ± 2^{0}C and 95% RH

3.4.2 LDPE films

LDPE bags of 260 ± 1 gauge were used. Cucumbers coated with bee wax, commercial wax and non-coated cucumbers were packed using LDPE bags with 0.25% and 0% perforations and stored at various conditions. The different treatments were represented as follows,

TL1: Sample coated with bee wax, packed in 0.25% perforated bags and stored at 11 ± 2^{0}C and 95% RH

TL2: Sample coated with bee wax, packed in 0% perforated bags and stored at 11 ± 2^{0}C and 95% RH

TL3: Sample coated with commercial wax, packed in 0.25% perforated bags and stored at 11 ± 2^{0}C and 95% RH

TL4: Sample coated with commercial wax, packed in 0% perforated bags and stored at 11 ± 2^{0}C and 95% RH

TL5: Sample without wax coating, packed in 0.25% perforated bags and stored at 11 ± 2^{0}C and 95% RH

TL6: Sample without wax coating, packed in 0% perforated bags and stored at 11 ± 2^{0}C and 95% RH

3.4.3 Gas composition determination

One of the important parameters affecting the shelf life of the packed product is the gas composition inside the package. The gas composition inside the package was determined using O_2 /CO_2 head space gas analyser (Check Mate2; Plate 3.3). The Check Mate2 O_2 version is based on zirconia or an electrochemical sensor. The zirconia sensor produces a small voltage or electromotive force (emf) in the presence of oxygen. The CO_2 sensor is a self-contained non dispersive infrared sensor complete with infrared source and dual wavelength sensor. The Check Mate2 works by drawing a small sample of the head space gas into the sensors. The gas is then analysed and the result is displayed on the display within a few seconds.

A needle was penetrated into the gas stream (make sure the needle does not touch the contents in the package) through a silicon septum placed on the package. The continuous measuring was started by pressing the start/stop button. The measured O_2 and CO_2 values and balance were displayed.

Plate 3.3 Experimental setup for gas composition determination (Check Mate2)

Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

This chapter enunciates and discusses the outcomes of various experiments conducted to evaluate the change in different quality parameters on storage.

4.1 Physio-chemical characteristics of slicing cucumber

The estimated bio-chemical composition and quality parameters before various treatments and packaging of *Nikerson* variety of slicing cucumber are presented in table 4.1. The average moisture content of slicing cucumber was found to be 96.02% (wb). The average values of the chemical components viz; TSS, ascorbic acid and titrable acidity were estimated to be 4^{0}Brix, 3.23 mg/100g, and 0.43% respectively for the average moisture content.

Table 4.1. Physio-chemical characteristics of fresh slicing cucumber

<table>
<tr><td colspan="3">Chemical characteristics</td><td colspan="2">Value</td></tr>
<tr><td colspan="3">Moisture (%)</td><td colspan="2">96.02</td></tr>
<tr><td colspan="3">TSS (^{0}Brix)</td><td colspan="2">4</td></tr>
<tr><td colspan="3">Ascorbic acid (mg/100g)</td><td colspan="2">3.23</td></tr>
<tr><td colspan="3">Titrable acidity (%)</td><td colspan="2">0.43</td></tr>
<tr><td colspan="5">Physical characteristics</td></tr>
<tr><td></td><td colspan="2">Texture (peel)</td><td colspan="2">Texture (pulp)</td></tr>
<tr><td>Firmness (N)</td><td colspan="2">20.96</td><td colspan="2">11.11</td></tr>
<tr><td>Toughness (N.sec)</td><td colspan="2">79.75</td><td colspan="2">80.28</td></tr>
<tr><td>Stiffness (N/sec)</td><td colspan="2">10.47</td><td colspan="2">5.39</td></tr>
<tr><td rowspan="2">Colour value (peel)</td><td>L</td><td colspan="2">a</td><td>b</td></tr>
<tr><td>44.24</td><td colspan="2">-10.07</td><td>21.26</td></tr>
<tr><td>Colour value (pulp)</td><td>63.69</td><td colspan="2">-8.55</td><td>32.98</td></tr>
</table>

4.2 Post harvest behavior of slicing cucumber during storage period

The post-harvest behaviour during storage of slicing cucumber in cold storage (11 ± 2^{0}C, 95% RH) were evaluated by finding the quality parameters as described in section 3.2.

Cucumbers packed in various MAP and stored at cold storage conditions showed the signs of spoilage on the 15th day of analysis and hence they were discarded. However, the fruits kept as control cannot last for 10 days in cold storage condition.

4.2.1 Moisture content

The variation in moisture content of cucumbers of various treatments during the period of storage is shown in Fig. 4.1. In general the cucumbers showed an increasing trend in moisture content with storage irrespective of the treatment. This increase may be due to increased rate of metabolic activity. The maximum moisture content was observed in TL4 treatment (commercial wax + 0% perforated LDPE) with 98.24% after the 15th day of storage. This might be due to the restricted metabolic activity of wax coated cucumbers at MAP created by non-perforated LDPE bags (Banks *et al.*, 1997). The variation in moisture content for the treatments could predict with a polynomial equation as given below:

$$M.C = 0.122\, x^2 + 0.024\, x + 95.85 \quad (R^2 = 0.997) \qquad (4.1)$$

where, x is the storage period in days.

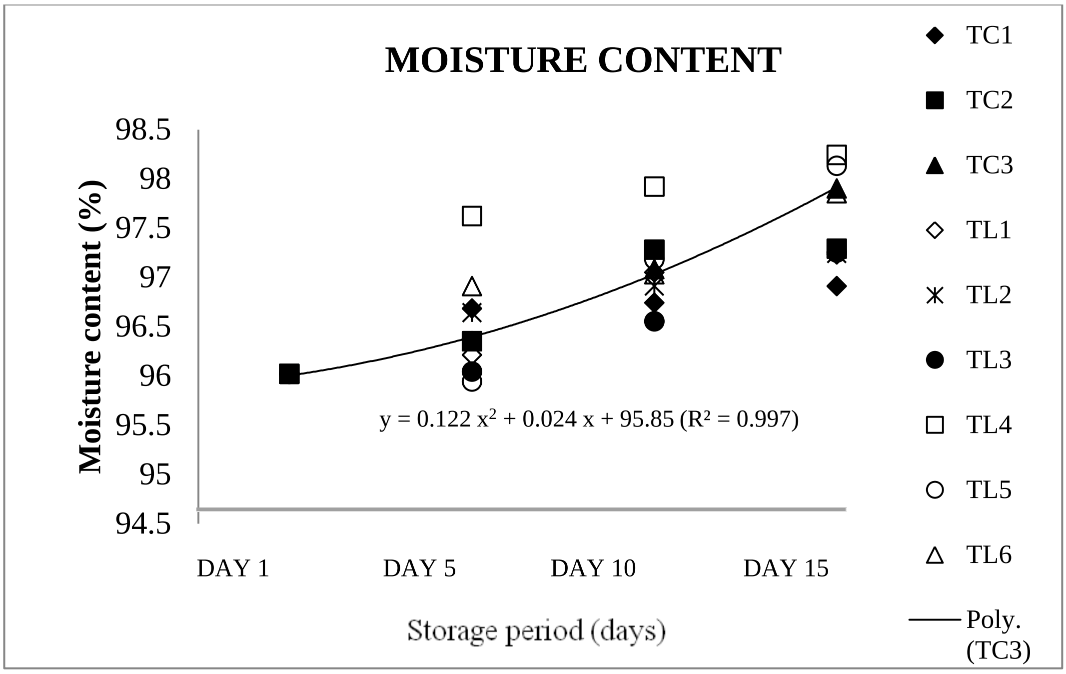

Fig. 4.1 Change in moisture content of cucumber stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.2 Total soluble solids

The variation in TSS concentrations is illustrated in Fig. 4.2. The increase in TSS concentration during storage period may be due to the increased respiration rate and the transit of fruits towards ripening. At the end of storage period the TSS in TL5 (uncoated + 0.25% perforated LDPE) and TL6 (uncoated + 0% perforated LDPE) were the highest (6.2^{0}Brix). The lowest of 5.4^{0}Brix was observed for TL1 (bee wax + 0.25% perforated LDPE). The lowest TSS may be attributed to retarded respiration due to the combined effect of MAP and wax coating. This result corresponds to Mota *et al.,* (2003). The increasing trend in TSS for fruits kept in self-breathing bags is depicted by the equation

TSS = 0.66 x + 3.4 (R^2 = 0.994) …………………………………………… (4.2)

where x is storage period (days).

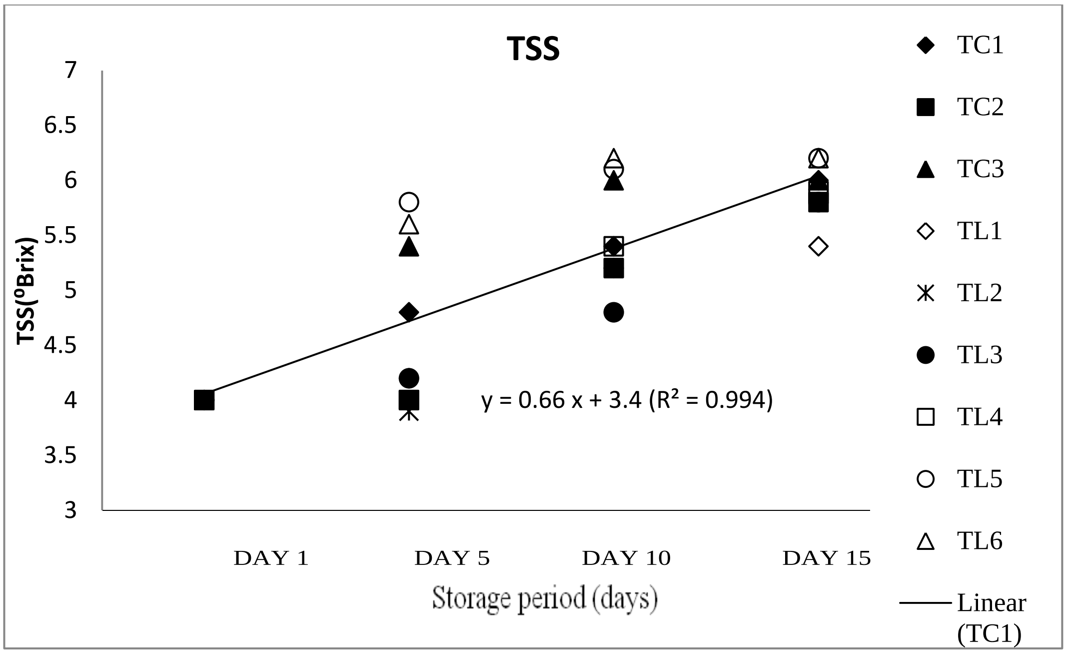

Fig. 4.2 Change in TSS of cucumber stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.3 Ascorbic acid

Fig. 4.3 shows the effect of various treatments on ascorbic acid content of stored slicing cucumber. It was observed that the concentration of ascorbic acid had a decreasing trend with storage irrespective of the treatment. Izumi *et al.*, (1984) had also reported similar findings. At the end of 15th day of storage, the values of ascorbic acid range from 0.975 to 1.219 mg/100 ml. The minimum value was due to the inhibited respiration rate of fruits. From the graph it is evident that the wax coating or the modified atmosphere inside the packet does not have much influence in nutritional parameters of the fruits. The decreasing trend was explained by the equation

Vitamin C = - 0.796 x + 3.956 (R^2 = 0.948) ………………………………… (4.3)

Where x is the storage period in days.

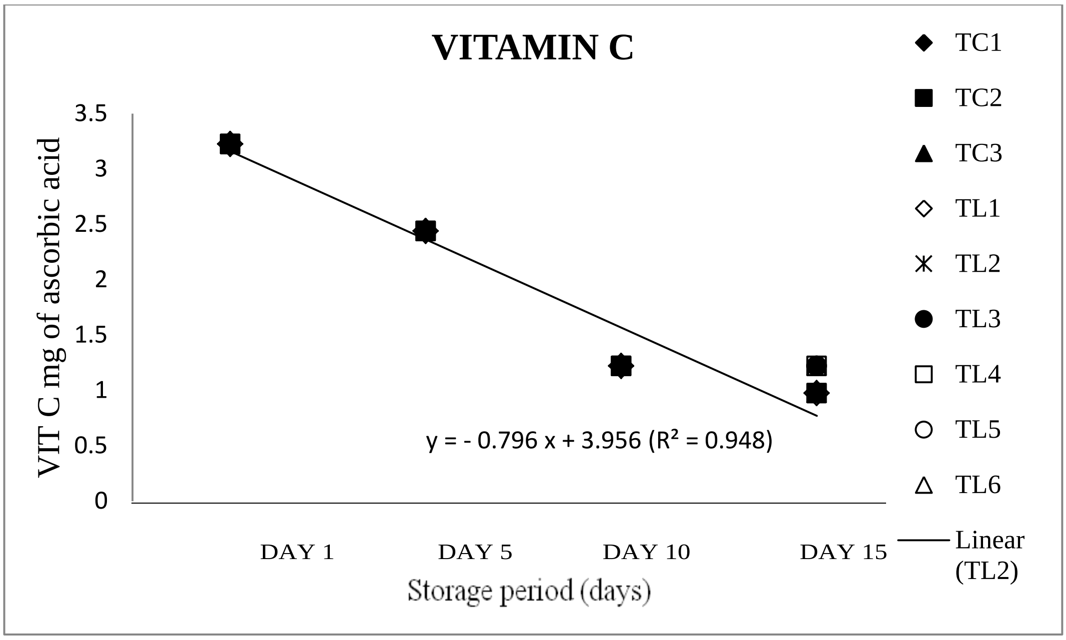

Fig. 4.3 Change in vitamin C of cucumber stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.4 Titable acidity

The titrable acidity of cucumber fruits decreased with storage, which could be expressed using the polynomial equation given below.

Titrable acidity = 0.056 x^2 - 0.375 x + 0.740 (R^2 = 0.992) ………………….. (4.4)

where x is the storage period in days.

This could be account for the degree of ripening of the fruits. Titrable acidity of cucumber significantly decreased compared to initial values, regardless of the treatment (Nunes *et al.*, 2011). This decrease may be due to the increased rate of respiration and starch hydrolysis. However a slight hike (0.20%) in the titrable acidity was observed in TC1 (bee wax + self-breathing), TC3 (uncoated + self-breathing) and TL6 (uncoated + non perforated LDPE). This is due to the delayed ripening in CO_2 enriched MAP.

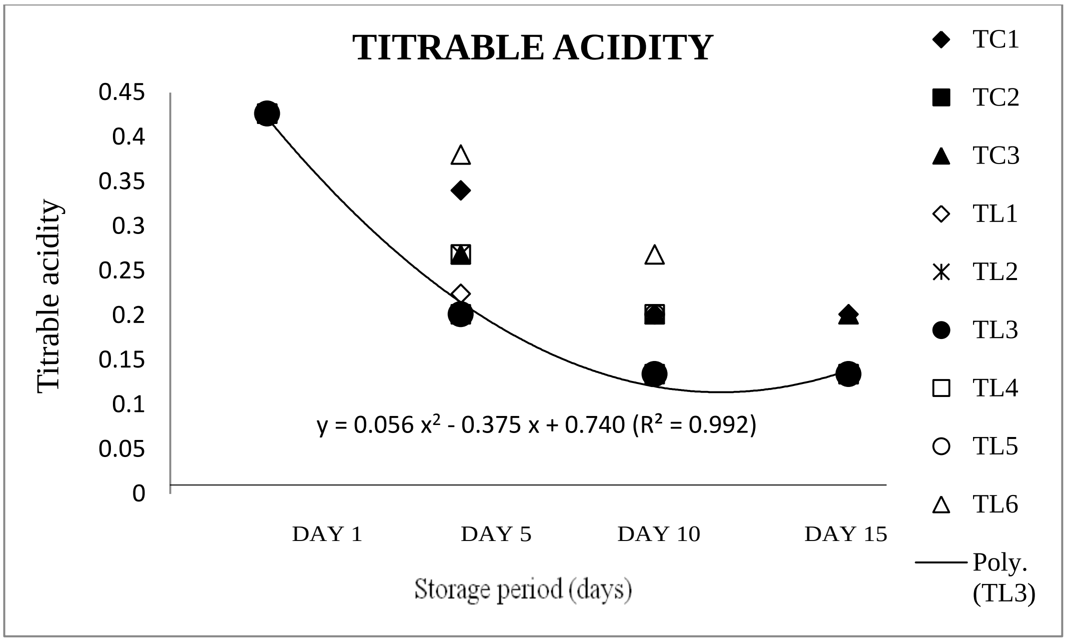

Fig. 4.4 Change in titrable acidity of cucumber stored at 11 ± 2^{0}C and 95% RH

4.2.5 Texture

4.2.5.1 Change of firmness on storage.

From the Fig. 4.5 and Fig. 4.6 it is clear that there was a sharp increase and then a gradual decrease in firmness of both peel and pulp occurred with storage. This initial increase in the firmness may be due to the hardening caused by the effect of low temperature storage. The decline in firmness after this hike may account to the increased ripening of the fruits. It was observed that the fruits in the self-breathing bags were comparatively more firm at the end of storage period. This was due to the retardation in ripening of fruits because of the combined barrier properties of both wax and self-breathing bags (Mota *et al.,* 2003; Hagenmaier, 2000). The trend of firmness change of peel and pulp were described by the given below equations.

Firmness (peel) = $- 2.775 x^2 + 13.53 x + 10.55$ ($R^2 = 0.926$) ………………… (4.5)

Firmness (pulp) = $-1.545 x^2 + 7.169 x + 5.545$ ($R^2 = 0.993$) …………………… (4.6)

where x is the storage period in days.

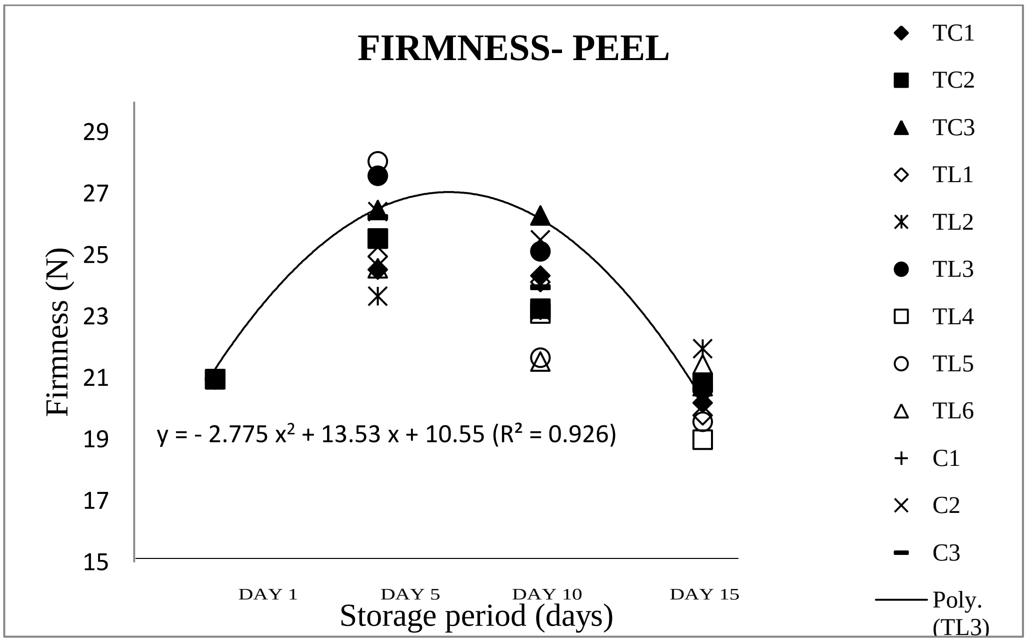

Fig. 4.5 Change in firmness of cucumber peel stored at 11 ± 2^0C and 95% RH.

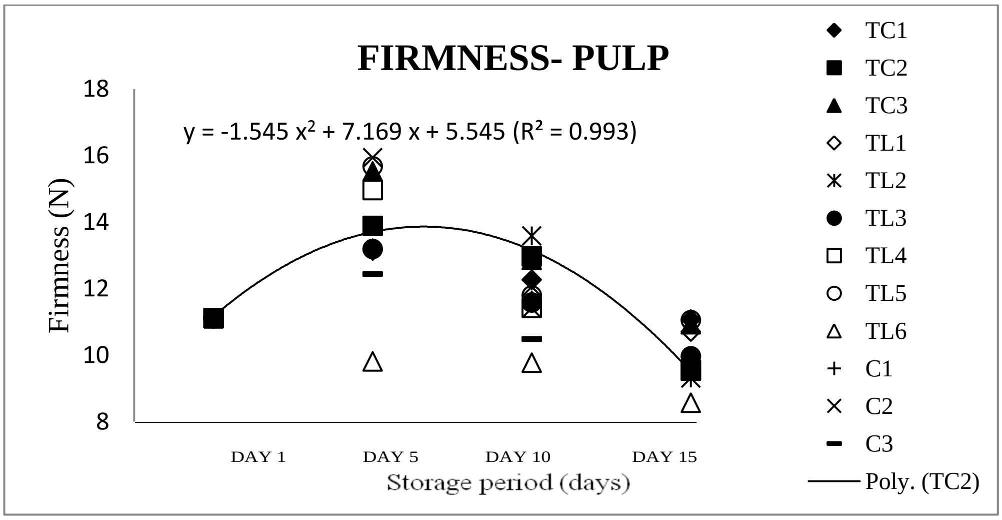

Fig. 4.6 Change in firmness of cucumber pulp stored at 11 ± 2^0C and 95% RH.

4.2.5.2 Change of stiffness on storage.

Stiffness also had the same trend as that of firmness mentioned above. Fig. 4.7 and Fig. 4.8 show the variation of stiffness of peel and pulp respectively of stored cucumber with storage. It was observed that the stiffness of the peel was much higher than the stiffness of the pulp irrespective of the treatment. This result was in line with Thompson *et al.*, (1982) who reported that penetration force was about five times greater for mesocarp than endocarp. The trend of stiffness variation in peel and pulp can be depicted by the following equations.

Stiffness (peel) = $-1.545x^2 + 7.169x + 5.545$ ($R^2 = 0.993$) ………………… (4.7)

Stiffness (pulp) = $-0.333x^2 + 0.627x + 5.138$ ($R^2 = 0.994$) …....................... (4.8)

where x is the storage period in days

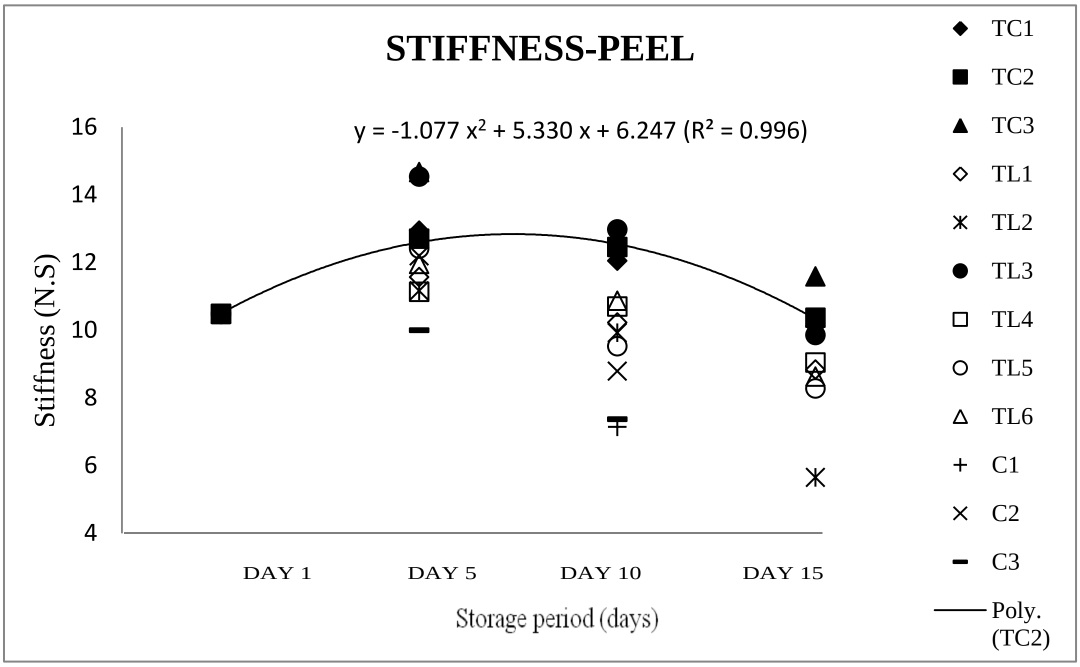

Fig. 4.7 Change in stiffness of cucumber peel stored at 11 ± 2^{0}C and 95% RH.

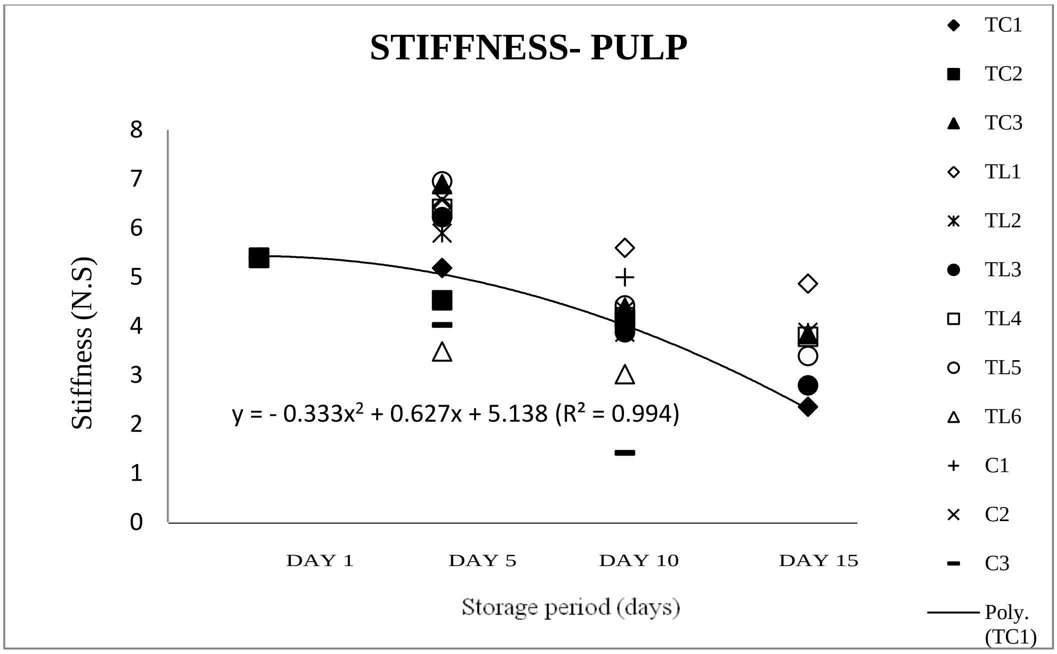

Fig. 4.8 Change in stiffness of cucumber pulp stored at 11 ± 2^{0}C and 95% RH.

4.2.5.3 Change of toughness on storage.

From the Fig. 4.9 and Fig. 4.10 it is clear that toughness of cucumber pulp and peel initially increases and then decreases with storage. TL6 (non-wax + LDPE, 0% perforation) has the minimum toughness at the end of the 15th day of storage. The minimum toughness may be due to the increased metabolic activities due to the absence of wax coating. This result corresponds to Fahad *et al.,* (2012). The trend in the toughness change of peel and pulp are indicated by the equations given below.

Toughness (peel) = - 3.155 x^2 + 6.669 x + 76.24 (R^2 = 1) …………………… (4.9)

Toughness (pulp) = - 7.015 x^2 + 18.81 x + 74.07 (R^2 = 0.708) …………… (4.10)

Where x is the storage period in days.

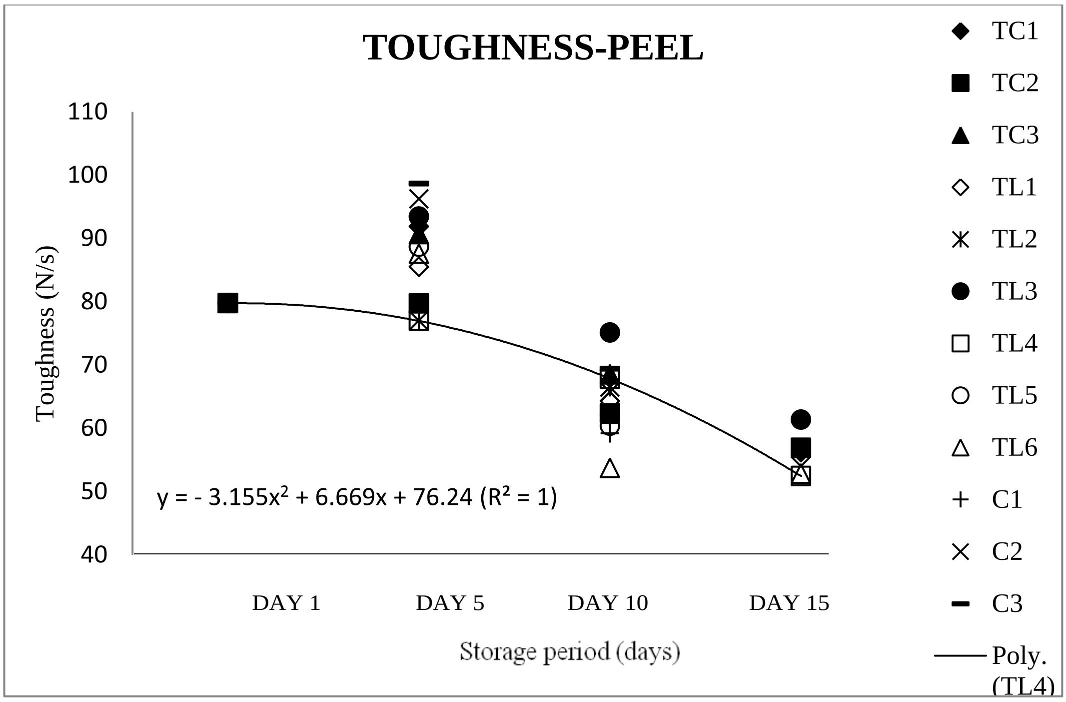

Fig. 4.9 Change in toughness of cucumber peel stored at 11 $\pm$ 2^{0}C and 95% RH.

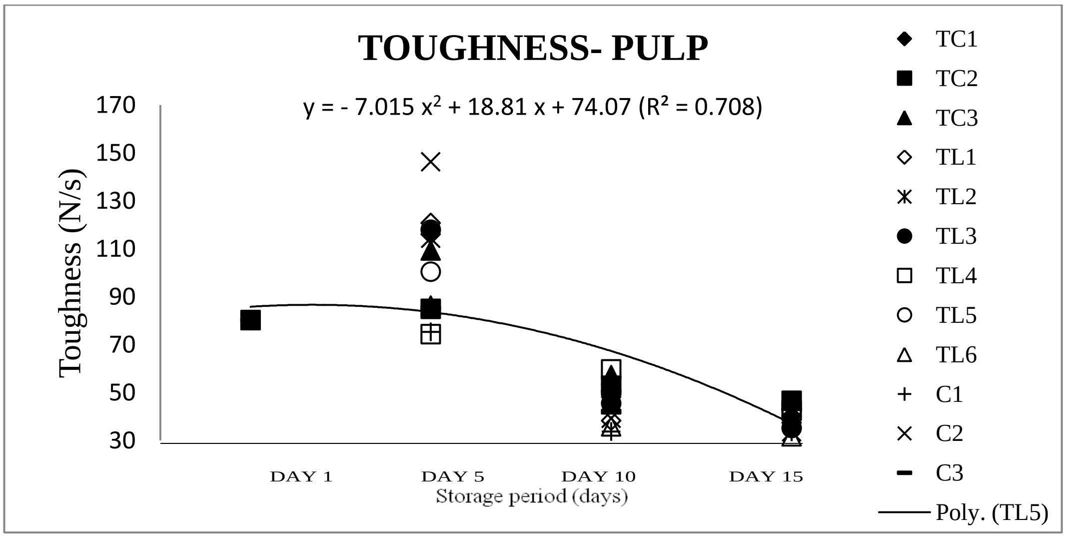

Fig. 4.10 Change in toughness of cucumber pulp stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.6 Colour

A significant change in colour was observed during the storage period of slicing cucumber. The degree of brightness (+L) and yellowness (-b) decreased and the greenness (-a) increased during the period of storage irrespective of the treatments. This was in conformity with Nunes *et al*. (2011) who reported that packaged cucumbers received higher visual colour scores, that is, they appeared brighter and greener than bulk cucumbers.

4.2.6.1 Effect of treatments on lightness 'L' of cucumber

It was observed that the lightness of the cucumber fruits had a decreasing trend with storage. This was due to the controlled transpiration rate and chlorophyll retention (Santana *et al.*, 2011; Petracek *et al.*, 1998). The decrease in the L value of the cucumber peel and pulp is shown in Fig. 4.11 and Fig. 4.12. The figures given below revealed that the fruits kept in TL1 (bee wax + LDPE, 0.25% perforation) gave the lowest 'L' value. The decreasing trend can be expressed using the given below equations.

L value (peel) = $2.482\,x^2 - 18.21\,x + 59.75$ ($R^2 = 0.995$) ………………… (4.11)

L value (pulp) = $2.282\,x^2 - 20.15\,x + 81.72$ ($R^2 = 0.999$) ………………… (4.12)

where x is the storage period in days

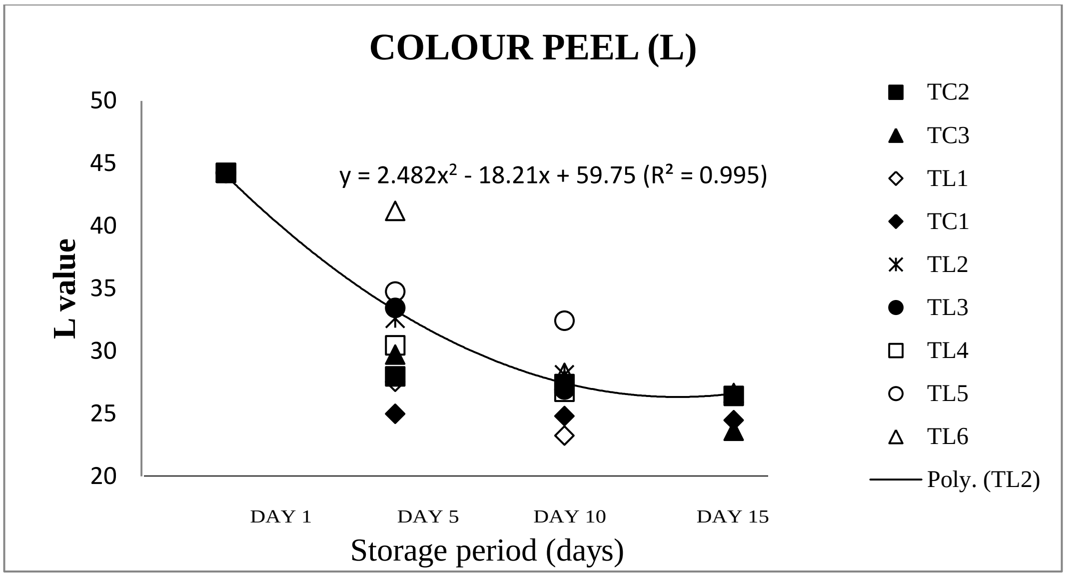

Fig. 4.11 Change in L value of cucumber peel stored at 11 $\pm$ 2^{0}C and 95% RH.

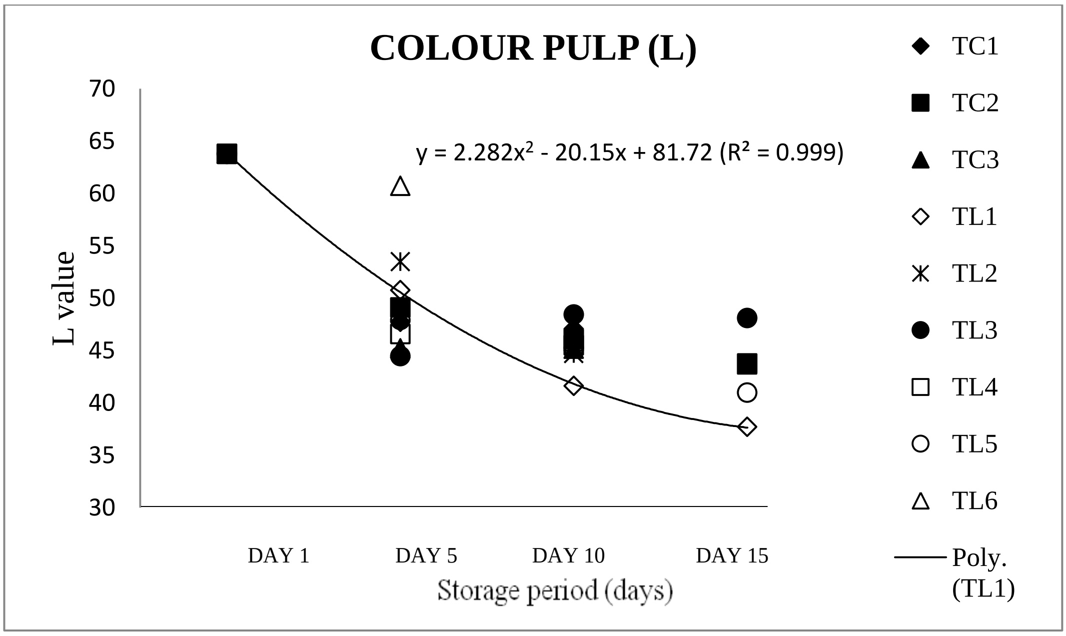

Fig. 4.12 Change in L value of cucumber pulp stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.6.2 Effect of treatments on greenness 'a' of cucumber

The 'a' value of cucumber pulp and peel was found to decrease with storage. This variation in 'a' value is shown in Fig. 4.13 and Fig. 4.14. The change in 'a' value for peel was found minimum in TL4 (commercial wax + LDPE, 0% perforation) and the minimum value for pulp was found in TL2 (bee wax + LDPE, 0% perforation). The lowest value indicates the greenness which was due to the creation of MA around the fruits (Mir and Beaudry, 2009). The maximum change in greenness for both peel and pulp was found in TL5 (non-wax + LDPE, 0.25% perforation). This might be due to the increased rate of metabolic activities. The varying trend of 'a' value of peel and pulp are represented using the equations

'a' value (peel) = 1.54 x - 11.52 (R^2 = 0.977) ……………………………... (4.13)

'a' value (pulp) = 2.161 x - 10.38 (R^2 = 0.983) ……………………………. (4.14)

where x is the storage period in days.

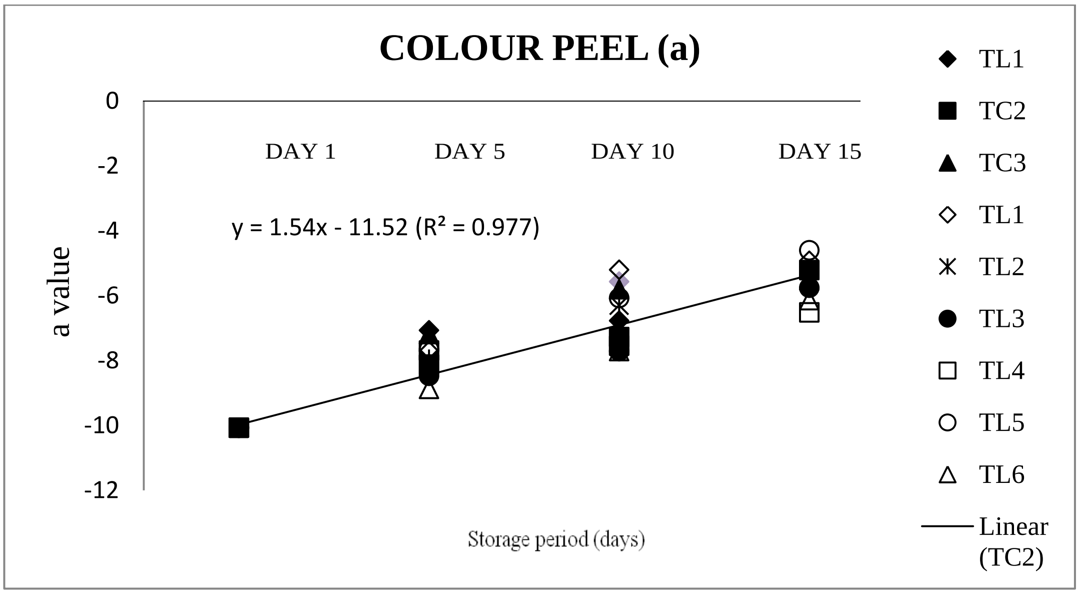

Fig. 4.13 Change in 'a' value of cucumber peel stored at 11 $\pm$ 2^{0}C and 95% RH.

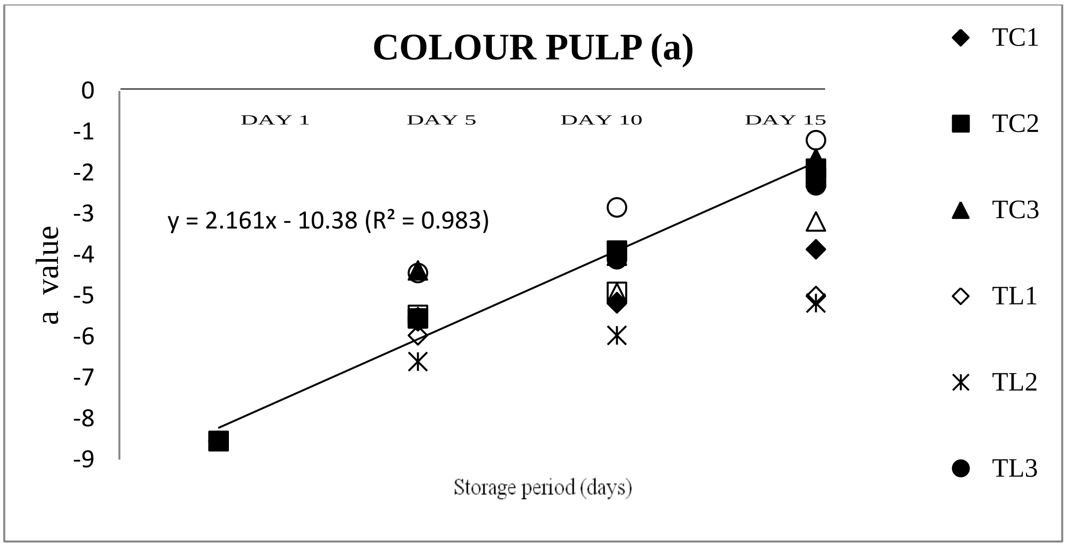

Fig. 4.14 Change in 'a' value of cucumber pulp stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.6.3 Effect of treatments on yellowness 'b' of cucumber.

From the Fig. 4.15 and Fig. 4.16, it is clearly understandable that all the 'b' values are positive which shows the yellowness of the stored cucumbers. It was evident from the figures that there was a decreasing trend in the 'b' value. This trend can be illustrated using the equations

'b' value (peel) = - 0.622 x^2 + 0.389 x + 21.31 (R^2 = 0.984) ……………… (4.15)

'b' value (pulp) = - 4.109 x + 35.87 (R^2 = 0.935) ………………………….. (4.16)

Where x is the storage period in days.

This decreasing trend shows that the fruits were not still ripened after the 15th day of storage. This was due to the controlled rate of respiration of fruits generated by the MA around the fruits. Similar results were observed by Singh *et al.* (1998). From the above obtained result it was able to conclude that all the treatments were very effective in retarding the ripening of the fruits.

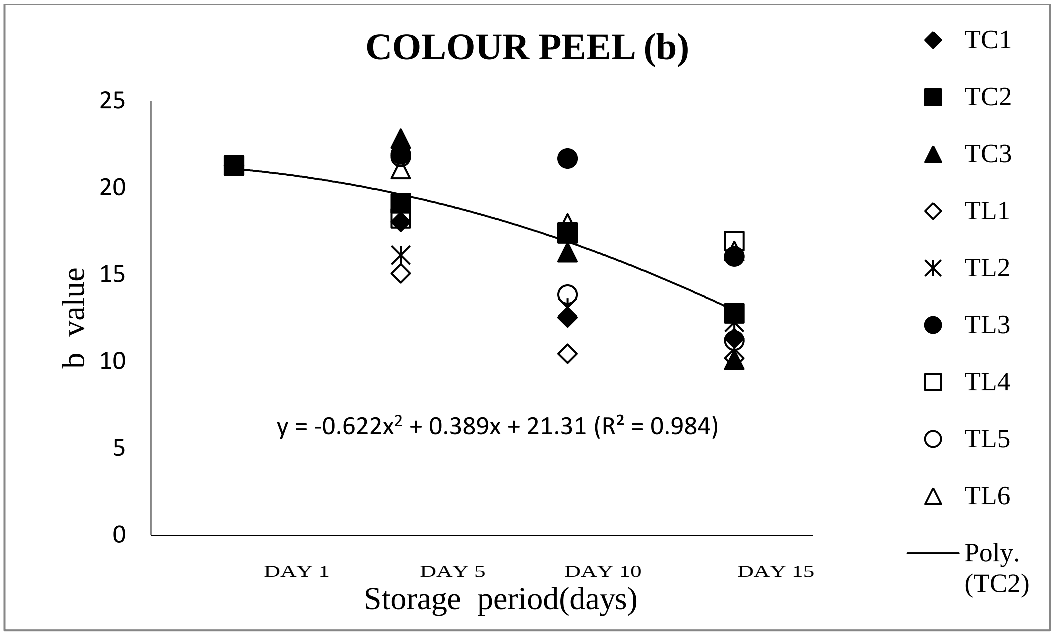

Fig. 4.15 Change in 'b' value of cucumber peel stored at 11 $\pm$ 2^{0}C and 95% RH.

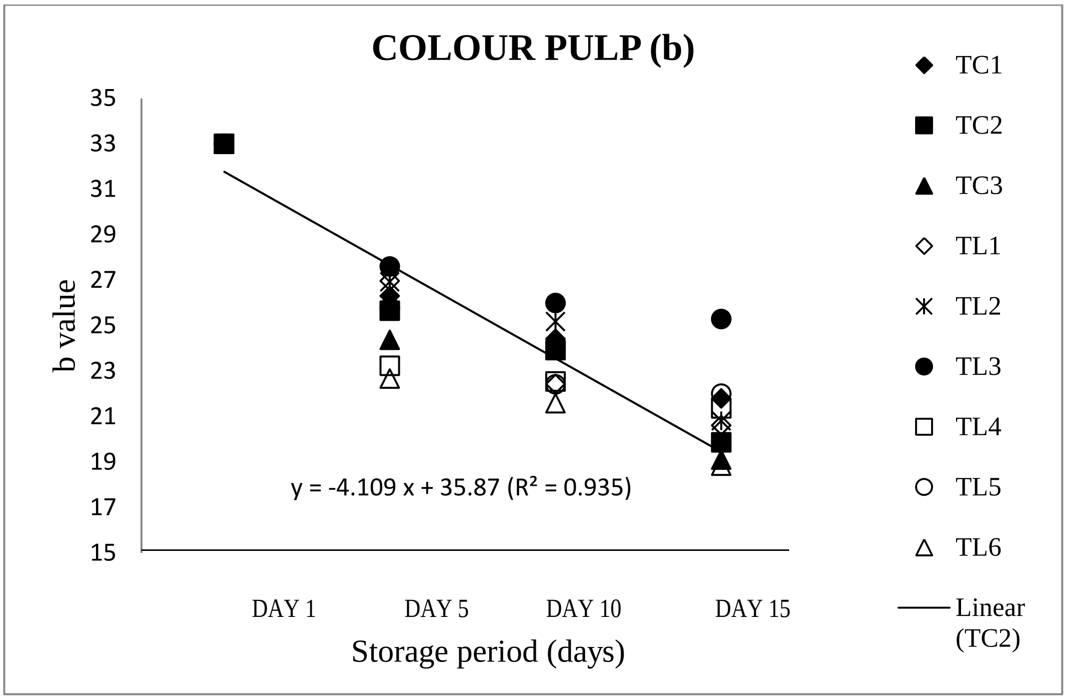

Fig. 4.16 Change in 'b' value of cucumber pulp stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.7 Physiological loss in weight

The PLW of slicing cucumber occurs due to the reduction in moisture content. This leads to the formation of wrinkles on the fruit and eventually increases the rate of shrinkage. The PLW increased consistently as a function of storage. In general it was observed that the rate of increase of PLW was lesser in wax coated fruits when compared to uncoated fruits. The possible reason may be that bee wax and commercial wax served as a semi permeable membrane around fruit surface which resulted in reduction of water loss and rate of respiration, thereby reducing the moisture loss and hence the PLW. These results were similar to the findings of Souza *et al*. (2010).

4.2.7.1 Change in PLW of cucumber packed in non-perforated LDPE bags

The variation in PLW observed in bee wax coated, commercial wax coated and uncoated cucumber fruits packed in non-perforated LDPE bags (260 $\pm$ 2 gauge) is shown in Fig. 4.17 and is given by the equation

PLW = 1.754 x - 1.754 (R^2 = 1) ………………………………………… (4.17)

Where x is the storage period in days.

At the end of 15th day of storage the lowest PLW was observed in TL2 (bee wax + LDPE). This result is in agreement with Thakur *et al.* (2002). This minimum loss may be due the combination of barrier properties of bee wax and LDPE bags (Kore and Kabir, 2012). The highest PLW (15%) observed for C3 (uncoated control), after the 10th day of storage may be due to the absence of LDPE bags, which enhanced the moisture migration and respiration rate. Similar results were reported by Hailu *et al.* (2011).

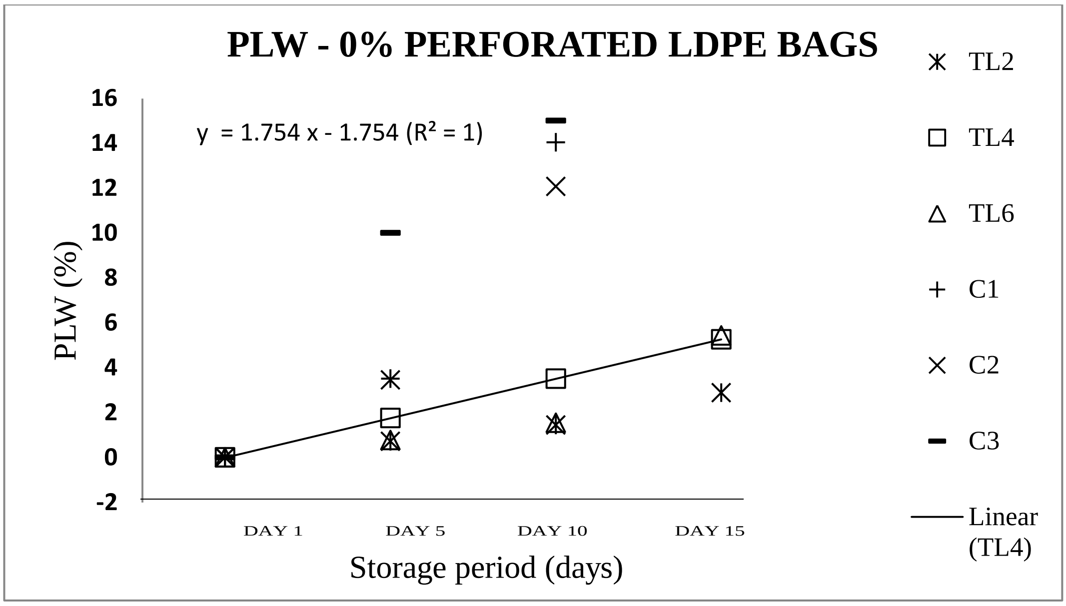

Fig. 4.17 Change in PLW of cucumber packed in non-perforated LDPE bags and stored at 11 ± 2^0C and 95% RH.

4.2.7.2 Change in PLW of cucumber packed in perforated LDPE bags

From the Fig. 4.18 the minimum weight loss after 15^{th} day of storage was observed in TL1 (bee wax + LDPE). The rate of change of PLW was slightly higher for the fruits packed in 0.25% perforated LDPE bags when compared with its non-perforated counterpart. The expected reason for this increased weight loss might be due to the increased water vapour transmission. Similar to the above case the maximum PLW (15%) was observed for C3 (uncoated control), after the 10^{th} day of storage followed by C1 (bee wax control) (14.04%), thus reducing its consumer acceptability (Wills *et al*., 1998). The varying trend can be expressed using the equation

PLW = 1.778 x - 1.403 (R^2 = 0.970) ……………………………………….. (4.18)

where x is the storage period in days.

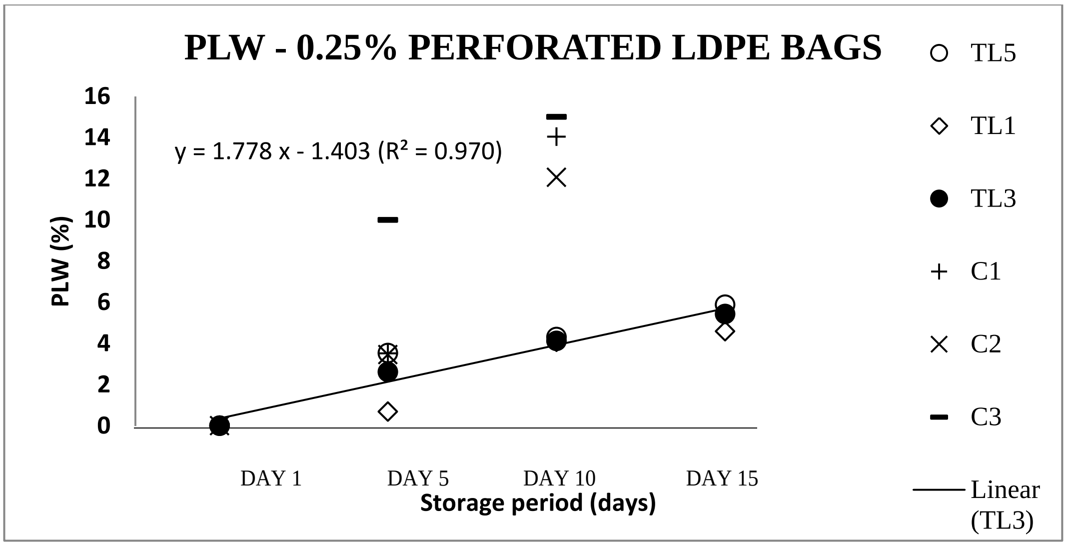

Fig. 4.18 Change in PLW of cucumber packed in 0.25% perforated LDPE bags and stored at 11 $\pm$ 2^{0}C and 95% RH.

4.2.7.3 Change in PLW of cucumber packed in self-breathing bags

Fig. 4.19 shows that apart from the control samples maximum PLW (7.52%) was observed in TC3 (uncoated + self-breathing bags). The minimum PLW was observed in TC2 (commercial wax + self-breathing) which were close to that of TC1 (bee wax + self-breathing bags). As the produce consumes oxygen and gives of carbon dioxide, an equilibrium gas concentration is established in the package. This process is a function of the membrane permeability and its CO_2 to O_2 selectivity ratio. The variation in PLW can be explained by the equation

PLW = 0.891 x - 0.581 (R^2 = 0.92) …………………………………….. (4.19)

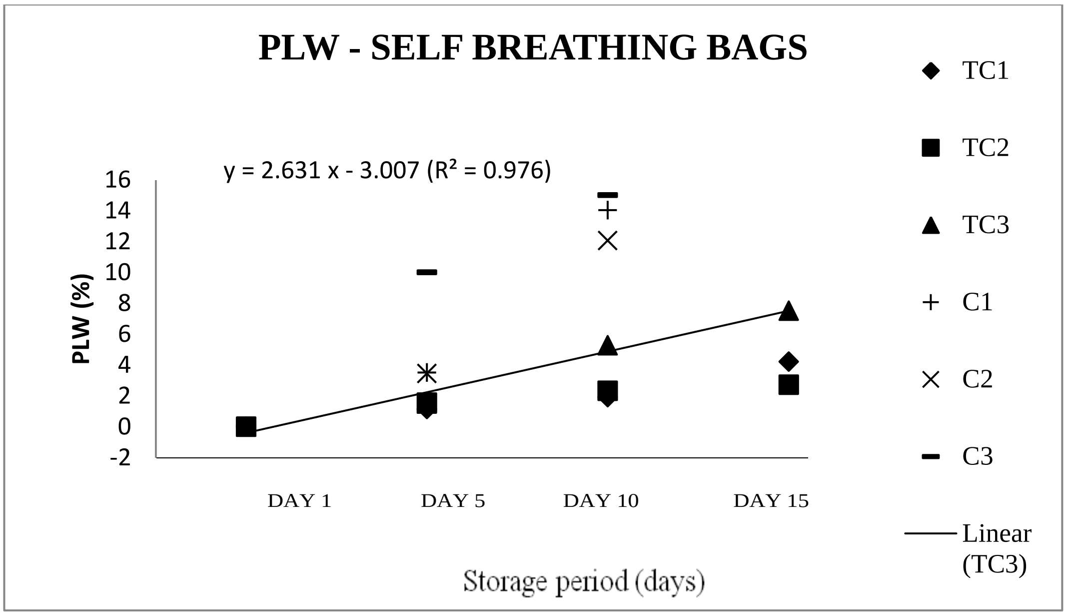

Fig. 4.19 Change in PLW of cucumber packed in self-breathing bags and stored at 11 $\pm$ 2^{0}C and 95% RH

4.2.8 Gas kinetics under MAP

4.2.8.1 MAP of fruits in non-perforated LDPE bags

The percentage of CO_2 and O_2 present in the non-perforated bags were showed in Fig. 4.20 and 4.21 and this variation is given by the polynomial equations

CO_2 concentration = $- 0.6875 x^2 + 5.6925 x - 5.1375$ ($R^2 = 0.987$) ……….(4.20)

O_2 concentration = $1.397 x^2 - 10.98 x + 26.13$ ($R^2 = 0.972$) ………………. (4.21)

where x is the storage period in days.

From the figures it is clear that O_2 decreases and CO_2 increases during the entire storage period. This CO_2 enrichment and O_2 depletion is due to the respiration of fruits inside the enclosed packages (Sudheer and Indira, 2007). Among the treatments, TL2 (bee wax coated) has the minimum percentage of CO_2 (6.5%) when compared to the other treatments. This may be due to the bee wax coating which acts as a barrier against respiration, thus controlling the respiration rate.

In TL6 (without coating), the percentage of CO_2 (10.9%) was found to be maximum. This may be due to the metabolic activity of the fruits, as these fruits lacked surface coatings. This result corresponds to that of Singh *et al.*, (1998) who found MA storage to be effective in controlling the rate of metabolic activities.

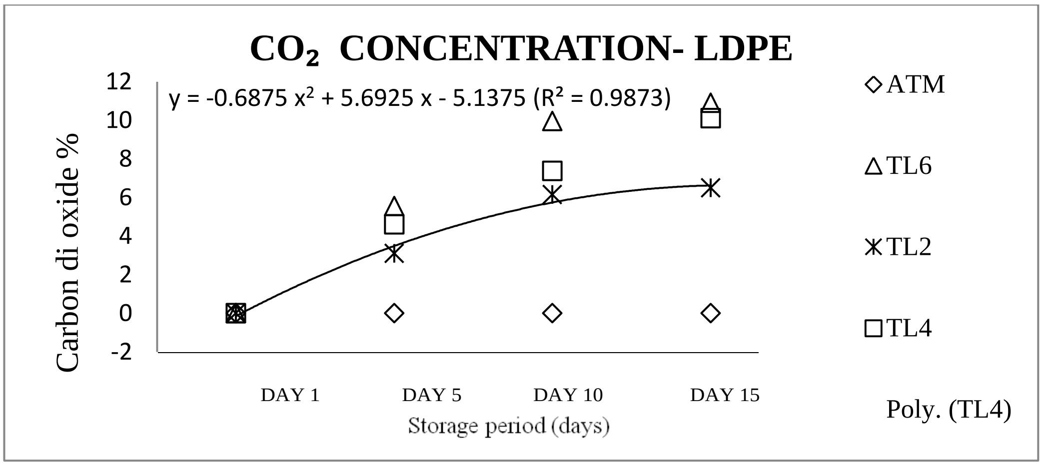

Fig. 4.20 Enrichment of CO_2 (%) in non-perforated LDPE bags in cold storage

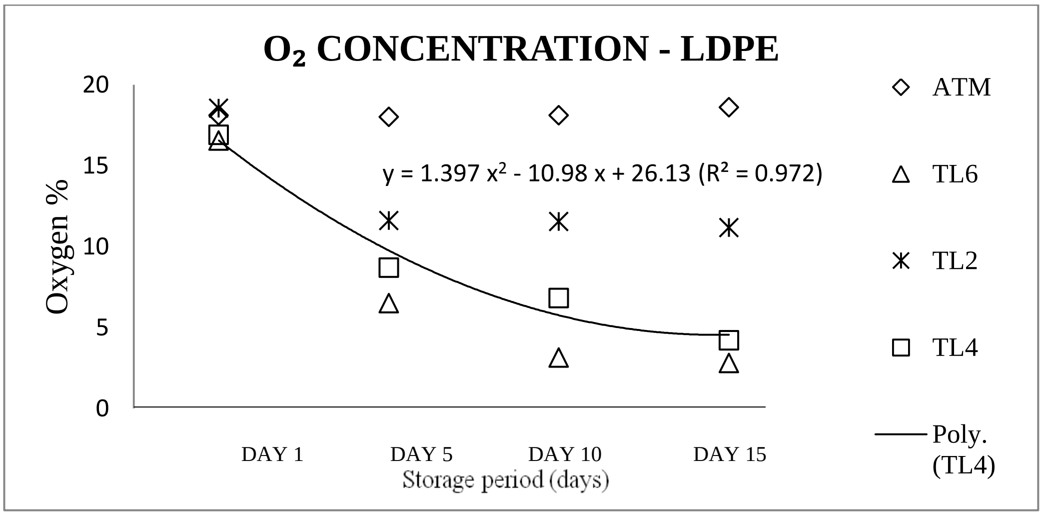

Fig. 4.21 Depletion of O_2 (%) in non-perforated LDPE bags in cold storage

4.2.8.2 MAP of fruits in self-breathing bags

The result of gas analysis done in fruits kept in self-breathing bags is presented in Fig. 4.22 and Fig. 4.23 and is illustrated by the equations

$O_2 = 1.1125\ x^2 - 8.2415\ x + 25.093\ R^2 = 0.9937$ ………………………… (4.22)

$CO_2 = 0.4\ x^2 - 0.99\ x + 0.6\ (R^2 = 0.999)$ …………………………………… (4.23)

where x is the storage period in days.

The composition of O_2 (%) decreases and CO_2 (%) increases which was similar as in the case of fruits kept in LDPE bags. The rate of decrease and increase was comparatively less due to the controlled gas transmission rate by the nano composite window. About one week after storage it was observed that the concentrations of both CO_2 and O_2 were stabilized and an EMA was attained. The attainment of EMA was facilitated by the nano composite incorporated window on the packets in addition to the respiration of the stored cucumber.

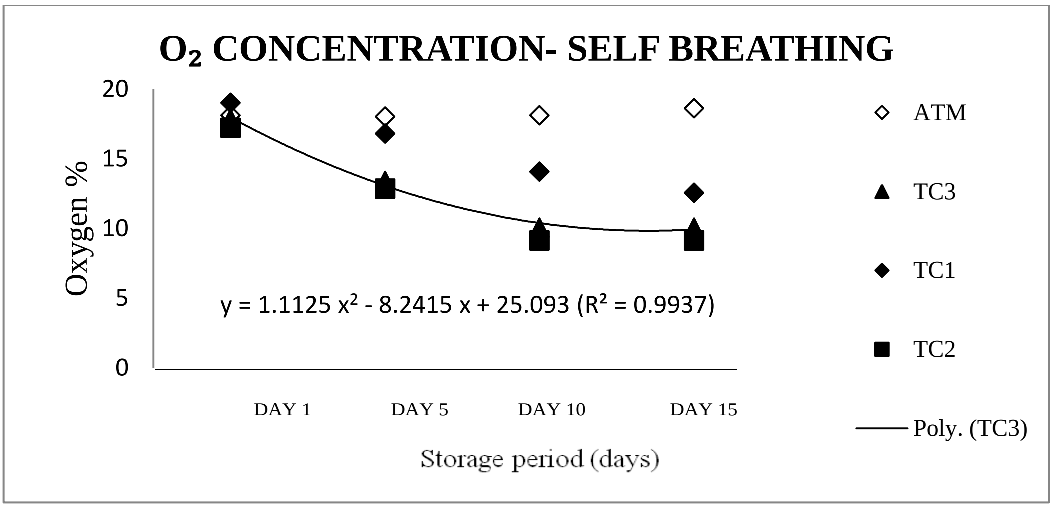

Fig. 4.22 Depletion of O_2 (%) in self-breathing bags in cold storage

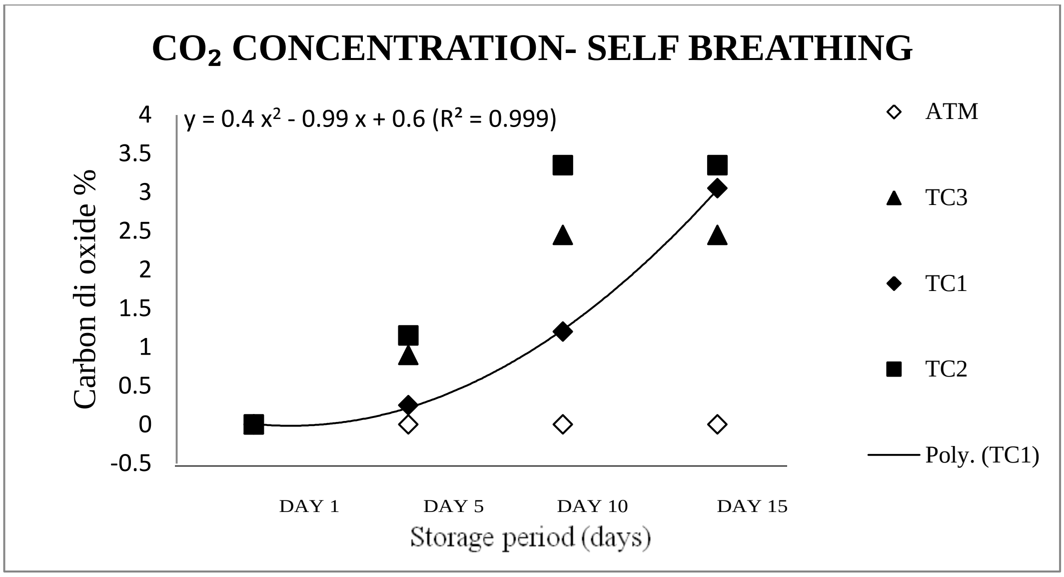

Fig. 4.23 Enrichment of CO_2 (%) in self-breathing bags in cold storage

4.2.9 Shelf life studies

From the observations, it was found that the fruits coated with wax and packed in self-breathing bags had acceptable qualities even after the 25th day of storage, while the control samples (wax coated alone) became unacceptable on the 10th day. The wax coated fruits kept in LDPE bags retain their qualities upto the 17th day of storage. The change in appearance of various treatments during storage is shown in plate 4.1, plate 4.2, plate 4.3 and plate 4.4.

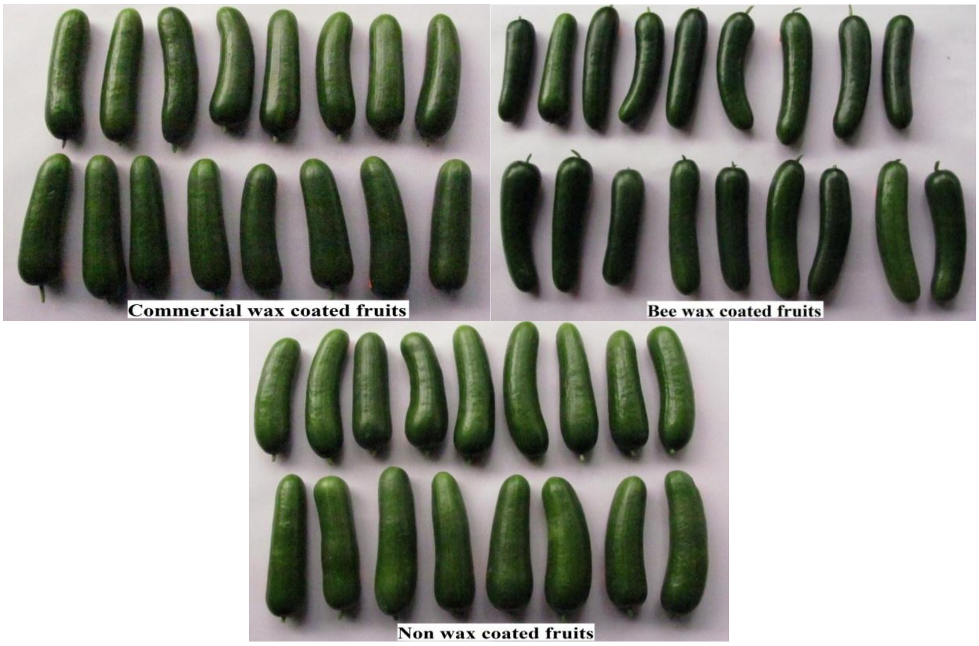

Plate 4.1 Treated fruits before packaging

Plate 4.2 Fruits after tenth day of storage

Plate 4.3 Fruits after seventeenth day of storage

Plate 4.4 Fruits packed in self-breathing bags after twenty sixth day of storage

Summary and Conclusions

CHAPTER 5

SUMMARY AND CONCLUSIONS

India, the world's second largest producer of fruits and vegetables after China and has an output of 775.25 lakh tons and 1496.07 lakh tons respectively, in 2011-12 which is about 3% higher than previous year. India is blessed with a large variety of fruits and vegetables and is known as fruit and vegetable basket of the world. Though India is one of the largest producers of fruit and vegetables, it processes only less than 2.5% of the huge production as compared to 70-83% in advanced countries. The post-harvest losses in India are estimated to be 5.8-18% of the total production which valued over Rs.27, 500 crores annually.

Cucumbers are vegetables belonging to the gourd family, *Cucurbitaceae.* Since cucumbers have around 95% of water content they are good to increase fiber and water intake. There is a high content of vitamins A, B6 and C present in the flesh of the cucumber. These inherent compositions of cucumber make it highly perishable, which adversely affects the market potential. Proper post-harvest technology for prolonging shelf life is necessary to increase its availability. The objective of the present study was to study the suitability of wax coating and various packaging methods for extending the shelf life of cucumber.

The effects of MAP and edible wax (natural bee wax and commercial semperfresh wax) coating on extending the shelf life of slicing cucumbers were studied under cold condition (11 ± 2^0C and 95% RH). The bee wax was emulsified with rice bran oil and standardized in the ratio of 1:100. In addition, commercial wax coating was used at dilution in water (20 gm/l). Nine samples with five replications each were prepared based on treatment of wax coating (bee wax and commercial wax), perforated LDPE bags of 260 gauge (0% and 0.25% levels of perforations) and self-breathing bags of 200 gauge and their combination for use on fruits for the purpose of study under cold condition. Their initial weight, TSS, acidity, ascorbic acid, moisture content, texture, colour and gas composition inside the packages were noted.

The postharvest behaviour of the fruits kept in all the treatments were evaluated at an interval of 5 days for fruits kept in cold storage. The results obtained for different parameters are summarised below.

Among the treatments, wax coating in combination with the use of self-breathing 200 gauge bags were found to be effective. The cucumbers coated with commercial wax and packed in self-breathing bags showed minimum PLW of 2.71% when compared to that of uncoated fruits after the 15^{th} day of storage. The fruits kept as control exhibited higher PLW of 15% after 10^{th} day of storage.

The results revealed that in general the TSS concentration has an increasing trend and ascorbic acid has a decreasing trend with storage. Both the variations were irrespective of the treatments. The cucumbers coated with bee wax and packed in 0.25% perforated LDPE bags showed the lowest TSS concentration of 5.4^0Brix whereas the maximum TSS concentration (6.2^0Brix) was observed in uncoated fruits in LDPE bags.

Generally the titrable acidity of the stored cucumbers had an increasing trend with storage. It was also observed that there was no significant change in titrable acidity with treatment. The moisture content of cucumbers varied significantly with respect to the various treatments and their interactions. The moisture content of bee wax coated fruits kept in self-breathing bags was found to be minimum (96.91%).

Even after the 15^{th} day of storage there was no significant change in fruit colour irrespective of the treatments. However fruits packed in self-breathing bags had a better visual appearance compared to the other treatments. The fruits packed in self-breathing bags were found to have better texture when compared to other treatments. After the 17 days of storage, the fruits kept without coating became softer, due to softening/ripening and were discarded.

It was found that the O_2 concentration decreased and CO_2 concentration increased with storage period. It was also noticed that the amount of CO_2 present inside the self-breathing bags was much lesser than its LDPE counterpart; this was because of the attainment of EMA condition inside the packet due to the nano-composite incorporated window.

Observing the results of various analyses conducted, it was concluded that the sample of fruits coated with bee wax and commercial wax coated fruits kept in self-breathing 260 gauge bags proved to be the best in terms of physical and biochemical characteristics. But some traces of fungal growth were observed in the case of bee wax coated fruits and commercial wax coated fruits packed in LDPE perforated and non-perforated bags after seventeenth day of storage.

This study shows that use of edible coating (natural bee wax or commercial wax) and EMA condition could reduce the metabolic activity/ respiration rate and thereby extending the shelf life of the slicing cucumbers. The observations of various quality parameters (biochemical, physical and textural) during the study also support this result. From this study it was able to conclude that wax coating in combination with EMA condition created by self-breathing bags is the best treatment suited for extending the shelf life of slicing cucumbers at 11 ± 2^oC and 95% RH.

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Appendices

Appendix I

a. Effect of non-perforated LDPE bags on PLW(%) of slicing cucumber

TREATMENT	DAY 1	DAY 5	DAY 10	DAY 15
TL2	0	0.72	1.44	2.88
TL4	0	1.75	3.51	5.26
TL6	0	0.78	1.55	5.43
C1	0	3.51	14.04	
C2	0	3.45	12.07	
C3	0	10.00	15.00	

b. Effect of 0.25% perforated LDPE bags on PLW(%) of slicing cucumber

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TL1	0	0.68	4.08	4.59
TL3	0	2.62	4.12	5.43
TL5	0	3.53	4.31	5.88
C1	0	3.51	14.04	
C2	0	3.45	12.07	
C3	0	10.00	15.00	

c. Effect of self-breathing bags on PLW(%) of slicing cucumber

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	0	1.15	1.92	4.22
TC2	0	1.55	2.33	2.71
TC3	0	1.50	5.26	7.52
C1	0	3.51	14.04	
C2	0	3.45	12.07	
C3	0	10.00	15.00	

Appendix II

a. Change in TSS (^{0}Brix) during storage of slicing cucumber fruits

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	4.0	4.8	5.4	6.0
TC2	4.0	4.0	5.2	5.8
TC3	4.0	5.4	6.0	6.0
TL1	4.0	4.2	5.2	5.4
TL2	4.0	3.9	5.2	5.8
TL3	4.0	4.2	4.8	5.8
TL4	4.0	4.0	5.4	5.9
TL5	4.0	5.8	6.1	6.2

TL6	4.0	5.6	6.2	6.2

Appendix III

a. Variation in acidity during storage of slicing cucumber

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	0.43	0.34	0.20	0.20
TC2	0.43	0.20	0.13	0.13
TC3	0.43	0.27	0.20	0.20
TL1	0.43	0.22	0.13	0.13
TL2	0.43	0.27	0.13	0.13
TL3	0.43	0.20	0.13	0.13
TL4	0.43	0.27	0.20	0.13
TL5	0.43	0.20	0.20	0.13
TL6	0.43	0.38	0.27	0.20

Appendix IV

a. Variation in vitamin C during storage of slicing cucumber

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	3.23	2.44	1.22	0.98
TC2	3.23	2.44	1.22	0.98

TC3	3.23	2.44	1.22	0.98
TL1	3.23	2.44	1.22	0.98
TL2	3.23	2.44	1.22	0.98
TL3	3.23	2.44	1.22	1.22
TL4	3.23	2.44	1.22	1.22
TL5	3.23	2.44	1.22	1.22
TL6	3.23	2.44	1.22	1.22

Appendix V

a. Variation in moisture content during storage of slicing cucumber

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	96.02	96.68	96.74	96.91
TC2	96.02	96.35	97.28	97.29
TC3	96.02	96.35	97.08	97.90
TL1	96.02	96.21	97.05	97.23
TL2	96.02	96.64	96.91	97.24
TL3	96.02	96.04	96.55	97.25
TL4	96.02	97.62	97.92	98.24
TL5	96.02	95.94	97.18	98.13
TL6	96.02	96.91	97.03	97.85

Appendix VI

a. **Variation in oxygen concentration in non-perforated LDPE bags during storage**

TREATMENTS	DAY 1	DAY5	DAY 10	DAY 15
ATM	18.10	18.00	18.10	18.60
TL6	16.55	6.51	3.13	2.80
TL2	18.55	11.6	11.55	11.18
TL4	16.90	8.70	6.81	4.20

b. **Variation in oxygen concentration in self-breathing bags during storage**

TREATMENTS	DAY 1	DAY5	DAY 10	DAY 15
ATM	18.10	18.00	18.10	18.60
TC3	17.85	13.40	10.04	10.04
TC1	19.00	16.80	14.05	12.54
TC2	17.20	12.85	9.13	9.13

c. **Variation in carbon dioxide concentration in self-breathing bags during storage**

TREATMENTS	DAY 1	DAY5	DAY 10	DAY 15
ATM	0	0	0	0
TC3	0	0.90	2.45	2.45

TC1	0	0.25	1.20	3.05
TC2	0	1.15	3.35	3.35

d. **Variation in carbon dioxide concentration in non-perforated LDPE bags during storage**

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
ATM	0	0	0	0
TL6	0	5.55	9.95	10.90
TL2	0	3.10	6.15	6.50
TL4	0	4.60	7.38	10.1

Appendix VII

a. Variation in lightness 'L' of slicing cucumber (peel) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	44.24	24.98	24.81	24.47
TC2	44.24	27.96	27.36	26.41
TC3	44.24	29.72	27.66	23.62
TL1	44.24	27.54	23.25	18.88
TL2	44.24	32.6	28.11	26.40
TL3	44.24	33.45	26.91	24.98
TL4	44.24	30.46	26.75	25.55

TL5	44.24	34.75	32.43	27.41
TL6	44.24	41.19	28.25	26.63
C1	44.24		27.35	
C2	44.24	33.20	20.37	
C3	44.24	29.07	22.90	

b. Variation in lightness 'L' of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	63.79	47.73	47.07	43.78
TC2	63.79	49.1	46.08	43.76
TC3	63.79	45.2	45.16	43.67
TL1	63.79	50.75	41.61	37.70
TL2	63.79	53.48	44.7	40.92
TL3	63.79	44.48	48.45	48.09
TL4	63.79	46.57	45.50	44.4
TL5	63.79	47.91	45.21	40.97
TL6	63.79	60.73	45.88	45.70
C1	63.79		41.56	
C2	63.79	60.56	37.83	
C3	63.79	51.5	42.39	

c. Variation in 'a' value of slicing cucumber (peel) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	-10.07	-7.07	-6.78	-5.84
TC2	-10.07	-8.13	-7.28	-5.22
TC3	-10.07	-7.19	-5.81	-5.53
TL1	-10.07	-7.71	-5.21	-4.93
TL2	-10.07	-7.95	-6.30	-6.12
TL3	-10.07	-8.47	-7.71	-5.76
TL4	-10.07	-7.69	-7.55	-6.52
TL5	-10.07	-7.67	-6.08	-4.60
TL6	-10.07	-8.88	-7.71	-6.14
C1	-10.07		-5.57	
C2	-10.07	-8.96	-6.03	
C3	-10.07	-8.55	-6.75	

c. Variation in 'a' value of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 4	DAY 10	DAY 15
TC1	-8.55	-5.63	-5.19	-3.87
TC2	-8.55	-5.56	-3.90	-1.90
TC3	-8.55	-4.39	-4.03	-1.65

TL1	-8.55	-5.97	-5.16	-5.01
TL2	-8.55	-6.61	-5.97	-5.18
TL3	-8.55	-5.55	-4.11	-2.31
TL4	-8.55	-5.47	-4.91	-2.12
TL5	-8.55	-4.45	-2.85	-1.21
TL6	-8.55	-5.53	-4.93	-3.19
C1	-8.55		-3.29	
C2	-8.55	-8.07	-4.91	
C3	-8.55	-5.12	-3.90	

d. Variation in 'b' value of slicing cucumber (peel) during storage

SAMPLE	DAY 1	DAY 5	DAY 10	DAY 15
TC1	21.26	18.01	12.50	11.31
TC2	21.26	19.08	17.41	12.74
TC3	21.26	22.80	16.27	10.08
TL1	21.26	15.04	10.42	10.16
TL2	21.26	16.10	13.07	12.23
TL3	21.26	21.91	21.66	16.02
TL4	21.26	18.22	17.36	16.91
TL5	21.26	21.75	13.84	11.18

TL6	21.26	21.06	17.93	16.33
C1	21.26		19.51	
C2	21.26	16.17	12.71	
C3	21.26	18.30	15.35	

e. Variation in 'b' value of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	32.98	26.30	24.41	21.78
TC2	32.98	25.65	23.92	19.86
TC3	32.98	24.37	24.09	19.09
TL1	32.98	26.96	22.42	20.60
TL2	32.98	26.91	25.16	20.8
TL3	32.98	27.59	25.98	25.28
TL4	32.98	23.22	22.53	21.35
TL5	32.98	25.78	22.41	22.00
TL6	32.98	22.66	21.57	18.83
C1	32.98		25.16	
C2	32.98	31.78	21.32	
C3	32.98	23.94	20.98	

Appendix VII

a. Variation in firmness of slicing cucumber (peel) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	20.96	24.53	24.33	20.19
TC2	20.96	25.54	23.26	20.85
TC3	20.96	26.47	26.29	20.735
TL1	20.96	24.96	24.12	19.78
TL2	20.96	23.66	23.19	21.95
TL3	20.96	27.58	25.12	20.64
TL4	20.96	25.54	23.1	18.99
TL5	20.96	28.05	21.66	19.572
TL6	20.96	24.57	21.532	21.44
C1	20.96		23.26	
C2	20.96	26.42	25.5	
C3	20.96	26.24	23.96	

b. Variation in firmness of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	11.11	13.14	12.26	11.07
TC2	11.11	13.88	12.97	9.56

TC3	11.11	15.52	12.86	10.92
TL1	11.11	13.2	11.77	10.7
TL2	11.11	13.87	13.58	9.31
TL3	11.11	13.19	11.58	9.96
TL4	11.11	14.96	11.42	9.53
TL5	11.11	15.67	11.79	11.05
TL6	11.11	9.81	9.77	8.57
C1	11.11		11.66	
C2	11.11	15.93	11.409	
C3	11.11	12.44	10.48	

c. Variation in toughness of slicing cucumber (peel) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	79.75	91.86	62.12	56.18
TC2	79.75	79.73	62.29	56.89
TC3	79.75	90.67	68.46	55.15
TL1	79.75	85.49	64.29	55.42
TL2	79.75	76.99	66.45	56.85
TL3	79.75	93.42	75.09	61.32
TL4	79.75	76.99	67.83	52.45

TL5	79.75	88.67	60.36	58.73
TL6	79.75	87.56	53.69	52.79
C1	79.75		59.17	
C2	79.75	96.19	65.67	
C3	79.75	98.66	69.38	

d. Variation in toughness of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	80.28	116.03	48.13	40.21
TC2	80.28	84.99	52.82	46.62
TC3	80.28	109.33	57.31	42.77
TL1	80.28	120.77	38.23	37.53
TL2	80.28	114.32	45.24	33.57
TL3	80.28	117.91	45.45	35.24
TL4	80.28	74.43	59.71	42.39
TL5	80.28	100.39	50.61	42.66
TL6	80.28	86.33	35.86	31.69
C1	80.28	75.25	33.76	
C2	80.28	146.36	39.28	
C3	80.28	85.05	41.99	

e. Variation in stiffness of slicing cucumber (peel) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	10.47	12.93	12.04	10.11
TC2	10.47	12.69	12.45	10.36
TC3	10.47	14.66	12.654	11.58
TL1	10.47	11.56	10.22	8.83
TL2	10.47	11.15	9.91	5.64
TL3	10.47	14.53	12.97	9.85
TL4	10.47	11.12	10.69	9.03
TL5	10.47	12.4	9.52	8.27
TL6	10.47	11.95	10.86	8.62
C1	10.47		7.13	
C2	10.47	12.18	8.78	
C3	10.47	9.99	7.36	

f. Variation in stiffness of slicing cucumber (pulp) during storage

TREATMENTS	DAY 1	DAY 5	DAY 10	DAY 15
TC1	5.39	5.185	3.89	2.35
TC2	5.39	4.52	4.12	3.54
TC3	5.39	6.89	4.37	3.83
TL1	5.39	6.43	5.59	4.86

TL2	5.39	5.89	3.87	3.871
TL3	5.39	6.22	3.87	2.79
TL4	5.39	6.39	4.18	3.78
TL5	5.39	6.95	4.422	3.388
TL6	5.39	3.48	3.02	2.48
C1	5.39		4.99	
C2	5.39	6.57	4.32	
C3	5.39	4.02	1.41	

EFFECT OF EDIBLE WAX COATING AND MODIFIED ATMOSPHERIC PACKAGING ON SHELF LIFE OF SLICING CUCUMBER (*Cucumissativus*)

By

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ABSTRACT

Submitted in partial fulfillment of the requirement for the degree

Bachelor of Technology
In
Agricultural Engineering

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2013

ABSTRACT

The cucumbers (*Cucumis sativus*) which are belonging to the gourd family, *Cucurbitaceae* is of very high demand due to its high nutritional quality. The fruit is highly perishable and losses its quality immediately after the second or third day of harvest. The postharvest loss in quality and commercial value is due to the intense respiratory activity and significant moisture loss. Hence a study has been undertaken to increase to increase the shelf-life of cucumbers by using various edible coatings and MAP. Various samples of the cucumbers were treated with bee wax and commercial wax and were packed in 260 ± 1 gauge LDPE bags (0% perforations and 0.25% perforations) and 200 gauge self-breathing bags and was stored at $11 \pm 2^{o}C$ and 95% RH.

The effect on the shelf life extension of fruits was investigated. The physical, biochemical and engineering quality parameters of stored samples were tested periodically at an interval of 5 days. Prediction equations were also developed for various post-harvest quality parameters of slicing cucumber under EMA storage. This study showed that use of edible coating (natural bee wax or commercial wax) and EMA condition could reduce the respiration rate and thereby extend the shelf life of the slicing cucumbers for two weeks. From this study it was able to conclude that wax coating in combination with EMA condition created by self-breathing bags was the best treatment suited for extending the shelf life upto twenty fifth day for slicing cucumbers at $11 \pm 2^{o}C$ and 95% RH with acceptable quality while the control fruits and fruits in LDPE bags lasted only for ten and fifteen days respectively.