Effects of Ethrel, Packaging and Waxing on Quality and Shelf Life of Guava (*Psidium guajava* L.) Fruits

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B.Sc. (Hons.) in Agricultural Sciences (Horticultural Sciences)

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Department of Horticultural Sciences

Faculty of Agricultural Sciences

February, 2015
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Date: February/2015
Effects of Ethrel, Packaging and Waxing on Quality and Shelf Life of Guava (*Psidium guajava* L.) Fruits

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<th>Name</th>
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<td>Prof. Mohamed Elhaj Elkashif</td>
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</table>

Date of Examination: 15 /February/2015
DEDICATION

To

my parents
my brother and sister
my cousin Mosab
my friend Entisar
my teachers, friends and colleagues
with everlasting love

For their diligence and encouragement during all my life

Altaya
ACKNOWLEDGEMENTS

First of all, my full praise and thanks to “Allah” who gave me the health and patience to conduct this study.

I avail this opportunity to express my deepest thanks, appreciation and gratitude to my supervisor Prof. Mohamed Elhaj Elkashif who suggested the research topic. His critical guidance, continued interest, support and encouragement during the course of this study are highly appreciated. His insightful comment for the betterment of the whole work was appreciable.

I wish to express my deep sense of gratitude to my co-supervisor Prof. Osman Mohamed Elamin for his remarkable role in giving constructive comments from the very inception of the work and guiding me throughout the study.

Finally, I am so grateful to everyone who gave me some help during the course of this work.
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M.Sc. in Horticultural Sciences (Postharvest Physiology) (February, 2015)
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Abstract

Guava is one of the most popular fruits in the Sudan. It is usually harvested at the ripe stage which results in quick deterioration and huge post-harvest losses. Therefore, the objective of this research work was to effects of Ethrel, packaging and waxing on quality and shelf life of guava (*Psidium guajava* L.) fruits. Experiments were conducted at the University of Gezira, Wad Medani, Sudan, during December of 2013 and March of 2014. Guava fruits were harvested at the mature-green stage and treated with Ethrel or left as control. Fruits were packed in either intact or perforated polyethylene film, waxed or left unpackaged. The treatments were set up in a completely randomized design with two replicates. Ethrel treatment significantly accelerated the rate of fruit ripening as shown by an increase in total soluble solids, peel colour, vitamin C content, taste and a decrease in fruit firmness in both seasons. Packaging and waxing treatments had significant effects on weight loss, TSS, vitamin C content, firmness, taste and skin colour in both seasons. Packaging guava fruits in intact polyethylene film resulted in the lowest weight loss, followed by waxing, perforated polyethylene film and the highest weight loss was observed in the control treatment in both seasons. The highest vitamin C content, the best skin colour and the longest shelf life were recorded in fruits packaged in intact polyethylene film followed by perforated, waxing and control treatments in both seasons. However, the highest TSS content, the best taste and the shortest shelf life were recorded in the control fruits in both seasons. It could be recommended that, in order to prolong the shelf life and maintain the quality of guava fruits, they should be packaged in intact polyethylene film or waxed and treated with Ethrel at destination markets.
تأثير الإثيل والتغليف والتشميع على نوعية وفترة صلاحية ثمار الجوافة

التأتي عطا المنان حمدون موسى

ماجستير العلوم في علوم البساتين (فسيولوجيا ما بعد الحصاد) (فبراير، 2015م)

قسم علوم البساتين
كلية العلوم الزراعية
جامعة الجزيرة

ملخص الدراسة

الجوافة من أكثر الفواكه شعبية في السودان. وهي عادةً تحصاد في مرحلة النضج وهذا يؤدي إلى تدهورها السريع وعظم الفاقد ما بعد الحصاد. الهدف من هذا البحث هو العمل على دراسة تأثير الإثيل، التغليف والتشميع على نوعية وفترة صلاحية ثمار الجوافة. أجريت التجربة في جامعة الجزيرة، واد مدني، السودان خلال ديسمبر 2013 ومارس 2014م. تم حصاد ثمار الجوافة في مرحلة البلوغ الأخضر ومعاملتها بالإثيل أو تركها كشاهد. تم تغليف الثمار في أكياس بولينثين سليمة أو مخرمة أو تشميعها أو تركها كشاهد. صممت التجارب على نسق التصميم العشوائي الكامل بمكررين. معاملة الثمار بمادة الإثيل أدى إلى الإسراع في معدل نضج الثمار مما إنعكس على زيادة محتوى المواد الصلبة الذائبة والتغيير في لون القشرة والزيادة الملحوظة في محتوى فيتامين ج وتحسين الطعم والانخفاض في صلابة الثمار في كلا الموسمين. معاملات التغليف بالبولينثين والتشميع كان لها تأثيرات معنوية على فقدان الوزن والمواد الصلبة الذائبة وحصد الفيتامين ج وصلابة الثمار ومذاقها ولون لقشرة في كلا الموسمين. تعبئة ثمار الجوافة في أكياس البولينثين السليمة أدت إلى أقل فقدان في الوزن وأقل خسارة في منتجي الفيتامين ج وأفضل لون لقشرة الثمار وقلة الضجيج في كلا الموسمين. تعبئة ثمار الجوافة في أكياس البولينثين السليمة أدت إلى أعلى محتوى من فيتامين ج وأفضل لون لثمار وأطول فترة صلاحية للثمار يتمتعها الثمار المعيبة في الأكياس المخمرة ثم التشميع وأخيراً الشاهد في كلا الموسمين. الثمار الغير مغلفة (الشاهد) أعطى أعلى محتوى من المواد الصلبة الذائبة وأفضل طعم ولكن أقصر فترة صلاحية في كلا الموسمين. للحصول على أطول فترة صلاحية لثمار الجوافة وتحسين جودتها ، يوصى بتعبئتها في أكياس بولينثين سليمة أو تشميعها ومعاملتها بمادة الإثيل خصوصاً عند ترحيلها للأسواق البعيدة.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ENGLISH ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ARABIC ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER ONE: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>CHAPTER TWO: LITERATURE REVIEW</td>
<td>2</td>
</tr>
<tr>
<td>2.1 Origin, morphology and distribution</td>
<td>2</td>
</tr>
<tr>
<td>2.2 Harvesting</td>
<td>3</td>
</tr>
<tr>
<td>2.3 Respiratory pattern</td>
<td>3</td>
</tr>
<tr>
<td>2.4 Ripening</td>
<td>4</td>
</tr>
<tr>
<td>2.5 Handling and storage</td>
<td>6</td>
</tr>
<tr>
<td>2.6 Packaging</td>
<td>7</td>
</tr>
<tr>
<td>CHAPTER THREE: MATERIALS AND METHODS</td>
<td>9</td>
</tr>
<tr>
<td>3.1 Source of fruits</td>
<td>9</td>
</tr>
<tr>
<td>3.2 Packaging material</td>
<td>9</td>
</tr>
<tr>
<td>3.3 Experimental setup</td>
<td>9</td>
</tr>
<tr>
<td>3.3.1 Ethrel treatment</td>
<td>9</td>
</tr>
<tr>
<td>3.3.2 Packaging treatments</td>
<td>10</td>
</tr>
<tr>
<td>3.3.3 Weight loss experiments</td>
<td>10</td>
</tr>
<tr>
<td>3.4 Data taken consisted of the following</td>
<td>10</td>
</tr>
<tr>
<td>3.4.1 Total soluble solids (TSS)</td>
<td>10</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3.4.2 Skin colour</td>
<td>10</td>
</tr>
<tr>
<td>3.4.3 Firmness</td>
<td>11</td>
</tr>
<tr>
<td>3.4.4 Taste panel</td>
<td>11</td>
</tr>
<tr>
<td>3.4.5 Ascorbic acid (vitamin C)</td>
<td>11</td>
</tr>
<tr>
<td>3.5 Statistical analysis</td>
<td>11</td>
</tr>
<tr>
<td>CHAPTER FOUR : RESULTS AND DISCUSSION</td>
<td>12</td>
</tr>
<tr>
<td>4.1 Weight loss</td>
<td>12</td>
</tr>
<tr>
<td>4.2 Total soluble solids (TSS)</td>
<td>15</td>
</tr>
<tr>
<td>4.3 Vitamin C content</td>
<td>18</td>
</tr>
<tr>
<td>4.4 Skin colour</td>
<td>21</td>
</tr>
<tr>
<td>4.5 Firmness</td>
<td>24</td>
</tr>
<tr>
<td>4.6 Taste</td>
<td>27</td>
</tr>
<tr>
<td>CHAPTER FIVE : CONCLUSION</td>
<td>29</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>30</td>
</tr>
<tr>
<td>Figure no.</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Effects of packaging and waxing treatments on weight loss (%) of guava fruits (season one)</td>
</tr>
<tr>
<td>2</td>
<td>Effects of packaging and waxing treatments on weight loss (%) of guava fruits (season two)</td>
</tr>
<tr>
<td>3</td>
<td>Effects of Ethrel treatment on TSS of guava fruits (season one)</td>
</tr>
<tr>
<td>4</td>
<td>Effects of Ethrel treatment on TSS of guava fruits (season two)</td>
</tr>
<tr>
<td>5</td>
<td>Effects of packaging and waxing treatments on TSS of guava fruits (season one)</td>
</tr>
<tr>
<td>6</td>
<td>Effects of packaging and waxing treatments on TSS of guava fruits (season two)</td>
</tr>
<tr>
<td>7</td>
<td>Effects of Ethrel treatment on vitamin C content of guava fruits (season one)</td>
</tr>
<tr>
<td>8</td>
<td>Effects of Ethrel treatment on vitamin C content of guava fruits (season two)</td>
</tr>
<tr>
<td>9</td>
<td>Effects of packaging and waxing treatments on vitamin C content of guava fruits (season one)</td>
</tr>
<tr>
<td>10</td>
<td>Effects of packaging and waxing treatments on vitamin C content of guava fruits (season two)</td>
</tr>
<tr>
<td>11</td>
<td>Effects of Ethrel treatment on skin colour of guava fruits (season one)</td>
</tr>
<tr>
<td>12</td>
<td>Effects of Ethrel treatment on skin colour of guava fruits (season two)</td>
</tr>
<tr>
<td>Figure no.</td>
<td>Effects of packaging and waxing treatments on skin colour of guava fruits (season one)</td>
</tr>
<tr>
<td>------------</td>
<td>---------------------------------------------------------------------</td>
</tr>
<tr>
<td>13</td>
<td>....................................................................................</td>
</tr>
<tr>
<td>14</td>
<td>Effects of packaging and waxing treatments on skin colour of guava fruits (season two)</td>
</tr>
<tr>
<td>15</td>
<td>Effects of Ethrel treatment on firmness of guava fruits (season one)</td>
</tr>
<tr>
<td>16</td>
<td>Effects of Ethrel treatment on firmness of guava fruits (season two)</td>
</tr>
<tr>
<td>17</td>
<td>Effects of packaging and waxing treatments on firmness of guava fruits (season one)</td>
</tr>
<tr>
<td>18</td>
<td>Effects of packaging and waxing treatments on firmness of guava fruits (season two)</td>
</tr>
<tr>
<td>19</td>
<td>Effects of Ethrel treatment on taste of guava fruits</td>
</tr>
<tr>
<td>20</td>
<td>Effects of packaging and waxing treatments on taste of guava fruits</td>
</tr>
</tbody>
</table>
CHAPTER ONE

INTRODUCTION

Guava (Psidium guajava L.) is a popular fruit crop in the Sudan. It is grown in almost every State. The fruit is delicate and can be stored only for a few days at ambient conditions. Although the Sudan has a great potential to produce high quality guava and export it to other countries, yet its marketability is still limited to local markets. This is due to the delicate nature of the fruit, poor handling practices, and inadequate refrigerated transportation and storage facilities. Therefore, proper transportation techniques and control of the ripening process are crucial for the development of a sound guava industry in the Sudan (Mohamed-Nour and Abu-Goukh, 2013).

Postharvest losses are mainly caused during harvest and handling of fruits and are manifested in physical injury such as wounding, scratching and bruising. They are mainly caused by improper harvesting operations and also by the impact of fruits on the ground, which results in spongy tissue. This provides ports of entry for pathogenic microorganisms and hence results in decay and rot (Elkashif et al., 2010).

Weight loss is mainly due to water loss and usually results in fruit shriveling, loss of flavor and nutritional value and deterioration in quality.

In order to reduce these losses, there is a need to harvest guava at the mature-green stage to prolong the shelf life of fruits and use Ethrel to initiate ripening and enhance quality of fruits such as colour, taste and aroma (Elkashif et al., 2003).

Hence, this study was carried out to evaluate the effects of Ethrel, packaging and waxing treatments on quality and shelf life of guava fruits.
CHAPTER TWO
LITERATURE REVIEW

2.1 Origin, morphology and distribution

Guava (*Psidium guajava* L.) is an exotic fruit, member of the family Myrtaceae. It is known as the apple of the tropics and is popular for its penetrating aroma and flavor. Its place of origin is quite uncertain, extending in an area from southern Mexico thought Central and South America.

Currently, its cultivation has been extended to many tropical and subtropical parts of the world, where it also thrives well in the wild (Morton, 1987; Yadava, 1996; Mitra, 1997).

Guava shapes range from round, ovoid, to pear-shaped and with an average diameter and weight ranging from 4-10 cm and 100-400 g, respectively (Mitra, 1997).

Guava is classified as a berry and is composed of a fleshy mesocarp of varying thickness and a softer endocarp with numerous small, hard yellowish-cream seeds embeded throughout it (Malo and Campbell, 1994; Marcelin *et al*., 1993). Guava pulp contains stone cells and parenchyma cells. Stone cells are highly lignified, responsible for a characteristic sandy or gritty feeling in the mouth when the fruit is consumed; due to their nature, they are resistant to enzymatic degradation.

They account for 74% of the mesocarp. The rest of the mesocarp is composed of parenchyma cells, which give it a softer texture (Marcelin *et al*., 1993). Exterior skin colour ranges from light green to yellow when the fruit is ripe and its pulp may be white, yellow, pink or light red. Unripe guava fruit is hard in texture, starchy, acidic in taste and astringent, due to its low sugar and high polyphenol contents. Once it ripens, the fruit becomes very soft, sweet, non-acidic, and its skin becomes thin and edible (Malo and Campbell, 1994; Mitra, 1997). Many guava cultivars exist today, however, they can be broadly classified as pink or white. Seedless cultivars are desirable for export markets, but they are not available in the Sudan.
2.2 Harvesting

Guava tree requires 4-5 years to bear, while grafted, budded or layered plants start bearing at the age of 2-3 years. Fruits are ready for harvest 100 to 120 days after fruit set to ensure higher amounts of total sugars and appreciable amounts of minerals. Guava fruits are harvested throughout the year except during May and June depending on location and environmental conditions (Morton, 1987).

Guava fruits develop the best flavor and aroma only when they ripen on the tree. In most of commercial varieties, the stage of fruit ripeness is indicated by the colour development which is unusually yellow. For local markets, fully yellow but firm fruits are harvested, however, half yellow fruits are picked for distant markets. The fruits are harvested selectively by hand using the traditional picking poles (Elkasif et al., 2010).

Ripeness of guava starts on the tree and continues even after harvest. It is accelerated during the summer season due to high temperatures and slows down in the winter season due to low temperatures (Abu-Goukh and Bashir, 2002).

2.3 Respiratory pattern

Guava is a climacteric fruit which is characterized by a rise in respiration rate during ripening. Respiration climacteric is the critical phase which separates maturation processes concerned with growth from the onset of the essentially irreversible changes of senescence (Wills et al., 1998).

Generally, the majority of both temperate and tropical fruits followed a climacteric pattern of increase in respiration during ripening. The extent and rate of the process varies with temperature and species. In many tropical and subtropical fruits, the climacteric peak is only a transitory one with a rapid decline in respiration following the peak. Guava reaches its climacteric peak between 4 and 5 days after harvest and then declines (Akamine and Goo, 1979; Abu-Goukh and Bashir, 2002). Several workers reported that treatment of unripe climacteric fruits with ethylene promoted both the onset of the respiratory climacteric and other ripening changes (Burg and Burg, 1965; Elkasif et al., 2003; Kader, 2002).
2.4 Ripening

Ripening is the sum total of physio-chemical changes which make fruits edible. Ripening is the result of complex changes, many of them probably occur independently of each other. The number, complexity and commercial importance of these changes make fruit ripening a special case of plant organ senescence (Wills et al., 1981).

Guava is a climacteric fruit showing a typical increase in respiration and ethylene production during ripening. The colour of the rind changes from green to yellow or red during ripening while the colour of the flesh may change from white to creamy white, yellowish pink, deep pink or salmon red. Ripening can be induced by exposing the fruits to ethylene. Treating fruits with ethylene for 24 hours at 100 ppm an 20°C resulted in a significant increase in the rate of skin-yellowing and softening of mature-green fruits (Abu-Goukh and Bashir, 2002). The effect of ethylene on the ripening process varies with different types of fruits (Bassetto et al., 2005).

Guava fruit has a rapid rate of ripening. Therefore, they have a relatively short shelf life ranging from 3 to 8 days depending on the variety, harvest time, and environmental conditions (Reyes and Paull, 1995; Besseto et al., 2005). Visually, the ripeness level of guava can be characterized by it’s skin colour ranging from dark green when unripe to a bright yellow at full ripeness.

Ethylene gas plays a direct role in fruit ripening. In climacteric fruits, ethylene plays three distinct roles: 1, it is a component of the system of hormonal factors responsible for the initiation of the ripening process; 2, the transition from growth to senescence; and 3, it is produced auto-catalytically in response to exogenous ethylene (Reyes and Paull, 1995).

Ethylene appears to affect ageing of tissues. Burg and Burg (1965) showed that diffusion of ethylene through fruits obeys fick’s law. Ethylene has an important role in promoting directly the progress of some ripening changes. The role of ethylene in climacteric fruits may be to accelerate processes that are produced slowly in its absence (Ibrahim et al., 1994). The development of stimulatory levels of ethylene inside the tissues can be an important part of the ripening initiation process.

There are many ways of applying ethylene for the initiation of fruit ripening. It can either be applied as a gaseous mixture or in the form of ethylene-releasing chemicals such as ethephon (2-chloroethane phosphonic acid); the trade name of ethephon is Ethrel.
Generally, one ml of Ethrel is equivalent to 480 ppm of ethylene gas (Elkasif et al., 2003).

When mature green guava fruits were treated with Ethrel at 100 ppm at 15-20°C and 90%-95% relative humidity for 1-2 days, it accelerated the ripening of mature-green fruits to the full yellow stage. This treatment resulted in more uniform ripening, which is more important for guavas destined for fresh market or processing. Immature-green fruits do not ripen properly and develop a gummy texture. The use of ethylene gas in achieving faster and more uniform ripening of fruits is well documented (Kader, 2002). Ripening is promoted by dipping harvested fruits in an aqueous solution containing 2 ml of Ethrel /l (El Rayes, 2000; Ibrahim et al., 1994; Mohamed and Abu-Goukh, 2003).

2.5 Handling and storage

Depending on its further use (fresh or processed), postharvest conditions for guava may vary, however, its short shelf life is a problem to growers, packers and processors. Due to its delicate nature, it is carefully hand-harvested while still green, and immediately stored at cool temperatures. In Florida, guava fruits are usually stored at temperatures between 9 to 12°C (Florde, 2005) due to their sensitivity to chilling injury. They are typically shipped from packinghouses in the mature green stage (yellowish-green skin, firm), after harvesting at optimum fruit size. Reyes and Paull (1995) reported less disease incidence in mature green guava fruits stored at 15°C as compared with fruits that were quarter-and half-yellow under the same conditions. The optimum holding temperature for guava fruits is 15°C prior to marketing or processing, since it allowed gradual ripening of mature green fruits while delaying deterioration of quarter-yellow and half-yellow fruit. Guava fruits stored at 5°C did not ripen normally and developed skin bronzing after two weeks in storage, as a consequence of chilling injury.

2.6 Packaging

The most important factor in fruit for storage is the proper packing material and method of packaging. Singh (1968) reported the necessity of wrapping fruits to minimize transpiration. Tin foil, waxed paper, polyethylene and cellophane wraps gave excellent results. Tissue paper, bamboo wooden crates were also used for packaging fruits (Singh, 1968).
Waxing significantly reduced the permeability of fruit skin to gases. The fruits, through respiration, reduces oxygen and increases carbon dioxide in its environment. Under such restricted air-exchange, a modified atmosphere condition may be generated and its benefits are well documented (Kader, 2002). Waxing was reported to delay fruit ripening and senescence, reduce water loss, maintain quality, turgidity, firmness and covers injuries on the surface of the commodity (Wills et al., 1998). Waxing was also reported to extend the shelf life of lime (Ayoub, 2004), orange (Salih and Thompson, 1975), mango (Mohamed and Abu-Goukh, 2003), tomatoes (Ahmed and Abu-Goukh, 2003), grapefruits (Abu-Goukh and Elshiekh, 2008) and guava (Mohamed-Nour and Abu-Goukh, 2013).

The technique of polymeric film packaging has been used to modify O₂ and CO₂ concentrations within the package, improve water retention and reduce weight loss (Elkashif et al., 2013). However, the buildup of high relative humidity inside the package may result in water condensation which promotes decay and rot (Medlicott et al., 1990). In a similar study, bell peppers which were stored in perforated packages had a lower decay incidence than those stored in non-perforated packages (Yehoshua et al., 1998). Polyethylene film packaging has been found to extend the shelf-life of bananas (Mahmoud and Elkashif, 2003; Elkashif et al., 2005; Elamin and Abu-Goukh, 2009), mangoes (Elkashif et al., 2003), parsely (Heyes, 2004) and citrus fruits (Hussain et al., 2004).
CHAPTER THREE
MATERIALS AND METHODS

3.1 Source of fruits
Mature-green fruits of white-fleshed guava were obtained from an orchard at Wad Medani, Sudan. It is located at latitude 14° 6'N, longitude 33° 38'E and altitude 406 masl. The fruits were picked in December of 2013 (season one) and in March of 2014 (season two). Fruits were selected for uniformity of size, colour and freedom from blemishes. The fruits were washed, air-dried to remove water from the surface and transported in plastic baskets lined with perforated polyethylene sheets to the laboratory for further treatments.

3.2 Packaging material
Cartons and polyethylene films were purchased from the local market; some of these polyethylene films were perforated (PP) while others were left intact (IP).

3.3 Experimental setup
Mature-green fruits were washed in 5.3% sodium hypochlorite solution for disinfection. Fruits were divided into two lots: one lot received Ethrel treatment and the other remained as a control. Fruits from each plot were subjected to packaging treatments.

3.3.1 Ethrel treatment
Fruits were dipped for two minutes in Ethrel solution at a concentration of 4 ml/l or in distilled water (control). Then they were dried and subjected to packaging treatments.

3.3.2 Packaging treatments
The fruits were placed in the following packages: 1, cartons lined with intact polyethylene film; 2, cartons without film (control), 3, cartons lined with perforated polyethylene film and 4, fruits were waxed and placed in cartons. The experiments were arranged in a completely randomized design with two replicates. Data were taken every 2 days for a period of 10 days.
3.3.3 Weight loss experiment

Mature-green fruits were washed and then subjected to the previous packaging treatments, but without ethylene treatment. Cartons were initially weighed and then weighed every day until the fruit were fully ripe.

Weight loss (%) = [(Wo-Wt)/Wo] x 100

Where:
- Wo = Initial weight.
- Wt = Weight at designated time.

3.4 Data taken consisted of the following

3.4.1 Total soluble solids (TSS)

Total soluble solids were determined by a hand refractometer (Bellingham and Stanly Ltd, Tunbridge, Wells).

3.4.2 Skin colour

It was visually assessed using a scale of 1 to 3 as follows: 1, green; 2, greenish yellow and 3, yellow.

3.4.3 Firmness

It was evaluated by measuring the resistance of fruit to hand pressure using the fore finger and thumb and was rated according to a scale of 1, very soft; 2, soft, 3, fairly soft, 4, firm and 5, very firm.

3.4.4 Taste panel

A taste panel was conducted at the end of the experiments, panelists were asked to rate the taste of guava fruit samples taken from the different treatments according to a scale of 1 to 5 as follows: 1, unacceptable; 2, slightly acceptable; 3, acceptable; 4, good; 5, excellent.

3.4.5 Ascorbic acid (vitamin C)

A sample 400 mg of iodine powder was dissolved in 100 ml distilled water and then 25 ml of diluted H₂SO₄ were added. This makes 0.1 N iodine. One ml of 0.1 N iodine is
requirement to 8.806 mg vit. C/100 ml juice. Starch solution was prepared by dissolving 1 g of wheat flour in 100 ml distilled water then boiled and cooled.

A sample of 10 g of guava flesh were taken and blended in 250 ml H₂O and filtered. A sample of 25 ml of guava juice was taken and 10 drops of starch solution were added and titrated against 0.1N iodine to a faint blue colour.

Ascorbic acid (mg/100 g guava flesh) = number of ml of 0.1 N iodine x 8, 806 x 25
(dilution factor)

3.5 Statistical analysis

Data were subjected to the analysis of variance procedure. Means were separated using Duncan’s Multiple Range Test (DMRT).
CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Weight loss

The effects of packaging and waxing treatments on weight loss of guava fruits are shown in Figs. 1 and 2. Weight loss progressively increased during storage of guava fruits in both seasons. Packaging guava fruits in intact polyethylene film resulted in the lowest weight loss, followed by waxing, perforated film and the highest weight loss was observed in the control treatment in both seasons. Waxing treatment resulted in lower weight loss than that of the perforated film and much less than the control treatment. This was most probably due to the fact that the wax layer covered most of the stomatal openings in the epidermal layer of the skin and hence significantly reduced water loss. These results support the findings of Osman and Abu-Goukh (2008); Elkhair and Abu-Goukh (2010) and Irving and Warren (1960). Packaging guava fruits in intact film resulted in high relative humidity inside the package and hence reduced weight loss (Elkashif et al., 2005; Mae and Abu-Goukh, 2009; Osman and Abu-Goukh, 2008; Batagurki and Orsat, 1995; Ben Yehoshua et al., 1979). Polymeric film packaging has been extensively used to reduce water loss and enhance fruit quality (Wills et al., 1998). Osman and Abu-Goukh (2008) reported that banana packaged in intact polyethylene film had the lowest weight loss followed by those packaged in perforated ones whereas unpackaged fruits had the highest weight loss. Nevertheless, waxing also improved fruit quality, reduced post-harvest losses and extended storability of guava fruits. Similar results were reported by Mohamed and Abu-Goukh (2003); Abu-Goukh and Shattir (2012); Ahmed and Abu-Goukh (2003) and Abu-Goukh and Elshiekh (2008). Therefore, guava fruits intended for the local market or export should be packaged in intact thin polymeric film or coated with wax.
Fig. 1. Effects of packaging and waxing treatments on weight loss (%) of guava fruits (season one)

Fig. 2. Effects of packaging and waxing treatments on weight loss (%) of guava fruits (season two)
4.2 Total soluble solids (TSS)

The effects of Ethrel treatment on TSS content of guava fruits during storage are shown in Figs. 3 and 4. Generally, TSS content increased and then decreased with storage period in both seasons. The highest TSS content was recorded after 6 days of storage in both seasons. Guava fruits treated with Ethrel had higher TSS content than those without Ethrel in both seasons. Ethrel released ethylene hormone which triggered the ripening processes in fruits and resulted in early ripening as compared to the control. Similar results were obtained by Lam and Wong (1986) and Lam (1988).

The effects of packaging and waxing treatments on TSS content of guava fruits during storage are shown in Figs. 5 and 6. The highest TSS values were recorded in unpackaged control fruits, however, the lowest values were obtained by fruits packaged in intact film in both seasons. This was because packaging in intact polyethylene film and waxing maintained high relative humidity around the fruit which reduced water loss and hence maintained TSS content. On the other hand, guava fruits packaged in perforated film or unpackaged had higher TSS values because these treatments encouraged water loss during storage and hence resulted in the concentration of fruit juice which was manifested in higher TSS contents. These results were consistent with the reports that TSS increased during storage of lime (Elkheir and Abu-Goukh, 2010), Ayoub (2004), mango (Elkashif et al., 2003) and grapefruits (Abu-Goukh and Elsheikh, 2008).
Fig. 3. Effects of Ethrel treatment on TSS of guava fruits (season one).

Fig. 4. Effects of Ethrel treatment on TSS of guava fruits (season two).
Fig. 5. Effects of packaging and waxing treatments on TSS of guava fruits (season one).

Fig. 6. Effects of packaging and waxing treatments on TSS of guava fruits (season two)
4.3 Vitamin C content

The effects of Ethrel treatment on vitamin C content of guava fruits are shown in Figs. 7 and 8. Vitamin C content was significantly increased with the advancement of fruit ripening and then declined during the senescence stage in both seasons. The highest vitamin C content was recorded for fruits treated with Ethrel compared to the control fruits which lost vitamin C rapidly. Ethylene has been shown to increase vitamin C content of climacteric fruits such as mango (Elkashif et al., 2003) and guava (Abu-Goukh and Bashir, 2002).

The effects of packaging and waxing treatments on vitamin C content of guava fruits are shown in Figs. 9 and 10. Vitamin C content increased with storage and then slowly decreased. The highest vitamin C content was found in fruit packaged in intact polyethylene film, followed by perforated and waxing treatment. However, the control fruits had the lowest values during storage. This was probably due to the fact that fruits packaged in intact or perforated polyethylene film resulted in higher relative humidity inside the package and hence reduced moisture loss from guava fruits. However, the unpackaged control fruits lost more water, were shriveled and hence resulted in more loss of vitamin C content. Similar results were reported by Elkashif et al. (2005) and Osman and Abu-Goukh (2008). Waxed fruits lost less moisture as compared to the control and hence conserved more ascorbic acid which was comparable to the perforated polyethylene film treatment. These results were consistent with those reported by Irving and Warren (1960), Oosthuyse (1997), Samah and Abu-Goukh (2009) and Elkheir and Abu-Goukh (2010).
Fig. 7. Effects of Ethrel treatment on vitamin C content of guava fruits (season one).

Fig. 8. Effects of Ethrel treatment on vitamin C content of guava fruits (season two).
Fig. 9. Effects of packaging and waxing treatments on vitamin C content of guava fruits (season one).

Fig. 10. Effects of packaging and waxing treatments on vitamin C content of guava fruits (season two).
4.4 Skin colour

The effects of Ethrel treatment on skin colour of guava fruits during storage are shown in Figs. 11 and 12. Ethrel treatment significantly enhanced colour development in both seasons. Ethylene released from Ethrel caused the degradation of chlorophyll and enhanced the development of carotene. This is in agreement with the results of Sargent et al. (1992) who demonstrated the role of ethylene in climacteric fruit ripening. Also, Lam (1988) showed that ethylene accelerated mango fruit ripening which was reflected in rapid fruit yellowing as compared to the untreated control.

The effects of packaging and waxing on skin colour of guava fruits during storage are shown in Figs. 13 and 14. Skin colour score progressively increased during storage of guava fruits. The intact and perforated polyethylene films encouraged the development of yellow colour of guava. Polyethylene film liners trapped ethylene hormone which resulted in the degradation of chlorophyll and enhancement of carotene. Elkashif et al. (2003) reported that mango fruit packaged in intact polymeric film developed excellent yellow colour than the unpackaged control. Osman and Abu-Goukh (2008) found that banana fruits held in intact polyethylene packages had the best colour development, followed by those held in perforated ones and unpackaged fruits had the worst. Waxing was less effective in colour development because waxed fruits were not able to trap ethylene hormone which was responsible for chlorophyll degradation. This agrees with reports that waxing delayed chlorophyll degradation and skin colour development in tomatoes (Ahmed and Abu-Goukh, 2003) and mango (Mohamed and Abu-Goukh, 2003).
Fig. 11. Effects of Ethrel treatment on skin colour of guava fruits (season one).

Fig. 12. Effects of Ethrel treatment on skin colour of guava fruits (season two).
Fig. 13. Effects of packaging and waxing treatments on skin colour of guava fruits (season one).

Fig. 14. Effects of packaging and waxing treatments on skin colour of guava fruits (season two).
4.5 Firmness

The effects of Ethrel treatment on firmness of guava fruits are shown in Figs. 15 and 16. Generally, fruit flesh firmness progressively declined during storage of guava fruits in both seasons. Ethrel treatment significantly decreased fruit firmness in both seasons.

Ethylene released from Ethrel induced the biosynthesis of cell wall hydrolases which accelerated the hydrolysis of cell wall components and hence resulted in fruit softening. These results were in agreement with those shown by Elkashif and Huber (1983) who reported that exposure of fruit to exogenous ethylene resulted in the induction of hydrolytic enzymes such as cellulase and polygalacturonase which enhanced the hydrolysis of cellulose, hemicellulose and pectins and resulted in reduced fruit firmness.

The effects of packaging and waxing on firmness of guava fruits during storage were significant in the first season only (Figs. 17 and 18). Waxing resulted in the most firm fruits followed by packaged fruits and the least firm fruits were the control. This was most probably due to the fact that waxing resulted in higher concentrations of CO$_2$ inside the fruits which inhibited the action of ethylene hormone released from Ethrel, and, hence, prevented the hydrolysis of pectic compounds which is usually responsible for fruit softening. These results agree with the findings of Osman and Abu-Goukh (2008) who reported that polyethylene film liners resulted in a modified atmosphere with lower O$_2$ and higher CO$_2$ concentrations. Modified atmospheres, particularly those containing high CO$_2$, inhibit the breakdown of pectic substances, so that firmer texture is retained for a longer period of time (Kader, 2002). It has been shown that banana fruits packaged in intact polyethylene film had a longer shelf-life than control fruits (Elkashif et al., 2005; Osman and Abu-Goukh, 2008).
Fig. 15. Effects of Ethrel treatment on firmness of guava fruits (season one).

Fig. 16. Effects of Ethrel treatment on firmness of guava fruits (season two).
Fig. 17. Effects of packaging and waxing treatments on firmness of guava fruits (season one).

Fig. 18. Effects of packaging and waxing treatments on firmness of guava fruits (season two).
4.6 Taste

The effects of Ethrel treatments on the taste of guava fruits after storage are shown in Fig. 19. Guava fruits treated with Ethrel had significantly better taste than the untreated control in both seasons. Ethylene hormone released from Ethrel triggered the ripening process and induced the biosynthesis of hydrolytic enzymes. These enzymes hydrolysed starch and cell wall components into sugars and, hence, resulted in high TSS contents. These results are supported by those presented in Figs. 3 and 4 which showed that guava fruits treated with Ethrel had significantly higher TSS content than the untreated control. These results are consistent with those of mango fruits reported by Elkashif et al. (2003).

The effect of packaging and waxing treatments on taste of guava fruits during storage are shown in Fig. 20. The best taste was recorded for the control fruits, followed by the perforated film, waxed and the worst taste was found in fruits packaged in intact polyethylene film. This was most probably because fruits packaged in intact film trapped CO₂ which acted as a competitive inhibitor of ethylene, thereby preventing its action and consequently hindering the ripening process. These events led to the lack of the hydrolysis of starch and cell components resulting in low TSS content and, hence, unacceptable taste. These results confirm those presented in Fig. 5 which showed that fruits packaged in intact film had the lowest TSS content.

Interaction effects of Ethrel and packaging and waxing treatments on the chemical composition of guava fruits were not significant.
Fig. 19. Effects of Ethrel treatment on taste of guava fruits.

Fig. 20. Effects of packaging and waxing treatments on taste of guava fruits.
CHAPTER FIVE

CONCLUSION

It could be concluded that, in order to prolong the shelf-life and maintain the quality of guava fruits, they should be packaged in intact polyethylene films or waxed and treated with Ethrel at destination markets.
REFERENCES


**Ayoub, S.O. 2004.** Effect of 2,4,5-trichlorophenoxy acetic acid (2, 4.5 T) and waxing on quality and storability of lime fruit. M.Sc. Thesis, University of Khartoum.


