EFFECT OF DEHYDRATION AND COOLING STORAGE PRACTICES ON THE SHELF LIFE OF LIME (*Citrus aurantifolia* Swingle)

By

Mannapperumage Thanuja Suranjani

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Faculty of Applied Sciences,
Sabaragamuwa University of Sri Lanka,
Buttala,
Sri Lanka.
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DECLARATION

The work described in this thesis was carried out by myself at the Food Research Unit, Gannoruwa and the Food Science laboratory at Faculty of Applied Sciences, Buttala under the supervision of Mr. T.D.W Siriwardana and Dr. K.K.D.S Ranaweera.

M.T. Suranjani
99/AS/047

Suranjani
(Signature of the student)
24-04-2003
Date

Certified by

External Supervisor,
Mr. T.D.W. Siriwardana,
Head of Food Research Unit,
Gannoruwa,
Peradeniya.

(Signature /External supervisor)
24/04/2003
Date

Internal Supervisor,
Dr. K.K.D.S. Ranaweera,
Senior Lecturer,
Faculty of Applied Sciences,
Sabaragamuwa University of Sri Lanka,
Buttala.

(Signature /Internal supervisor)
28/4-2003
Date

Prof. M.S. Rupasinghe,
Head of the Department,
Department of Natural Resources,
Faculty of Applied Sciences,
Sabaragamuwa University of Sri Lanka,
Buttala.

MSRupasinghe
(Signature /Head of the department)
28/4/2003
Date

DEDICATED TO MY LOVING
PARENTS AND TEACHERS

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ABSTRACT

Acid lime (*Citrus aurantifolia* Swingle) is a popular acidulant used for culinary purposes and fresh fruit has a high demand at the local market. Also the dried, whole black lime fruit has a very good market potential in Middle- Eastern countries.

Perishability of the crop caused to high post harvest losses during its season. During the harvesting season, there is a peak of lime production, which lasts for 3 to 4 months and all the harvest enters to the market at once resulting in low price as less as one rupees per one kilogram of lime. Seasonability of the crop is a very discouraging factor in lime cultivation in this country. If fruits could be stored or processed into an attractive form, the price fluctuation and losses could be minimized.

In this study, attempts were taken to optimize of preservation method namely cooling and dehydration techniques in order to minimize the post harvest losses while extending the storage life of lime.

The effect of cold room preservation on the storage life of lime fruits was investigated by using 150± 10g samples, belonging to three maturity stages with two different sizes. The samples were stored under ordinary cold storage at 10^0C temperature and Modified Atmospheric (MA) condition with 10^0C temperature and 85 – 90% relative humidity. Periodical observations were made at 7-day intervals on different physico-chemical parameters of fruits.

Lime fruits kept in MA storage conditions had higher storage life span (more than two and half months) than the ordinary cold stored counterparts with good internal and external quality characters. Fully matured large sized fruits of MA storage condition had longer storage life than those having lower maturity or colour break stage.

The effect of dehydration on the preservation of lime fruits was investigated by storing fully matured uniform sized fruits at different temperature levels with pre treatment conditions.

Dehydration of lime fruits under gradually increasing temperature from 45^0C to 55^0C with pretreatment of 40% brine solution is more successful than the other treatments. It gives more attractive uniformly distributed smooth appearance.

Shelf life of fruits kept in MA storage conditions can be extend with success during the peak season with view to provide the market with lime in off-season maintaining regular supply of lime fruits at a reasonable price.

Dehydration of whole lime fruit is successful food preservation method for achieving a longer storage life.

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CHAPTER 1

1. INTRODUCTION

1.1 Introduction

Acid lime (*Citrus aurantifolia* Swingle) is one of the commercially grown citrus in Sri Lanka. Citrus plants are being mainly grown as backyard plants in arid and semi-arid regions especially in Bibile-Moneragala belt as a rained crop and in Vavunia-Omantai district with irrigation (Ghosh & Singh, 1993). According to estimates of the Agricultural Research Unit of Moneragala, (1998) the annual lime production of Sri Lanka is about 15000 MT (Metric Tons) and the Moneragala district alone produces 75% of the total harvest. Moneragala lime and Thimbutana lime are two promising cultivars of acid lime in Sri Lanka. According to FAO/RAPA 1990/15, 5.0 MT of limes and lemon were exported from Sri Lanka in 1988 (Ghosh & Singh, 1993).

As many perishables water content in lime fruit is very high being about 88%. Therefore water to carbohydrate ratio is also very high. Since all the water can not bound by the carbohydrate, more free water is available in fruits (Jayaweera, 1992). Due to above reasons acid lime is also highly susceptible to deterioration being good microhabitats for microorganisms such as moulds and bacteria etc. (Fruits and vegetables are made up live tissues in which active metabolism continue to take place even after harvest). On the other hand, the main biological factor responsible for decay is the high respiration rate of this commodity (respiration rate is proportional to the rate of deterioration). Production of ethylene, transpiration, compositional changes such as changes in pigments, carbohydrates, organic acids, proteins, amino acids, lipid and physiological breakdowns are other biological factors responsible for deterioration.

Due to above reasons perishable items can not stored at room temperatures for more than a few days or weeks. Hence proper storage conditions have become essential in preventing postharvest losses. Therefore in recent times different preservation techniques such as cooling, drying etc. are used for preserving perishable commodities. Citrus fruit is classified as a non-climacteric fruit. Mature, sound citrus fruits show no respiration peak and little ethylene production in normal conditions after harvest (Murata, 1997).

Respiratory rate of citrus fruits are affected by temperature, humidity, air movement, atmospheric composition (O_2, CO_2, C_2H_4) and dropping, bruising and microbial infection (Murata, 1977).

Reduction of storage temperature is the most important method of prolonging the storage life of citrus fruits as it delay deterioration and fruit ripening. The optimum storage temperature for lime ranges from 10 –13^0 C with a Relative Humidity of 90 – 95 % (RH) depending on culture, maturity – ripeness stage at harvest and duration of storage is up to 6 –8 weeks (Arpia & Kader, 1998).

Use of modified atmosphere (MA) conditions with low temperature and high relative humidity is the most effective method for prolonging storage life of products, which delay senescence, and decaying. Commodities kept in MA storage conditions, the gaseous environment of stored atmosphere is modified by the process of respiration lowering O_2 and elevation of CO_2 (Kader, 1992). It has been found that, lime can be kept for 6-8 weeks under active MA conditions with 5% of O_2 and 0 –10% of CO_2 at 10 – 12^{0}C with 85 – 90% RH.

Dehydration of perishable commodity is one of the oldest, most effective and highly efficient techniques of food preservation. The most essential feature of dehydration is that the moisture content of the food is reduced to a level below which the growth of microorganism in food is suppressed. In addition chemical reactions carried out mainly by the natural food enzymes are also reduced to a negligible level due to removal of water. Commodity specific dehydration process such as spray, oven and sun drying are being employed as dehydration procedure. The water requirement for the growth of many microorganisms is defined in terms of water activity (a_W) (a_W = P/ Po where P = vapour pressure of the water in food, Po = vapour pressure of the pure water at the same temperature) of their environment of growth. Microorganisms do not growth either in pure water or in its absence. Therefore, the reduction in a_W is achieved either by adding salt or by removing water to reduce the growth of microorganisms. The dried, whole black lime fruit has very good market potential in Middle Eastern countries. In Arabian countries, the whole black lime fruits are used for rice preparation, as well as curry preparations. Therefore it is very significant to find out ways and means of preserving lime suitably fit in to the local and international market.

1.2 Objectives

Accordingly the objectives of the current study was,

1. To extend storage life of lime which enable the regular supply of the fruit through the year.

1.2.1 Specific objectives

In accordance with the main objective, the specific objectives were the following.

1. Extension of self-life by keeping fruits at low temperature and modified Atmospheric (MA) conditions.
2. Extension of self-life of lime by dehydrating lime fruit while keeping its sensory characteristic unchanged.
3. To study on the effect of cold room preservation, dehydration on storage life of lime.

CHAPTER 02

2. LITERATURE REVIEW

2.1 Citrus

Group of citrus, which belongs to family Rutaceae, is one of the most important subtropical fruits in the world. Cultivation of citrus fruits is widespread in the tropical, subtropical and temperate regions. The fruits have differentiated in to many varieties to adopt to new surroundings, and many cultivars have been bread in various countries (Murata , 1997).

The genus citrus contain 16 species. Six of them have acid oil droplets in the pulp vesicles and are inedible. The other 10 are edible, having pulp vesicles filled with acid, subacid or sweet juice, which is nearly or completely free from oil droplets.

Following are cultivated citrus,

Citrus aurantifolia (christm) swingle	- Lime
Citrus aurantium L.	- Sour orange
Citrus limon L. Burm .F	- Lemon
Citrus grandis (L) osb	- Pummelo/Pomelo
Citrus medica L	- Citron
Citrus paradisimacfad	- Grape fruit
Citrus reticulate swingle	- Mandarine or Tangerine
Citrus sinensis (L) osb	- Sweet orange

Source: FAO food and nutrition paper 42, (1987).

2.2 Morphology of citrus fruits

Citrus fruit is composed of three distinctly different morphological parts. The epicarp consists of the colored portion of the peel and is known as the flavedo. In the flavedo are cells containing the carotenoids, which give the characteristic color to the different citrus fruits.

Immediately under the epicarp is the mesocarp or the albedo. The albedo consists of large parenchymatous cells rich in pectic substances and hemicelluloses. It completely envelops the endocarp. The edible portion of citrus fruit is composed of many carpels or segments. Inside each segment is located the juice vesicle, which is attached to the segment membrane by the vesicle stalk (Figure2.1.).

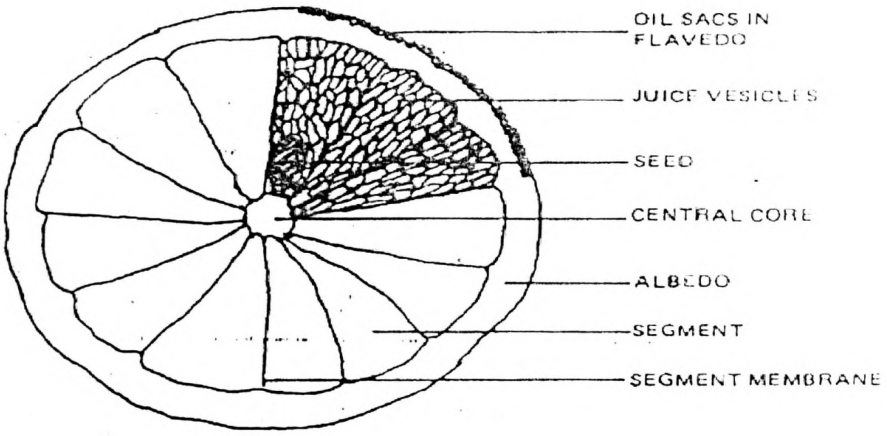

Figure2.1: Cross section of the fruit.

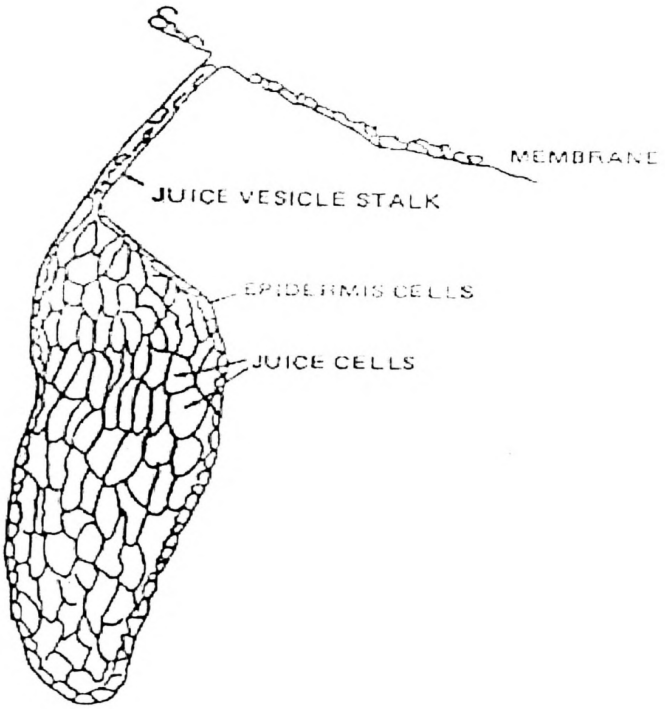

Figure2.2: Sketch of a juice vesicle showing multicell structure.

2.3 Lime

2.3.1 Botany of lime

Family -: Rutaceae

Botanical name -: *Citrus aurantifolia*

Vernacular names -: Sinhala : Dehi, Hindehi

Tamil : Ambu, Arunam, Thesikkai

English : Acid lime, Sour Lime , Lime

(Rajapaksha, 1998).

2.3.2 Origin and distribution

Acid lime (*Citrus aurantifolia* swingle) is one of the commercially grown citrus fruits in Sri Lanka other than sweet orange and mandarin orange. The tree is originated in India and its distribution is limited to the tropics and warm, humid subtropical regions (Randhaw & Srivastava, 1986).

Citrus plants in Sri Lanka are mainly grown as backyard plants in arid and semi-arid regions especially in Bibile-Moneragala belt as a rained crop and in Vavunia-Omantai district with irrigation (Ghosh & Singh, 1993).

2.4 Morphology of lime

2.4.1 Tree

Lime trees are extremely vigorous, possessing an upright to very spreading growth habit. A small glabrous tree with stiff sharp spines which are simple by the side of buds(Davies & Albrigo,1994).

2.4.2 Leaves

Simple, alternate, glandular dotted, elliptic-oblong, 5-7cm long blunt or sometimes rounded at apex, petioles short, narrowly winged, articulated at the top.

2.4.3 Flowers

Regular, bisexual, solitary or mostly clustered in the axils of leaves, usually about 1.2cm long, white, fragrant throughout.

2.4.4 Fruits

Round- oval to oval and small 3.7-6.5cm diameter, The fruit of lime is a hesperidium berry, consisting of approximately ten united carpels clustered around and joined to the floral axis. The fruit consists of flavedo (exocarp), albedo(mesocarp), juice sacs (vesicles), seed and fruit segments, which expand in to segments containing juice vesicles and seeds. The presence of the leathery rind in all citrus fruits protects the fruit from damage during handling and desiccation during storage. The exocarp consists of the fruit, which is made up of the cuticle-covered epidermis. The vesicles are cuticle-covered epidermis enclosing large, vacuolated cells containing juice, which is released when the fruit is sequeezed (Murata, 1997).

2.5 Cultivation of lime

Area for cultivation - cultivated in both wet and dry zone in Sri Lanka.

Planting materials - propagation is either by seed or budding onto root stock

Planting and space - Seed should be obtained from fully matured fruit from adult trees. They are planted at a depth of 2.5cm and as a spacing of 15-23 cm ×25 cm in well drained, shaded and mulched beds (Rajapaksha, 1998).

2.5.1 Environmental response

It can grow in a range of soil but is thrives well in deep, loose, well-drained soil. Ideal pH range is 5.5 -7.5 for citrus. Temperature 5^0C and below is considered too injurious to young trees (Rajapaksha, 1998).

2.5.2 Irrigation

For high yields of good quality fruit in arid and semi-arid regions where rainfall is less than 800mm, irrigation is essential especially during the dry periods (Rajapaksha, 1998).

2.5.3 Fertilizer

Respond to fertilizer well.

2.6 Harvesting

2.6.1 Time to harvest

It reaches full bearing in ten years, but could start producing some fruits 3.5 years from planting.

2.6.2 Maturity stage of the harvesting

The fruits pass from immature to mature and finally to over-mature conditions while remaining on the tree, but the changes are slow and spread over several months. When picked at any stage of maturity the fruit does not change after picking except as it may slowly dry out. The degree of harvest maturity of citrus fruits significantly affects the fruit quality after harvest (Murata, 1997). There is a considerable period of time during which the fruit has desirable quality, and during this period the fruit is considered properly mature (Murata, 1997). Percentage juices volume of 30% or higher is used as a maturity index to harvest mature-green limes (Arpaia & Kader, 1998).

2.7 Climacteric and Non-climacteric fruits

2.7.1 Climacteric fruits

Climacteric fruits have a period of rapid ripening known as the climacteric. Respiration rate and heat evolution increase, ethylene evolution increases; and the fruit softens and develops flavor and aroma.

2.7.2 Non-climacteric fruits

Non-climacteric fruits that do not undergo a rapid ripening phase. They mature slowly while attached to the parent plant, and their eating quality cannot improve after harvest. Non climacteric fruits have relatively low respiration rates that decline slowly after harvest. They produce ethylene at low rates. Application of ethylene to non-climacteric fruits has been though to have little effect other than the harvesting of senescence changes, such as change in color from green to yellow, pedical abscission, increased susceptibility to disease, and the development of off-flavours.

2.7.3 Citrus as a Non-climacteric fruit

Citrus fruits are classified as non- climacteric fruits and have low respiration rates and thus are quite amenable to long-term storage. Mature, sound citrus fruits show no respiratory peak and little ethylene production in normal conditions after harvest (Murata, 1997). The Internal ethylene concentrations of lime are 0.30 – 1.96 µl/l (Salunkhe & Desai, 1984). Some citrus species such as oranges, grapefruit and satsuma mandarins show a pseudo- climacteric rise in respiration with degreening, their response to ethylene is different from that of climacteric fruit (Murata, 1997). Ripening of climacteric fruits is relatively independent of the concentration of applied ethylene having more than one rise in respiration (Salunkhe & Desai, 1984). The respiratory rates of the rind is nearly ten times as high as that of vesicles; the rind, therefore, has an important physiological role in the qualitative changes that take place during storage of the fruits (Murata, 1997). Respiratory rate of citrus fruit are affected by several factor, including temperature, humidity, air movement, atmospheric compositions (O_2, CO_2, C2H4 and other olefins), dropping, bruising and microbial infection (Murata, 1997).

2.8 Factors affecting the quality of lime

The market prize for citrus fruits is entirely based upon the internal and external quality of fruits. For most citrus fruits, the internal quality is concerned with juiciness, flavor and taste while external quality reflects eye appeal. Most important determinants of citrus fresh fruit quality are fruit size and shape, peel color, peel quality, lack of surface blemishes, peel firmness and texture. But fruit for the processing industries does not need high external quality, while internal quality must be as high or higher. Hence, the quality determination of citrus is a complex process. Commercially lime producers harvest fresh fruits primarily on fruit size and percentage of juice by volume and processing fruit on acid and peel oil contents (Davies & Albrigo, 1994).

Acidity is an important factor of internal quality of citrus fruits such as lime and lemon. It has been found that the acid content in the juice tends to decrease after reaching full size (Murata, 1997). Therefore acid-limes should be harvested before reaching full fruit size (Murata, 1997).

The quality standards of acid-lime indicate, %juice volume – 45-58%, Brix- 8.1-10.4^0, acidity- 6.7-7.7% and Brix/acid ratio – 1.22-1.48(Rajput & Haribadu, 1995).

Stage of maturity at harvest is important in determining the quality of lime as citrus fruits do not undergo rapid chemical and physical changes after the fruit is detached from the tree (Salunkhe & Desai, 1984). Green lime has a long storage life while yellow ones have a higher juice content (Arpaia & Kader, 1998). Thus unit size is an important factor in meeting quality standards in the export market and also in grading and packing of fruits. Lime is greatly effected by low temperature storage, developing chilling injury, which markedly shortens the storage life (salunkhe & Desai, 1984).

2.9 Disorders of citrus fruits

2.9.1 Physiological disorders

- Chilling injury:

  Symptoms include pitting, and brown discoloration. Pits disorders may coalesce and from leathery, brown sunken areas on the rind. Severity increases with lower temperature below 10^{0}C and longer duration of exposure to these temperatures.

- Oil spotting (oleosellosis):

  Harvesting and handling turgid limes may result breakage of oil cells in the flavedo and release of the oil that damage surrounding tissues.

- Stylar-end-breakdown:

  This disorders results from rough handling during harvesting and handling. Its severity varies among cultivars and harvest season (Arpaia and Kader, 1998).

2.9.2 Pathological disorders

- Green mold *(Penicillium digi tatum)*
- Blue mold (*Penicillium italicum*)
- Stem-end rot (*Lasiodiploidia thiobromae*).
- Phomopsis stem –end rot (*Phomopsis citri*)
- Alternaria stem-end rot (*Alternaria citri*)

(Arpaia and Kader, 1998).

2.10 Storage

The citrus fruit as any other fruits are perishable in nature. During the harvesting seasons there is a glut in the market leading to low rates as well as spoilage. Whereas during lean periods there will be shortage in supply, consequently the price go up. This situation can only be avoided by the phased selling of the produce. This is possible with the aid of suitable storage facilities. Fruits can be stored under refrigerated conditions and also cold storage facilities. Fresh fruit can be stored in cool place for a short time. In homes, they are kept in under sand. Fruit can be salted and sun dried and preserved in its own juice for prolonged keeping (Rajapaksha, 1998).

2.10.1 Cold storage

Even after the detachment of fruit from the tree, the fruit respires and transpires and biochemical processes continue without interruption in the fruit leading to deterioration. The main purpose of storage by cold storage is to minimize these metabolic activities to prolong the life of fruit. Low temperature may retard the development of decay both by maintaining the resistance of the host to parasitism and also by retarding the growth of the pathogen directly (Salunkhe & Desai, 1984).

The temperature of a storage room should not fluctate and it should be closely controlled at the optimum temperature for the particular fruit. The humidity of the room should also be optimal for the product. Equilibrium humidity for most of the fruits 98.4 ±0.8%, with a range from 96.4% to 99.8%. When fruit has cooled to the temperature of their surrounding they will lose water to the surrounding air when the relative humidity of that air is less than the equilibrium relative humidities of the fruit. Room humidity is important during storage because product water loss during storage is directly proportional to the vapor-pressure gradient between the fruit and the room air. As the humidity of the room air approaches the internal humidity of the fruit, water loss becomes less. It is usually not practicable or even desirable to match the internal humidity (ERH) of the fruit exactly because of problems with condensation, disease, and excessive turgor.

Cooling lime immediately after harvest improves storage life, increases juice yield and retards the reduction of vitamin "C" during storage.

The optimum storage temperature for lime from 10-13^{0}C depending on cultivar, maturity –ripeness stage at harvest and duration of storage and transport is up to 6-8 weeks (Relative humidity 90-95%) (Arpaia & Kader, 1998).

2.10.2 Methods of cooling

Produce may be cooled by means of cold air (room cooling, forced-air cooling), cold water (hydrocooling), direct contact with ice, and evaporative cooling, vacuum cooling). Fruits are normally cooled with cold, air.

2.10.3 Evaporative cooling

This is a simple process in which dry air is cooled by blowing it across a wet surface. Although the technique is restricted to regions with low relative humidity but with a good quality water supply, it has the advantage of low energy cost. The commodity may be cooled by either the humidified cool air or by misting with water and then blowing dry air over the fruit. The extent to which air may be cooled by evaporation of water is limited by the water holding capacity of the air.

2.11 Modified Atmospheres (MA) storage

Modified atmospheres (MA) or controlled atmospheres (CA) mean removal or addition of gases resulting in an atmospheric composition around the commodity that is different from that air (78.08 percentN_2, 20.95 percent O_2, 0.03 percent CO_2). Usually this involves reduction of oxygen (O_2) and/or elevation of carbon dioxide (CO_2) concentrations. MA and CA differ only in the degree of control; CA is more exact.

The use of Modified Atmosphere (MA) storage is a good supplement for proper temperature and relative humidity management. The potential for benefit or hazard from using MA is dependent upon the commodity, variety, physiological age, atmospheric composition, and temperature and duration of storage. Commodity-generated MA (passive MA) storage involves the modification of gaseous environment of stored atmosphere through the process of respiration.

2.11.1 Potential benefits of MA

- Retardation of senescence (ripening) occurs, along with associated biochemical and physiological changes, i.e., slowed down respiration and ethylene production rates, softening, and compositional changes.
- Reduction of fruit sensitivity to ethylene action occurs at O_2 levels below about 8 percent and /or CO_2 levels above 1 percent.
- MA conditions controls disease development and physiological disorders extending the shelf life of perishables.

2.11.2 Potential harmful effect of MA

- Initiation and/or aggravation of certain physiological disorders can occur.
- Irregular ripening of fruits
- Off-flavors and off-odors at very low O_2 concentrations may develop as a result of anaerobic respiration.
- Susceptibility to decay may increase when the commodity is physiologically injured by too low O_2 or two-high CO_2 concentrations (Kader, 1992).

2.12 Lime Constituents

Lime fruit and juice have a high nutritional value and unique refreshing aroma due to its numerous chemical constituents. But constituents like vitamin C, volatile compounds and pectin affect the quality and the nutritional value of citrus products are interest to food technologists.

2.12.1 Vitamin C

Eventhough other fruits and vegetables have higher level of vitamin C, few have attractive a color, taste, flavour and thus popularity as citrus. Also vitamin C is very stable in limejuices and degrades very little with storage. Limes contains 20-40 mg of vitamin C per 100ml of juice. But the level decreases with maturity. The major portions of ascorbic acid are in the peel and the rag. (The rag is the residue after juice extraction, which contain the membrane and pulp.) Atmospheric oxygen is responsible for most of the vitamin C loss during long term storage. Common methods used for vitamin C analysis are vitamin C indophenol titration and HPLC vitamin C determination (Chan, 1998).

2.12.2 Volatile Compounds

The most characteristic property of lime is its unique aroma. The volatile compound is essential oils impart this pleasant characteristic. These volatile compounds are produced by the ductless oil glands located in the flavedo layer of the peel. The essential oils of all citrus fruit are complex mixtures of many compounds. Alcohol, Aldehydes, Esters, Hydrocarbons, Ketons, Miscellaneous like volatile compounds are found in lime.

2.12.3 Pectin

The term pectin refers to a class of high molecular weight compounds, with molecular weight of 100,000 to 200,000. There are carboxyl groups, which are esterified with methonal to form methoxy groups. The degree of this esterification is a measure of the gelling ability of pectin or the grade of pectin. Citrus peel is a source for commercial pectin production. Most of the pectin in lime is concentrated in albedo and only minute amounts are present in juice. Pectin is used in manufacture of jelly, fruit jams and marmalades (Chan, 1998).

2.13 Lime juice

The juice of the fruit contains citric acid, malic acid and tartaric acids in small quantities and pectin sugar and trace of salts. Juice of the fruit is extensively used for flavouring foods (Rajapaksha, 1998).

2.13.1 Nutritional and therapeutic value

Table 2.1. Nutritional and therapeutic value of limejuice.

component	Amount
Energy	59kcal
Moisture	8406g
Protein	1.5g
Fats	1.0g
Carbohydrates	10.9g
Calcium	90mg
Phosphorus	20mg

Iron	0.3mg
Carotene	15mcg
Thiamine	20mcg
Riboflavin	30mcg
Niacin	0.1mg
Vitamin C	63mg

Source: Perera, *et al.*, (1979).

2.14 Lime fruit usage

2.14.1 Food use

The antioxidant properties of L ascorbic acid of lime juice are useful as a natural food preservative. In fact limejuice is a popular flavouring agent in almost all-Asian fruit and vegetables salads. The fruit it self is salted, dried and preserved as a pickle and juice of lime is used in the commercial production of juice jelly jams, cordials and marmalades. Lime fruits are a good source of pectin and roughage and it has small quantities of sugar too.

2.14.2 Medicinal Use

Ascorbic acid is an important vitamin, which prevents scurvy and latest research findings reveal that it has many desirable affects on human health such as increase the absorption of non- heme iron, protection from cancer, cataract formation and cardio-vascular diseases etc. (Gershoff, 1993). Lime juice is a popular medicine in traditional Ayurvedic preparations and help in curing vomiting, headaches, coughs, stomachache and also it has some antiseptic properties (Jayaweera, 1981).

2.14.3 Other Uses

Boiled fruits are usually used in Sri Lanka as shampoo. Lime is used in cleaning of brasswear.

2.15 Products of lime

In Sri Lankan market lime pickle, sauce and RTS drinks are available. Though not very popular. Many lime products are processed and consumed throughout the world.

2.15.1 Lime squash

The fruit is cut and juice is pressed out by roller type presses. Seeds are removed by sieving. The sugar syrup is added. Preserved squash is bottled.

2.15.2 Lime juice cordial

The whole fruit is cut between granatle vollers orin screw pressers. After a course screening the juice is stored for 2 or 3 weeks in deep tanks. Under the action of natural enzymes which is slow at the low pH of limejuice, the juice separate in to three layers by flotation and setting. The intermediate layer of lime juice is drown off, filtered, preservatized with 500 to 800 ppm SO_2, and filled in to sacks to become the basic raw material for lime juice cordial.

2.15.3 Canned lime juice

Limejuice is extracted from the fruit using the commercial auto mated juice extractors. Then the juice is de-oiled by flashing in to a vacuumed tank at 52°C. The oil accumulates an upper layer of condensate and removed Subsequently. De-oiling also removes air, which is incorporated. Limejuice is then pasteurized at 88°C in 3 seconds. Due to low pH the time temperature requirement for pasteurization is low. Heated juice is then pasteurized at 88°C in 3 seconds. Due to low pH time temperature requirement for pasteurization is less. Heated juice is pumped to filler and filled containers are cooled rapidly (Lal & Siddappaa, 1998).

2.15.4 Lime Concentrate

De-oiled and de-aerated juice (as in canned limejuice) is pumped into the evaporator as it comes out of the tank. The most proper evaporator used is Temperature Accelerated Shout Time Evaporator (TASTE). Juice can be concentrated from single strength to about 12^{O} Brix to 68^{O} Brix in few minutes. Then concentrated juice packed while hot. When diluted with the proper amount of water, the product is a refreshing drink (Chan, 1998).

2.15.5 Lime Pickle

Whole limes are cleaned and cuts are made to open the fruit. The powdered salt is added in high concentration and leave to season for eight weeks. This has a long shelf life and a strong flavour. Produced in tropics in domestic level. Spices can be added if needed.

2.15.6 Lime Nectar

Limejuice is squeezed using a squeeser. Then juice is mixed with water, sugar, Carboxy Methyl Cellulose (CMC), and preservatives. Then heated for 20 minutes and filled to sterilized RTS bottles while hot and sealed (Lal & Siddappaa).

2.15.7 Lime Sauce

Lime sauce is produced by blending seasoned lime pickle with sugar and spices and addition of a thickening agent. Pumpkin and corn flour are most commonly used thickening agents. Then cooked until desired consistency ($Brix^{O}$ 40-50) is obtained. And filled to sterilize bottles while hot. The final product has a dark brownish, opaque appearance and a strong falvour with some bitterness.

2.16 Dehydration

2.16.1 Principle of dehydration

Dehydration is defined as a process of moisture removal due to simultaneous heat and mass transfer. Heat transfer from the surrounding environment evaporates the surface moisture. The moisture can be either transport to the surface of the product and then evaporated or evaporated internally at a liquid vapor to the surface (Leon & Sonido, 1996).

A convenient, though arbitrary, definition of dehydration applied to foods is "drying under controlled condition of temperature and humidity to a specific end point in a given time". Water may be evaporated in to two ways, isothermally or adiabatically (Fennama *et al.*, 1975).

2.16.2 Goals for dehydration foods

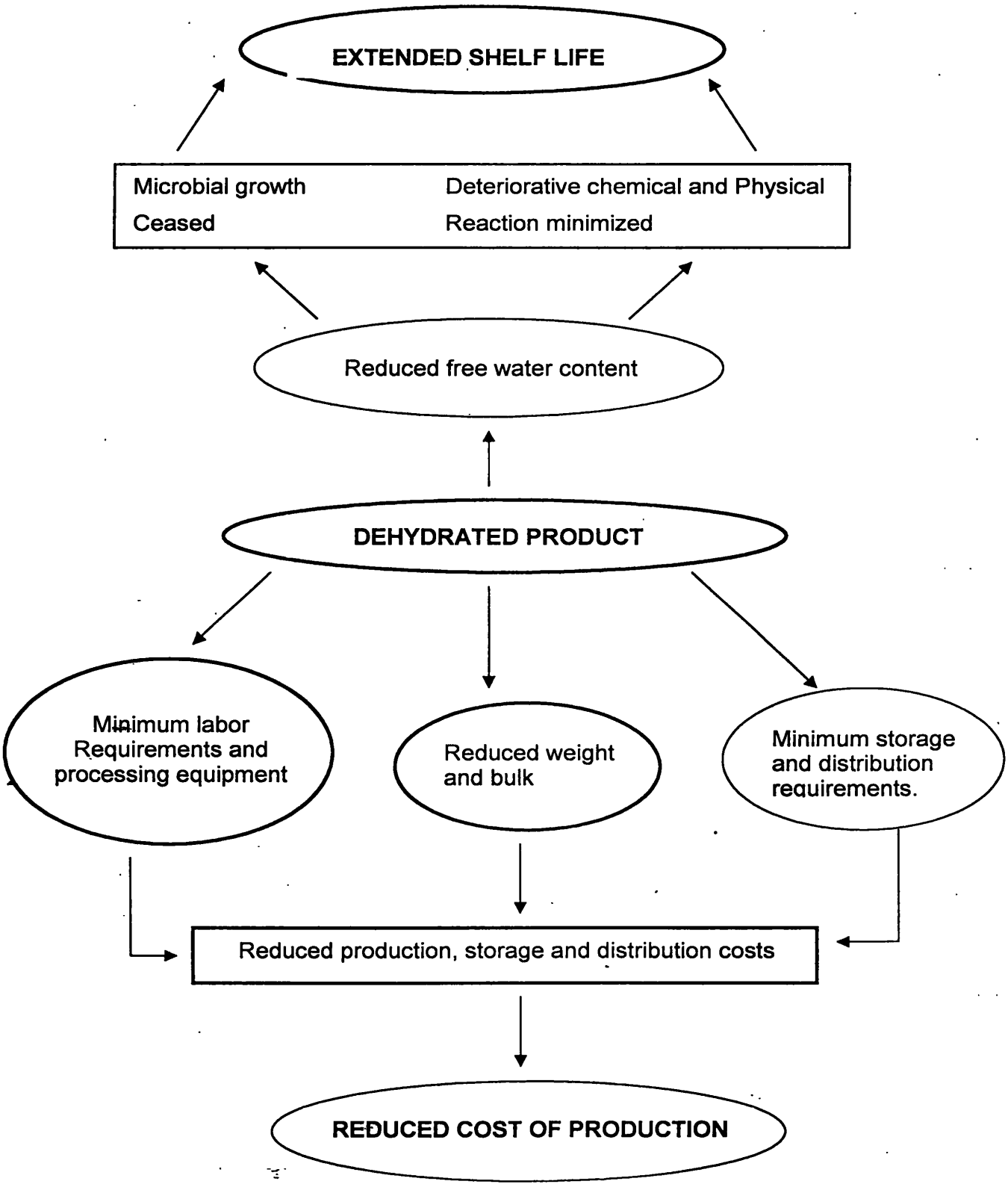

Figure2.3. Objectives of dehydration

2.16.3 Mechanism of dehydration

1. Surface evaporation
2. Moisture migration
3. Drying rates

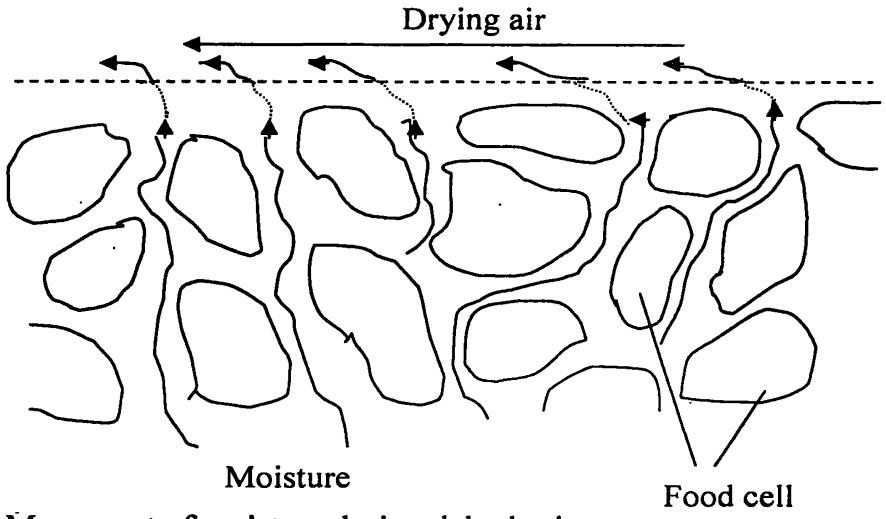

Figure 2.4. Movement of moisture during dehydration

2.16.3.1 Surface evaporation

Surface evaporation is the evaporation of moisture from any free water surface. The principle factors affecting the rate of evaporation from a free water surface are:

- The velocity of air over the surface
- The temperature of the air
- Humidity of the air (Leon & Sonido, 1996).

2.16.3.2 Moisture migration.

There are two principal mechanisms governing the migration of moisture from the internal structure of the food.

- Diffusion
- Capillary flow

2.16.4 Drying process

Drying process is completed in two periods as;

- Constant rate period
- Falling rate period

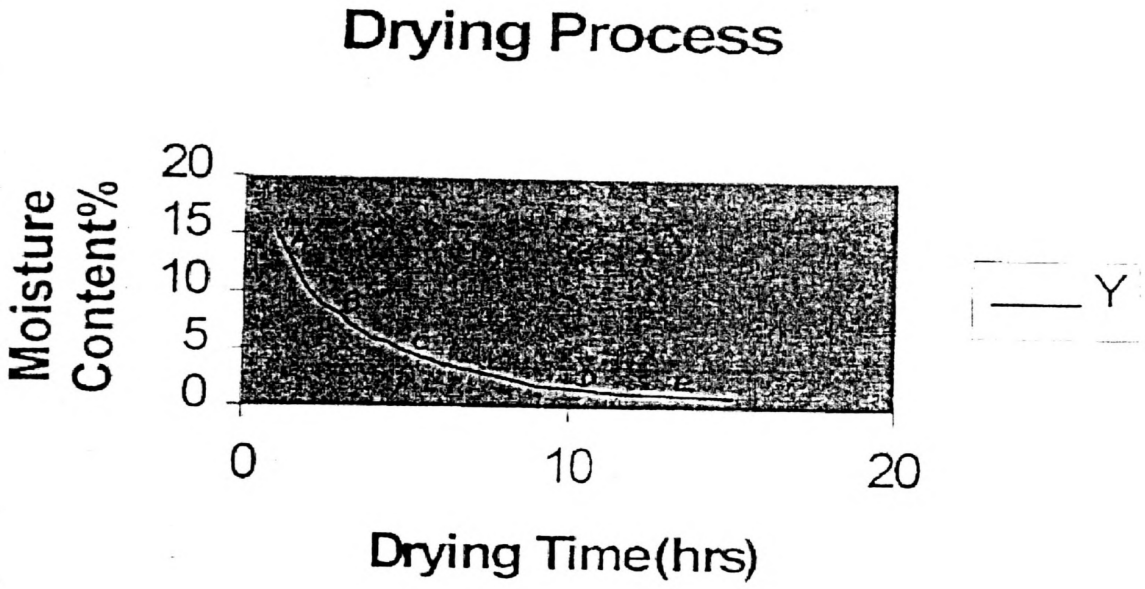

Figure 2.5. Drying curve

A-B: heating or cooling

B-C: Constant rate drying period

C: Critical moisture constant

C-D: 1st Falling rate drying period

D-E: 2nd falling rate drying period

The rate of drying is affected by the properties of the drying is affected by the properties of the solid.

The important properties of the air and temperature, humidity and velocity. The properties of the solid to consider are the type and variety of vegetables or fruit the free moisture contents; the method of preparation prior to drying; and the shape and size of the pieces.

It has been found that the drying process be divided into two parts. The constant rate drying period and the falling rate drying period.

During the former the rate of drying is governed by how rapidly the air can supply heat to the water vapor produced. During this period the water is diffusing to the surface of the air is cooled. Since the water in the solid absorbs.

During the falling moisture loss rate period the rate of drying is determined by the rate at which the water at the center of the food particle diffuses to the surface. The nature of the solid and the thickness of the food product are important. It is assumed that the surface of the product is at a moisture content, which is in equilibrium with the drying air. This equilibrium moisture is called the critical moisture.

2.16.5 Drying medium

The main drying mediums are

- Hot air
- Steam
- Hot oil
- Osmotic agents

Foodstuffs may be in air, superheated steam in vacuum in inert gas and by the direct application of heat. Air is generally used as the drying medium because it is plentiful, convenient and over heating of the food can be controlled. Air is used to conduct heat to the food can be controlled. Air is used to conduct heat to the food being dried and to carry liberated moisture vapor from the food. No elaborate moisture recovering system is required with air as is needed with other gases. Drying can be accomplished gradually and tendencies to scorch and discolor are within control. Air conveys heat to the food; causing waters to vaporize and is the vehicle to transport the liberated moisture vapor the dehydrating food.

2.16.6 Stages of drying

(1) Heating of the food to drying temperature

(2) Evaporation of moisture from the surface

(3) The migration of moisture from the interior of a particle to the surface (Leon & Sonido, 1996).

2.16.7 Chemical and other changes during dehydration

Chemical changes during dehydration affect quality of both the dried items and their reconstituted counterparts in food color, flavor, texture viscosity reconstitution rate, nutritional value and storage stability (Potter, 1981).

Used high temperature cells can be damaged, case hardening and shrinkage can be occur. Those will load the decrease in dehydration ratio of final products (Harry, 1955).

- Browning

- When the moisture content is 20%-30% due to concentration of reactive groups. Caramelization of sugar and scorching of other materials due to high heat. Loss in the easy of dehydration due to physical shrinkage and distortion of cells and capillaries (potter, 1981).

CHAPTER 03

3. MATERIALS AND METHODS

3.1 Raw Materials and equipment

3.1.1 Raw materials and chemical reagent used for cold room preservation

- Lime fruits
- Distilled water
- Chlorex
- Sodium Hydroxide (NaOH)
- Phenolpthalene

3.1.2 Equipment used for cold room preservation

- Plastic trays
- Stainless steel knife
- Plastic cutting board
- Plastic strainer
- Beakers (100ml , 500ml)
- Measuring cylinders(50ml,100ml,250ml)
- Conical flask(100ml,250ml)
- Volumetric flask (100ml , 1000ml)
- Pipettes(10ml,25ml)
- Burette(0-100ml)
- Funnel
- Porcelain plate
- Dropper
- Electronic balance (AND HF-400)
- pH meter (HM-205)
- Refractometer (Leia 10430 , 0-30 Brix)
- Cold room

3.1.3 Raw materials and equipment for dehydration

- Lime fruits
- Water
- Cotton cloth

- Sauce pans
- Gas cooker
- Thermometer (rang : from 0-100^{0}C)
- Dryer (Memmert)
- Oven (Memmert)
- Moisture dish
- Analytical balance (Libber or Aeg-220)

3.2 Experiment 01: Effect of cold room preservation on storage life of lime.

3.2.1 Sample preparation

Lime fruits were harvested with different sizes and three different maturity stages. They were collected in to plastic crates and transported to the Food Research Unit at Gannoruwa. Disease free and damage free healthy fruits were selected from the lot transported. Selected fruits were rinsed with clean running water (tap water) and then they were treated with 0.1% chlorex treatment to remove any contaminants. Surface of the fruits was dried well under normal condition. Lime fruits were separated in to three groups according to their maturity stages; lower mature stage fruit, full mature stage fruits, and color break stage fruits. Then above three stages fruits were sorted in to two distinct size ranges as size one (small size fruits) and size two (large size fruits).

Lime fruits were categorized as follows

Lower mature small size (M_1S_1)

Lower mature large size (M_1S_2)

Full mature small size (M_2S_1)

Full mature large size (M_2S_2)

Color break small size (M_3S_1)

Color break large size (M_3S_2)

Each batch of lime fruits categorized were divided in to two groups according to storage method as ordinary cold storage at 10^{0}C temperature and Modified Atmosphere (MA) at 10^{0}C temperature conditions.

Samples of 150±10g were prepared from each category by using electronic balance. Samples were prepared for four months sufficient and each treatment with three replications. Initial weight of each sample was tagged with sample name and sample number.

Samples were placed for ordinary cold storage in labeled plastic crates and they were stored in cold room at 10^0C and 85-90% relative humidity. Samples intended for MA storage were sealed with perforated Low-Density Polyethylene (LDPE) film of 200 gauge (50.8μ) with labels and they were kept in a cold room at 10^0C temperature and 80-90% relative humidity. The size of the film was 6"×7".

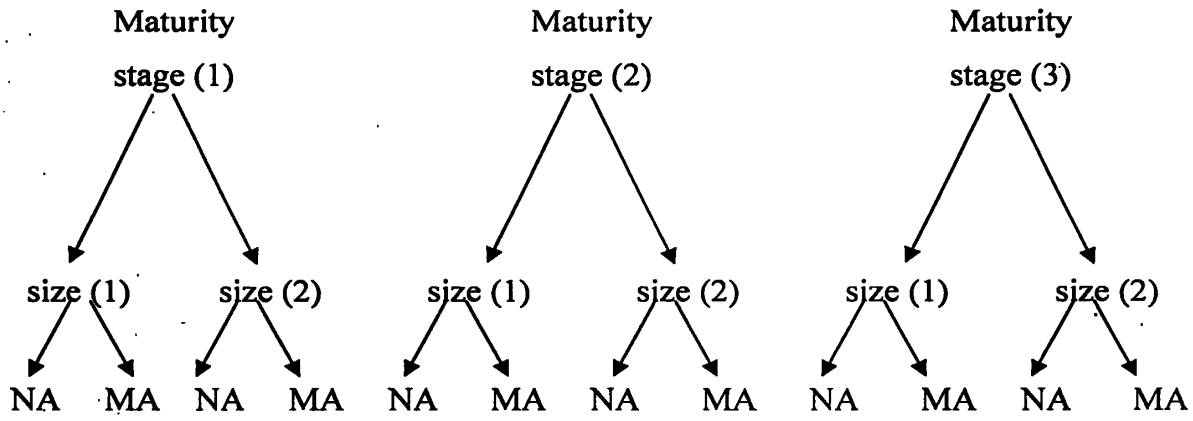

Figure 3.1.Treatments applied in the experiment 01

Maturity stage (1)	- Lower maturity
Maturity stage (2)	- Full maturity
Maturity stage (3)	- Over maturity (colour break stage)
Size (1)	- Small size fruits
Size (2)	- Large size fruits
NA	- Normal Atmosphere storage (Ordinary cold storage at 10°C)
MA	- Modified Atmosphere storage (MA storage at 10°C)

3.2.2 Qualitative estimation of the quality parameters

Subjective estimation of the fruits at the initial stage of each category, were made by the visual examination of their peel color, Visual Quality Rating (VQR), and disease incidence by using appropriate indices (Table 3.1, 3.2, 3.3). Sensory firmness of fruits was also recorded on a three-point scale (Table3.4). These parameters were taken for individual fruit in a sample and an average value for each sample was recorded. Fruits were evaluated for above parameters at the initial stage and as well as once a week with decided day. And also browning index was used for the quality parameters for ordinary cold storage sample peel color after one to two months (Table 3.5).

Table 3.1: Color index for the estimation of peel color of lime fruits.

Number	Description of the peel color
1	Dark green
2	Colour break
3	More green than yellow
4	More yellow than green
5	Full yellow

Table 3.2: Index for the estimation of Visual Quality Rating (VQR) of lime fruits.

Number	Description for the Visual Quality Rating
1	Not edible
3	Edible, cannot be sold
5	Moderate defects
7	Slight defects
9	Excellent

Table 3.3: Index for the estimation of disease incidence of lime fruits.

(When observe the fruit if appeared some fungal like disease spots. Description of disease condition, no any spots - None, 0-5spots - Low, 5-10spots - Moderate, more than 10 spots - High).

Number	Description of the Disease incidence
0	None
1	Low
2	Moderate
3	High

Table 3.4: Index for the estimation of sensory firmness of lime fruits.

(When slightly press the fruit with the thumb and the first finger of the fruit is press down for 0-1mm - Firm, 1-2mm - Slightly soft, 2-3mm – Moderate soft, more than 3mm -Very soft).

Number	Description of the sensory firmness
1	Very soft
2	Moderate soft
3	Slightly soft
4	Firm

Table 3.5: Browning index for the estimation of peel brown color of lime fruits

Number	Description of the browning index
0	None brown
1	Brown
2	Slight brown
3	Moderate brown
4	Dark brown

3.2.3 Quantitative estimation of the quality parameters

A representative sample of each category (M_1S_1, M_1S_2, M_2S_1, M_2S_2, M_3S_1 M_3S_2) were used for the detection of percentage juice volume, percentage weight loss.

3.2.3.1 Percentage weight loss

Percentage weight loss of stored lime was calculated by measuring the weight of the each sample at each stage with three replicates and average weight was taken (each sample's initial weight tagged with sample name and sample number at initial stage).

Percentage weight loss was calculated as follows;

$$\% \text{ Weight loss} = \frac{\text{(Initial weight- Final weight) of the sample/g}}{\text{Initial weight of the sample/g}} \times 100$$

3.2.3.2 Percentage juice volume

Each sample categorized fruits was separately subjected to squeezing with help of a simple glass device. The pooled juice of sample fruits was filtered using a plastic strainer in to a clean dry ladled 100ml beakers. Volume of each juice samples collected was measured by a measuring cylinder. Percentage juice content was calculated.

$$\% \text{ juice volume} = \frac{\text{Juice volume of the sample fruits/cm3}}{\text{Initial volume of the sample fruits/cm3}} \times 100$$

Using, Total soluble solids (TSS), pH value, and percentage Titrable Acidity (% TA) of the above extracted and filtered lime juice were determined as well.

3.2.3.3 Determination of pH value

The pH value of the extracted juice was determined by using electronic pH meter (HM-205), pH value of each sample was recorded respectively.

3.2.3.4 Determination of Total Soluble Solids (TSS) and percentage Titrable Acidity (%TA).

Preparation of dilution sample

A sample of 10ml of extracted limejuice was measured by using dry clean pipette (10ml) and poured in to 100ml volumetric flask. The volume adjusted by using distilled water and the mixture was properly shaken. The solution was used for the determination of TSS and %TA

$$\text{Dilution factor} = \frac{\text{Weight of the sample/g} \times \text{Volume of the water added/ml}}{\text{Weight of the sample}}$$

(a) Total Soluble Solids (TSS)

TSS was measured with hand held refactometer (Leica 10430,0-30 Brix automatically temperature compensated) using one drop from the diluted sample. TSS was calculated as follows.

TSS= Refractometer reading × Dilution factor.

(b) Titrable Acidity (%TA)

A sample of 25ml of above diluted limejuice was pipetted out poured in to dry clean 100ml flask. Two drops of phenolphalein indicator was added and mixed well. This solution was titrated to a faint pink color end point against 0.1N Sodium Hydroxide (NaOH) solution. This was done three times and obtained the mean value of the used volume of 0.1N NaOH.

Calculated the percentage Titrable Acidity (%TA) as follows.

$$\%TA = \frac{\text{Equivalent weight of the acid} \times \text{Spend volume of NaOH} \times \text{N: of NaOH}}{1000 \times \text{Volume of sample}} \times 100$$

N = Normality of NaOH(0.1N)

Equivalent weight of citric acid=70.03

3.3 Experiment 02: Effect of drying temperature and pretreatment on dehydration of lime fruits

3.3.1 Sample preparation and method

Freshly harvested approximately uniform size full mature fruits were selected for dehydration of whole lime fruits.

In order to study on the effect of drying temperature and pretreatments, four experiments was carried out on different batches of lime fruits selected. (figure 3.2a and figure 3.2b).

In three experiments, Lime Samples with or without blanching for different time duration were subjected to drying at a hot air flows at different temperatures. In the fourth experiment the samples were pretreated with or without 40% brine solution and subjected to drying at 45^{0}C for two days followed with a time break for about 1-2 hours. After the time break the samples were again dried at a hot air flow at 50^{0}C for two days. With a similar time breath the third drying operation was carried out at 55^{0}C for three days. Each treatment was done with three replications and dehydrated until 8-12% of the find moisture content. Initial time was recorded at the stage of any sample place on the dryer.

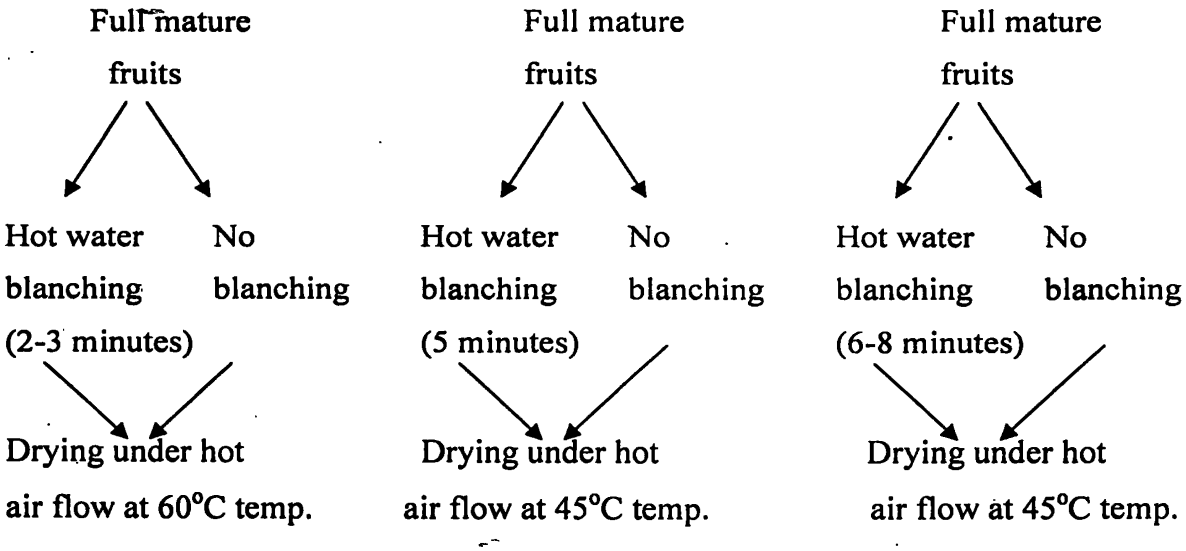

Figure 3.2.a. Treatment applied in the experiment 02

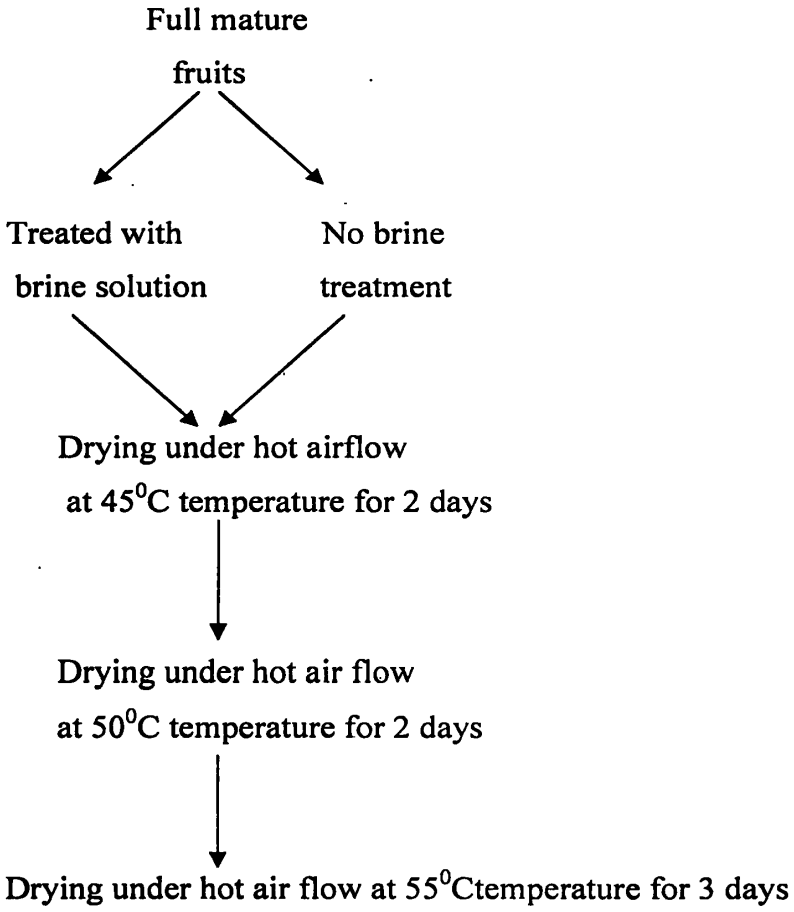

Figure 3.2.b. Pretreatment with or without brine solution and drying of lime sample

3.3.2. Quantitative estimation of quality parameters

3.3.2.1 Drying time

Initial time was recorded just after the samples were placed on the dryer and end of the drying process-ending time was also recorded.

Drying time = Ending time – Initial time

3.3.2.2 Percentage weight loss

Percentage weight loss of dehydrated lime sample was calculated by measuring the weight of the each sample before dehydrated and after the dehydration process.

$$\% \text{ Weight loss} = \frac{\text{(Initial weight} - \text{Final weight) of the sample/g}}{\text{Initial weight of the sample /g}} \times 100$$

3.3.2.3 Moisture content

The clean and dry moisture dishes were weighted accurately, weighted about 5.000 ±1.000 gram of the sample in a tared moisture dishes with three decimal point accurately the dishes were placed in an oven maintain at 105 °C ± 1 and dried for at least three hours. The samples were kept in a desiccator to cool, and then they were weighed. Process of heating, cooling and weighing was repeated until the difference between two successive weightings did not exceed 0.001g.

$$\text{Moisture percentage} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

W_1= weight of empty moisture dish

W_2=weight of the dish + sample

W_3=weight of the dish + dried sample

3.4 Experimental design and analyses of data

3.4.1 Experimental design and analysis of data for cold room preservations

Treatment combinations were form using factorial experiment with tree and analyzed by using four-way ANOVA at 0.05 significant level.

H_0= null hypothesis

H_1= alternative hypothesis

H_0= there is no significant difference in between any variable (maturity stage, fruit size, storage condition, time)

H_1= there is significant difference at least in between one variable .

P= probability value

If P <0.05 at 5% significant level reject H_0 accept H_1.

3.4.2 Experimental design of analysis of data for dehydrated lime fruits

Treatment combination were form using factorial experiment with tree replication And analyzed by using one- way ANOVA at 0.05 significant level.

H_0 = null hypothesis

H_1= alternative hypothesis

H_0= there is no significant difference among any treatments

H_1= there is a significant difference among any treatments

P= probability value, If P <0.05 at 5% significant level reject H_0, accept H_1.

CHAPTER 04

4. RESULTS AND DISCUSSION

4.1 Experiment 01

Effect of cold room preservation on storage life of lime.

4.1.1Qualitative estimation of quality parameters

Peel colour

There was a significant difference in peel colour in between maturity stage of the fruits, size of the fruits, and storage condition with time at 5% significant level (Appendix 1).

Fruits with colour break stage and full maturity stage showed highly changeable peel colour than the lower maturity stage fruits did during their storage period. Also smaller fruits had more attractive peel colour than the larger fruits (Appendix 2). Considering the size of fruits, smaller fruits peel colour, during the storage period was very close to the range of " colour break" to "more green than yellow" in the peel colour index (Table3.1). But large size fruit's peel colour was very close to "more yellow than green". Fruits kept in Modified Atmosphere (MA) storage condition had a better quality peel colour than those kept in ordinary cold storage conditions. Ordinary cold storage conditions fruits peel colour turned to brownish colour after 21 days during their storage period. Hence, after 21 days peel colour of fruits kept in ordinary cold storage conditions was measured by using a brown colour index.

Chlorophyll is the responsible factor for green colour of the fruit peel. Degradation of chlorophyll and subsequent demasking of carotenoids, yellow colour pigments in chromoplast lead to fruit degreening and yellowing. So during the storage period, fruits gradually change their colour from their initial colour to more yellow or brown especially in ordinary cold storage conditions than in the MA storage conditions.

High respiration rate and transpiration rate increases the fruit ripening by producing ethylene gas. Production of ethylene in turn again enhances the fruit ripening. As under low temperature conditions like 10°C, biochemical activities (chlorophyll degradation enzymes) in living tissues are slow, the colour-changing rate during the storage period is reduced remarkably. Larger fruits have higher rate of colour development than the smaller fruits with the same maturity stage. Due to this reason peel colour of larger fruits changes more apparently than the smaller fruits.

Respiration rate of the fruit rind is nearly ten times as high as that of vesicles (Murata, 1997). After 21 days, in ordinary cold storage conditions fruits peel colour turns in to brown. This change is not desirable for marketing. But internal quality of the fruit remains high. During the MA storage, accumulation of CO_2 is higher inside the package than the O_2 level. Carbon dioxide is capable of restricting fruit ripening and yellowing. This is the reason that the fruits kept in the MA storage condition have an attractive peel colour than those kept in ordinary cold storage condition. Ethylene gas enhances the ripening process. There is a high tendency to accumulate ethylene inside the package due to less permeability of Low Density Polyethylene (LDPE) to ethylene. Since lime fruit is non-climacteric fruit, if generates a very small amount of ethylene, which is not sufficient enough to creating a problem.

In addition to CO_2, undesirable gases like CO can also be produced inside the package which can change the biochemical activities of the fruits giving poor appearance to the lower maturity fruits after one and half months during the storage period.

Storage temperatures below 10°C cause chilling injury symptoms in lime fruits and give bad appearance and poor quality (Arpaia & Kader, 2000).

Hence, in the present study the temperature in the cold room was adjusted to 10°C for proper storing of lime.

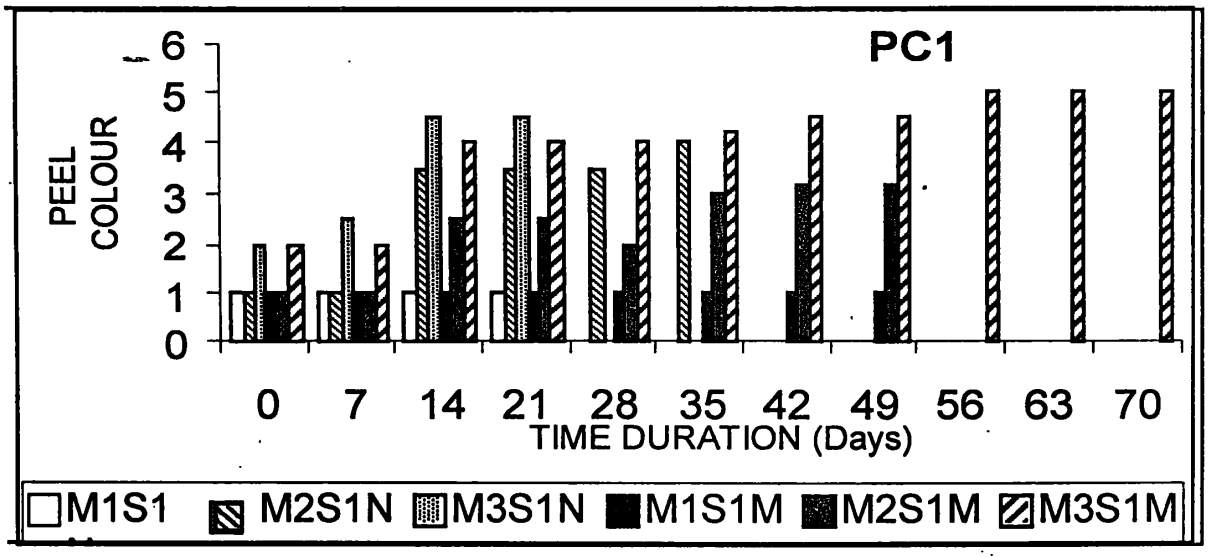

Figure 4.1. Effect of maturity stage and storage condition on peel colour of lime for small size fruits(1-Dark green, 2-colour break, 3- More green than yellow, 4- More yellow than green, 5- full yellow)

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2s1N = Full mature, large size, normal atmosphere storage fruits

M3s1N = Over mature stage, small size, normal atmosphere storage fruits

M1S1M= Lover mature, small size, MA storage fruits

M2S1M=Full mature, small size, MA storage fruits

M3S1M= Over mature, small size, MA stroge fruits

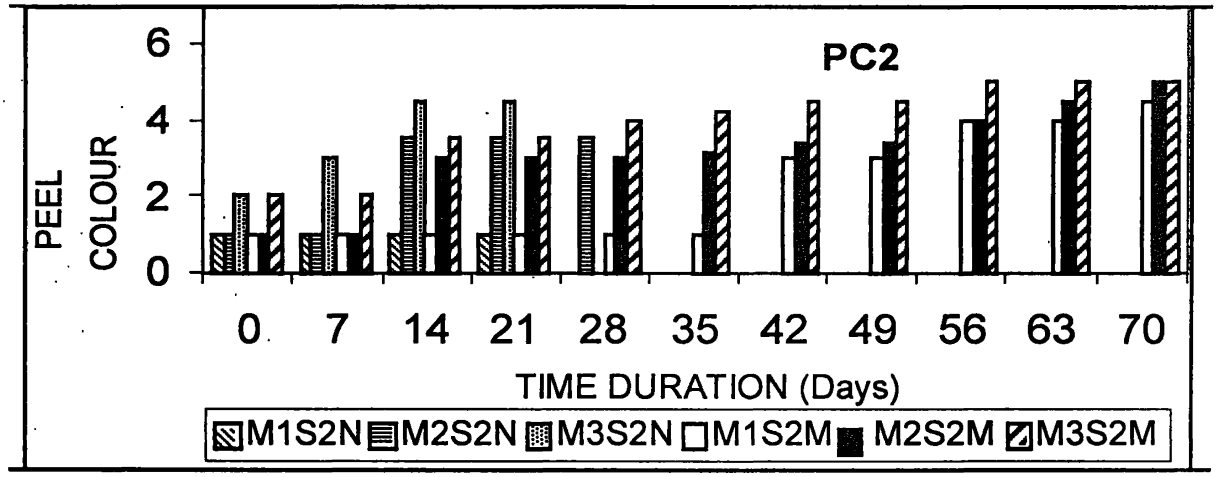

Figure 4.2. Effect of maturity stage and storage condition on peel colour of lime for large size fruit(1-Dark green, 2-colour break, 3- More green than yellow, 4- More yellow than green, 5- full yellow)

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S2N= Full mature, larger size, normal atmosphere storage fruits

M3S2N= Over mature, larger size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M= Full mature, large size , MA storage fruits

M3S2M= Overmature, large size ,MA storage fruits

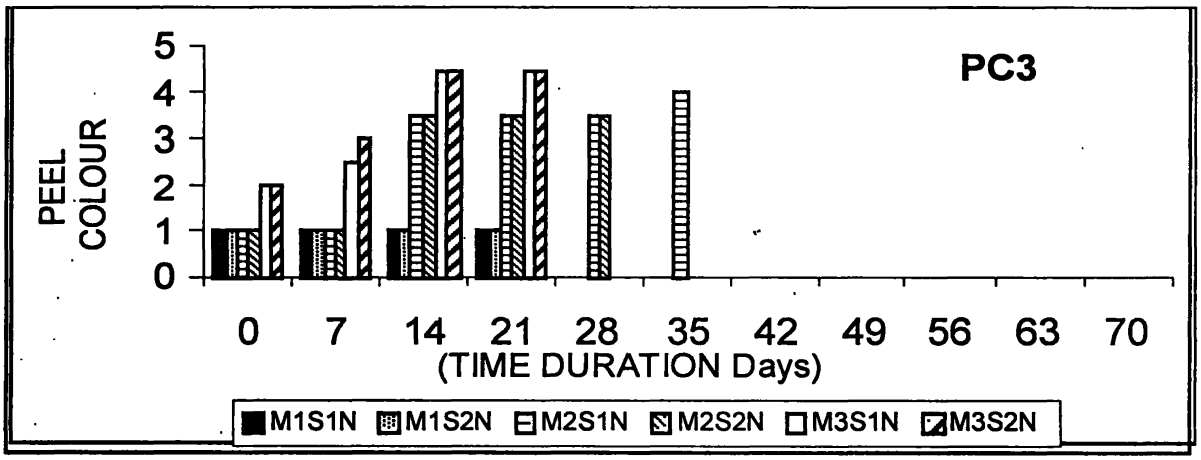

Figure 4.3. Effect of maturity stage and fruit size on peel colour of lime for normal atmosphere storage fruit (1-Dark green, 2-colour break, 3- More green than yellow, 4- More yellow than green, 5- full yellow)

- M1S1N= Lower mature, small size, normal atmosphere storage fruits
- M1S2N= Lower mature, large size, normal atmosphere storage fruits
- M2S1N= Full mature, small size, normal atmosphere storage fruits
- M2S2N= Full mature, large size, normal atmosphere storage fruits
- M3S1N = Over mature, small size, normal atmosphere storage fruits
- M3S2N= Over mature, large size, normal atmosphere storage fruits

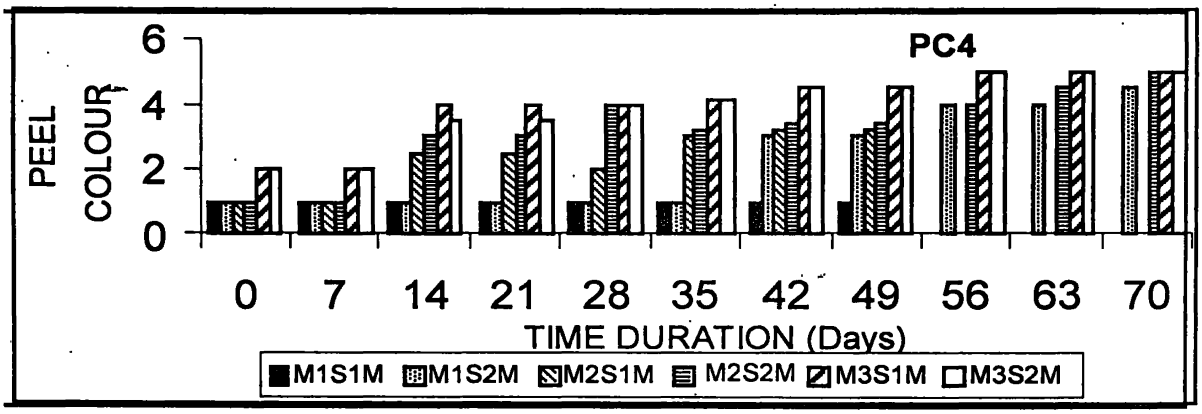

Figure 4.4. Effect of maturity stage and fruit size on peel colour of lime for MA storage fruit (1-Dark green, 2-colour break, 3- More green than yellow, 4- More yellow than green, 5- full yellow)

- M1S1M= Lower mature, small size, MA storage fruits
- M1S2M= Lower mature, large size, MA storage fruits
- M2S1M= Full mature, small size, MA storage fruits
- M2S2M= Full mature, larger size, MA storage fruits

M3S1M= Over mature, small size, MA storage fruits

M2S2M= Over mature, large size, MA storage fruits

Browning Index

There was a significant difference in brown colour index in between storage method with time at 5% significant level (Appendix 4).

Brown peel colour was developed only in samples of ordinary cold storage after 21 days (Appendix 5). MA storage fruits could not show brown peel colour (Figure 4.8.).

High respiration and transpiration rates cause more senescence and bad colour appearance to the fruit feel. Thereby reducing the market profitability although the fruit has a high external quality of the juice vesicles.

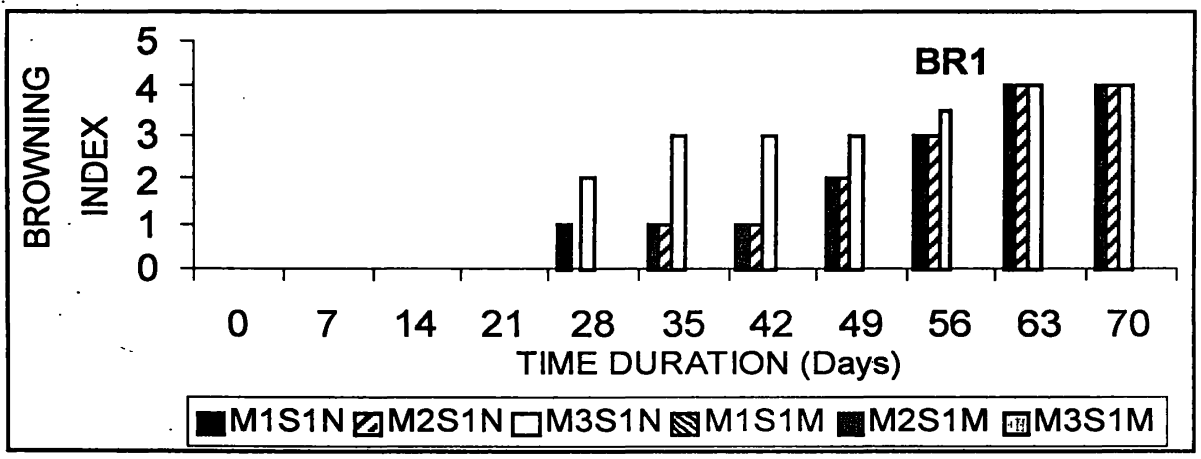

Figure 4.5. Effect of maturity stage and storage condition on brown colour index of lime for small size fruits(0-None brown, 1- Brown, 2- Slight brown, 3- Moderate brown, 4- Dark brown)

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2s1N = Full mature, large size, normal atmosphere storage fruits

M3s1N = Over mature stage, small size, normal atmosphere storage fruits

M1S1M = Lover mature, small size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M3S1M = Over mature, small size, MA stroge fruits

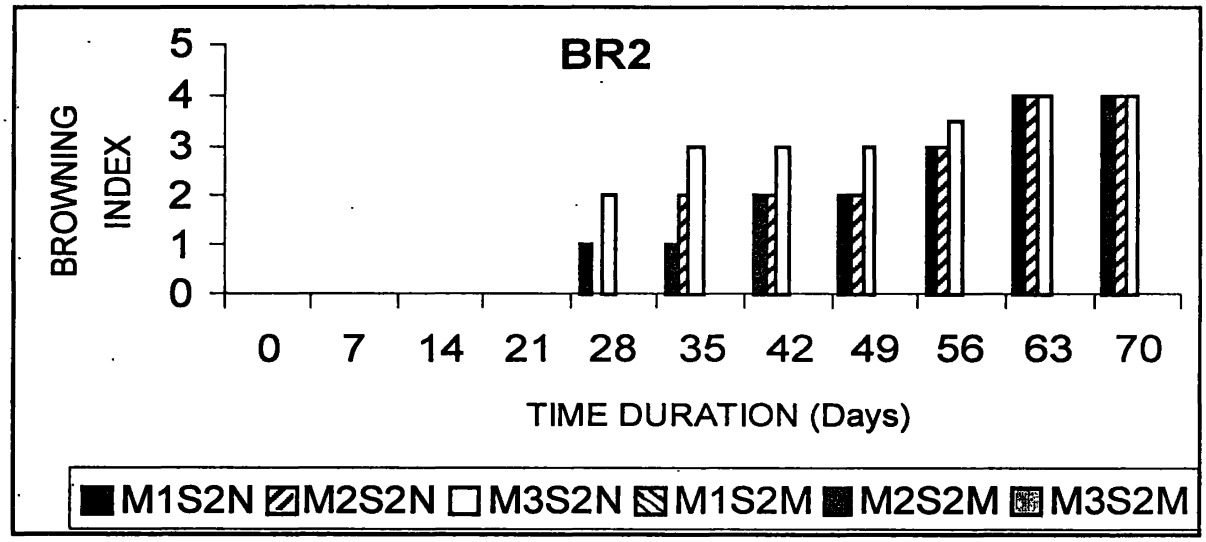

Figure 4.6. Effect of maturity stage and storage condition on brown colour index of lime for large size fruits(0-None brown, 1- Brown, 2- Slight brown, 3- Moderate brown, 4- Dark brown)

- M1S2N = Lower mature, large size, normal atmosphere storage fruits
- M2S2N= Full mature, larger size, normal atmosphere storage fruits
- M3S2N= Over mature, larger size, normal atmosphere storage fruits
- M1S2M = Lower mature, large size, MA storage fruits
- M2S2M= Full mature, large size, MA storage fruits
- M3S2M= Overmature, large size, MA storage fruits

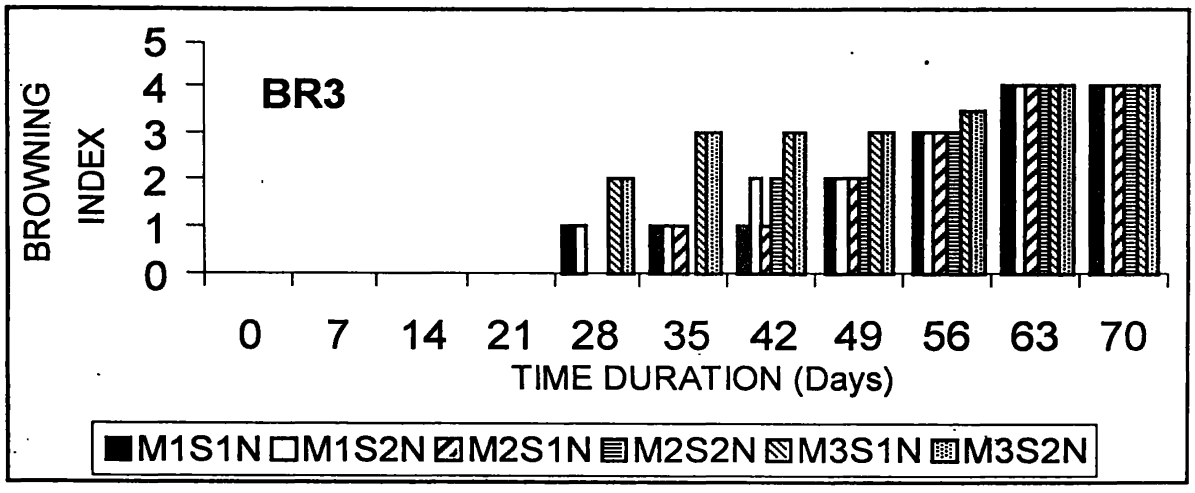

Figure 4.7. Effect of maturity stage and fruit size on brown colour index of lime for normal atmosphere storage fruits(0-None brown, 1- Brown, 2- Slight brown, 3- Moderate brown, 4- Dark brown)

M1S1N= Lower mature, small size, normal atmosphere storage fruits

M1S2N= Lower mature, large size, normal atmosphere storage fruits

M2S1N= Full mature, small size, normal atmosphere storage fruits

M2S2N= Full mature, large size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M3S2N= Over mature, large size, normal atmosphere storage fruits

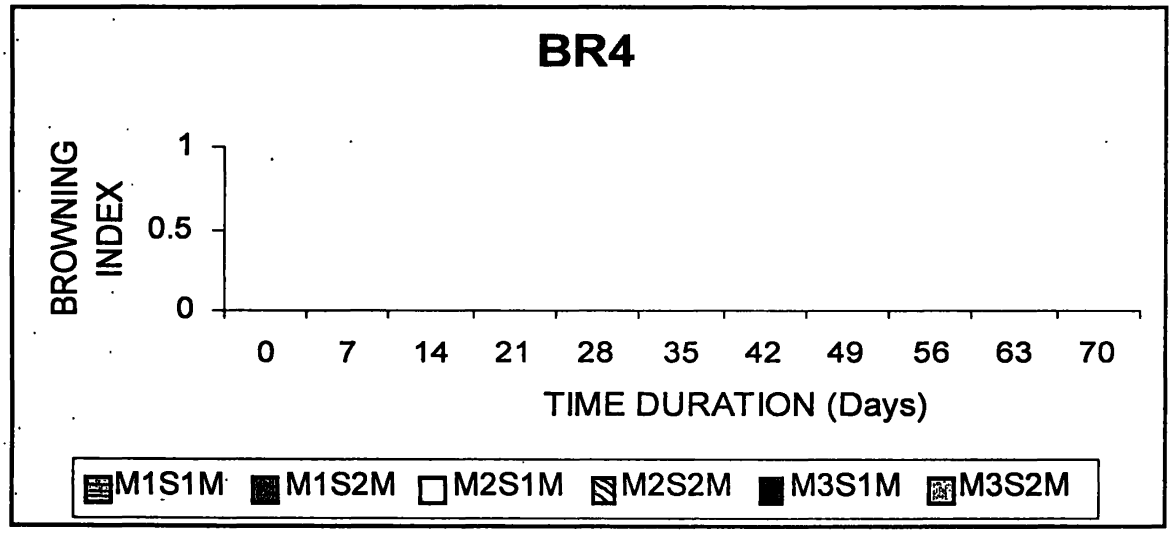

Figure 4.8. Effect of maturity stage and fruit size on brown colour index of lime for MA storage fruits(0-None brown, 1- Brown, 2- Slight brown, 3- Moderate brown, 4- Dark brown)

M1S1M= Lower mature, small size, MA storage fruits

M1S2M= Lower mature, large size, MA storage fruits

M2S1M= Full mature, small size, MA storage fruits

M2S2M= Full mature, larger size, MA storage fruits

M3S1M= Over mature, small size, MA storage fruits

M2S2M= Over mature, large size, MA storage fruits

Visual Quality Rating (VQR)

There was a significant difference in VQR in between storage methods of the fruits with time at 5% significant level (Appendix 6).

MA storage fruits had higher VQR than the ordinary cold storage fruits (Appendix7 and Figure 4.9. and 4.10.).

Characteristics like attractive peel colour, high firmness, free from disease and physical damage are mainly responsible for VQR than the internal quality factors of the fruits. Fruits of MA storage condition have higher VQR as the posses to high peel colour appearance and fruit firmness with longer storage life than the fruits kept in ordinary cold storage condition.

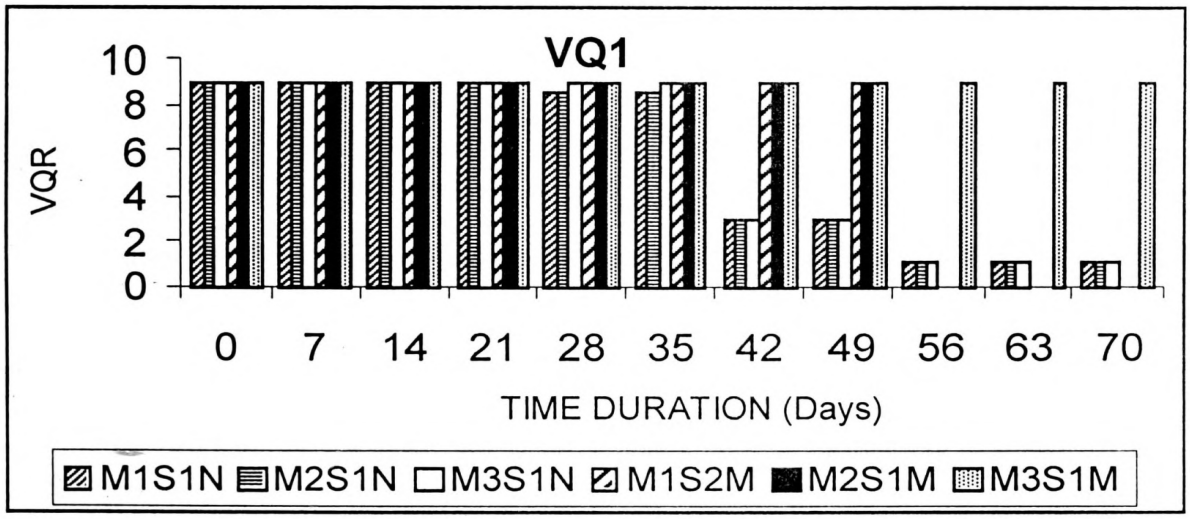

Figure 4.9. Effect of maturity stage and storage condition on Visual Quality Rating (VQR) of lime for small size fruits(1-Not edible, 3- Edible, can not be used, 5-Moderate defects,7- Slight defects, 9- Excellent)

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2s1N = Full mature, large size, normal atmosphere storage fruits

M3s1N = Over mature stage, small size, normal atmosphere storage fruits

M1S1M= Lover mature, small size, MA storage fruits

M2S1M=Full mature, small size, MA storage fruits

M3S1M= Over mature, small size, MA stroge fruits

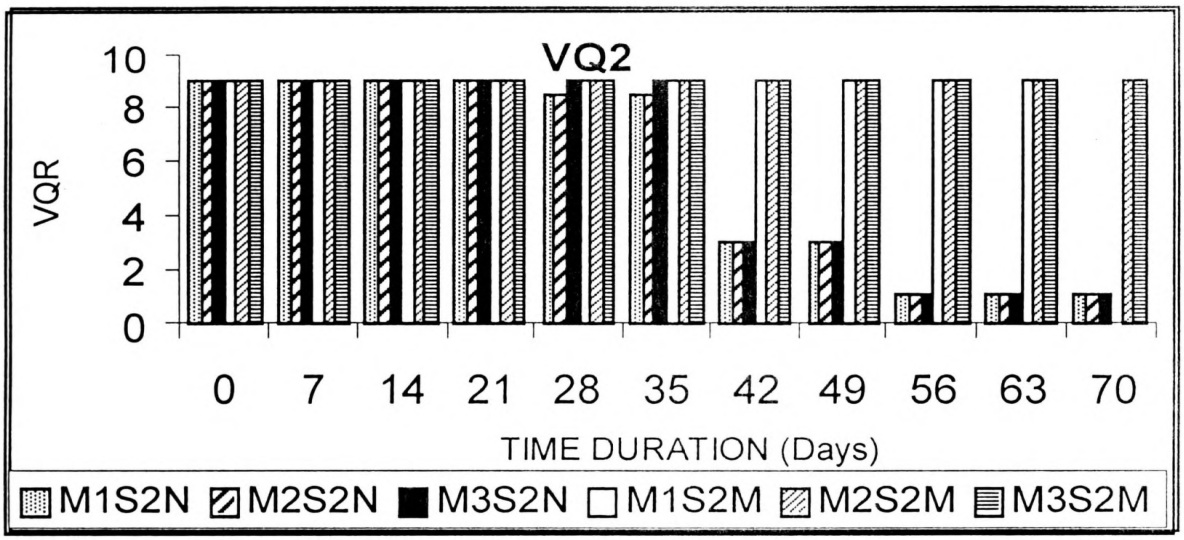

Figure 4.10. Effect of maturity stage and storage condition on Visual Quality Rating (VQR) of lime for large size fruits(1-Not edible, 3- Edible, can not be used, 5-Moderate defects,7- Slight defects, 9- Excellent)

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S2N= Full mature, larger size, normal atmosphere storage fruits

M3S2N= Over matur,e larger size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M= Full mature, large size, MA storage fruits

M3S2M= Over mature, large size, MA storage fruits

Sensory firmness

There was a significant difference in fruit firmness in between storage conditions with time at 5%significant level (Appendix 8).

MA storage fruits had higher fruit firmness than the ordinary cold storage fruits did (Appendix 9 and Figure 4.11. and 4.12.).

Firmness of fruits kept in MA storage conditions higher due to low respiration and transpiration they have.

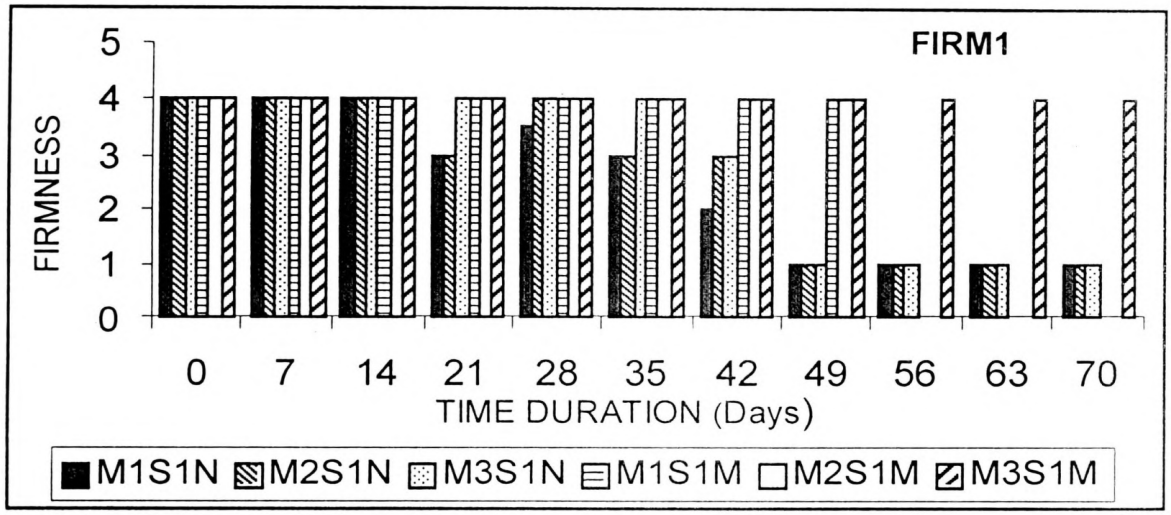

Figure 4.11. Effect of maturity stage and storage condition on sensory firmness of lime for small size fruits(1-Very soft, 2- Moderate soft, 3- Slight soft, 4- Firm)

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2s1N = Full mature, large size, normal atmosphere storage fruits

M3s1N = Over mature stage, small size, normal atmosphere storage fruits

M1S1M = Lover mature, small size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M3S1M = Over mature, small size, MA stroge fruits

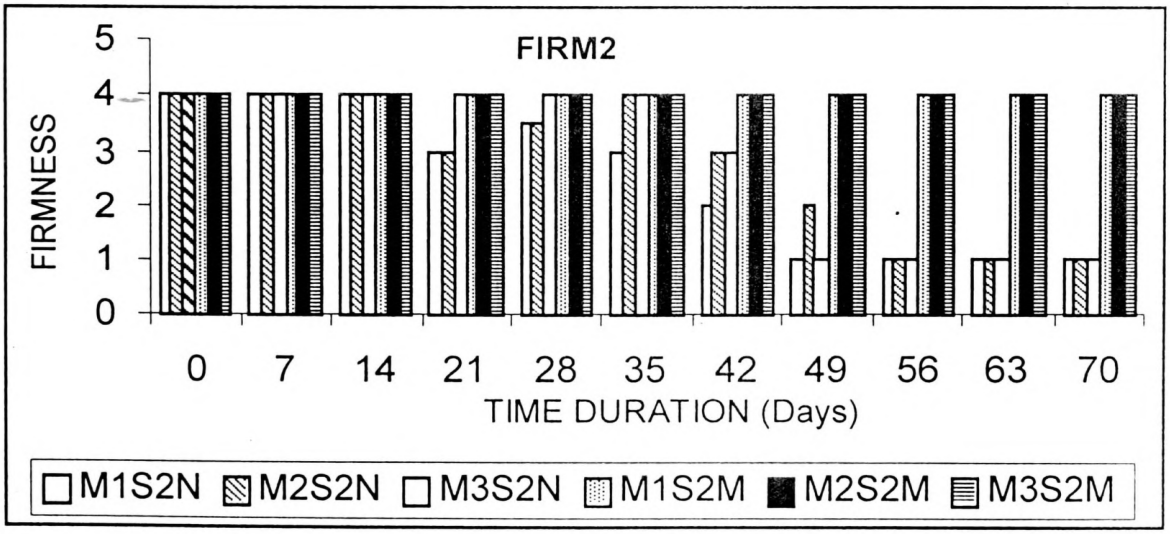

Figure 4.12. Effect of maturity stage and storage condition on sensory firmness of lime for large size fruits(1-Very soft, 2- Moderate soft, 3- Slight soft, 4- Firm)

M1S2N = Lower mature, large size, normal atmosphere storage fruit

M2S2N = Full mature, large size, normal atmosphere storage fruit

M3S2N = Over mature, large size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

Disease incidence

No significant difference was found in disease incidence with time at 5% significant level.

High acid content of the limejuice is not desirable for growth of microorganisms. However, some fungi can grow in lime fruits. Treatment of fruits with a fungicide like chlorex was effective in overcoming fungal attacks and other disease condition through out the storage period of the lime fruits.

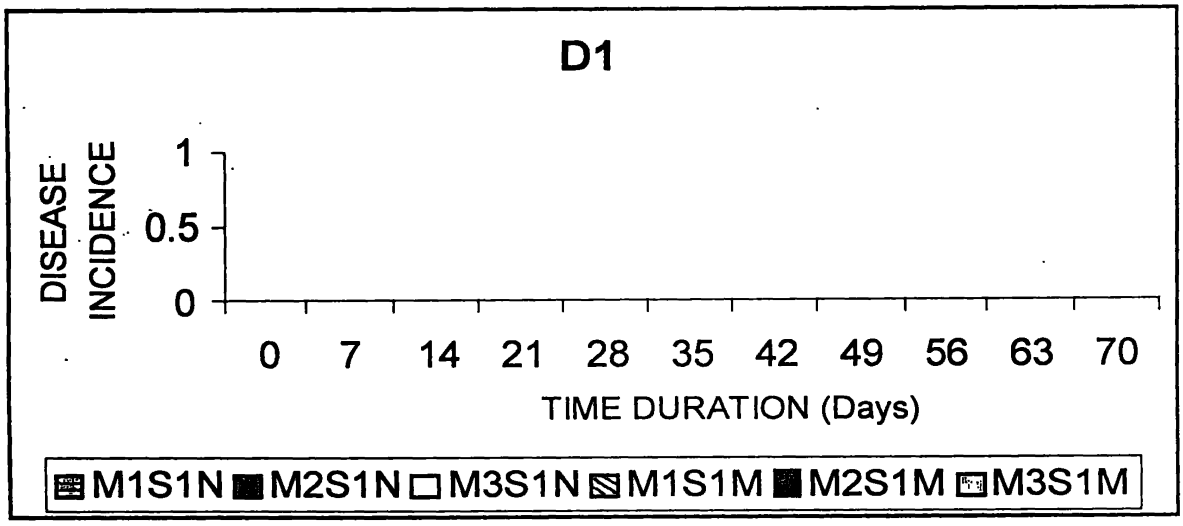

Figure 4.13. Effect of maturity stage and storage condition on Disease incidence of lime for small size fruits(0-None, 1- low, 2-Moderate, 3-High)

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M1S1M = Lower mature, small size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M3S1M = Over mature, small size, MA storage fruits

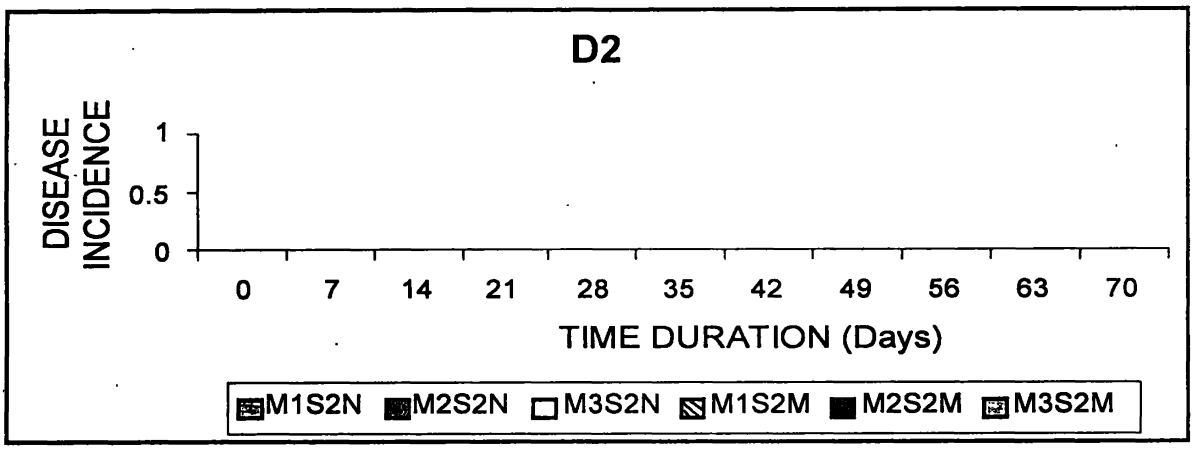

Figure 4.14. Effect of maturity stage and storage condition on Disease incidence of lime for large size fruits(0-None, 1- low, 2-Moderate, 3-High)

- M1S2N = Lower mature, large size, normal atmosphere storage fruits
- M2S2N = Full mature, large size, normal atmosphere storage fruits
- M3S2N = Over mature, large size, normal atmosphere storage fruits
- M1S2M = Lower mature, large size, MA storage fruits
- M2S2M = Full mature, large size, MA storage fruits
- M3S2M = Over mature, large size, MA storage fruits

Chilling injury

There was no chilling injury symptoms appeared during the storage period.

4.1.2 Quantitative estimation of quality parameters

Percentage weight loss (% wt. loss)

There was a significant difference in percentage weight loss in between fruit size, storage condition with time at 5% significant level (Appendix10). There was no significant difference in percentage weight loss in between maturity stage. Smaller fruits (size one) had high percentage weight loss than the large fruits (size two) (Appendix 11). Also ordinary cold storage fruits had high percentage weight loss than the Modified Atmosphere (MA) conditions (Appendix12).

The higher percentage weight loss was observed in lower maturity smaller fruits and colour break stage smaller fruits in ordinary cold storage (Figure 4.15.). According to figure4.17 in MA storage condition fruits were showed slight increase of percentage weight loss up to 21 days. But after 21 days reduce the percentage weight loss at once and that condition was continued throughout the storage period. Reduction of water loss achieved by reducing water-vapor difference between the produce and air inside the package. Due to low temperature, the gas permeability of the film was decrease and there by the relative humidity inside package is enhanced.
If any product showed less percentage weight loss throughout their storage period that condition can be considered as more desirable for market profitability. Transpiration, respiration rates are most responsible factors for percentage weight Loss. Smaller lime fruits kept in ordinary cold storage condition showed a higher percentage weight loss than the Modified Atmosphere (MA) storage conditions.
It can be noted that the surface area to volume ratio is higher in smaller fruits and therefore transpiration rate is higher. Low temperature and high relative humidity created a favorable micro- environment for perishable products by reducing the rate of water loss and the rates of respiration and transpiration. These conditions are readily provided in cold room conditions and the action of low temperature enhanced by the use of MA conditions. The passive MA conditions were generated through the respiration of fruits.

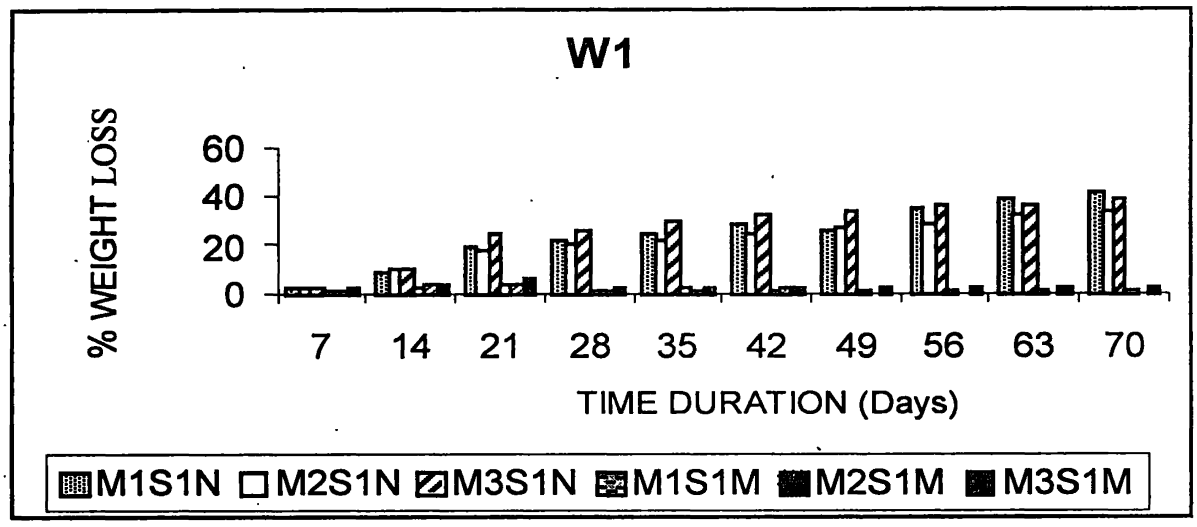

Figure 4.15. Effect of maturity stage and storage condition on Percentage weight loss(%wt. Loss) of lime for small size fruits

- M1S1N = Lower mature, small size, normal atmosphere storage fruits
- M2S1N = Full mature, small size, normal atmosphere storage fruits
- M3S1N = Over mature, small size, normal atmosphere storage fruits
- M1S1M = Lower mature, small size, MA storage fruits
- M2S1M = Full mature, small size, MA storage fruits
- M3S1M = Over mature, small size, MA storage fruits

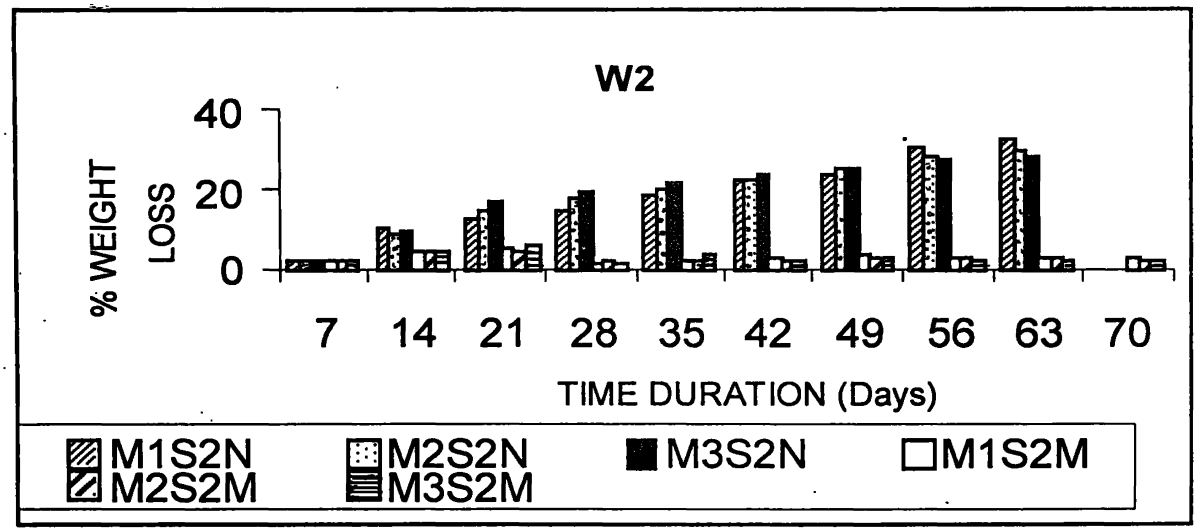

Figure 4.16. Effect of maturity stage and storage condition on Percentage weight loss(%wt. Loss) of lime for large size fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

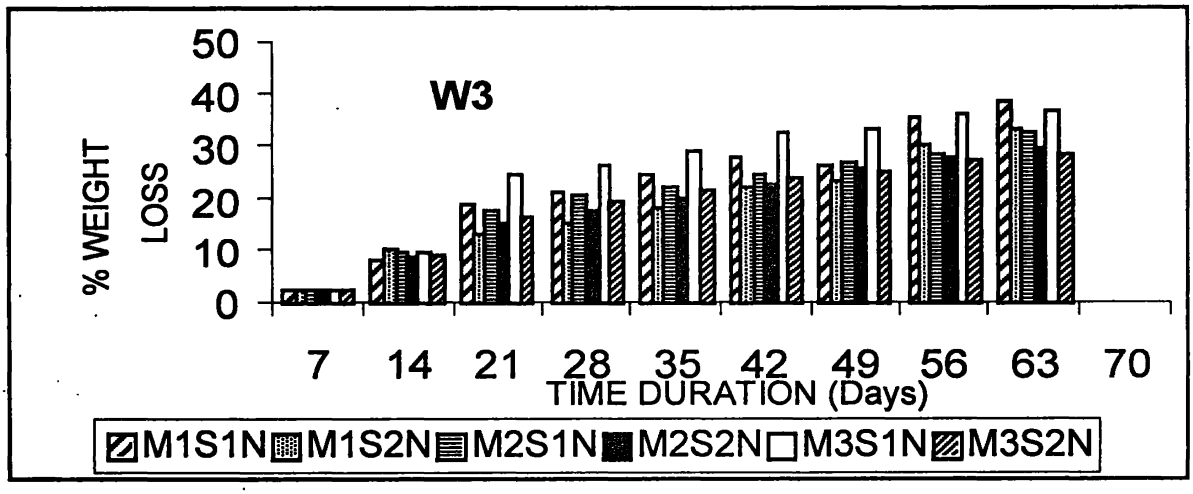

Figure 4.17. Effect of maturity stage and fruit size on Percentage weight loss(%wt. Loss) of lime for normal atmosphere storage fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

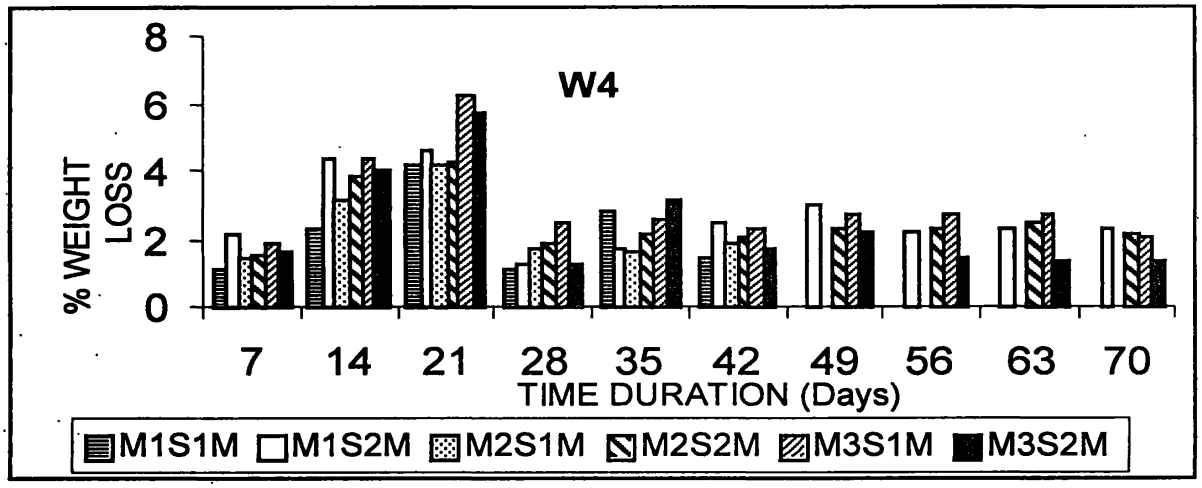

Figure 4.18. Effect of maturity stage and fruit size on Percentage weight loss(%wt. Loss) of lime for MA storage fruits

- M1S1M = Lower mature, small size, MA storage fruits
- M1S2M = Lower mature, large size, MA storage fruits
- M2S1M = Full mature, small size, MA storage fruits
- M2S2M = Full mature, large size, MA storage fruits
- M3S1M = Over mature, small size, MA storage fruits
- M3S2M = Over mature, large size, MA storage fruits

Percentage juice volume (% juice volume)

There was a significant difference in percentage juice volume in between maturity stage of the fruit, size of the fruit with time at 5% significant level (Appendix 13). Large size fruit had high percentage juice volume than the small size fruits did (appendix14).

In large fruits percentage juice volume may vary from (40-60)%. The percentage juice volume (45 –58)% is good quality standards of acid lime (Rajput & Haribady, 1995). Larger fruits have higher juice development than the small fruits with the maturity stage. So juice vesicles of larger fruits have high juice content than these in smaller fruits.

The juice of the fruits tends to increase throughout the fruit development period. During fruit development at colour break stage as well as full maturity stage, fruits have high juice content than in the lower maturity stages.

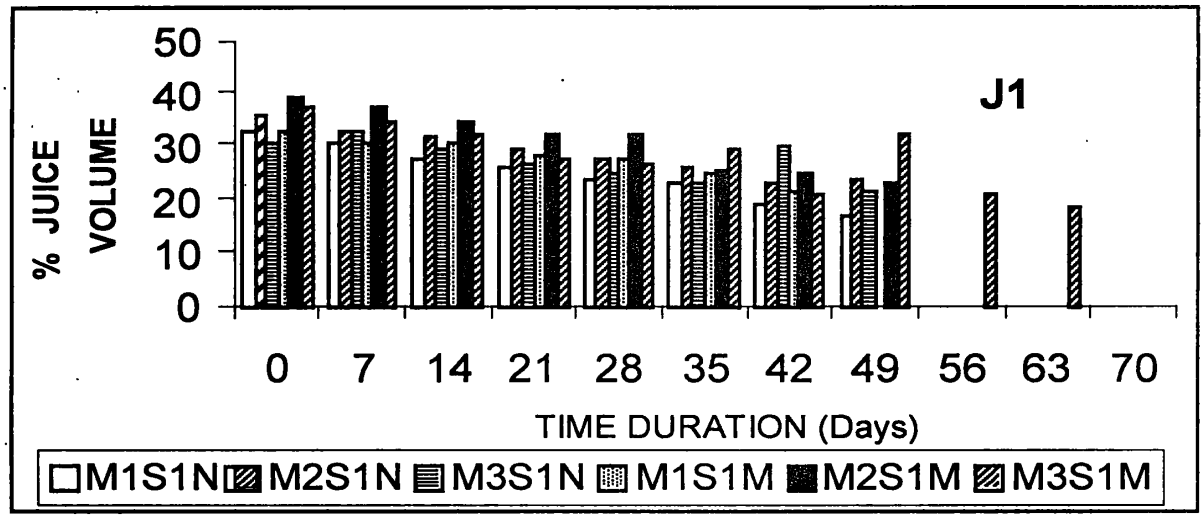

Figure 4.19. Effect of maturity stage and storage condition on Percentage juice volume (%juice volume) of lime for small size fruits

- M1S1N = Lower mature, small size, normal atmosphere storage fruits
- M2S1N= Full mature, small size, normal atmosphere storage fruits
- M3S1N = Over mature, small size, normal atmosphere storage fruits
- M1S1M = Lower mature, small size, MA storage fruits
- M2S1M = Full mature, small size, MA storage fruits
- M3S1M = Over mature, small size, MA storage fruits

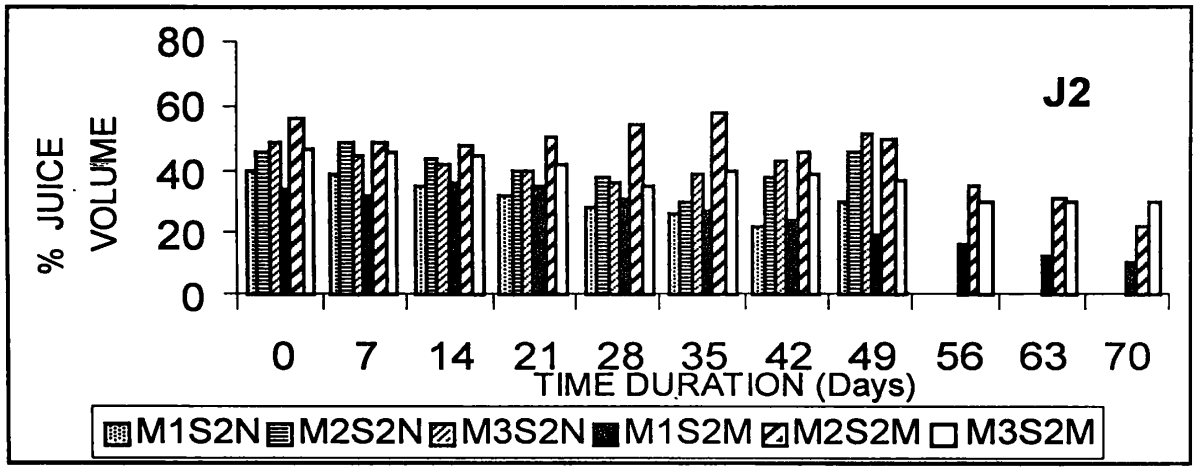

Figure 4.20. Effect of maturity stage and storage condition on Percentage juice volume (%juice volume) of lime for large size fruits

- M1S2N = Lower mature, large size, normal atmosphere storage fruits
- M2S2N = Full mature, large size, normal atmosphere storage fruits
- M3S2N = Over mature, large size, normal atmosphere storage fruits
- M1S2M = Lower mature, large size, MA storage fruits
- M2S2M = Full mature, large size, MA storage fruits
- M3S2M = Over mature, large size, MA storage fruits

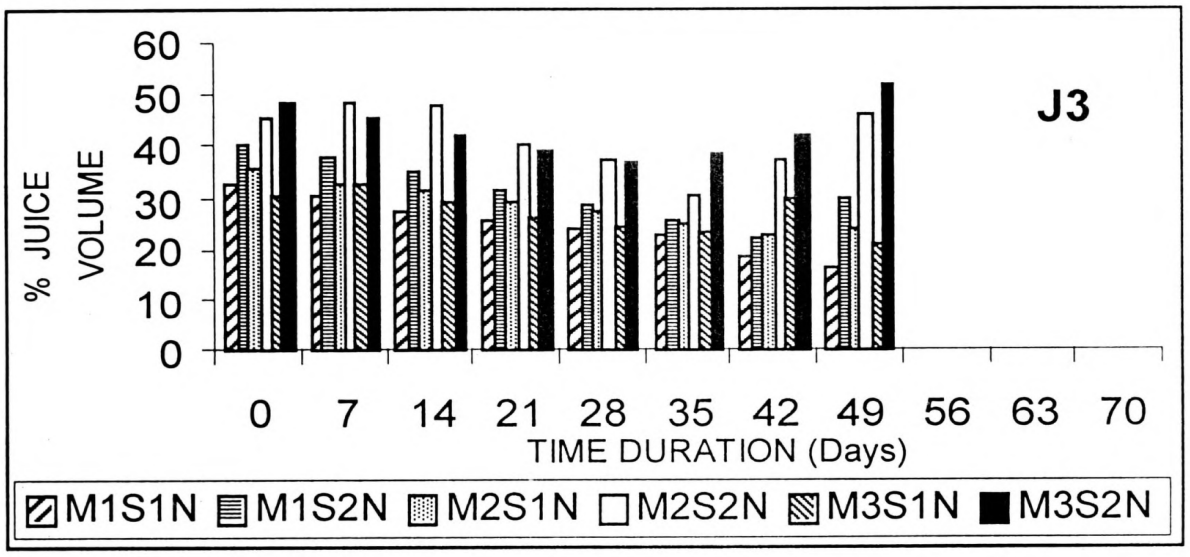

Figure 4.21. Effect of maturity stage and fruit size on Percentage juice volume (%juice volume) of lime for normal atmosphere storage fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits
M1S2N = Lower mature, large size, normal atmosphere storage fruits
M2S1N = Full mature, small size, normal atmosphere storage fruits
M2S2M = full mature, large size, MA storage fruits
M3S1M = Over mature, large size, MA storage fruits
M3S2M = Over mature, large size, MA storage fruits

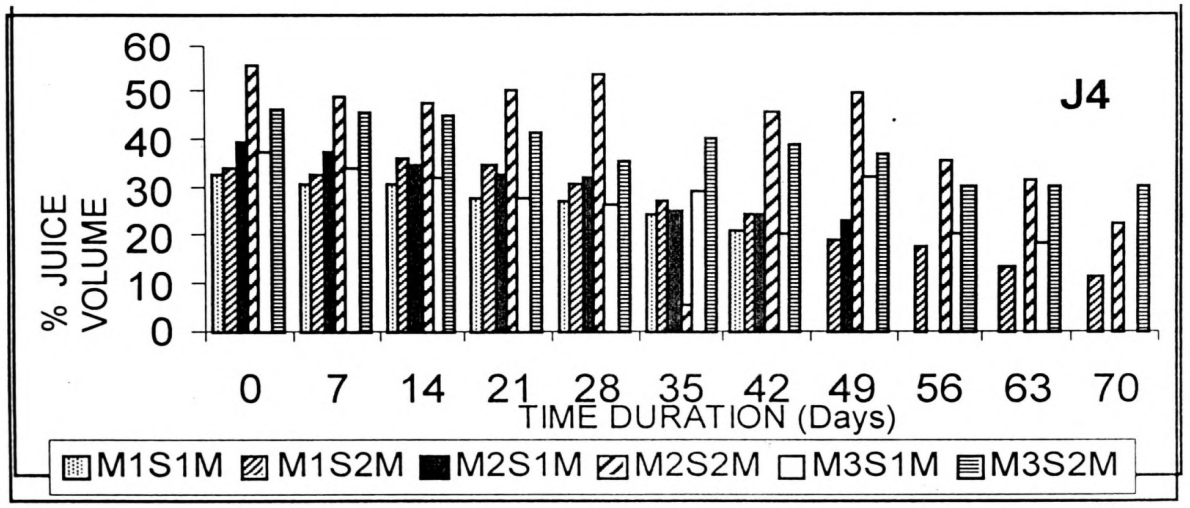

Figure 4.22. Effect of maturity stage and fruit size on Percentage juice volume (%juice volume) of lime for MA storage fruits.

M1S1M Lower mature, small size, MA storage fruits

M1S2M Lower mature large size, MA storage fruits

M2S1M Full mature, small size, MA storage fruits

M2S2M Full mature, large size, MA storage fruits

M3S1M Over mature, small size, MA storage fruits

M3S2M Over mature, large size, MA storage fruits

pH value

There was a significant difference in pH value of the juice only with time at 5% significant level (Appendix 15). During the storage period there was a slight increase in pH value after 35 days. pH value of the lime juice was 2.4 ± 1.

High acid content desirable for lime juice. pH measurement is one of the basic ways to measure acidity. But pH measurement only gives the value for free hydrogen in the solution of limejuice. The flavour of citrus juices is more attractive with pH measurements.

Due to respiration, Total Soluble Solid (TSS) content slightly increases leading to a slight decrease of the acidity of the lime juice during the storage period. This is the reason for slight increase of pH value after 35 days of the storage period.

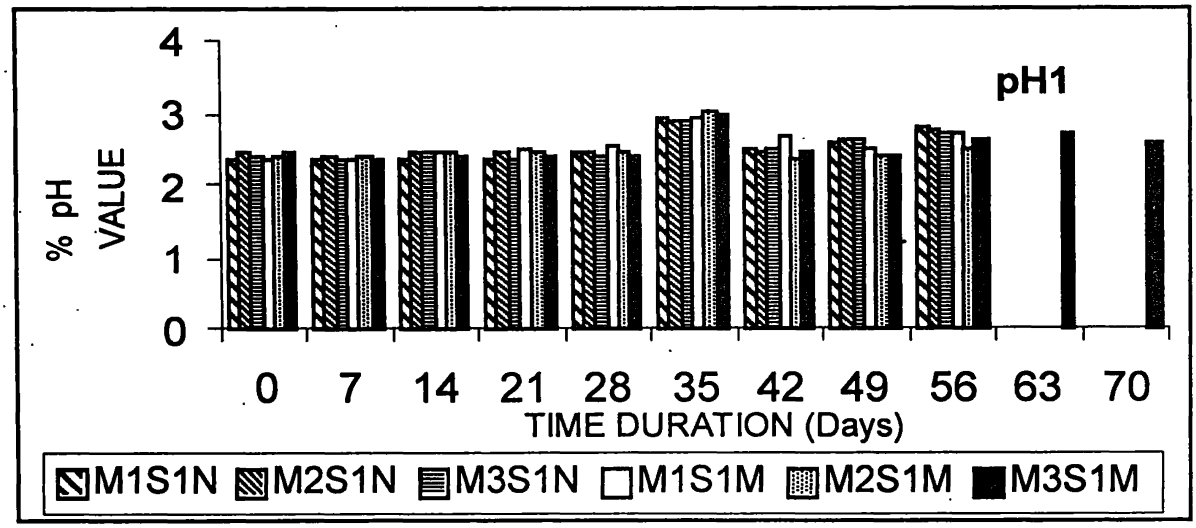

Figure 4.23. Effect of maturity stage and storage condition on pH value of lime for small size fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M1S1M = Lower mature, small size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M3S1M = Over mature, small size, MA storage fruits

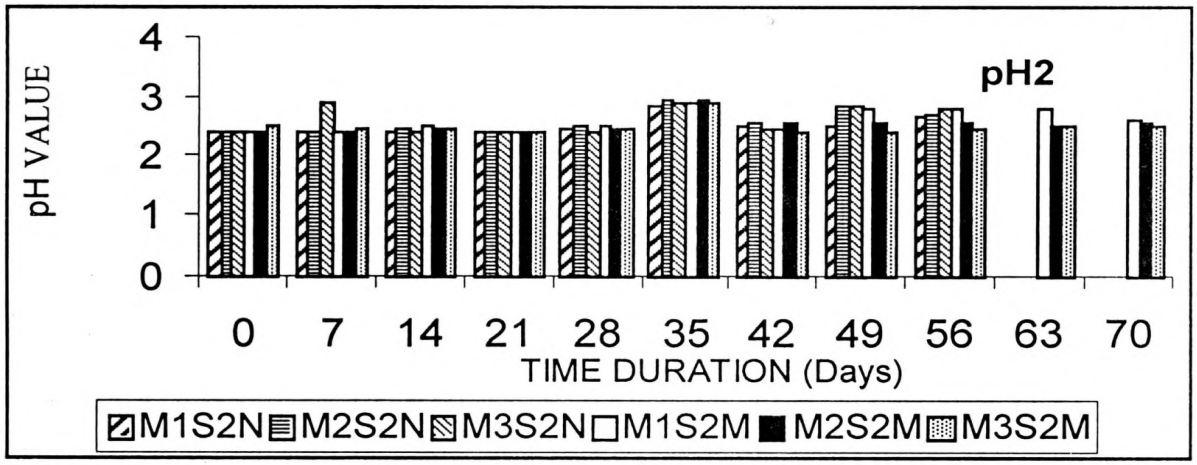

Figure 4.24. Effect of maturity stage and storage condition on pH value of lime for large size fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

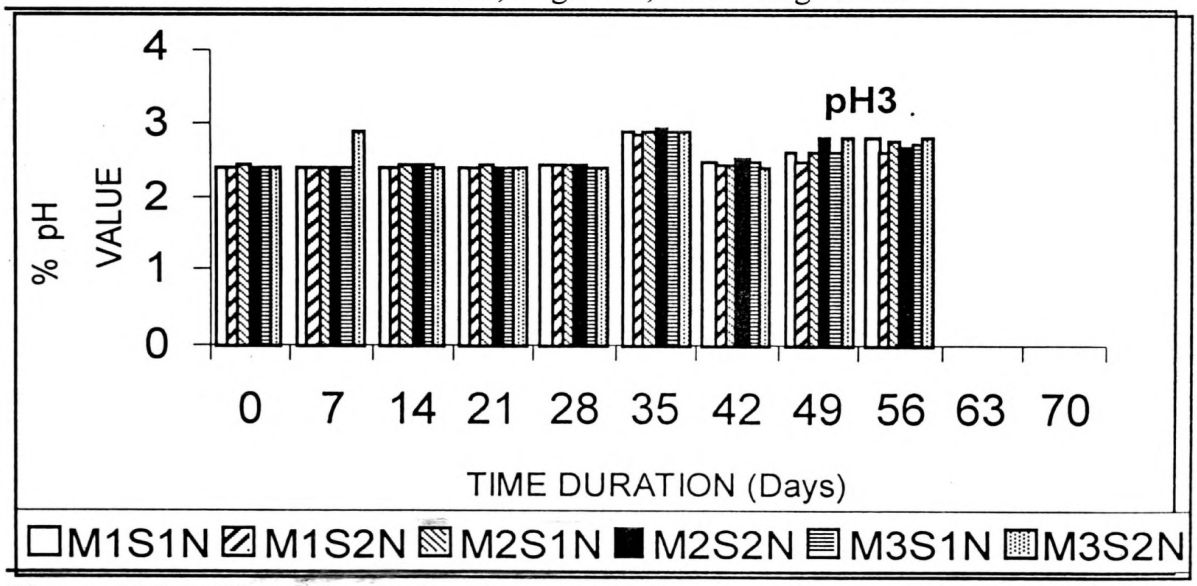

Figure 4.25. Effect of maturity stage and fruit size on pH value of lime for normal atmosphere storage fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

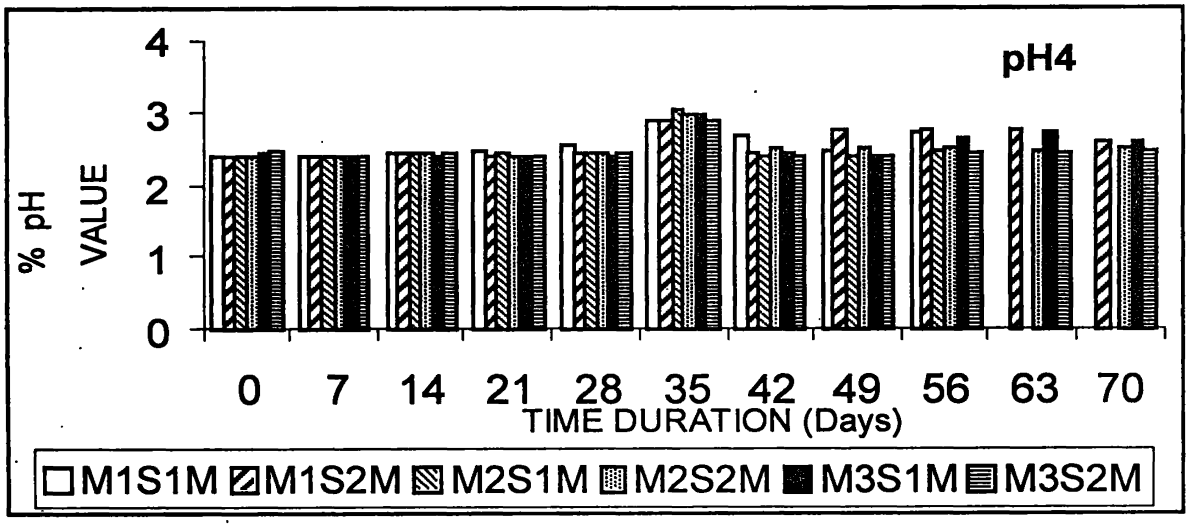

Figure 4.26. Effect of maturity stage and fruit size on pH value of lime for MA storage fruits

M1S1M = Lower mature, small size, MA storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S1M = Over mature, small size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

Percentage Titrable Acidity (% TA)

There was a significant difference in percentage titrable acidity in among samples with different maturity stage and storage conditions with time at 5% significant level (Appendix 16). According to the fruit size there is no clear difference in %TA.

Fruits in Modified Atmosphere (MA) storage fruits have higher acidity content than those kept in ordinary cold storage conditions (Appendix 17). At time of fruit

harvesting (initial stage of the storage) fruits had a higher acidity content of lime juice than in later stages of the storage period.

Acidity is an important factor of internal quality of citrus fruits. Acid content in the juice tends to decrease after reaching full size of the fruit (Murata, 1997). According to figure4.27 large fruits have high juice content than the smaller fruits. Acid titration with standards NaOH also is one basic way measures the acidity of limejuice. Acid titration measures the total number of acid hydrogens whether they are free or undissociated.

Fruits keep in Modified Atmosphere storage conditions has lower respiration rate and less senescence than of ordinary cold storage condition. That was the reason for high acid content in MA storage condition lime fruits than the ordinary cold storage condition fruits.

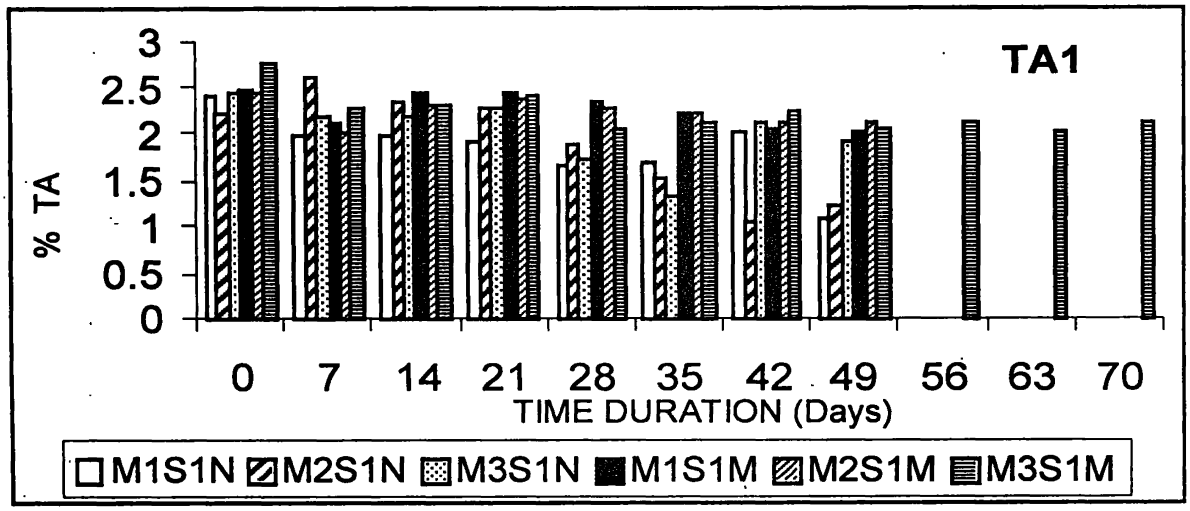

Figure 4.27. Effect of maturity stage and storage condition on Titrable Acidity (%TA) of lime for small size fruits

- M1S1N = Lower mature, small size, normal atmosphere storage fruits
- M2S1N = Full mature, small size, normal atmosphere storage fruits
- M3S1N = Over mature, small size, normal atmosphere storage fruits
- M1S1M = Lower mature, small size, MA storage fruits
- M2S1M = Full mature, small size, MA storage fruits
- M3S1M = Over mature, small size, MA storage fruits

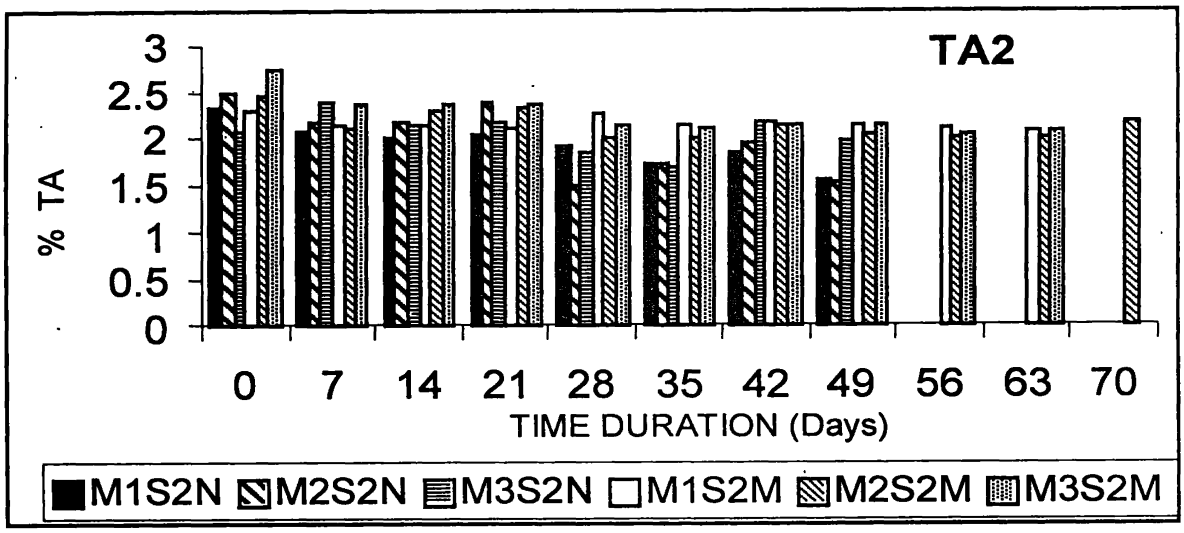

Figure 4.28. Effect of maturity stage and storage condition on Titrable Acidity (%TA) of lime for large size fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

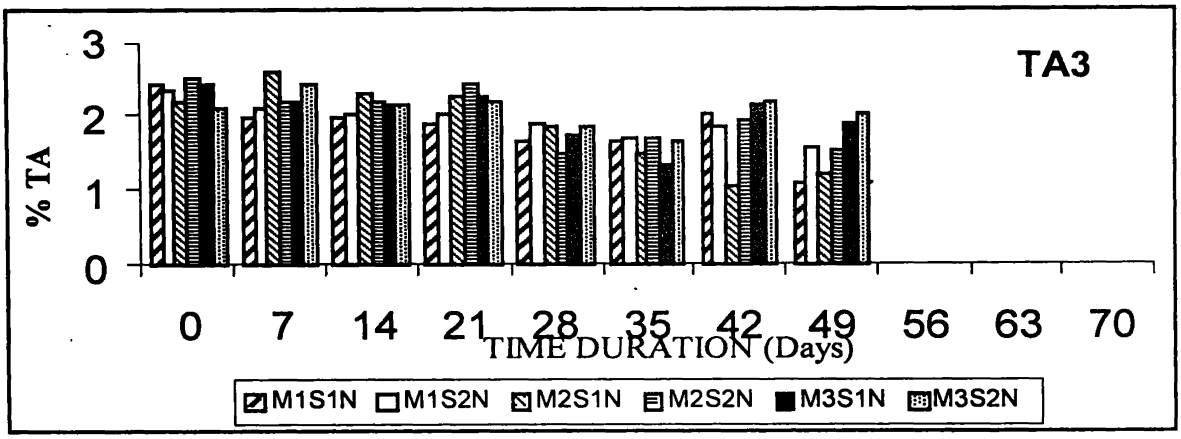

Figure 4.29. Effect of maturity stage and fruit size on Titrable Acidity (%TA) of lime for normal atmosphere storage fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M2S1N = Full mature, large size, normal atmosphere storage fruits

■ M3S1N = Over mature, small size, normal atmosphere storage fruits

▨ M3S2N = Over mature, large size, normal atmosphere storage fruits

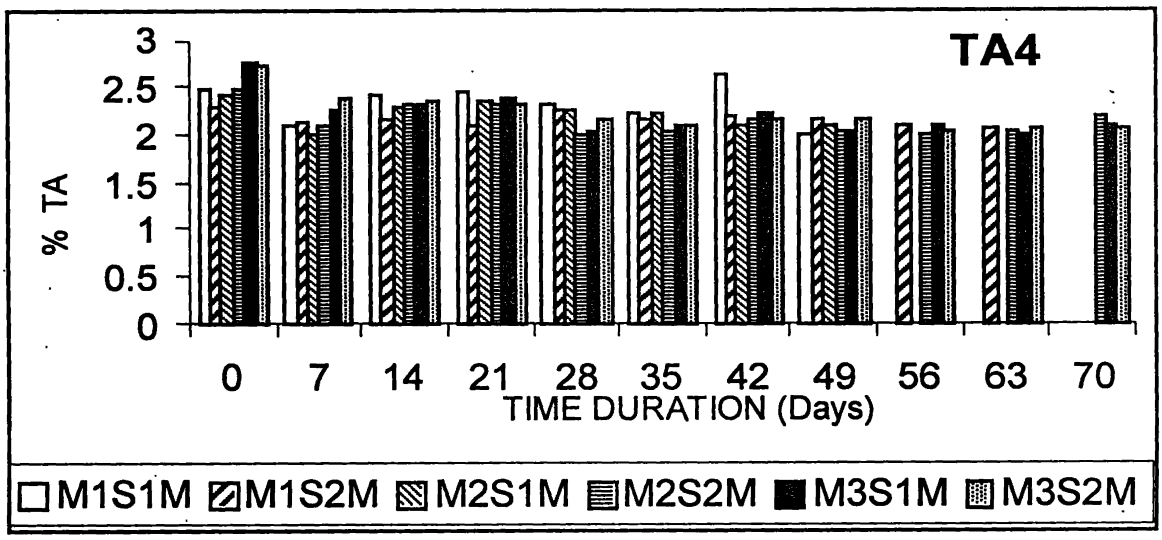

Figure 4.30. Effect of maturity stage and fruit size on Titrable Acidity (%TA) of lime for MA storage fruits

□ M1S1M = Lower mature, small size, MA storage fruits

▨ M1S2M = Lower mature, large size, MA storage fruits

▨ M2S1M = Full mature, small size, MA storage fruits

▤ M2S1M = Full mature, large size, MA storage fruits

■ M3S1M = Over mature, small size, MA storage fruits

▩ M3S2M = Over mature, large size, MA storage fruits

Total Soluble Solids (TSS)

There was a significant difference in TSS in between maturity stage of the fruit, size of the fruit and storage condition with time at 5% significant level (Appendix18). Larger fruit have high TSS content than the small fruit (Appendix19). Total Soluble Solid (TSS), include carbohydrate, organic acids, proteins, fats and various minerals. Amount of carbohydrate included in the juice is directly affects TSS. The major groups of carbohydrate in citrus fruits include monosaccharide (glucose, fructose). As the fruits matures, and starch is converted to sucrose, fructose and glucose. Total soluble solids level increase as the fruit size increases, becoming constant or increasing slightly during the storage.

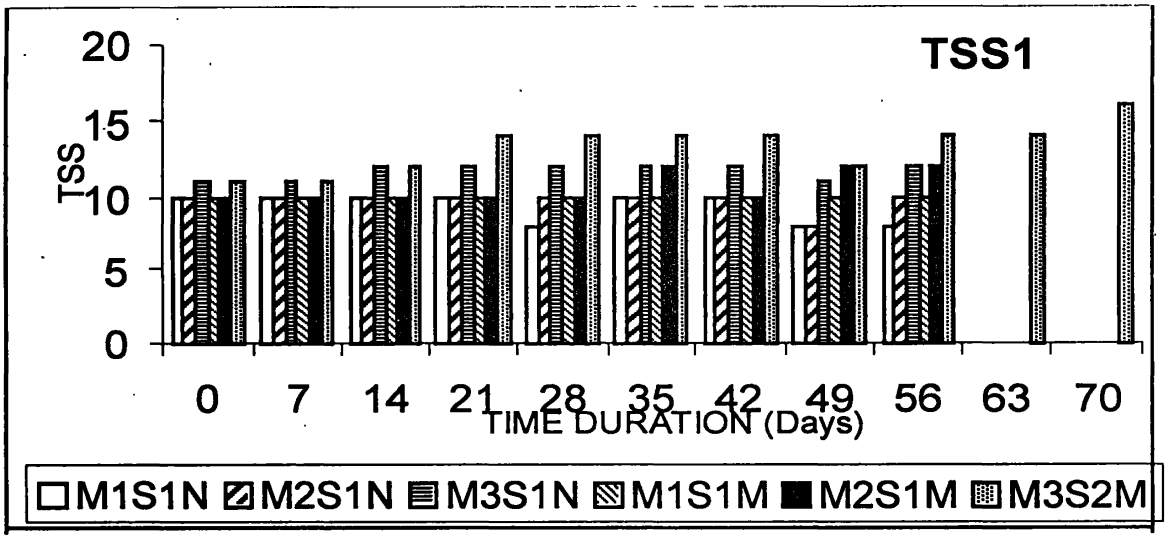

Figure 4.31. Effect of maturity stage and storage condition on Total Soluble Solid(TSS) of lime for small size fruits

- M1S2N = Lower mature, large size, normal atmosphere storage fruits
- M2S2N = Full mature, large size, normal atmosphere storage fruits
- M3S2N = Over mature, large size, normal atmosphere storage fruits
- M1S2M = Lower mature, large size, MA storage fruits
- M2S2M = Full mature, large size, MA storage fruits
- M3S2M = Over mature, large size, MA storage fruits

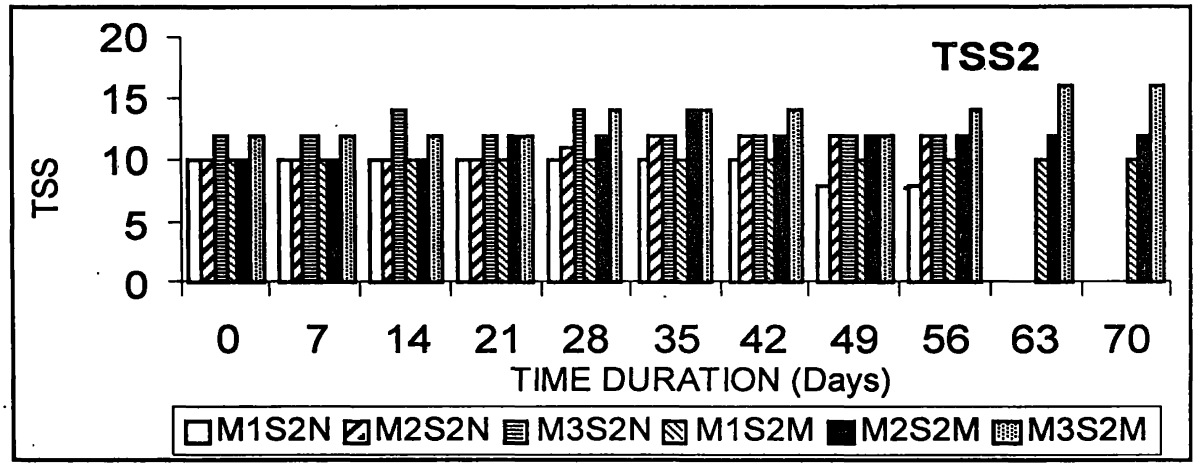

Figure 4.32. Effect of maturity stage and storage condition on Total Soluble Solid(TSS) of lime for large size fruits

- M1S2N = Lower mature, large size normal atmosphere storage fruits
- M2S2N = Full mature, large size, normal atmosphere storage fruits
- M3S2N = Over mature, large size, normal atmosphere storage fruits
- M1S2M = Lower mature, large size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

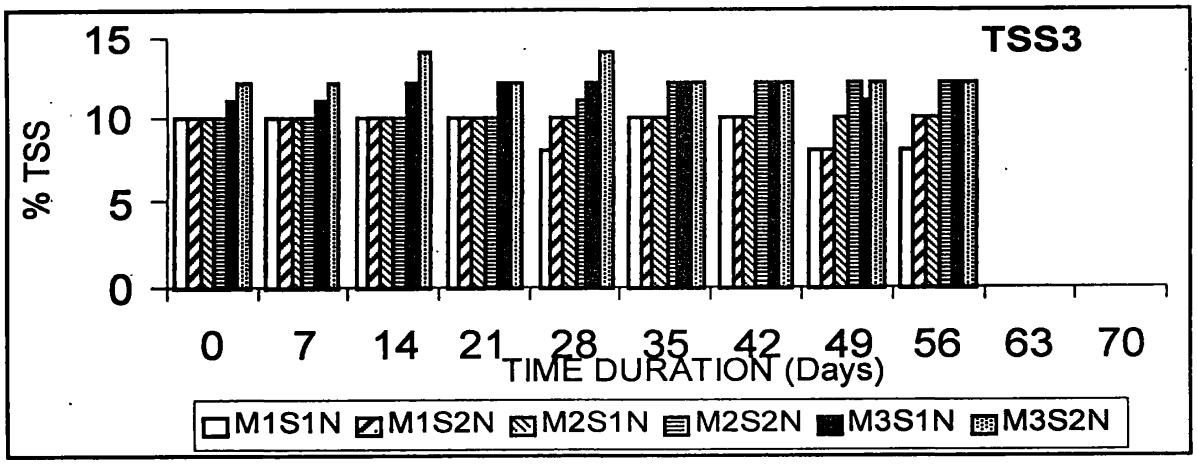

Figure 4.33. Effect of maturity stage and fruit size on Total Soluble Solid(TSS) of lime for normal atmosphere storage fruits

M1S1N = Lower mature, small size, normal atmosphere storage fruits

M1S2N = Lower mature, large size, normal atmosphere storage fruits

M2S1N = Full mature, small size, normal atmosphere storage fruits

M2S2N = Full mature, large size, normal atmosphere storage fruits

M3S1N = Over mature, small size, normal atmosphere storage fruits

M3S2N = Over mature, large size, normal atmosphere storage fruits

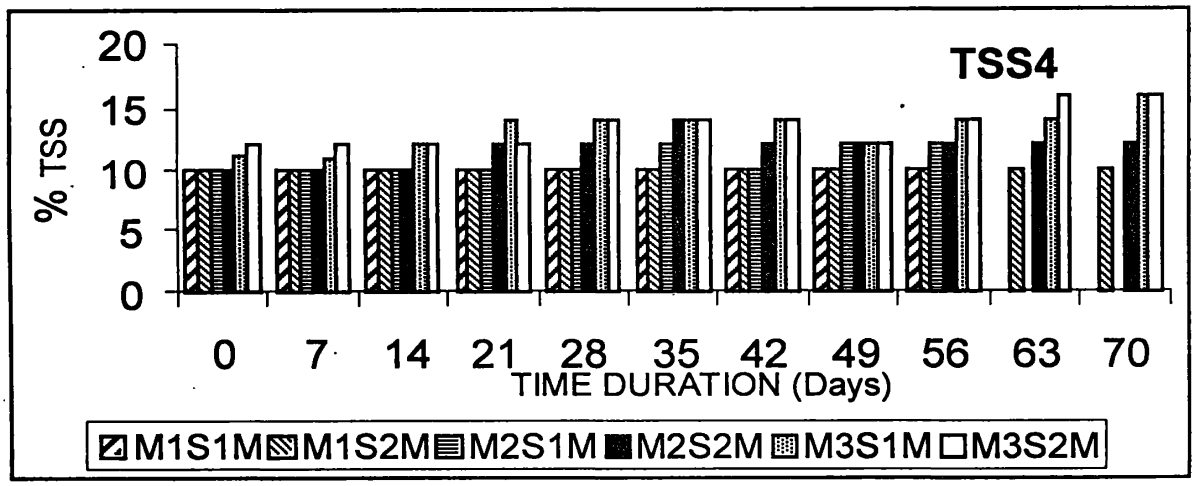

Figure 4.34. Effect of maturity stage and fruit size on Total Soluble Solid(TSS) of lime for MA storage fruits

M1S1M = Lower mature, small size, MA storage fruits

M1S2M = Lower mature, large size, MA storage fruits

M2S1M = Full mature, small size, MA storage fruits

M2S2M = Full mature, large size, MA storage fruits

M3S1M = Over mature, small size, MA storage fruits

M3S2M = Over mature, large size, MA storage fruits

4.2 Experiment 02

Effect of drying temperature and pretreatments on dehydration of lime fruits.

Drying Time

There was a significant difference in drying time among treatments at 5% significant level.

Table 4.1. Drying time of the samples.

Treatment Number	Drying Time (days)
1	3.5
1	3.75
1	3.25
2	3.75
2	4.00
2	4.00
3	3.00
3	3.00
3	2.75
4	3.25
4	3.50
4	3.50
5	7.50
5	7.00
5	6.25
6	9.00
6	8.50
6	8.75

7	6.75
7	7.00
7	7.25
8	8.00
8	8.50
8	7.50

Percentage Weight Loss (%wt. Loss)

There was a significant difference in percentage weight loss among treatments at 5% significant level.

Table 4.2. Percentage weight loss of the sample

Treatment number	% wt. loss
1	83.47
1	82.18
1	84.52
2	82.11
2	84.21
2	83.71
3	83.48
3	83.21
3	84.78
4	83.32
4	83.78
4	84.27
5	84.31
5	84.28
5	84.44
6	83.21
6	82.31
6	83.37
7	78.57
7	80.01

7	77.18
8	84.35
8	84.85
8	82.44

Moisture content of the lime product

There was a significant difference in % moisture content among treatments at 5% significant level.

Table 4.3. Percentage Moisture content of the dried product.

Treatment number	Moisture content %
1	10.2
1	9.78
1	10.34
2	10.52
2	9.91
2	10.57
3	9.72
3	9.64
3	10.03
4	11.02
4	10.74
4	10.84
5	8.45
5	9.01
5	9.11
6	12.34
6	13.32
6	13.64
7	9.41
7	8.52
7	8.94
8	11.31

8	10.48
8	10.27

There are several factors to affect drying time of the food material. Physical structure or high sugar content of the product makes difficulties in removing moisture from the product. Hence, whole lime fruits get more time to dehydrate compared with the lime pieces. Rapid flows of hot air through the product encourage the rapid drying. A high total volume of airflow is most suitable for rapid drying. Temperature gradient between the product and air is high. Therefore drying rate also high. Low relative humidity and low-pressure condition also increase the drying rate.

During dehydration, heat and removal of moisture are very important. Under mass transfer, water is migrated to the surface of foodstuff and gets heated. Then the water vapor is removed from the surface.

During drying process, surface water is firstly removed very easily. But after some time, heat-drying layer is developed around the surface of the foodstuff. It delays water vapor migration through the surface area, making difficult in transferring interior moisture to outer environment. Under high temperature conditions this process may occur rapidly causing case hardening. Case hardening give bad appearance to the food product, changing their uniform structure due to shrinkage. Hence high temperature conditions are undesirable as they damage the external appearance. Therefore, gradual increases of temperature most desirable condition to dehydration of food product as it promote a moisture migration through fruit peel regularly.

When the fruit is blanched the juice vesicles of lime fruits get ruptured and the cells may become still more permeable to moisture migration. But if blanch time is longer, some fractures can be created in the fruit peel, giving bad appearance to the fruit. Temperature of fruits with a brine solution may enhance the dehydration process by promoting osmotic dehydration.

Less percentage weight loss is desirable for market profitability according to results approximately 80% of weight loss occurred during dehydration. So, 15%-20% yields give from 100kg of raw lime fruits.

CHAPTER 05

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results obtained by these experiments the following conclusions can be made. Regarding the Modified Atmosphere storage (MA) at 10^0C and ordinary cold storage at 10^0C, the samples in MA storage conditions with low density polyethylene film and 85-90% RH had higher storage life span than samples of ordinary cold storage conditions with super external and internal quality characters.

The storage life of fully matured large sized lime fruits could be extended under MA storage conditions up to at least two and half months than fruits of lower maturity and color break stage. These fruits had better appearance, higher juice volume, less weight loss, high acid content than fruits of other stages.

Fruits kept in ordinary cold storage at 10^0C and 85-90 RH, fruits can be stored more than one month. But after 28 days time their external appearance turned out to non-attractive form (brown color) but with a good internal quality.

Fruits kept in MA condition had higher storage life may be good solution to minimize high post harvest losses during its season as they have short storage life at ambient condition due to perishability. Therefore by MA storage, regular supply of fruit through out the year with higher quality characters can be achieved.

Based on the results obtained by dehydration experiments, the following conclusions can be made. Dehydration of lime fruits under gradually increasing temperature from 45^0C to 55^0C with pretreatment of brine solution is more successful than the other treatments. It gives more attractive uniformly distributed smooth appearance. Brine treatment possibly enhances the porosity of the fruit skin promoting moisture migration thereby creating a good appearance.

5.2 Recommendation for further studies

Further studies should be carried out to find out,

- Recommend for optimal surface area to sample weight ratio at Modified Atmosphere (MA) storage conditions.

- The most suitable gas concentration and gas production ratio at MA storage conditions.

- Sensory evaluation should be carried out to determine best treatment system improving visual and gustatory qualities of the best sample.

- Shelf life should be further evaluated.

- Suitable packing material for prolonging shelf- life of dehydrated lime.

- Best parameters for brine treatment and about the temperature for dehydration.

- Experiment should be done with a solar-powered dryer as the drying temperature is achievable by a dryer of this nature which is cost effective.

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Appendix

Appendix 1

The SAS system for analysis of peel colour

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: PEELCO

Source	DF	Sum of Squares	Mean Square	F Value	pr > F
Model	14	175.9500760	12.5678626	98.75	0.0001
Error	72	9.1637171	0.1272738		
Corrected Total	86	185.1137931			

R-Square	C.V.	Root MSE	PEELCO Mean
0.950497	13.07950	0.356755	2.727586

Analysis of Variance Procedure

Dependent Variable: PEELCO

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	77.14779310	38.57389655	303.08	0.0001
SIZE	1	2.41200625	2.41200625	18.95	0.0001
STORAGE	1	4.49112644	4.49112644	35.29	0.0001
TIME	10	91.89915025	9.18991502	72.21	0.0001

Appendix 2

The Least Significant Difference (LSD) test for analysis of peel colcour according to fruit size

Analysis of Variance Procedure

T tests (LSD) for variable: PEELCO

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 72 MSE= 0.127274

Critical Value of T= 1.99

Least Significant Difference= 0.1527

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 43.35632

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	SIZE
A	2.88478	46	2
B	2.55122	41	1

Appendix 3

The Least Significant Difference (LSD) test for analysis of peel colcour according to storage condition

Analysis of Variance Procedure

T tests (LSD) for variable: PEELCO

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 72 MSE= 0.127274

Critical Value of T= 1.99

Least Significant Difference= 0.1648

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 37.24138

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	2.88000	60	M
B	2.38889	27	N

Appendix 4

The SAS system for analysis of brown colour index

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: BROWNIN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	184.9071245	13.2076518	20.35	0.0001
Error	113	73.3350630	0.6489829		
Corrected Total	127	258.2421875			

R-Square	C.V.	Root MSE	BROWNIN Mean
0.716022	92.89741	0.805595	0.867188

Analysis of Variance Procedure

Dependent Variable: BROWNIN

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	1.62205763	0.81102881	1.25	0.2905
SIZE	1	0.00220705	0.00220705	0.00	0.9536
STORAGE	1	90.42400568	90.42400568	139.33	0.0001
TIME	10	92.85885417	9.28588542	14.31	0.0001

Appendix 5

The Least Significant Difference (LSD) test for analysis of brown colour according to fruit size

Analysis of Variance Procedure

T tests (LSD) for variable: BROWNIN

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 113 MSE= 0.648983

Critical Value of T= 1.98

Least Significant Difference 0.2823

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes 63.9375

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	1.6818	66	N
B	0.0000	62	M

Appendix 6

The SAS system for analysis of Visual Quality Rating (VQR)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: VQRVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	894.2498918	63.8749923	22.84	0.0001
Error	110	307.5621082	2.7960192		
Corrected Total	124	1201.8120000			

R-Square	C.V.	Root MSE	VQRVA Mean
0.744085	23.07023	1.672130	7.248000

Analysis of Variance Procedure

Dependent Variable: VQRVA

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	1.0057916	0.5028958	0.18	0.8356
SIZE	1	0.7632821	0.7632821	0.27	0.6024
STORAGE	1	342.9938182	342.9938182	122.67	0.0001
TIME	10	549.4870000	54.9487000	19.65	0.0001

Appendix 7

The Least Significant Difference (LSD) test for analysis of VQR according to Storage method

Analysis of Variance Procedure

T tests (LSD) for variable: VQRVA

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 110 MSE= 2.796019

Critical Value of T= 1.98

Least Significant Difference 0.5937

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 62.304

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	9.0000	59	M
B	5.6818	66	N

Appendix 8

The SAS system for analysis sensory firmness.

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: FIRMVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	124.5906381	8.8993313	21.76	0.0001
Error	111	45.3954730	0.4089682		
Corrected Total	125	169.9861111			

R-Square	C.V.	Root MSE	FIRMVA Mean
0.732946	19.34641	0.639506	3.305556

Analysis of Variance Procedure

Dependent Variable: FIRMVA

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	0.97169869	0.48584935	1.19	0.3087
SIZE	1	0.25542929	0.25542929	0.62	0.4310
STORAGE	1	55.23989899	55.23989899	135.07	0.0001
TIME	10	68.12361111	6.81236111	16.66	0.0001

Appendix 9

The Least Significant Difference (LSD) test for analysis of sensory firmness according to storage method

Analysis of Variance Procedure

T tests (LSD) for variable: FIRMVA

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 111 MSE= 0.408968

Critical Value of T= 1.98

Least Significant Difference= 0.226

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 62.85714

Means with the same letter are not significantly different.

The SAS System

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	4.0000	60	M
B	2.6742	66	N

Appendix 10

The SAS system for analysis of percentage weight loss(% wt.loss)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	10	7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 120

Analysis of Variance Procedure

Dependent Variable: WTLOSS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	12891.38658	991.64512	56.58	0.0001
Error	93	1630.00713	17.52696		
Corrected Total	106	14521.39372			

R-Square	C.V.	Root MSE	WTLOSS Mean
0.887751	35.59260	4.186521	11.76234

Analysis of Variance Procedure

Dependent Variable: WTLOSS

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	12.335570	6.167785	0.35	0.7043
SIZE	1	273.513209	273.513209	15.61	0.0002
STORAGE	1	9043.432188	9043.432188	515.97	0.0001
TIME	9	3562.105614	395.789513	22.58	0.0001

Appendix 11

The Least Significant Difference (LSD) test for analysis of percentage weight loss (% wt.loss) according to fruit size

Analysis of Variance Procedure

T tests (LSD) for variable: WTLOSS

NOTE: This test controls the type I comparison wise error rate not the experiment wise error rate.

Alpha 0.05 df= 93 MSE= 17.52696

Critical Value of T= 1.99

Least Significant Difference= 1.6109

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 53.27103

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	SIZE
A	13.4694	50	1
B	10.2649	57	2

Appendix 12

The Least Significant Difference (LSD) test for analysis of percentage weight loss (%wt.loss) according to storage method

T tests (LSD) for variable: WTLOSS

NOTE: This test controls the type I comparison wise error rate not the experiment wise error rate.

Alpha 0.05 df= 93 MSE= 17.52696

Critical Value of T= 1.99

Least Significant Difference 1.6075

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 53.49533

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	20.8702	54	N
B	2.4826	53	M

Appendix 1

The SAS system for analysis of percentage juice volume (% juice volume)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: JUICEVO

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	6175.305930	441.093281	11.69	0.0001
Error	91	3433.418296	37.729871		
Corrected Total	105	9608.724226			

R-Square	C.V.	Root MSE	JUICEVO Mean
0.642677	18.72961	6.142465	32.79547

Analysis of Variance Procedure

Dependent Variable: JUICEVO

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	1786.917022	893.458511	23.68	0.0001
SIZE	1	2110.339929	2110.339929	55.93	0.0001
STORAGE	1	12.394724	12.394724	0.33	0.5680
TIME	10	2265.654254	226.565425	6.00	0.0001

Appendix 14

The Least Significant Difference (LSD) test for analysis of percentage juice volume according to fruit size

Analysis of Variance Procedure

T tests (LSD) for variable: JUICEVO

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 91 MSE= 37.72987

Critical Value of T= 1.99

Least Significant Difference= 2.377

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 52.69811

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	SIZE
A	36.932	57	2
B	27.983	49	1

Appendix 15

The SAS system for analysis of pH value

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: PHVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	2.69060048	0.19218575	24.19	0.0001

Error	101	0.80227107	0.00794328
Corrected Total	115	3.49287155	

R-Square	C.V.	Root MSE	PHVA Mean
0.770312	3.512557	0.089125	2.537328

Analysis of Variance Procedure

Dependent Variable: PHVA

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	0.00571050	0.00285525	0.36	0.6989
SIZE	1	0.00001429	0.00001429	0.00	0.9663
STORAGE	1	0.01064581	0.01064581	1.34	0.2497
TIME	10	2.67422989	0.26742299	33.67	0.0001

Appendix 16

The SAS system for analysis of Titrable Acidity(% TA)

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2
STORAGE	2	M N
TIME	11	0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: TAVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	5.72598099	0.40899864	9.92	0.0001
Error	92	3.79231060	0.04122077		
Corrected Total	106	9.51829159			

R-Square	C.V.	Root MSE	TAVA Mean
0.601577	9.715609	0.203029	2.089720

Analysis of Variance Procedure

Dependent Variable: TAVA

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	0.17622243	0.08811122	2.14	0.1238
SIZE	1	0.02083315	0.02083315	0.51	0.4789
STORAGE	1	1.67915882	1.67915882	40.74	0.0001
TIME	10	3.84976659	0.38497666	9.34	0.0001

Appendix 17

The Least Significant Difference (LSD) test for analysis of Titrable Acidity according to storage method

Analysis of Variance Procedure

T tests (LSD) for variable: TAVA

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 92 MSE= 0.041221

Critical Value of T= 1.99

Least Significant Difference= 0.0784

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 52.93458

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	2.20271	59	M
B	1.95083	48	N

Appendix 18

The SAS system for analysis of Total Soluble Solid

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
MATU	3	1 2 3
SIZE	2	1 2

STORAGE 2 M N

TIME 11 0 7 14 21 28 35 42 49 56 63 70

Number of observations in data set = 132

Analysis of Variance Procedure

Dependent Variable: TSSVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	261.9143969	18.7081712	35.90	0.0001
Error	101	52.6373272	0.5211617		
Corrected Total	115	314.5517241			

R-Square	C.V.	Root MSE	TSSVA Mean
0.832659	6.461587	0.721915	11.17241

Analysis of Variance Procedure

Dependent Variable: TSSVA

Source	DF	Anova SS	Mean Square	F Value	Pr > F
MATU	2	178.9188294	89.4594147	171.65	0.0001
SIZE	1	7.4148194	7.4148194	14.23	0.0003
STORAGE	1	22.1956907	22.1956907	42.59	0.0001
TIME	10	53.3850575	5.3385057	10.24	0.0001

Appendix 19

The Least Significant Difference (LSD) test for analysis of Total Soluble Solid according to fruit size

Analysis of Variance Procedure

T tests (LSD) for variable: TSSVA

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 101 MSE= 0.521162

Critical Value of T= 1.98

Least Significant Difference= 0.2661

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 57.93103

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	SIZE
A	11.4167	60	2
B	10.9107	56	1

Appendix 20

The Least Significant Difference (LSD) test for analysis of Total Soluble Solid according to storage method

Analysis of Variance Procedure

T tests (LSD) for variable: TSSVA

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 101 MSE= 0.521162

Critical Value of T= 1.98

Least Significant Difference= 0.2666

WARNING: Cell sizes are not equal.

Harmonic Mean of cell sizes= 57.72414

Means with the same letter are not significantly different.

Analysis of Variance Procedure

T Grouping	Mean	N	STORAGE
A	11.5806	62	M
B	10.7037	54	N

Appendix 21

The SAS System (one –way) ANOVA for analysis of drying time of the treatment combination of the sample

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
TREAT	8	1 2 3 4 5 6 7 8

Number of observations in data set = 24

Analysis of Variance Procedure

Dependent Variable: DRYT

	Sum of	Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	7	113.2682292	16.1811756	200.44	0.0001
Error	16	1.2916667	0.0807292		
Corrected Total	23	114.5598958			

R-Square	C.V.	Root MSE	DRYT Mean
0.988725	5.156212	0.284129	5.510417

Analysis of Variance Procedure

Dependent Variable: DRYT

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREAT	7	113.2682292	16.1811756	200.44	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: DRYT

NOTE: This test controls the type I comparisson wise error rate not the experimen twise error rate.

Alpha= 0.05 df= 16 MSE= 0.080729

Critical Value of T= 2.12

Least Significant Difference= 0.4918

Means with the same letter are not significantly different.

T Grouping	Mean	N	TREAT
A	8.7500	3	6
B	8.0000	3	8

Analysis of Variance Procedure

T Grouping	Mean	N	TREAT
C	7.0000	3	7
C	6.5833	3	5
D	3.9167	3	2
D	3.5000	3	1
E	3.4167	3	4
F	2.9167	3	3

Appendix 22
The SAS System (one –way) ANOVA for analysis of percentage weight loss of the treatment combination of the sample

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
TREAT	8	1 2 3 4 5 6 7 8

Number of observations in data set = 24

Analysis of Variance Procedure

Dependent Variable: WEIGHT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	70.88386667	10.12626667	10.86	0.0001
Error	16	14.92253333	0.93265833		
Corrected Total	23	85.80640000			

R-Square	C.V.	Root MSE	WEIGHT Mean
0.826091	1.163335	0.965742	83.01500

Analysis of Variance Procedure

Dependent Variable: WEIGHT

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREAT	7	70.88386667	10.12626667	10.86	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: WEIGHT

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 16 MSE= 0.932658

Critical Value of T= 2.12

Least Significant Difference= 1.6716

Means with the same letter are not significantly different.

T Grouping	Mean	N	TREAT
A	84.3433	3	5

A	83.8800	3	8

analysis of Variance Procedure

T Grouping	Mean	N	TREAT
A	83.8233	3	3
A	83.7900	3	4
A	83.3900	3	1
A	83.3433	3	2
B	78.5867	3	7

Appendix 23

The SAS System (one –way) ANOVA for analysis of percentage moisture content of the dried product .

Analysis of Variance Procedure

Class Level Information

Class	Levels	Values
TREAT	8	1 2 3 4 5 6 7 8

Number of observations in data set = 24

Analysis of Variance Procedure

Dependent Variable: MOIST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	37.43612917	5.34801845	31.26	0.0001
Error	16	2.73706667	0.17106667		
Corrected Total	23	40.17319583			

R-Square	C.V.	Root MSE	MOIST Mean
0.931868	4.000826	0.413602	10.33792

The Analysis of Variance Procedure

Dependent Variable: MOIST

Source	DF	Anova SS	Mean Square	F Value	Pr > F
TREAT	7	37.43612917	5.34801845	31.26	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: MOIST

NOTE: This test controls the type I comparisson wise error rate not the experiment wise error rate.

Alpha= 0.05 df= 16 MSE= 0.171067

Critical Value of T= 2.12

Least Significant Difference= 0.7159

Means with the same letter are not significantly different.

T Grouping	Mean	N	TREAT
A	13.1000	3	6
B	10.8667	3	4

Analysis of Variance Procedure

T Grouping	Mean	N	TREAT
C B	10.6867	3	8
C B D	10.3333	3	2
C D	10.1067	3	1
D	9.7967	3	3
E	8.9567	3	7
E	8.8567	3	5

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