UNIVERSITI PUTRA MALAYSIA

MATHEMATICAL MODELING OF COLOR AND TEXTURE KINETICS OF FRESH-CUT STAR FRUIT STORED AT DIFFERENT PACKAGING FILM AND STORAGE CONDITIONS

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198406

PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF ENGINEERING PROCESS AND FOOD WITH HONOURS

DEPARTMENT OF PROCESS AND FOOD ENGINEERING

FACULTY OF ENGINEEERING

UNIVERSITI PUTRA MALAYSIA

2022

ACKNOWLEDGEMENT

First of all, I would like to express my highest gratitude to Allah S.W.T, the most gracious and the source of all the knowledge for His guidance and for giving me strength to complete my final year project. Also, I want to thank my parents and family members for the endless support and encouragement throughout my degree.

Besides that, deepest gratitude and special thanks to my supervisor, Dr. Siti Hajar binti Ariffin who in spite of being extraordinarily busy with her duties, took time out to guide, give advices and encouragement throughout the project. Without the guidance from my supervisor, it will not be possible to complete the project.

Apart from that, I also would like to express my appreciation to my coordinator, Dr. Faiqa Shazeaa binti Mohd. Saleh for the guidance throughout the whole duration of the project completion and thesis talk. Not to be forgotten to my examiners, Prof. Madya Dr. Rosnita A. Talib and Prof. Ts. Dr. Rosnah Shamsudin for giving me useful feedbacks and recommendations during the project presentation.

A big thanks to master student, Zahrah Izzati binti Azhar Shapawi for her assistance during the lab works and her guidance in thesis writing. Lastly, I am using this opportunity to express my gratitude towards my friends for their support and encouragement upon completing this project.

ABSTRACT

The demand for fresh-cut products have increased by consumers that looking for healthy, safe and quick meals. Many initiatives have been taken up to reduce the food wastage as fresh-cut products have shorter shelf life. Star fruit is a rich source of antioxidant, but it has high moisture content resulting in shorter shelf life especially for fresh-cut star fruit due to tissue disruption during cutting. This study was conducted to evaluate the quality changes on the fresh-cut starfruits stored at different packaging films (LDPE, PET and PP) and storage conditions (-25°C, 5°C and 30°C). The kinetic models on color and texture were also evaluated using zero-order and first-order model. Regardless of the film type, fresh-cut star fruit were shown to have a shelf life of up to 16 days when stored at 5°C and up to 3 days when stored at 30°C and -25°C. However, at temperature 30°C, fresh-cut star fruit packed in PET film maintained its fresh-like properties up to day 6. The first-order model was proven to demonstrate the texture degradation for samples stored at 30°C and -25°C whereas the samples stored at 5°C fitted the zero-order model. As for kinetics models on color parameter, the samples stored at 5°C does not fitted zero-order and first-order model. However, zero-order and first-order model were proven to show a good fit in modeling a* value, b* value and ΔE value for samples stored at 30°C. L* value and ΔE value also showed best fitted the zero-order model for samples stored at -25°C.

ABSTRAK

Permintaan terhadap buah potongan segar telah meningkat dalam kalangan pengguna yang mencari makanan yang sihat, cepat dan selamat untuk di makan. Hal ini demikian, pelbagai inisiatif telah dijalankan untuk mengurangkan pembaziran makanan terutamanya untuk buah potongan segar kerana ia mempunyai jangka hayat yang pendek. Buah belimbing kaya dengan antioksidan, tetapi ia mempunyai kandungan air yang tinggi menyebabkan jangka hayat lebih pendek. Kajian ini dijalankan adalah untuk menilai kualiti bilimbing yang telah dipotong seterusnya dibungkuskan ke dalam tiga filem pembungkusan yang berbeza (LDPE, PET and PP) dan disimpan di bawah suhu (-25°C, 5°C dan 30°C). Tambahan pula, model pesanan sifar dan pesanan pertama digunakan untuk menggambarkan perubahan kepada kepejalan and warna belimbing. Belimbing didapati mempunyai jangka hayat sehingga 16 hari apabila disimpan pada suhu 5°C bagi semua filem pembungkusan dan hanya 3 hari apabila disimpan pada suhu 30°C and -25°C. Pada suhu 30°C, PET menunjukkan prestasi yang baik kerana ia dapat mengekalkan sifat seperti segar sehingga 6 hari. Model pesanan pertama terbukti menunjukkan tektur kepejalan belimbing apabila disimpan pada suhu 30°C dan -25°C dan model pesanan sifar sesuai digunakan pada suhu 5°C. Model yang paling sesuai untuk menunjukkan perubahan nilai a*, b* dan ΔE bagi buah belimbing disimpan pada suhu 30°C adalah model pesanan sifar dan pertama. Bukan itu sahaja, model pesanan sifar juga sesuai untuk menunjukkan perubahan nilai L* value dan ΔE bagi belimbing yang disimpan pada suhu -25°C.

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LIST OF ABBREVIATIONS

a*	Redness
b*	Yellowness
ΔE	Color difference
F_{max}	Maximum Force (N)
L*	Lightness
OTR	Oxygen Transmission Rate
PET	Polyethylene terephthalate
R^2	Correlation coefficient
W_{loss}	Fresh weight loss (%)
WTR	Water Transmission Rate

CHAPTER 1

INTRODUCTION

1.1 Background

Star fruit (*Averrhoa carambola L.*) is a dicotyledon crop belonging to the Oxalidaceae family and has a unique and appealing star-shaped fruit (Fan et al., 2020). Star fruit is categorized as tropical American species and it was introduced to Asia by Spanish galleons and is now widely cultivated and became native in tropical and warm subtropical countries in Southeast Asia and Malaysia (Luan et al., 2021; Wu et al., 2020). Star fruit has a distinct flavor that is usually sour and acidic in smaller size fruit and has sweet flavor in large size fruit. They are often made as preparation for fruit salads, garnish in beverages, fried in jellies and ice cream in tropical countries such as Malaysia, Singapore and Indonesia (Fan et al., 2020; Luan et al., 2021). Besides, star fruit is a rich source of antioxidant and the study of natural resources of antioxidants and their potential for nutraceutical and functional foods has been prompted by expanding the market (Adiyaman et al., 2019; Shui & Leong, 2006). However, due to star fruit's fragility and high moisture content resulting in shorter shelf life, make the commercialization of star fruit has not been successful despite having high nutritional values (Seth et al., 2021).

Proper conditions of storage are necessary to preserve the quality and extend the shelf life of star fruit due its fragility and high moisture content. Many losses could occur if a proper storage is not maintained throughout the post-harvest handling. Besides, fresh-cut star fruit have shorter shelf life as it is vulnerable to enzymatic browning when the fruits are being cut and speed up the ripening and aging process. This will result in loss of quality and food value. Freshness and appearance were the most important sensory aspect evaluated by consumers in the selection and consumption of fresh-cut products (Massaglia et al., 2019). However, in the literature, studies on the effect of storage conditions and packaging films towards quality and shelf life of star fruit are still lacking. Therefore, the objective of this report is to study the quality changes on the fresh-cut star fruit stored in different packaging films (LDPE, PET and PP) and storage conditions (-25°C, 5°C and 30 °C). Kinetic models on texture and color changes were also performed to have better understanding on the quality degradation of the fresh-cut star fruit.

1.2 Problem Statement

The current global trend toward healthy lifestyles has led to an increase in demand for convenient fresh foods that are additive-free and high in nutritional value (Singla et al., 2020). Fresh-cut products have grown rapidly in last decade, with an estimated retail market value of $11 billion, to meet consumer demand for the convenient and healthy product (Luna-Guzman, 1999, as cited in Zainal Abidin et al., 2013). According to Singla et al. (2020), fresh-cut fruits appeal to people looking for healthy, quick meals because they are neither heat-treated or contain any chemical preservatives. Besides, fresh-cut or minimally processed fruits have a number of advantages, including reduced preparation time and access to food with excellent nutritional and sensory quality (Graca et al., 2015). However, the quality and shelf life of carambola when stored at room temperature, 20 °C has shelf life up to 3 to 4 days (Paull & Chen, 2004) and this is not the case for fresh-cut star fruit. Fresh-cut fruits have short life span due to tissue disruption, wound ethylene and enzymatic browning when fruits are being cut which enhances microbial contamination and speed ripening and aging (Sommano et al., 2019). Regardless of the studies on storage condition and quality that have been done on star fruit, there is still lack information on storage condition and quality of fresh-cut star fruit stored at different packaging films and storage. Therefore, different storage conditions and packaging films were used in this study to observe the quality changes and shelf life of the fresh-cut star fruit. Besides, modelling the kinetic changes on fresh-cut star fruit throughout storage also important to better understand the quality changes in terms of color and texture.

1.3 Objectives

The objectives of this study are:

1. To evaluate the quality changes of fresh-cut star fruit stored at different packaging films (LDPE, PET and PP) and storage conditions (-25°C, 5°C and 30°C).
2. To perform kinetic models on color and texture of fresh-cut star fruit stored at different packaging films (LDPE, PET and PP) and storage conditions (-25°C, 5°C and 30°C).

1.4 Scope of Study

Throughout this project, I will study several scopes which is study on the origin, species and shelf life of star fruit including the benefits and nutrients found in star fruit. Other than that, study on the storage conditions that suitable for star fruit in terms of quality and shelf life in order to know how storage conditions influenced the quality and shelf life of the products. Furthermore, the properties of packaging films such as the barrier properties on gases and its suitability to store the fresh-cut fruits will be studied.

Besides, to study how the packaging films influenced the quality and prolong the shelf life of star fruit. In addition, the factors that affected the quality analysis such as physical appearance, color analysis, fresh weight loss, texture and fogginess will be studied. Lastly, a study is conducted on the kinetic model that can be used to analyze the color and firmness of fresh-cut fruits.

CHAPTER 2

LITERATURE REVIEW

2.1 Star fruit (*Averrhoa carambola L.*)

Star fruit has a star-shaped when horizontally cut as shown in Figure 2.1. According to Muthu et al. (2016), star fruit plants is a slow-growing woody plant with several stems and a short trunk that can reach a height of 6 to 9 meters. The plants can produce clusters of five-petaled red, lilac or purple flowers on the main stem and usually flowering year-round in tropical climates when temperature reach 27 °C (Muthu et al., 2016). Besides, star fruit plants contains leaflets that fold together at night and is sensitive to light and shock, as seen by abrupt leaf motions. In Malaysia, star fruit is a tropical fruit and is common on domestic markets and the most popular clones' varieties that are grown in Malaysia are B2, B10 and B7.

Figure 2.1 Horizontally cut star fruit.

2.1.1 Benefits of star fruit

Star fruit has a rich source of minerals, vitamins and natural anti-oxidant such as vitamin C (Fan et al., 2020). Anti-oxidant has beneficial effect on human body such as defense against inflammatory response (Warren & Sargent, 2011). Not only high in anti-oxidant, but star fruit also has high fiber content which aids in the absorption of glucose, retarding glucose diffusion into the bloodstream, and managing blood glucose levels (Fan et al., 2020). Besides, star fruit has many uses in pharmaceutical industry where in Brazil, carambola tonics are used to treat eye problems and as a diuretic for renal and bladder problems (Adiyaman et al., 2019). The nutritional facts of star fruit per 132 g serving is shown in Table 2.1 (RecipeLand, 2022).

Table 2.1 Nutritional information for star fruit (RecipeLand, 2022).

Nutritional Info (132 g per serving)	
Carbohydrates	8.9 g
Dietary fiber	4 g
Sugars	5.3 g
Protein	1.4 g
Sodium	2 mg
Vitamin A	2%
Vitamin C	76%
Iron	1%

2.2 Shelf life of star fruit

Star fruit can prolong their shelf life under proper storage for several weeks. Besides, star fruit is a perishable fruit due to high moisture content that is susceptible to mechanical injury during postharvest due to chemical and microbiological degradation (Ruiz-Lopez et al., 2001). The shelf life of star fruit has been thoroughly studied. Paull & Chen (2004) reported that at temperature 5°C, star fruit can be kept up to 35 days and only 4 days when kept at temperature 20°C. In addition, according to Paull et al. (2014), at low temperature storage, 0°C, only some minor surface pitting and ribbed edge occur as star fruit hardly gets cold wound. Even though there has been many study on shelf life of star fruit stored at different storage temperatures (Paull et al., 2014; Paull & Chen, 2004; Lameira et al., 2020) but studies on shelf life of fresh-cut star fruit have been limited. Nevertheless, shelf life of fresh-cut products is shorter compare to whole star fruit as there are many factors that associate on the shelf life reducing of fresh-cut.

2.3 Fresh-cut product

Based on the United Fresh Produce Association (UFPA) and Food and Drug Administration (FDA), fresh-cut products are minimally processed products where it has been washed, cut, mixed, packed, and ready for consumption. Fresh-cut products in retails include mixed salads, already peeled fruits such as pears, pineapple and cut products such as asparagus, and potatoes. Besides, fresh-cut fruits appeal to people looking for healthy, quick meals because they are neither heat-treated or contain any chemical preservatives (Singla et al., 2020). Despite the health benefits of eating fresh fruits and vegetables, quality and safety are still the main concerns because the cut surface is exposed to the air during handling and preparation can caused microbial contamination (Qadri et al., 2015). The microorganisms that are concerned in fresh-cut products are *Listeria monocytogene*, *Escherichia coli*, and *Salmonella* spp. (Francis et al., 2012). Furthermore, fresh-cut products have a shorter shelf life as it is vulnerable to wound ethylene and enzymatic browning when the fruits are being cut and speed up ripening and aging (Sommano et al., 2019). Therefore, in order to prolong the shelf life and retain the quality of fresh-cut products, extreme caution must be taken during its preparation and consumption.

2.3.1 Fresh-cut consumer perception

The rise in consumption and growth of fresh-cut products are characterized by a variety of preferences for the product's various qualities. According to Massaglia et al. (2019), freshness, appearance, and variety were the most important sensory aspects evaluated by consumers in the selection and consumption of fresh-cut products. In addition, consumers always concern towards the safety of the product and therefore, organic status, quality certifications, nutritional value and safety on the packaging are increasingly influence the purchase decisions (Massaglia et al., 2019; R. Deliza et al., 2013). Hence, to better serve the expectations of the consumer, it is critical that the desire for "convenience" of the product is constantly accompanied with the maintenance of nutritional and sensory quality.

2.4 Quality definition

Quality is defined as the requirements or attributions that are required to meet consumer's perception of the product integrity. Quality monitoring can be measured by measurable features such as color the physical, chemical, and microbiological characteristics of food products (Mihafu et al., 2020) and consumption preference where the smell, color, taste, texture and shapes of food products are measured to determine the quality and acceptability (Grunert, 2005). Therefore, in this study, the shelf life of fresh-cut star fruit can be determine by evaluate its fresh weight loss, texture, physical appearance, and color.

2.4.1 Color analysis

Color is one of the most significant factors that indicates the overall quality and the acceptability of the fresh-cut products (Mihafu et al., 2020). According to Mihafu (2020), the color changes can be caused by ripening, mechanical injury to cell tissues during handling and fresh-cut processing, and enzymatic activity. The key color changes in star fruit are due to the oxidation of the green hue. Besides, star fruit value added products are influence by its attractive yellow color (Roopa et al., 2014). When harvested, green star fruit can slowly become orange until fully mature, taking 60 to 75 days from fruit set to maturity, depending on the cultivar, processing method, and temperature (Small, 2012). Star fruit must be handled with great caution during the harvesting process as star fruit is easily to damage due to its high moisture content (Suhaimi et al., 2021). Hence, Colorimeter is a commonly instrument used to measure the color where the value of L*a*b* will be measured. L* value represents to the lightness or luminosity, a* value indicates the red and green color and b* indicates the yellow and blue color.

2.4.2 Fresh weight loss analysis

Moisture loss during storage and transportation is a key factor that affects the quality and marketability of delicate products like fruits and vegetables. It has been reported that water loss of products were affected by intrinsic factor and extrinsic factor (Mihafu et al., 2020). The intrinsic factor includes the size, surface-to weight and volume ratio, maturity stage, and physical injuries, and as the extrinsic factors like temperature, and relative humidity. Plant tissues such as leafy vegetables are more susceptible to water loss, wilting and shriveling meanwhile fruits such as apples and pears are more resistant to water loss (Xanthopoulos et al., 2014; Yildiz, 1994). However, fresh-cut products are more susceptible to the water loss that intact product due to large surface-area-to-volume ratio cause during cutting processing (Mihafu et al., 2020). Therefore, the water loss has major consequences for the quality characteristics of perishable goods, such as firmness, turgidity, wilting, and withering (Aindongo et al., 2014).

2.4.3 Firmness of carambola

Firmness is one of the most significant factor that influences the mouth-feel of consumers (Toivonen & Brummell, 2008). Plant tissue texture of fruit products varies during postharvest handling due to a variety of circumstances, including maturity stage, water stress, storage temperature and relative humidity, physical handling, and the ripening process (Mihafu et al., 2020). Besides, the activity of enzymes such as B-galactosidase, cellulose, cellulose, peroxidase, pectin methyl esterase may cause the cell-wall modification and pectin degradation due to the mechanical injury during storage and transportation of food products. Therefore, the levels of maturation, firmness, and color of star fruit are shown in Table 2.2 below.

Table 2.2 The levels of maturation, firmness, and color of star fruit (Muthu et al., 2016).

Level	Firmness	Color
Young	Firm texture	100% green color
Half-ripe	Firm texture	Yellowish green color
Ripe	Soft texture	100% yellow color

2.5 Packaging film

Packaging can extend shelf life, maintain safety, provide convenience, and enhance value of fresh-cut products (Forney, 2007). According to Rojas-Grau et al., (2009), fresh-cut products has high respiration rate due to mechanical injury during the processing of fresh-cuts products and causing wounding stresses in the cut tissues. The use of packaging that has low oxygen, O_2 atmosphere (1-5 %) and has high carbon dioxide, CO_2 atmosphere (5-10 %) have been used to reduce the respiration rate, product transpiration and ethylene production of fresh-cut products by extending the shelf life and enzymatic browning, firmness and deterioration of fresh-cut products have also been shown to be efficiently controlled by low O_2 and CO_2 atmosphere (Rojas-Grau et al., 2009). Hence, packaging materials must be designed by taking into considerations the efficiency of the polymer packaging to guarantee the food quality, add value to fresh-cut products and also to meet the growing demands from the consumers, producers and legislative forces which is Food and Drug Administration's (FDA) for food contact application (Forney, 2007; Ncube et al., 2020).

Packaging that is widely used in the food packaging industry are low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and expanded polystyrene (EPS) and they can be classified as thermoplastic (Ncube et al., 2020). According to Ncube et al., (2020), thermoplastics have found the most use in the food packaging as they are inexpensive, have strong tensile qualities, and can provide an effective barrier against O_2, CO_2, and water vapor (Ncube et al., 2020). However, different types of storage will result in different quality changes of food products such as respiration rate, flavor, odor, discoloration, nutritional value and also texture alteration (Barret et al., 2010). Therefore, the use packaging must suitable to the properties of fresh-cut products and the packaging must be sufficiently flexible to withstand the physical and chemical reaction and to atmosphere gases such as O_2 and CO_2 between the internal and external of the packages (M. J. Galotto et al., 2008). Hence, in this study, polypropylene (PP), polyethylene terephthalate (PET), and low-density polyethylene (LDPE) packaging film were chosen to store the fresh-cut star fruit.

2.5.1 Polypropylene (PP) packaging film

Polypropylene (PP) packaging film is widely used polymers in the food industry because the material is safe, inexpensive, flexible and versatile (Syahidah et al., 2005). Besides, PP is a high-strength, puncture-resistant clear glossy film that is good optical properties for storing food products and has moderate permeability to O_2 and CO_2 gases and has high barrier to water vapor (Allahvaisi, 2012). Furthermore, in the study of fresh-cut cantaloupe, PP packaging preserved the samples up until day 18 when stored at 2°C (Syahidah et al., 2005). Study on the fresh-cut potatoes under PP films and the gas permeability and thermal behavior of PP films also have been reported by Siracusa et al., (2012).

2.5.2 Polyethylene terephthalate (PET) packaging film

Polyethylene terephthalate (PET) film is a transparent glossy film with excellent moisture and gas barrier properties (Fellows, 2009). In addition, according to Fellows (2009), PET able to maintain its flexibility at temperature ranging from -70 °C to 135 °C and can shrinkage due to temperature and humidity. PET is widely used in many applications in a food packaging and also in industries such as face shields, carrier films, insulation for electronic wiring and, laminates. PET can be classified into two types which are amorphous and crystalline. Amorphous PET suitable to be used in a carbonated drinks bottle as it is clear meanwhile, crystalline PET is opaque and suitable to be used for trays in a microwave and container. Moreover, PET films has been used in the study of fresh-cut mangosteen and able to maintain the overall appearance of samples up until day 9 at 5 °C (Ayudhya et al., 2014).

2.5.3 Low-density polyethylene (LDPE) packaging film

Low-density polyethylene (LDPE) is the most common plastic material used in the world as bags, papers or board coating, and as a component in laminates as it is less expensive than other films (Allahvaisi, 2012). There is more usage of LDPE in industries such as copolymer in some tubs and tray. Besides, LDPE has high moisture barrier however, has poor odor barrier due to transparent film properties and; therefore, it is commonly used in applications requiring heat sealing (Fellows, 2009; Mangaraj et al., 2009). Moreover, many studies have been reported on fresh-cut products stored in LDPE films. LDPE film under active modified atmosphere has been used in the study of fresh-cut cabbage which showed LDPE packaging proved suitable to store the fresh-cut cabbage (Rinaldi et al., 2009). In addition, LDPE films preserved the star fruit samples up to 16 days stored at 5°C able to prevent from chilling injury however, the carambola showed retention of yellow color and the firmness of carambola was reduced (Lameira et al., 2020).

CHAPTER 3

METHODOLOGY

Preparations and handling of samples are discussed in this chapter. The method to determine the quality changes of fresh-cut star fruit during storage such as physical appearance analysis, color analysis, fresh weight loss, texture and fogginess will be discussed here. Furthermore, this chapter will discussed the modeling method and the mathematical equation used for texture and color of fresh-cut star fruit. All the procedures and equipment used will be elaborated in this chapter.

3.1 Sample preparation

Index 2 and grade B of star fruit were purchased from a farm located in Kuala Pilah, Malaysia. The star fruits were then cleaned by using tissue that is wet by tap water to remove the dirt. After the cleaning processed completed, the star fruits were cut into star shape with diameter of (4± 0.5) cm and thickness of 1.4 cm (Maharaj & Badrie, 2016). The fresh-cut star fruits were then soaked in 0.5g/L concentration of sodium chloride solution for 1 minute to reduce the browning effect of the fresh-cut products (Lu et al., 2007). After soaking processed, the fresh-cut star fruits were dried at ambient temperature before packed in three different packaging films; polypropylene (PP) (OTR; 1000 cc/m^2/day), low-density polyethylene (LDPE) (OTR; 8000 cc/m^2/day, WTR; 200 g/m^2/day), and polyethylene terephthalate (PET) (OTR; 90 cc/m^2/day, WTR; 35 g/m^2/day) that have dimensions of 200 mm × 300 mm and thickness of 0.01 μm. Then, the fresh-cut star fruits were stored for 16 days at three different storage temperature (-25 °C, 5 °C and 30 °C). The process flow chart and images of star fruits preparation were provided in Appendix A.

3.2 Physical appearance analysis

Physical appearance analysis was done by using black box where 12 replicates of fresh-cut star fruits were arranged on a white paper placed inside the box to ensure absent of external light as shown in Figure 3.1. LED ring light were placed inside the box as a source of lighting when snapping the image and mobile camera (iPhone 6, Apple, Malaysia) was used to snap the image. The standard-setting for LED ring light and mobile camera are shown in Table 3.1 and Table 3.2 below. The observation was done at day 0, day 3, day 6, day 9, day 12, day 14, and day 16 for all samples.

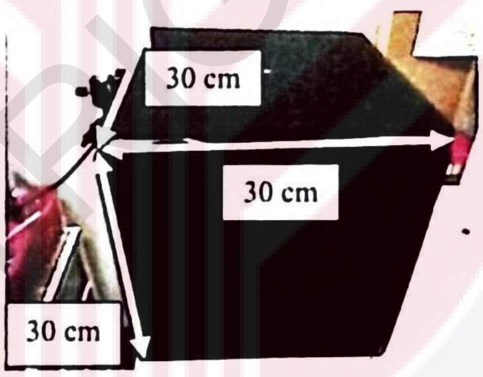


Figure 3.1 Black box for physical appearance analysis.

Table 3.1 LED ring light settings for image acquisition.

Options	Settings
Power	12 W
Luminous	1500Lux
Color Light	White Light
Outer Diameter	26 cm
Inner Diameter	20 cm

Table 3.2 Mobile camera settings for image acquisition.

Options	**Settings**
Megapixels	8 MP (3264 ×2448 pixel)s
Focal Distance	29 mm
Aperture, Av	$f2.2$
Shutter Speed	1/100s
ISO	50
Flash	Off

3.3 Fresh weight loss analysis

The fresh weight loss of fresh-cut star fruit before and after storage were measured using an electronic weighing scale, BE610 (Beetle, UK) as shown in Figure 3.2. Each film has three replicates and each pack has four fresh-cut star fruit which made the total replicate for each film measured was 12 replicates. The samples were measured at day 0, day 3, day 6, day 9, day 12, day 14, and day 16. Equation 2 below was used to find the percentage of fresh weight loss.

$$W_{loss} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \quad (2)$$

Where W_{loss} is the weight loss (%), $W_{initial}$ is the weight of the fresh-cut star fruit before storage (g), and W_{final} is the weight of the fresh-cut star fruit after storage (g).

Figure 3.2 Electronic weighing scale, BE610 (Beetle, UK) to measure the weight of the samples.

3.4 Color analysis

The color analysis was done by using colorimeter (CR-200, Konica Minolta U.S.A) and the samples of fresh-cut star fruits were measured at day 0, day 3, day 6, day 9, day 12, day 14, and day 16. The measurements were done at random location on the surface of fresh-cut star fruits. The results obtained for color difference, ΔE was expressed as luminosity, L*, greenness, a* and yellowness, b* and it was calculated by using equation 1 below:

$$\Delta E = ((\Delta L)^2 + (\Delta a^2) + (\Delta b^2))^{1/2} \qquad (1)$$

where, ΔL, Δa and Δb indicates the changes of the individual value before and after storage of fresh-cut star fruit.

Figure 3.3 Colorimeter (CR-200, Konica Minolta U.S.A) to determine L*a*b* value for fresh-cut star fruit.

3.5 Firmness analysis

Firmness analysis was done by using texture analyzer (TA.XT2 Stable Micro Systems, UK) with a 2 mm diameter (P/2) cylindrical probe attached in order to measure the firmness of fresh-cut star fruit. A 5000 N load was set on the equipment for calibration. The pre-test speed was 1.5 mm/s, the test speed was 1.5 mm/s and the post-test speed was 10 mm/s. The depth of the probe punctured into the edge of fresh-cut star fruit was 5 mm. The results was recorded as maximum force, F_{max} in Newtons (N) and it was measured on day 0, day 3, day 6, day 9, day 12, day 14, and day 16.

Figure 3.4 Texture analyzer (TA.XT2 Stable Micro Systems, UK) (left); and 2mm cylindrical stainless-steel probe (P/2N) function to measure the Fmax of fresh-cut star fruit (right).

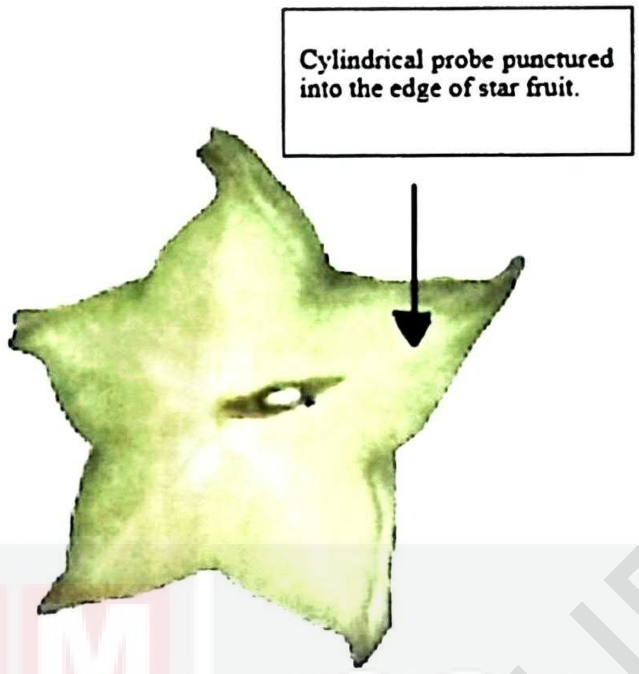


Figure 3.5 Location firmness of fresh-cut star fruit is determined

Table 3.3 Setting and parameters set in the texture analyzer software.

Settings	**Parameters**
Mode	Measure force
Option	Return to start
Pre-test speed	1.5 mm/s
Test speed	1.5 mm/s
Post-test speed	10.0 mm/s
Distance	5 mm
Trigger type	Auto - 25 g
Data acquisition rate	200 pps

3.6 Kinetic modelling on texture and color

Texture and color were modelled by zero-order model and first-order model. The kinetics of fresh-cut star fruit were obtained by zero-order model (equation 3) (Goncalves et al., 2010).

$$P = P_0 - kt \quad (3)$$

where P is the parameter to determine, P_0 is the initial observed parameter, k is the rate constant at temperature and t is the storage time. To plot the graph of first-order model the equation was converted into equation 4 (Goncalves et al., 2010).

$$1 - \frac{P}{P_0} = kt \quad (4)$$

where the x-axis, t is duration of blanching in minutes and the slope of graph is determined as the kinetic reaction rate.

3.7 Statistical analysis

Statistical analysis, two-way ANOVA was performed using IBM SPSS (Version 27) to compare the mean differences between groups. It was used to understand the interaction between two independent variables on the dependent variable. Hence, post hoc test, Turkey's and Bonferonni were used to find the least significant difference between the compared groups (P < 0.05).

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the data analyzed from the experiment that has been described in Chapter 3. The analysis started with the quality measurement on the fresh-cut star fruit stored in different packaging films and storage temperatures such as digital image analysis, fresh weight loss analysis, color analysis and texture analysis. After that, zero order, first order and fractional order models were used to compare the theoretical data and experiment data of color and texture of fresh-cut star fruit.

4.1 Physical appearance analysis

Appearance of fresh produce such as color, appearance, texture, flavor, and nutritional value is important to describe the quality (Barrett et al., 2010). Besides that, the consumers evaluated the freshness and appearance of fresh-cut products in the selection and for consumption (Massaglia et al., 2019). Hence, during this project the physical appearance of fresh-cut star fruits were observed throughout the samples storage period.

Based on the digital image analysis, fresh-cut star fruits stored at 30°C started to change the color from green to yellowish green with some rib-edge browning on day 3 and started to decay and turn mushiness on day 6 when packed in polypropylene (PP) and low-density polyethylene (LDPE) whereas the samples packed in polyethylene terephthalate (PET) started to decay and turn mushiness on day 9 (Table 4.1). The degradation of quality in fresh-cut occur due to the increase in respiration rate during storage which have been reported to speed up the enzymatic browning and loss of tissue texture such as become mushiness (Samsul Rizal et al., 2018). Besides that, polyethylene terephthalate (PET) showed good performance in extending the shelf life of samples stored at 30°C due to its excellent moisture and gas barrier properties (Fellows, 2009).

Fresh-cut star fruits that are stored at 5°C able to maintain its fresh-like properties up to day 12 as the samples showed no obvious color changes from day 0 of storage despite stored in different packaging films (Table 4.2). However, some rib-edge browning started to display on day 14 of storage. Low storage temperatures are recommended to store the fresh-cut fruit due to the decrease of microbial contamination and respiration rates during the storage which can extend the shelf life of products (Garcia & Barret, 2005). For fresh-cut star fruit stored at -25°C showed a freezing injury on day 9 of storage as the samples showed changes in color from green to brown with serious injury, reduced in size and lost the texture shape (Table 4.3). However, fresh-cut star fruits can be categorized as least susceptible to freezing injury as the samples able to maintain its fresh-like properties until day 3 before it showed serious damage in tissue (Wang, n.d.). Wang (n.d.) also stated that freezing injury occurs due to tissue injury as the ice crystal form in the tissue can cause the fruits to lose its rigidity and become mushy after thawing.

Table 4.1 Changes in physical appearance throughout storage for fresh cut star fruit stored at 30°C.

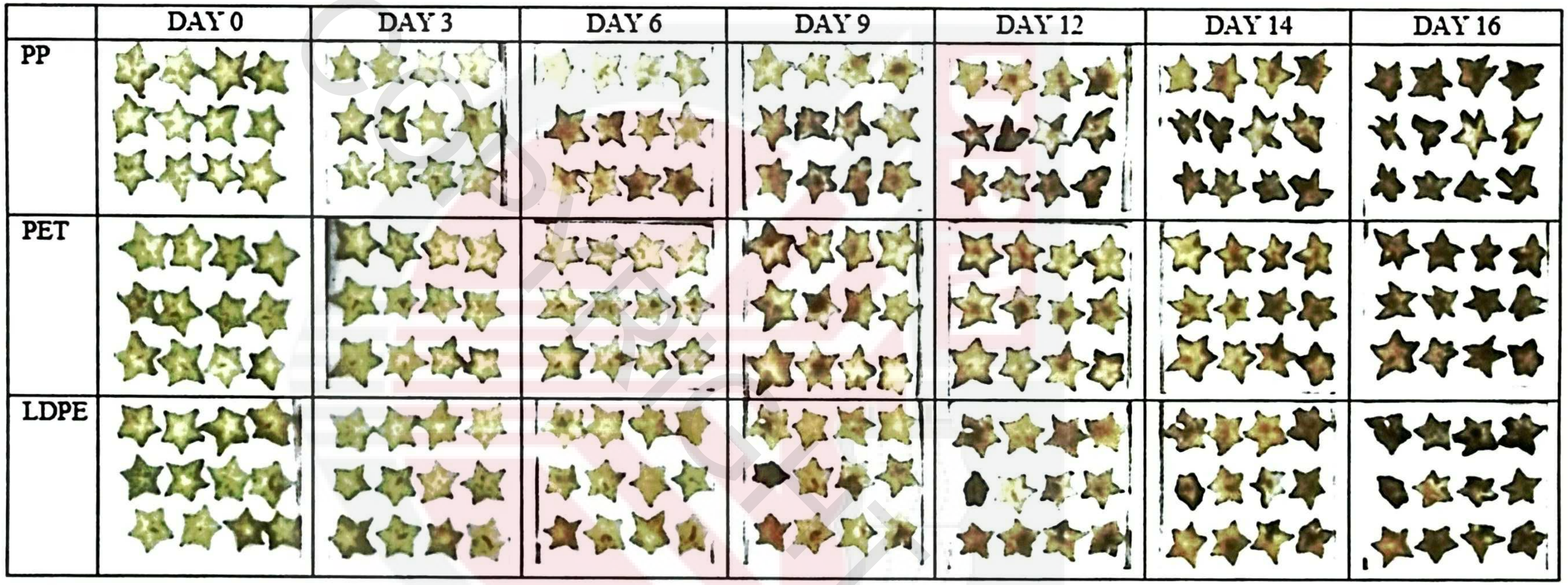


Table 4.2 Changes in physical appearance throughout storage for fresh cut star fruit stored at 5°C.

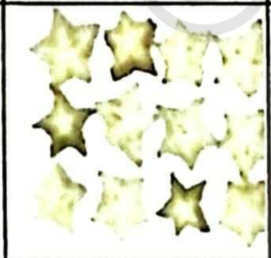
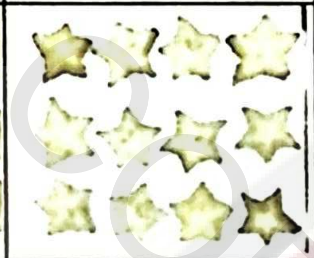
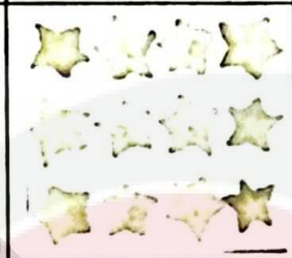
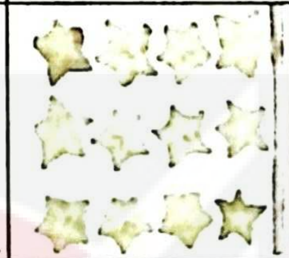
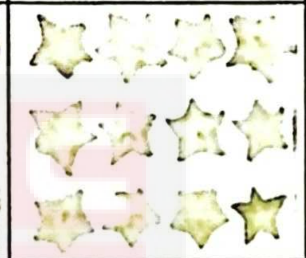
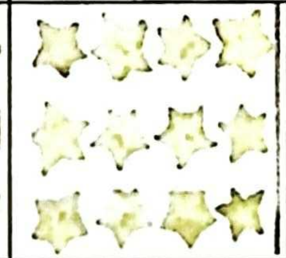
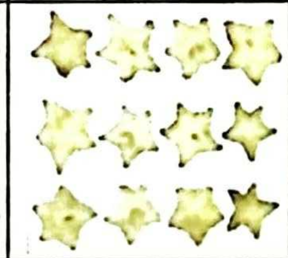
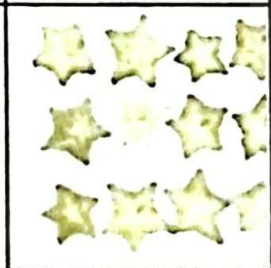
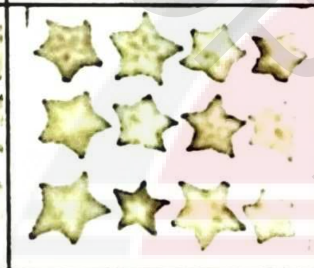
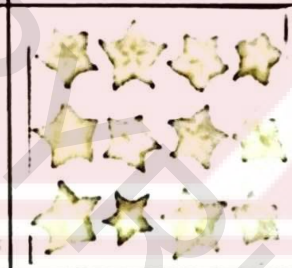
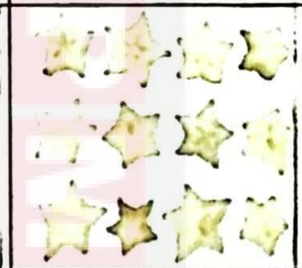
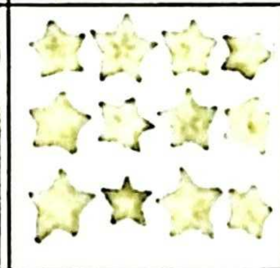
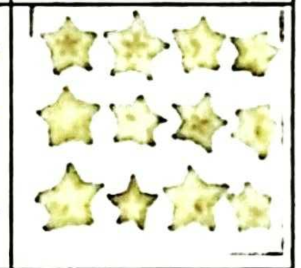
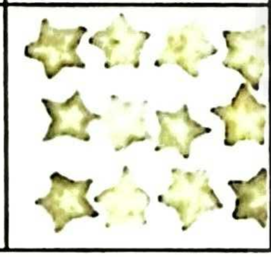
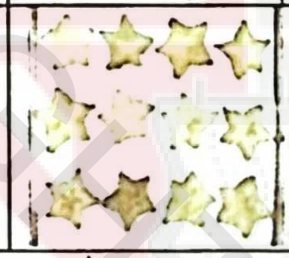
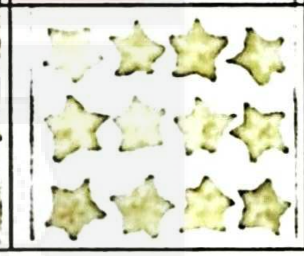
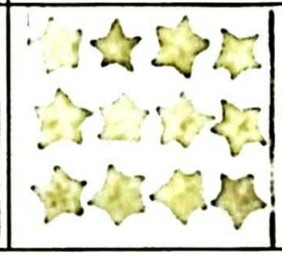
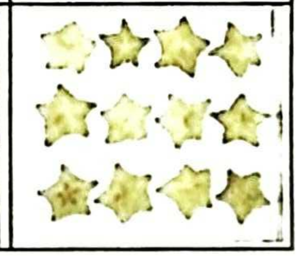
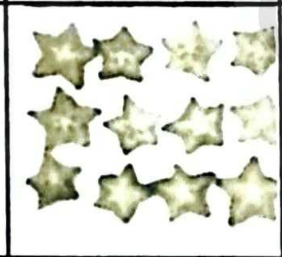
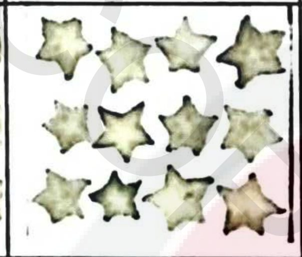
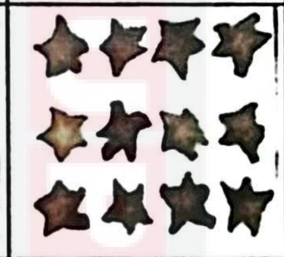
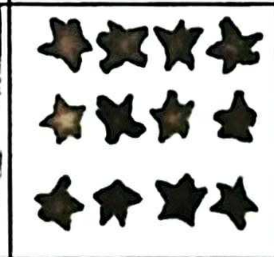
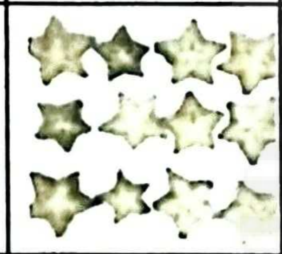
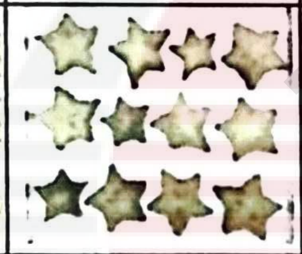
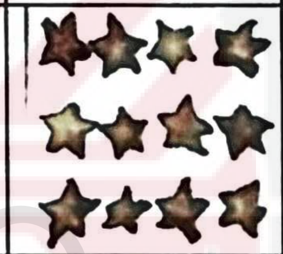
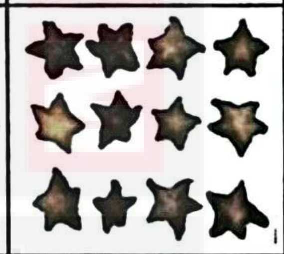
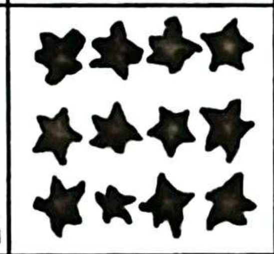
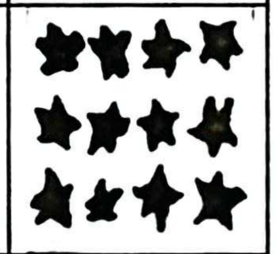
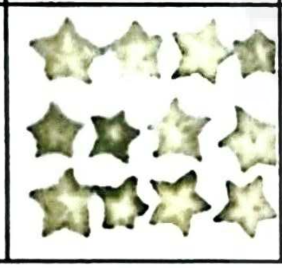
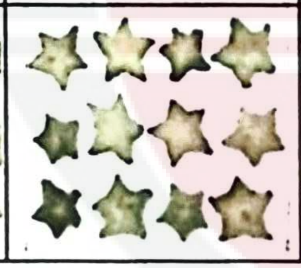
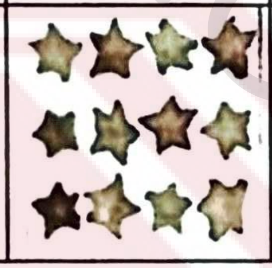
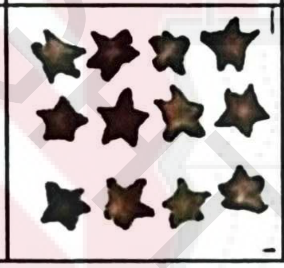
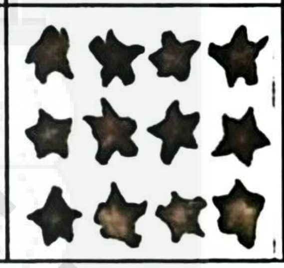
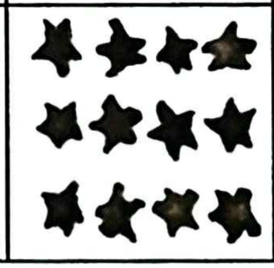
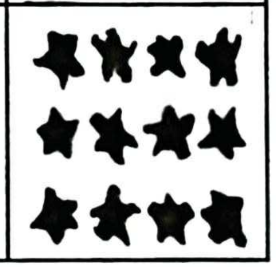
	DAY 0	DAY 3	DAY 6	DAY 9	DAY 12	DAY 14	DAY 16
PP							
PET							
LDPE							

Table 4.3 Changes in physical appearance throughout storage for fresh cut star fruit stored at -25°C.

	DAY 0	DAY 3	DAY 6	DAY 9	DAY 12	DAY 14	DAY 16
PP							
PET							
LDPE							

4.2 Fresh weight loss analysis

The water loss has major consequences for the quality characteristics of fresh produce such as firmness, turgidity, wilting, and withering (Aindongo et al., 2014). Besides that, fresh-cut products are more susceptible to the water loss that intact product due to large surface-area-to-volume ratio cause during cutting processing (Mihafu et al., 2020). Therefore, the fresh weight loss analysis were analyzed throughout the experiment to determine the quality of the fresh-cut starfruits.

Samples stored at -25°C in polypropylene (PP) has the highest percentage of weight loss at day 16 which was 51.34% followed by polyethylene terephthalate (PET) and low-density polyethylene (LDPE) with percentages of 47.67% and 47.09% while at 30°C the fresh weight losses were 50.23%, 25.94%, and 23.71% for polypropylene (PP), polyethylene terephthalate (PET) and low-density polyethylene (LDPE). Then, the samples stored at 5°C were 7.9%, 2.98% and 2.51% for polypropylene (PP), low-density polyethylene (LDPE) and polyethylene terephthalate (PET) respectively with ($P>0.05$) (figure 4.1). For all the three films tested, the fresh weight loss for samples stored at -25°C is significantly higher than samples stored 30°C and 5°C. This is because, when starfruits were transferred from cold storage to room temperature, they lost more water due to chilling injury (Thompson, 2010). Hence, according to Siracusa (2012), the fresh produce has shorter shelf life due to rapid deterioration and quality loss when the weight loss is higher.

According to Bovi et al. (2016), the water vapor permeability of the packaging films influenced the moisture in packed fresh produce. Consequently, lower water transmission rate (WTR) of film packaging can reduced its permeability to keep the product moisture within the package. Furthermore, the retail value of fresh produce can lower when it the weight loss is more than 5% (Ohta et al., 2002). Therefore, polyethylene terephthalate (PET) was determined to be the best film packaging at limiting the moisture loss to the surrounding area due to its lower water transmission rate (WTR) value compared to low-density polyethylene (LDPE) and polypropylene (PP) when samples stored at 5°C.

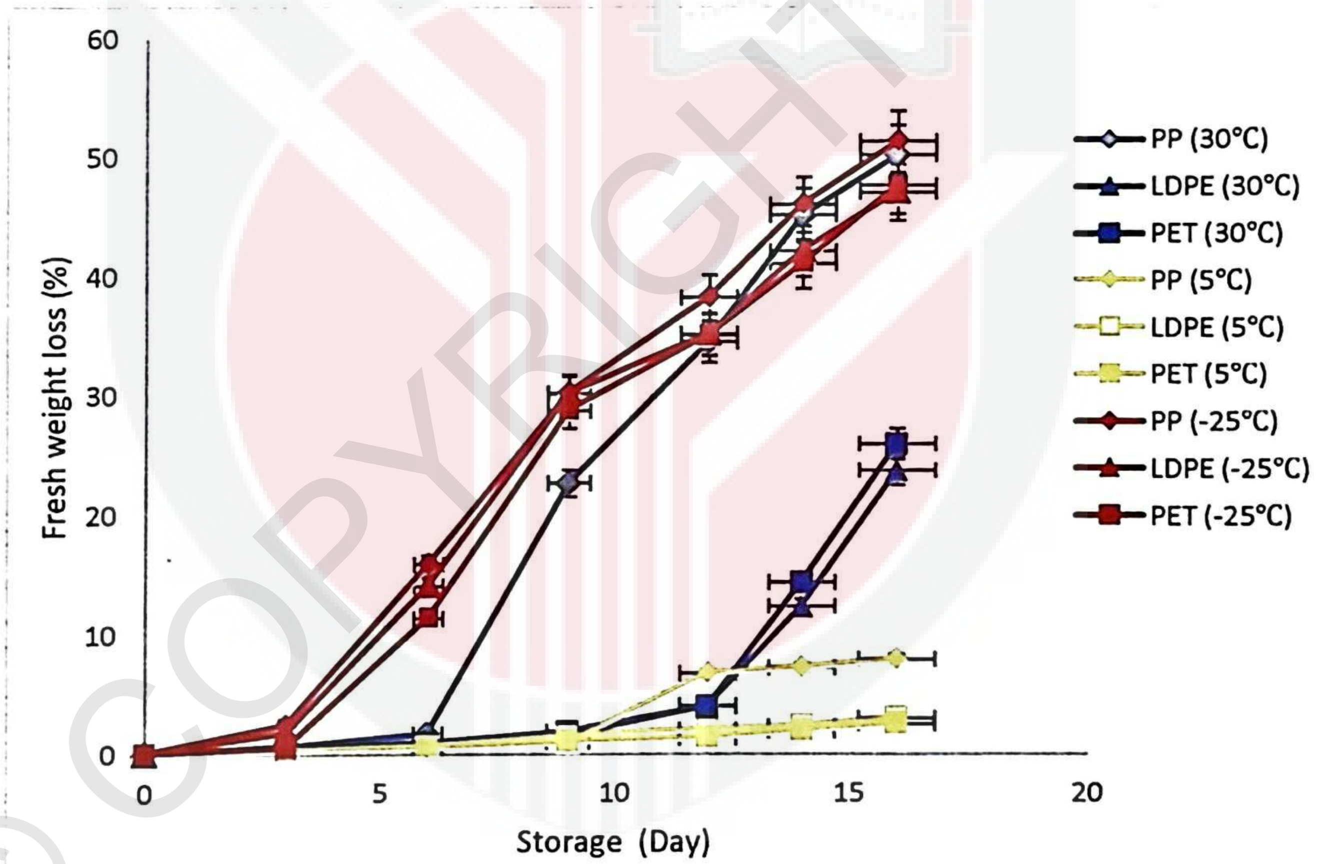


Figure 4.1 Fresh weight loss of fresh-cut star fruit in different packaging films stored at 30°C, 5°C and -25°C.

4.3 Color analysis

Color is one of the most significant factors that indicates the overall quality and the acceptability of the fresh-cut products (Mihafu et al., 2020). The color changes of fresh-cut star fruits were measured in terms of L*a*b* values and total color difference, ΔE. L* value represents to the lightness (+ve) or darkness (-ve), a* value indicates the red (+ve) and green color (-ve) and b* indicates the yellow (+ve) and blue color (-ve).

From the analysis, it is observed that the fresh-cut starfruits packed in all packaging films stored at -25°C showed the highest decrement in its lightness followed by samples stored at 30°C, 5°C (Figure 4.2, Figure 4.3 and Figure 4.4). It is observed that the L* value of fresh-cut star fruit is not dependent on storage day and packaging films having value of ($P > 0.05$). The darker color of samples stored at -25°C showed a freezing injury (Table 4.3). Elisabeth et al. (2002) stated that the discoloration and dehydration happened due to water lost form the commodities that led to flaccidity and pithiness. Hence, as the L* value decreased, the quality of samples decreased due to discoloration.

Regardless of film type and storage temperature, there was insignificant difference ($P > 0.05$) in a* and b* values for fresh-cut star fruit stored in all packaging films (Figure 4.2, Figure 4.3 and Figure 4.4). Samples stored in 30°C have the highest changes in b* values while at 5°C has the lowest changes of b* values. This is because, at higher temperature, it exhibited more oxidation and degradation of pigmented phytochemicals (K. D. Atigan et al., 2019). It can be concluded that, as the temperature and storage time increased, the b* parameters also increased resulting in the yellowness of fresh-cut star fruit.

The ΔE values also not showed significant changes of samples stored in different packaging films throughout storage with ($P > 0.05$) however the differences can be seen through observation from the digital image (Figure 4.5). The samples have the lowest value of ΔE when packed in polyethylene terephthalate (PET) at 5°C which is 8.99 after 16 days of storage followed by low-density polyethylene (LDPE) and polypropylene (PP) which are 15.72 and 24.74. Hence, polyethylene terephthalate (PET) was determined to have good barrier properties as it able to limit the moisture content and oxygen from passing through the films which reduce the product degradation and browning reactions.

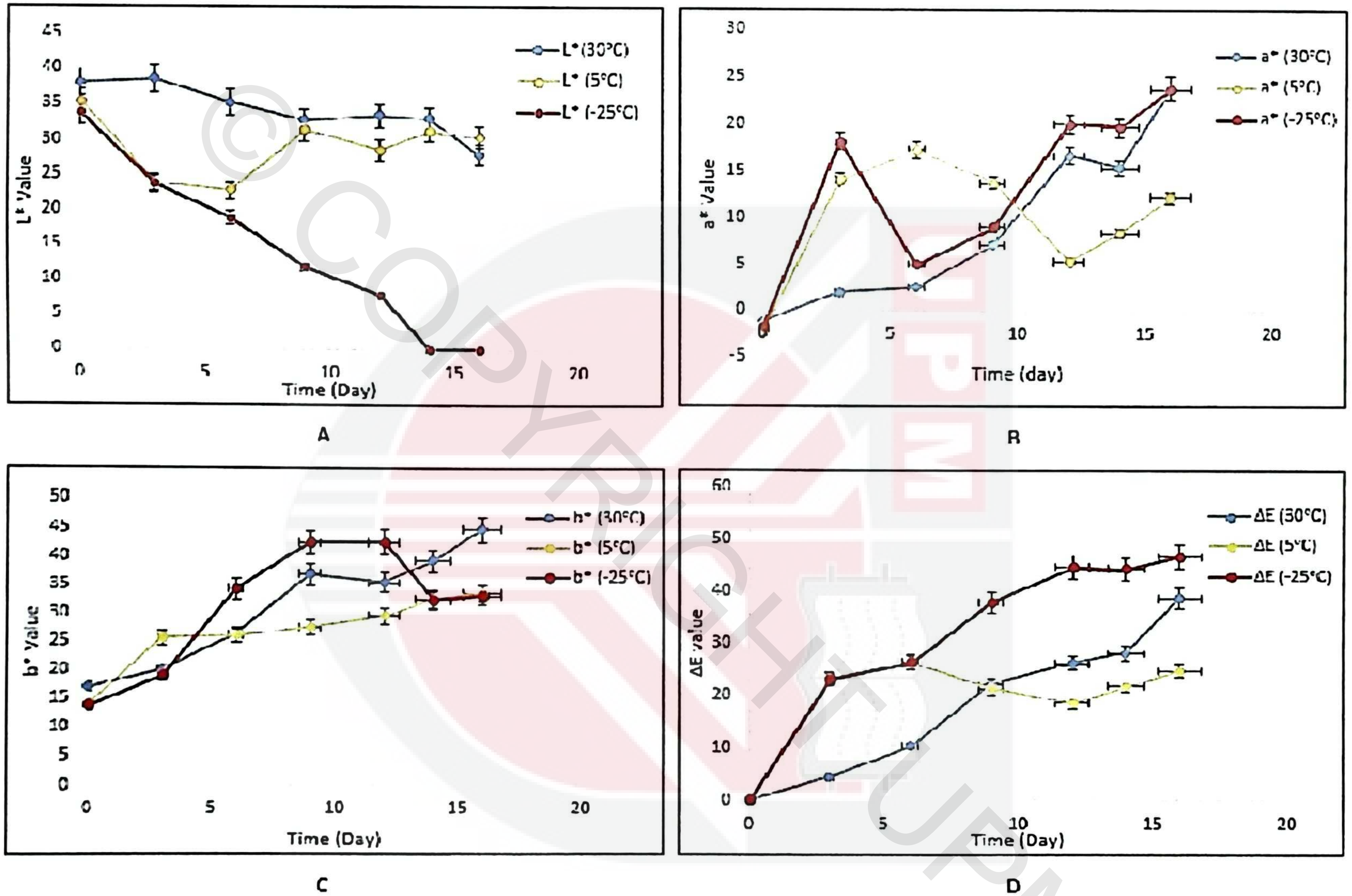


Figure 4.2 Color parameters (A) L* (B) a* (C) b* (D) ΔE for fresh-cut star fruit in Polypropylene (PP) film stored at different storage conditions.

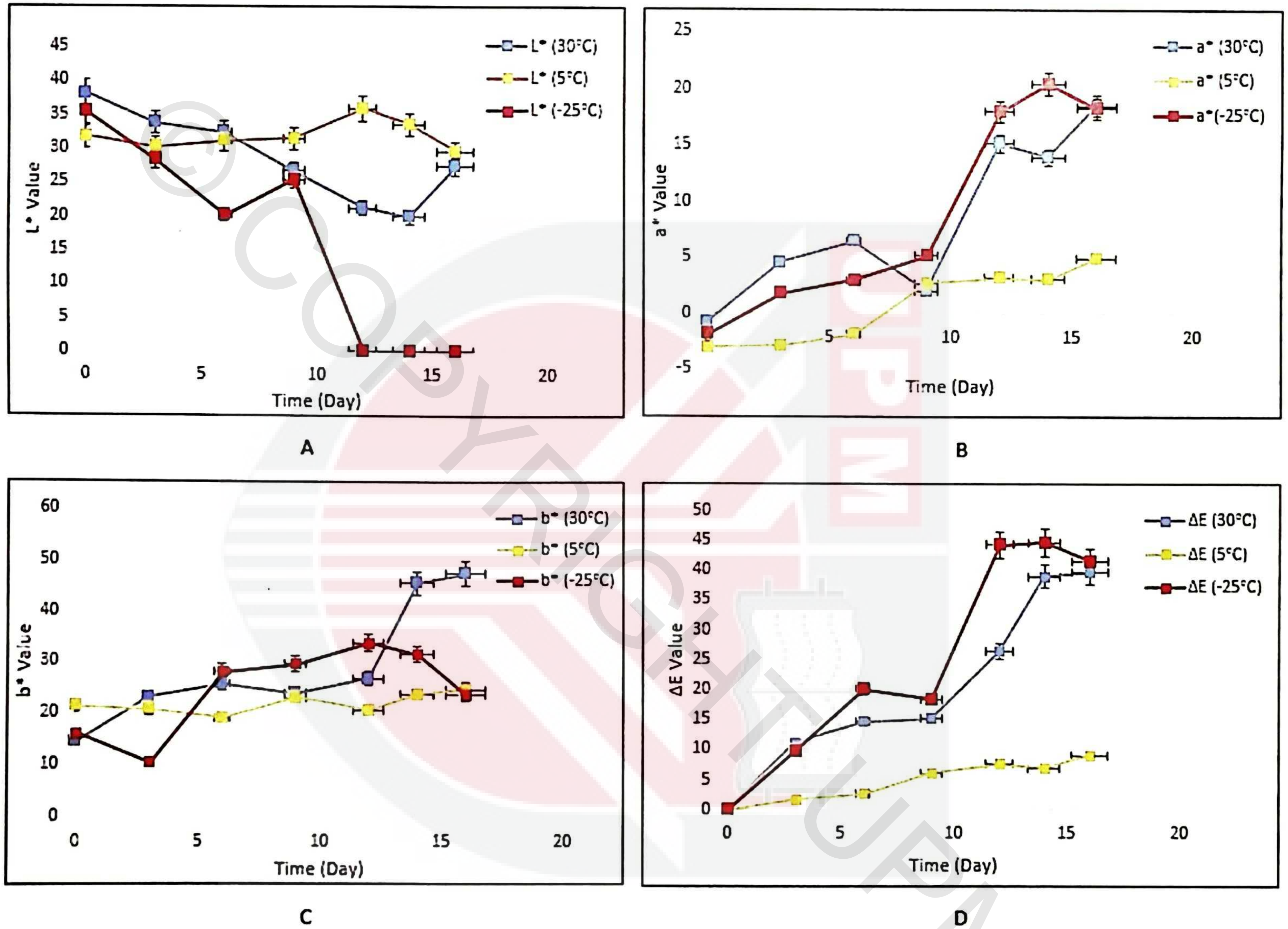


Figure 4.3 Color parameters (A) L* (B) a* (C) b* (D) ΔE for fresh-cut star fruit in polyethylene terephthalate (PET) film stored at different storage conditions.

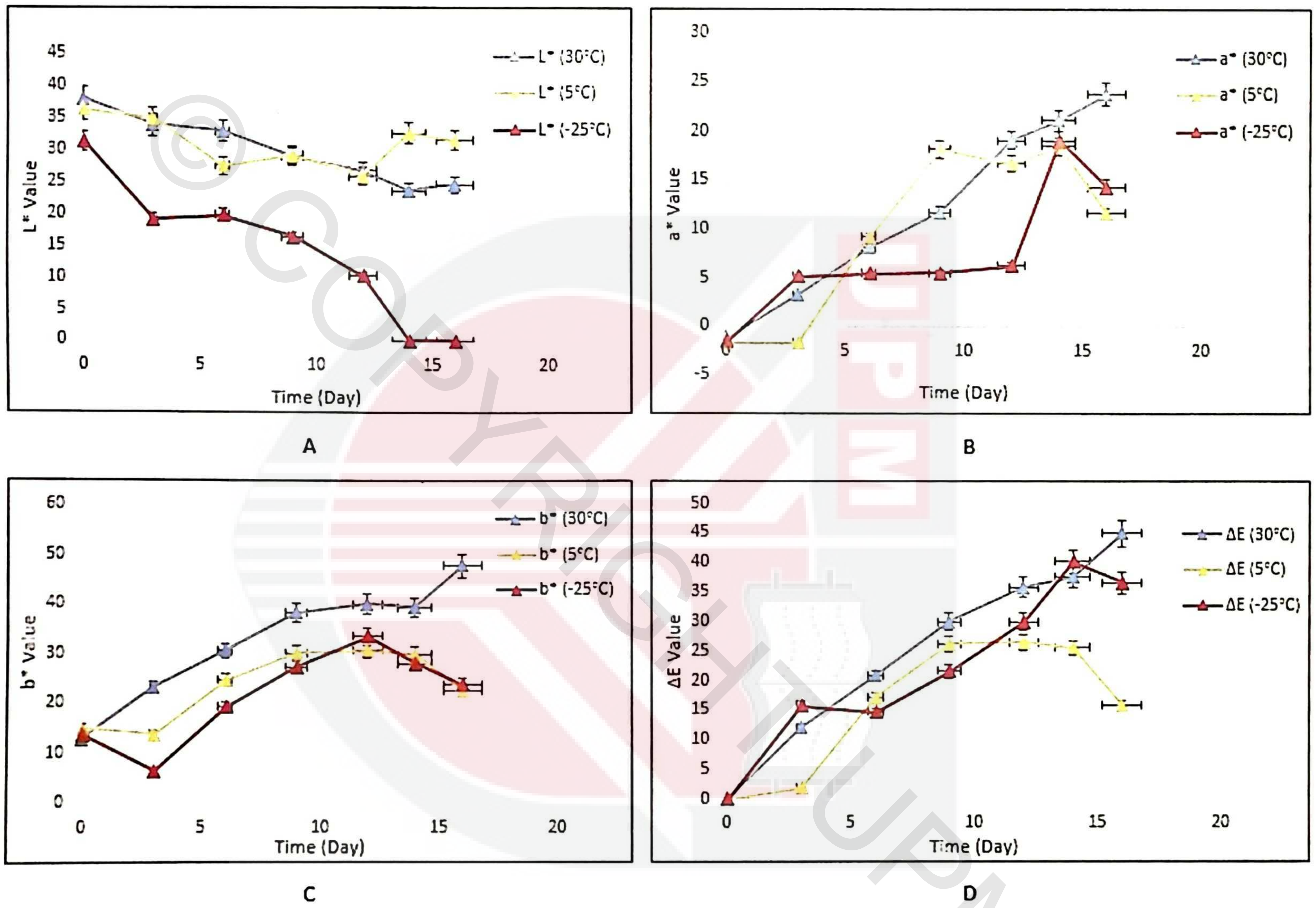


Figure 4.4 Color parameters (A) L* (B) a* (C) b* (D) ΔE for fresh-cut star fruit in low-density polyethylene (LDPE) film stored at different storage conditions.

4.4 Firmness analysis

Plant tissue texture of fruit products varies during postharvest handling due to a variety of circumstances, including maturity stage, water stress, storage temperature and relative humidity, physical handling, and the ripening process (Mihafu et al., 2020). Therefore, texture analysis was done to determine the textural properties and firmness of fresh-cut star fruit throughout the storage by puncture test.

At temperature 5°C, the samples packed in polypropylene (PP) have the highest maximum force (F_{max}) with values 3.07 N followed by low-density polyethylene (LDPE) and polyethylene terephthalate (PET) with values 2.45 N and 2.01 N after 16 days of storage. The firmness of samples stored at -25°C were 1.83 N, 1.75 N and 1.69 N after 16 days of storage for polypropylene (PP), polyethylene terephthalate (PET) and low-density polyethylene (LDPE) while at 30°C the firmness of samples were 0.76, 0.58 and 0.5 for polyethylene terephthalate (PET), low-density polyethylene (LDPE) and polypropylene (PP) (Figure 4.6). There was insignificance difference for firmness of sample stored at different packaging films ($P > 0.05$). For all the three films tested, fresh-cut starfruits stored at 30°C has higher texture degradation compared to samples stored at -25°C and 5°C. This is because, the star fruits have higher deterioration rate as the samples started to become mushiness and loss in shape texture after day 3 of storage. Furthermore, the rupture of plasma membrane and cell-wall modification due to the mechanical injury such as cutting of starfruits results in deterioration and quality loss (Mihafu et al., 2020). Therefore, the firmness of fresh-cut star fruit decreased as storage time increased.

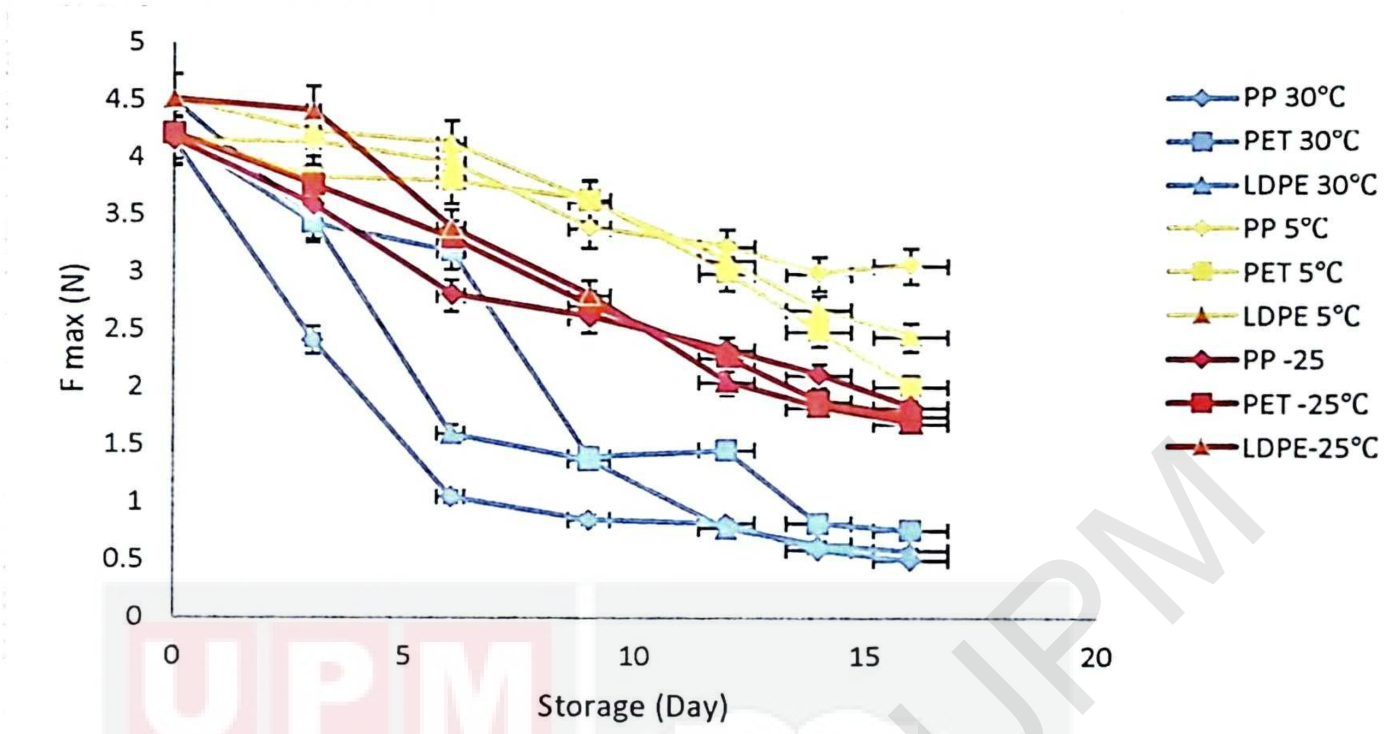


Figure 4.6 F_{max} value for fresh-cut star fruit in different packaging films stored at 30°C, 5°C and -25°C.

4.5 Fogginess

Fresh products moisture loss can lead to an accumulation of moisture on the product packaging. Bovi et al. (2016) stated that the moisture loss accumulate within the packaging system would foster the growth of microorganism and causing the quality of fresh produce to deteriorate. Therefore, the fogginess within the packaging were observed throughout the fresh-cut-storage period.

From the observation, the fogginess inside the film packaging that stored at 30°C started to increase before the samples became mushy and spoiled (Table 4.4). As it can be seen on Table 4.4, the fogginess formed inside the polyethylene terephthalate (PET) increased on day 9 and the samples started to spoil on day 12 of storage. This means that, the degradation of quality in fresh-cut star fruit occurs due to condensation of moisture loss that accumulate within the polyethylene terephthalate (PET) which promotes the growth of spoilage microorganisms. However, the formation of fogginess inside the film packaging stored at 5°C showed a steady formation and there is no obvious changes in the fogginess accumulate inside of the three film packaging (Table 4.5). For film packaging stored at -25°C, there is no fogginess formed in the surface of packaging as shown in Table 4.6. This is due to the fact that at low temperatures, the water vapor present in air is lower compared to in high temperature (Othman et al., 2017).

The formation of water vapor inside film packaging is due to transmission rate of film packaging and transpiration rate of fresh products (Linke & Geyer, 2012). Furthermore, according to Othman et al. (2017), when the temperature is high, the capacity of the surrounding air to store more water in vapor state is higher than when the temperature is low which leads to an increase in moisture content. Hence, polyethylene terephthalate (PET) was determined to be the best film packaging at limiting the formation of fogginess and showed good performance in extending the shelf life of samples until day 6 when stored at 30°C due to its excellent moisture and gas barrier properties compared to low-density polyethylene (LDPE) and polypropylene (PP) (Fellows, 2009).

Table 4.4 Changes in fogginess inside film packaging throughout storage for fresh cut star fruit stored at 30°C.

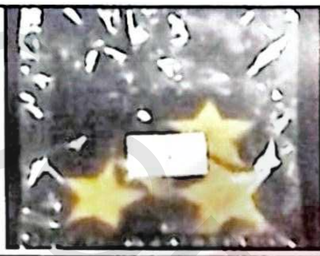
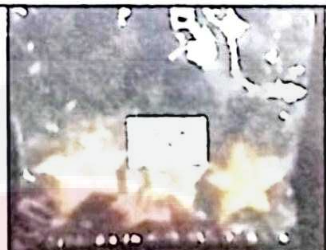
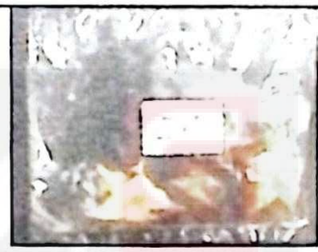
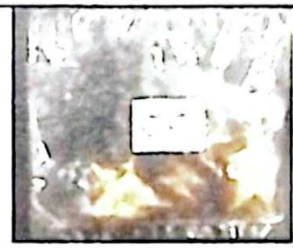
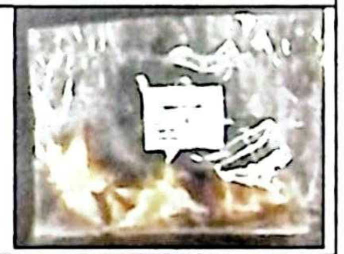
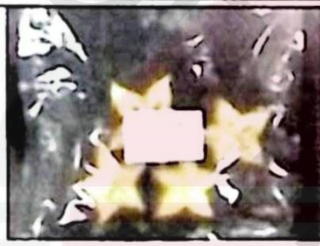
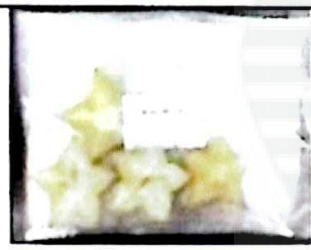
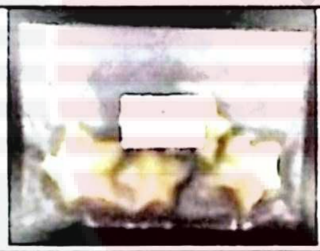
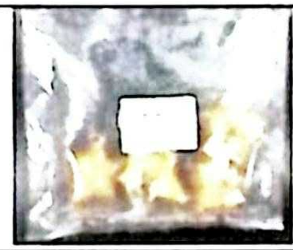
	DAY 3	DAY 6	DAY 9	DAY 12	DAY 14	DAY 16
PP						
PET						
LDPE						

Table 4.5 Changes in fogginess inside film packaging throughout storage for fresh cut star fruit stored at 5°C.

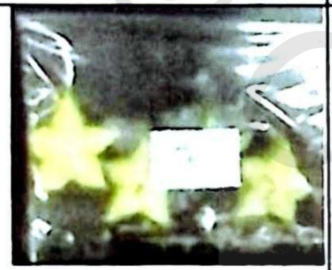
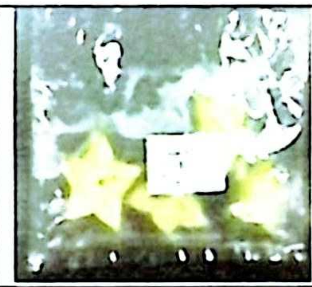
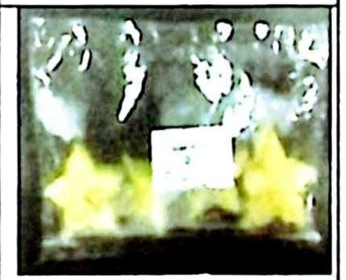
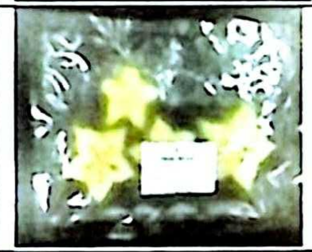
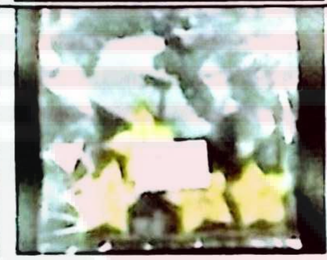
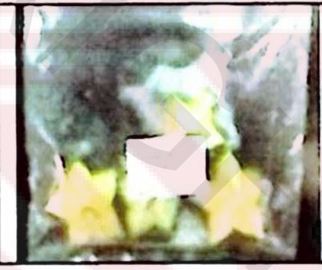
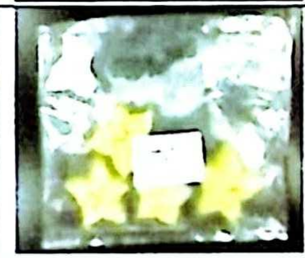
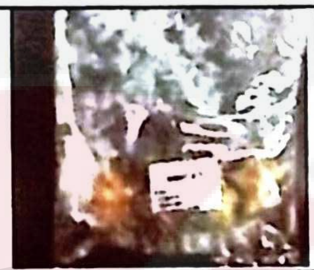
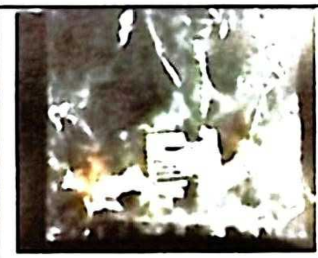
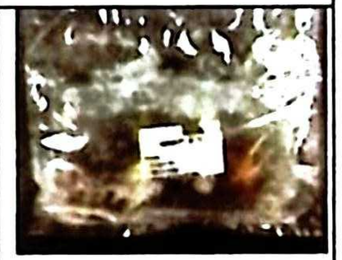
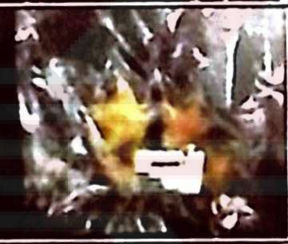
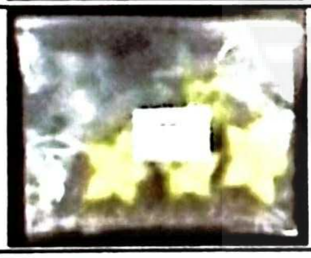
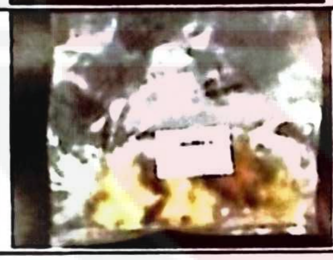
	DAY 3	DAY 6	DAY 9	DAY 12	DAY 14	DAY 16
PP						
PET						
LDPE						

Table 4.6 Changes in fogginess inside film packaging throughout storage for fresh cut star fruit stored at -25°C.

	DAY 3	DAY 6	DAY 9	DAY 12	DAY 14	DAY 16
PP						
PET						
LDPE						

4.6 Kinetic changes of color

In this section, the kinetic modeling on color parameters which are a*, b*, L*and ΔE values. The kinetic modeling on color parameters were compared between 0th order and 1st order except for a* values and ΔE values as it is not suitable to be used in 1st order due to its initial value that is negative and zero value for a* and ΔE values respectively.

The kinetic changes of a* values were tabulated in Table 4.7. From the analysis, the changes of a* value for samples stored at 30°C fitted the zero-order model with 0.80, 0.99 and 0.92 for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) meanwhile samples stored at 5°C and -25°C does not fit in zero-order model. Figure 4.7 (A) showed that the slope is getting steeper as the storage time increased, indicating higher k. This is because, as the storage period increased, the samples started to decay and change color from green to red when stored at 30°C.

The kinetic changes for b* and L* values also do not fit in both zero-order and first-order model in all packaging films and storage temperature (Table 4.8 and Table 4.9). However, the color parameter for b* value for samples stored at 30°C fitted the first-order model with value 0.83, 0.85 and 0.94 for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) and the L* value for samples stored at -25°C fitted the zero-order model with value 0.86, 0.92 and 0.97 for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) respectively. Samples stored in 30°C have the highest changes in b* values and based on

Figure 4.8 (A) it can be concluded as the temperature and storage time increased, the b* parameters also increased resulting in the yellowness of fresh-cut starfruits.

The kinetic changes of color for ΔE value were tabulated in Table 4.10. The samples stored at 30°C and -25°C fitted the zero-order model where the value are 0.93, 0.98 and 0.97 for samples stored at 30°C and 0.9, 0.93 and 0.89 at -25°C for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) respectively. 4)

Table 4.7 Kinetic changes of color (a*) for fresh-cut star fruit at different packaging films and storage temperatures.

Parameter	Packaging films	Temperature	Zero-order model	
			k	R^2
a*	PET	30°C	1.12	0.80
		5°C	0.55	0.91
		-25°C	1.49	0.88
	LDPE	30°C	1.62	0.99
		5°C	1.22	0.67
		-25°C	0.98	0.73
	PP	30°C	1.51	0.92
		5°C	0.28	0.07
		-25°C	1.24	0.60

Table 4.8 Kinetic changes of color (b*) of fresh-cut star fruit at different packaging films and storage temperatures.

Parameter	Packaging films	Temperature	Zero-order model		First-order model	
			k	R^2	k	R^2
b*	PET	30°C	1.84	0.79	0.06	0.83
		5°C	0.22	0.42	0.01	0.40
		-25°C	0.99	0.46	0.05	0.46
	LDPE	30°C	1.94	0.93	0.07	0.85
		5°C	0.86	0.60	0.04	0.54
		-25°C	1.21	0.59	0.07	0.54
	PP	30°C	1.72	0.95	0.06	0.94
		5°C	0.99	0.83	0.04	0.74
		-25°C	1.31	0.60	0.05	0.57

Table 4.9 Kinetic changes of color (L*) of fresh-cut star fruit at different packaging films and storage temperatures.

Parameter	Packaging films	Temperature	Zero-order model		First-order model	
			k	R^2	k	R^2
L*	PET	30°C	-0.98	0.74	-0.03	0.69
		5°C	0.09	0.06	0.002	0.05
		-25°C	-2.43	0.86	-0.28	0.79
	LDPE	30°C	-0.89	0.97	0.69	0.19
		5°C	-0.30	0.22	-0.01	0.19
		-25°C	-1.85	0.92	-0.21	0.75
	PP	30°C	-0.56	0.84	0.004	0.02
		5°C	-0.97	0.74	0.003	0.02
		-25°C	-2.11	0.97	0.75	0.84

Table 4.10 Kinetic changes of color (ΔE) of fresh-cut star fruit at different packaging films and storage temperatures.

Parameter	Packaging films	Temperature	Zero-order model	
			k	R^2
ΔE	PET	30°C	2.42	0.93
		5°C	0.56	0.95
		-25°C	2.91	0.90
	LDPE	30°C	2.66	0.98
		5°C	1.46	0.58
		-25°C	2.29	0.93
	PP	30°C	2.35	0.97
		5°C	0.85	0.32
		-25°C	2.69	0.89

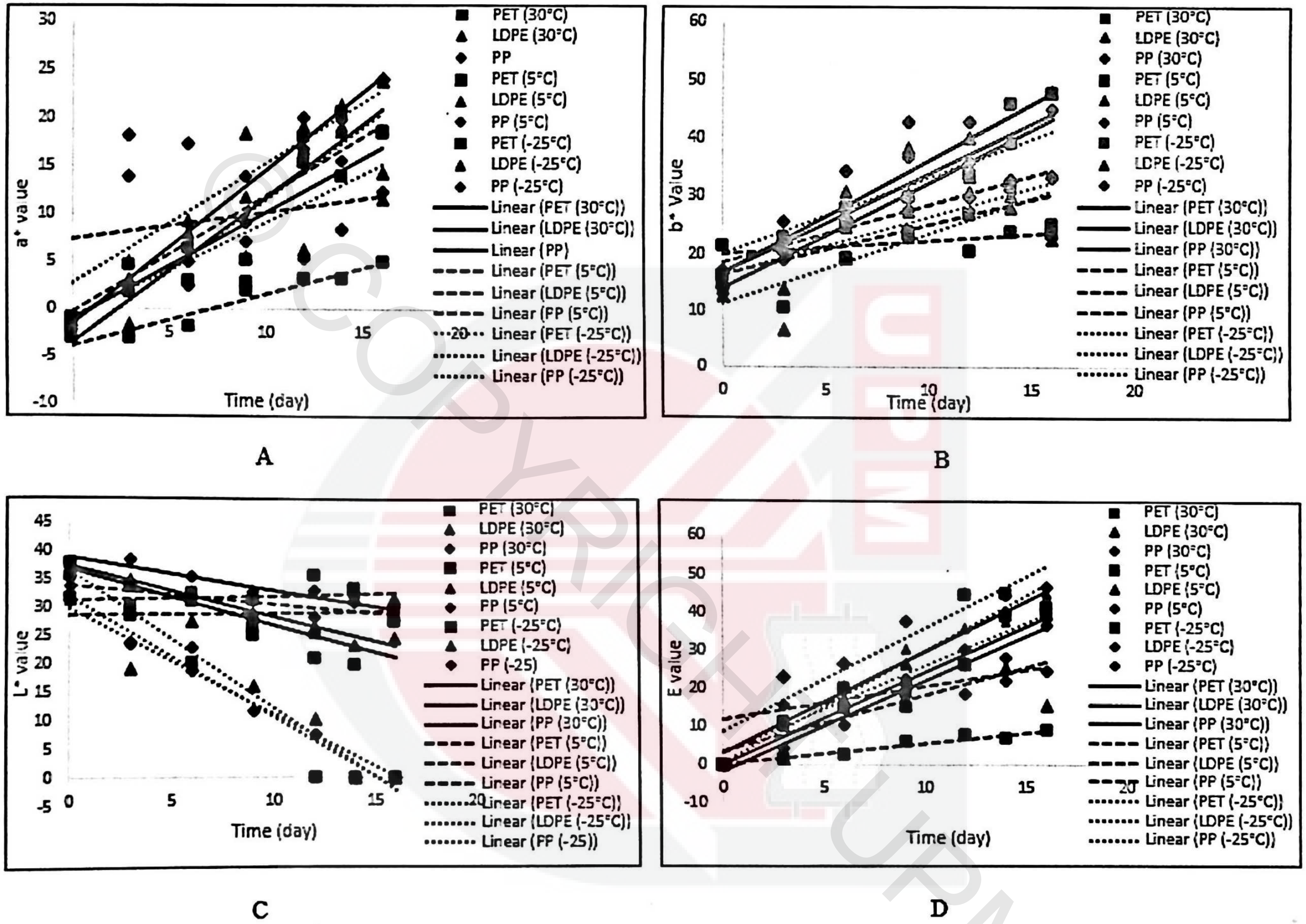


Figure 4.7 Zero-order kinetic model on color parameters of fresh-cut star fruit stored for value (A) a*, (B) b*, (C) L* and (D) ΔE.

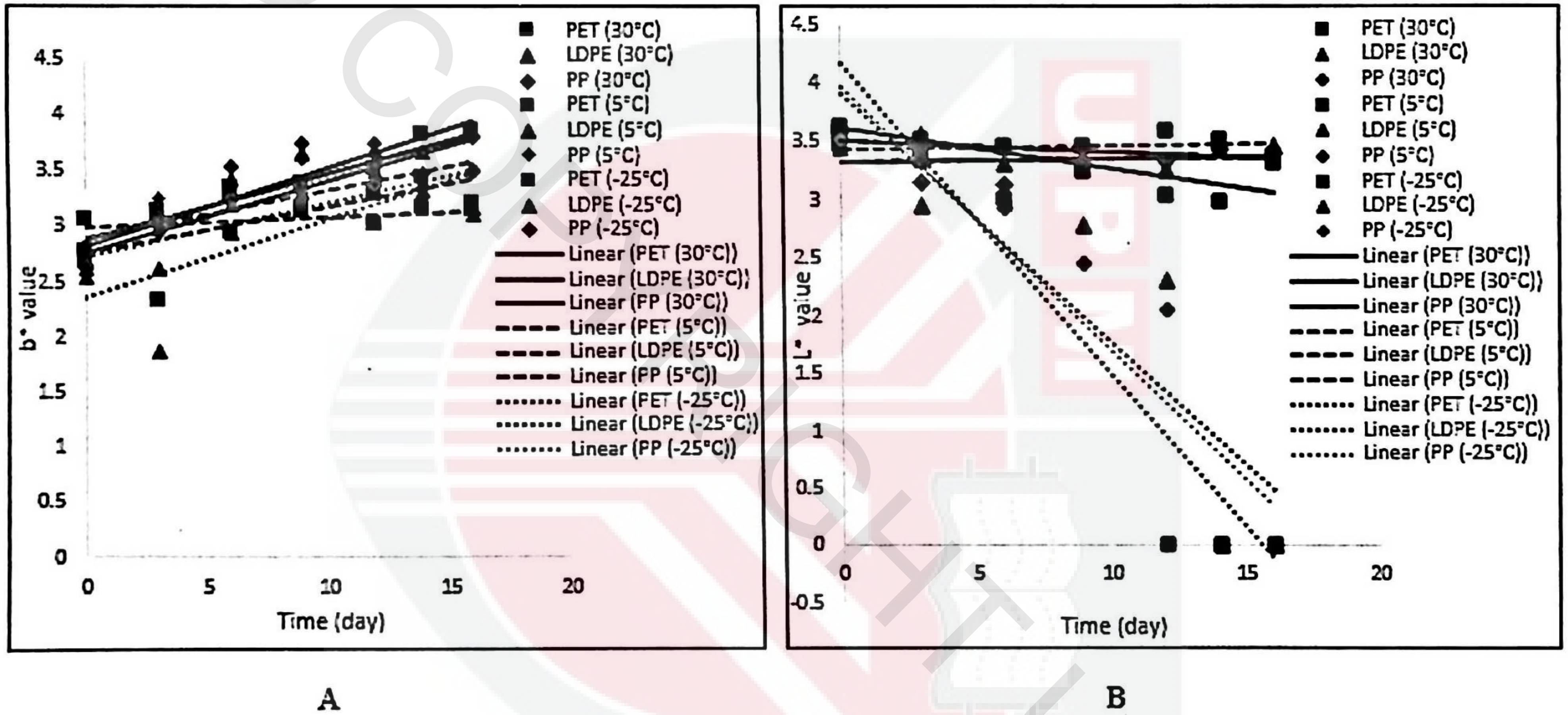


Figure 4.8 First-order kinetic model on color parameters of fresh-cut star fruit stored for value (A) b* and (B) L*.

4.7 Kinetic degradation of firmness

The maximum force, N used to puncture fresh-cut starfruits throughout 16 days of storage were tabulated in Table 4.11. The kinetic modeling on texture were compared between 0th order and 1st order. From the analysis, the changes of firmness of samples stored in 30°C and -25°C could be sufficiently (R^2 values range from 0 to 1) characterized by first-order model where R^2 values are 0.93, 0.97 and 0.92 (30°C) and 0.99, 0.97 and 0.96 (-25°C) for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) (Figure 4.10). However, the changes of firmness for samples stored in 5°C fit the zero-order model where R^2 values are 0.90, 0.96 and 0.93 for polyethylene terephthalate (PET) low-density polyethylene (LDPE) and polypropylene (PP) (Figure 4.9).

Regardless of the model used, fresh-cut starfruits stored at 30°C showed higher changes of firmness compared to when stored at -25°C and 5°C. As it can be seen on the plotted graph, it can be concluded that different storage temperature affect the k values (Figure 4.9 and Figure 4.10). Besides that, the texture degradation rate was higher at 30°C compared to when stored at lower temperature, -25°C and 5°C. This is because, the fresh products have higher deterioration at high temperature due to the increase in respiration rate during storage which have been reported to speed up the enzymatic browning and loss of tissue texture such as become mushiness (Samsul Rizal et al., 2018). Thus, the changes of firmness increased as the storage time increase despite the packaging film used to pack the samples.

Table 4.11 Kinetic parameter for changes of firmness of fresh-cut star fruit at different packaging films and storage temperatures.

Packaging films	Temperature	Zero-order model		First-order model	
		k	R^2	k	R^2
PET	30°C	-0.23	0.94	-0.11	0.93
	5°C	-0.13	0.90	-0.04	0.85
	-25°C	-0.16	0.99	-0.06	0.98
LDPE	30°C	-0.25	0.88	-0.14	0.97
	5°C	-0.13	0.96	-0.04	0.93
	-25°C	-0.19	0.97	-0.06	0.97
PP	30°C	-0.20	0.77	-0.13	0.92
	5°C	-0.08	0.93	-0.04	0.93
	-25°C	-0.14	0.96	-0.04	0.98

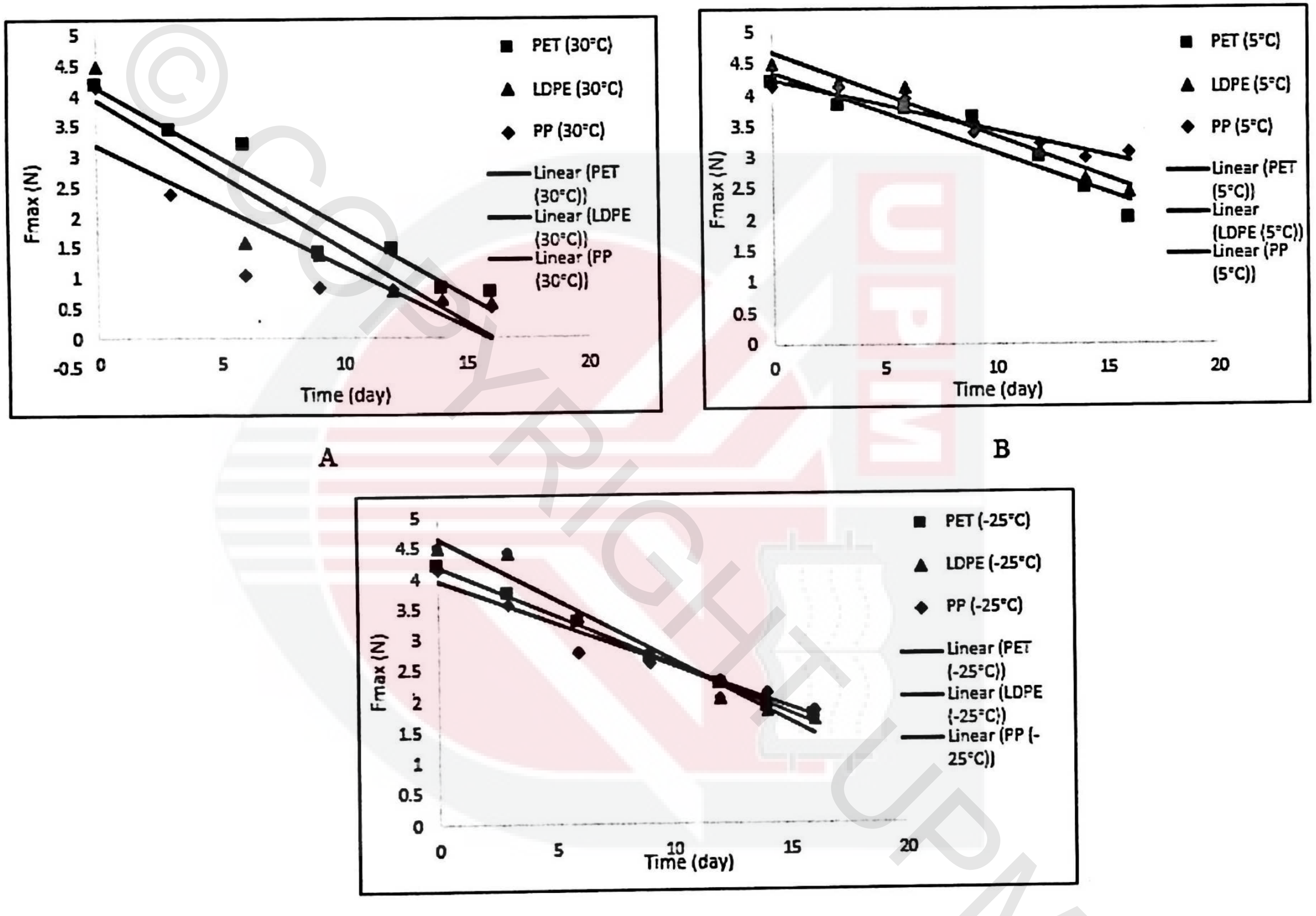
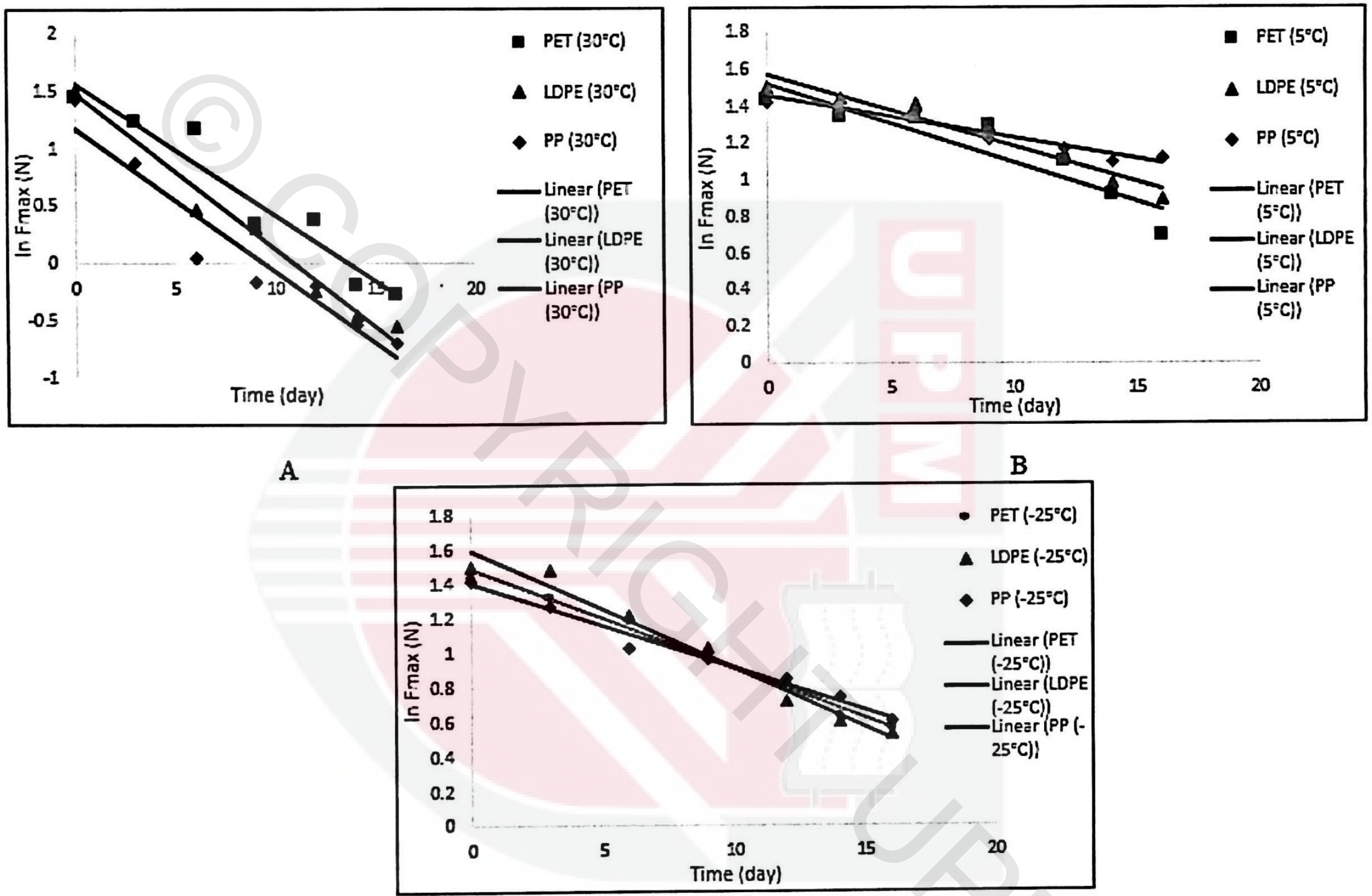


Figure 4.9 Zero-order kinetic model on the firmness of fresh-cut star fruit stored at (A) 30℃, (B) 5℃ and (C) -25℃.



C

Figure 4.10 First-order kinetic model on the firmness of fresh-cut star fruit stored at (A) 30°C, (B) 5°C and (C) -25°C.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The quality of fresh-cut starfruits stored at different packaging films (LDPE, PET and PP) and storage conditions (-25°C, 5°C and 30°C) such as physical appearance, fresh weight, color and texture were determined. Besides, the texture and color of fresh-cut starfruits were modeled using zero-order model and first-order model.

Samples packed in polyethylene terephthalate (PET) showed a better performance in terms of color, physical appearance, weight loss and textural properties. As presented, fresh-cut starfruits maintained its fresh-like properties up to day 6 when packed in PET film meanwhile only up to day 3 when stored at LDPE film and PP film at temperature 30°C. At 5°C, the fresh-cut star fruit able to extend its shelf life for up to 16 days in all packaging films. At -25°C, the samples stored at all packaging films able to maintain its fresh-like properties until day 3 before it showed serious damage due to freezing injury. Hence, the samples stored at 5°C showed a better performance to extend the shelf life compared when stored at 30°C and -25°C.

The texture and color were modeled using a zero-order and first order. The kinetic modeling on texture for samples stored at 30°C and -25°C were best fitted in first-order model while samples stored at 5°C fitted the zero-order model. The texture degradation rate was higher at 30°C compared to when stored at lower temperature, -25°C and 5°C. It can be concluded from the kinetic modeling that, the texture degradation of fresh-cut starfruits increased as the storage time and temperature increased. As for kinetic model for color, a* value and b* value for samples stored at 30°C well described with zero-model and first-model respectively meanwhile the L* value for samples stored at -25°C best fitted the zero-model and ΔE value best fitted zero-model for samples stored at 30°C and -25°C. However, the samples stored at 5°C for color parameters did not fit zero-order and first-order model. Therefore, the data obtained from this study can be used as a guide for retail market to pack fresh-cut products by using the best packaging films and store at suitable temperature to minimize the quality loss during the postharvest handling and extend the shelf life during storage.

5.2 Recommendation

Due to the increase in demand for fresh-cut fruits, the quality and freshness of fresh products must be retained during the retail. Hence, there are many other ways to extend the shelf life of fresh-cut products by using chemical for preservation and physical packaging to protect the products.

In order to delay the browning of fresh-cut products due to oxidation, the use of chemical such as calcium ascorbate and chitosan solution could delay the browning effectively and does not give harm to consumers (Mola et al., 2016). Besides that, the use of packaging treatment can effectively extend the shelf life and quality of fresh-cut products as it can prevent microbial contaminations such as spoil microbes. For instance, modified atmosphere packaging (MAP) technology reported to extend the shelf life of fresh products due to good barrier properties and low cost. Furthermore, promising results for the quality and shelf life of products would be obtained through the combination of chemical and packaging treatment. In addition, the shelf life of fresh-cut starfruits can be observed by determining its pH, water activity, total soluble solid (TSS) and antioxidant activity

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APPENDICES

APPENDIX A – SAMPLE PREPARATION

Clean unpeeled carambola with tissue that is wet by tap water.

↓

Cut carambola into star shape (Diameter = (4± 0.5) cm, Thickness = 1.4 cm).

↓

Soak carambola in 0.5g/L concentration of sodium chloride solution (1 minute).

↓

Let dry under ambient temperature (30°C, 5 minutes).

↓

Pack fresh-cut carambola in packaging films; (PP (OTR; 1000 cc/m²/day, LDPE (OTR; 8000 cc/m²/day, WTR; 200 g/m²/day), PET (OTR; 90 cc/m²/day, WTR; 35 g/m²/day).

↓

Store fresh-cut carambola at three different storage temperatur (-25°C, 5°C and 30°C).

Figure A.1 Process flow of fresh-cut carambola preparation.

Figure A.2 Fresh-cut carambolas were dried at ambient temperature

Figure A.3 Samples packed in 3 different packaging films (PP, LDPE, PET)

Table A-1 Sample Preparations of fresh-cut carambola

	-25 ℃	5 ℃	30 ℃
PP	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.
LDPE	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.
PET	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.	3 bags = 3 replicates where each bags have four pieces of fresh-cut carambolas.

APPENDIX B – STATISTICAL ANALYSIS

Tests of Between-Subjects Effects

Dependent Variable: WEIGHT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13871.292[a]	21	660.538	2.240	.013
Intercept	15811.049	1	15811.049	53.608	<.001
DAY	7130.445	6	1188.407	4.029	.003
TEMPERATURE	1924.009	1	1924.009	6.523	.014
FILM	2716.015	2	1358.008	4.604	.016
FILM * DAY	2100.824	12	175.069	.594	.835
Error	12092.564	41	294.941		
Total	40511.474	63			
Corrected Total	25963.857	62			

a. R Squared = .534 (Adjusted R Squared = .296)

Figure B.1 statistical analysis for fresh weight analysis

Tests of Between-Subjects Effects

Dependent Variable: L*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5023.695[a]	21	239.224	3.510	<.001
Intercept	36446.926	1	36446.926	534.754	<.001
DAY	1937.191	6	322.865	4.737	<.001
TEMPERATURE	3006.622	1	3006.622	44.114	<.001
FILM	5.044	2	2.522	.037	.964
FILM * DAY	74.839	12	6.237	.092	1.000
Error	2794.413	41	68.156		
Total	48269.870	63			
Corrected Total	7818.108	62			

a. R Squared = .643 (Adjusted R Squared = .459)

Figure B.2 statistical analysis for L* value analysis

Tests of Between-Subjects Effects

Dependent Variable: a*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3067.399[a]	21	146.067	4.484	<.001
Intercept	5287.526	1	5287.526	162.325	<.001
DAY	2535.414	6	422.569	12.973	<.001
TEMPERATURE	5.104	1	5.104	.157	.694
FILM	280.564	2	140.282	4.307	.020
FILM * DAY	246.316	12	20.526	.630	.804
Error	1335.520	41	32.574		
Total	9757.526	63			
Corrected Total	4402.918	62			

a. R Squared = .697 (Adjusted R Squared = .541)

Figure B.3 statistical analysis for a* value analysis

Tests of Between-Subjects Effects

Dependent Variable: b*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3901.328[a]	21	185.778	4.287	<.001
Intercept	44272.476	1	44272.476	1021.644	<.001
DAY	3122.809	6	520.468	12.010	<.001
TEMPERATURE	285.938	1	285.938	6.598	.014
FILM	230.216	2	115.108	2.656	.082
FILM * DAY	262.365	12	21.864	.505	.900
Error	1776.717	41	43.335		
Total	51996.294	63			
Corrected Total	5678.044	62			

a. R Squared = .687 (Adjusted R Squared = .527)

Figure B.4 statistical analysis for b* value analysis

Tests of Between-Subjects Effects

Dependent Variable: ΔE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8959.916[a]	21	426.663	4.011	<.001
Intercept	27029.609	1	27029.609	254.122	<.001
DAY	7894.840	6	1315.807	12.371	<.001
TEMPERATURE	323.399	1	323.399	3.040	.089
FILM	429.755	2	214.878	2.020	.146
FILM * DAY	311.922	12	25.993	.244	.994
Error	4360.946	41	106.365		
Total	40065.431	63			
Corrected Total	13320.862	62			

a. R Squared = .673 (Adjusted R Squared = .505)

Figure B.5 statistical analysis for ΔE value analysis

Tests of Between-Subjects Effects

Dependent Variable: TEXTURE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	65.466[a]	21	3.117	4.511	<.001
Intercept	473.610	1	473.610	685.348	<.001
DAY	53.667	6	8.945	12.943	<.001
TEMPERATURE	9.428	1	9.428	13.643	<.001
FILM	.384	2	.192	.278	.759
FILM * DAY	1.987	12	.166	.240	.995
Error	28.333	41	.691		
Total	557.996	63			
Corrected Total	93.799	62			

a. R Squared = .698 (Adjusted R Squared = .543)

Figure B.6 statistical analysis for texture analysis