UNIVERSITY OF CAPE COAST

EFFECT OF EDIBLE COATINGS ON THE POSTHARVEST QUALITY OF EGGPLANT (*Solanum aethiopicum* L.) FRUITS DURING LOW TEMPERATURE STORAGE

ROSEMOND GODBLESS DADZIE

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BY

ROSEMOND GODBLESS DADZIE

Thesis submitted to the Department of Agricultural Engineering of the School of Agriculture of the College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy degree in Postharvest Technology

SEPTEMBER, 2018

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's signature ………………………. Date ……………..

Name: ……………………………………………………………….

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's signature ……………… Date ……………….....

Name: ……………………………………………………………..

Co-Supervisor's signature …………………… Date …………………..

Name: ……………………………………………………………..

ABSTRACT

Eggplant is an important fruit with numerous health benefits, but it has a relatively short postharvest life. Edible coating in combination with low temperature storage can improve quality and extend shelf life but they are normally imported and are costly. This work, therefore, sought to study the effect of edible coatings prepared from inexpensive, locally available materials on the quality of eggplant fruits during storage. Fruits were coated with beeswax, Aloe vera or cassava starch solution (with or without citric acid pre-treatment) and stored at 10 °C. Beeswax coating was the most effective in minimizing fruit weight loss, maintaining firmness and delaying colour deterioration. Aloe vera coating also improved the fruit quality but starch coating was not very effective. Total phenolic content generally decreased during storage while ascorbic acid levels increased except for beeswax-coated fruits. Total antioxidant capacity was unaffected, irrespective of the coating treatment. Citric acid pre-treatment before starch coating minimized weight loss at 10 °C and in shelf life. The coating conditions for beeswax, starch and Aloe vera were then optimized using Response Surface Methodology Box Behnken Design. The optimized coating conditions were 4.6 % (w/v) coating concentration, 1 % (w/v) citric acid concentration and 3 min coating duration for beeswax coating; 4.99 % (w/v) coating concentration, 2.98 % (w/v) citric acid concentration and 10 min coating duration for starch coating; and 96.92 % (v/v) coating concentration, 1.07 % (w/v) citric acid concentration and 10 min coating duration for Aloe vera. Verification experiment gave a good correlation coefficient (R^2) of 0.87 between the predicted and measured physicochemical properties of eggplant fruits coated with beeswax, cassava starch and Aloe vera.

KEY WORDS

Edible coating

Eggplants

Storage

Shelf life

Quality

Beeswax

Cassava starch

Aloe vera

Response surface methodology

Box Behnken design

Optimization

Low temperature storage

Physicochemical

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DEDICATION

To my children, Ekua Ntaama Dadzie and Efua Anaama Dadzie

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LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization
F	Firmness
TPC	Total phenolic content
AA	Ascorbic acid
AOA	Total antioxidant capacity
DPPH	2,2-Diphenyl-1-picrylhydrazyl
DNPH	2,4-Dinitrophenylhydrazine
RSM	Response Surface Methodology
BBD	Box Behnken design
2FI	Two Factor Interaction
3D	3 Dimensional
% (v/v)	percent volume per volume
% (w/v)	percent weight per volume
g/kg	gram per kilogram
mg/kg	Milligram per kilogram
N	Newton
PPO	Polyphenol oxidase
POD	Peroxidase
d	Day
Eqn.	Equation
RH	Relative humidity
NS	Not significant

CHAPTER ONE

INTRODUCTION

Background to the study

Eggplant (*Solanum aethiopicum* L.) is a widely adaptive and highly productive crop grown in both tropical and subtropical regions (Sidhu et al., 2014). It is among the 30 commonly produced and consumed horticultural crops worldwide (Concellon et al., 2007; Florkowski et al., 2014). The eggplant fruit is egg-shaped or globular and has a bright green calyx and firm texture (Gross et al., 2014; Jha & Matsuoka, 2002). It is of high nutritional and economic importance (Cortbaoui, 2015; Okmen et al., 2009). Commonly known in Ghana as garden eggs, it is an important fruit crop, serving as a source of income for farmers and vendors. It is high in polyphenols, vitamins and minerals, which provide a wide variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer properties (Boulekbache-Makhlouf et al., 2013; Cortbaoui, 2015). Despite these benefits, the eggplant fruit is highly perishable, and their phenolic content can be affected by poor postharvest handling practices (Agarwal et al., 2012; Boulekbache-Makhlouf et al., 2013; Mishra et al., 2012).

Excessive post-harvest loss of fruits is a major problem in Africa. In Ghana for example, farmers and vendors watch helplessly while their produce go waste, causing financial loss and depriving consumers of the much-needed nutrition and nourishment. Kitinoja & Cantwell (2010) estimated postharvest losses of eggplant fruits in Ghana to be 13.9 % in the farm, 11.3 % at the wholesale market and 16.2 % at the retail market. Eggplant fruits are normally left at ambient conditions in Ghana, which results in undesirable colour changes and weight loss that causes the fruits to shrivel and become unacceptable for sale and consumption.

Among the factors that contribute to the deterioration of fruits after harvest include high respiration rates, moisture loss and the activity of microorganisms (Kadar, 1992). In countries like Ghana, the high tropical temperatures also contribute to hastening fruit senescence by speeding up spoilage reactions and increasing the growth of microorganisms (Snowden, 2008). Techniques have, therefore, been developed to help reduce fruit deterioration and extend the storage life of fruits after harvest. Among these techniques include storage at low temperatures alone or combined with certain postharvest treatments like the application of an edible coating on fruits. Low temperature storage involves keeping fruits above the freezing point and below temperatures of about 20 °C (Fidler, 1968; Lyons, 1973). Most tropical fruits, however, have relatively short storage life under low temperature storage since they suffer chilling injury (Lyons, 1973). For example, at an optimum storage temperature of 12 °C for eggplant, the fruits can be stored for a maximum period of 14 days, and after this storage period, undesirable changes occur in the fruits making it unacceptable by consumers (Kitinoja & Kader, 2002). However, edible coatings can modify the internal atmosphere of fruits, reduce respiration rate, moisture loss and physiological activity by serving as a barrier to respiratory gases, moisture, and solutes (Guerreiro, 2016). It is therefore hoped that by combining low temperature storage with the use of edible coating, the storage life of tropical fruits as well as the quality of the fruits after harvest can be enhanced.

Edible coatings for fruits and vegetables

Edible coating helps preserve the quality of fruits and vegetables by reducing water loss and the symptoms of chilling injury during postharvest storage (Valenzuela et al., 2017). Edible coatings are obtained from biodegradable edible materials and used to coat food produce by dipping, spraying, or brushing to create a film around the product. The film formed around the food functions by restricting loss of moisture from the fruit to the environment and minimizes oxygen uptake and thereby delaying respiration (Kester and Fennema, 1986). Among the advantages derived from using edible coatings include enhancing the colour of fruits, minimizing weight loss, and preserving fruits firmness leading to improved quality and increased storage life (Dhall, 2013). Edible coatings may also improve the biochemical quality and reduce decay of fruits especially when incorporated with bioactive compounds and antimicrobial agents (Quirós-Sauceda et al, 2014).

The main substances that are used as edible coating of fruits and vegetables include polysaccharides (starches and modified starches, cellulose derivatives, chitosan, pectin, alginate and other gums) (Hernandez-Izquierdo & Krochta, 2008; Tzoumaki et al., 2009), proteins (soy, milk, gelatin, corn zein and wheat gluten) and lipids (oils, waxes and resins) (Sánchez-González et al., 2011). Composite films and coatings are heterogeneous in nature consisting of a mixture of polysaccharides, protein, and/or lipids (Bourtoom, 2008).

Although edible coatings have been proven to be effective in extending the postharvest storage life of fruits, commercially available edible coatings are expensive and unaffordable for most Ghanaian farmers. It is, therefore, important to investigate locally available materials as sources of alternative and relatively affordable edible coatings. Cassava starch, Aloe vera and beeswax are among the materials that can be studied for their potential to be used as edible coatings for fruits.

Cassava, Aloe vera and beeswax as sources of edible coatings for fruits and vegetables

Cassava is an important source of starch worldwide. This is because cassava starch is one of the most naturally abundant biopolymers, and the most used component for polysaccharides films. It is widely available, inexpensive (Souza et al., 2010), and has good film-forming properties (Souza et al., 2013). In recent years, the potential use of cassava starch as an edible film or coating have been studied widely with promising results (Bertuzzi et al., 2007; Castricini et al., 2012; Chillo et al., 2008; De Moraes et al., 2013). Flores et al. (2007) described films developed from starch as isotropic, odourless, tasteless, colourless, non-toxic and biodegradable.

Aloe vera is a tropical and subtropical plant widely known for its medicinal properties. When used as an edible coating, Aloe vera forms a protective layer against oxygen and moisture loss, and serves as an antimicrobial agent (Misir et al., 2014). Several reports have shown Aloe vera coating to prevent loss of moisture (Brishti et al., 2013; Ergun & Satici, 2012; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004), preserve firmness (Brishti et al., 2013), delay respiration (Ahmed et al., 2009; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004), delay colour changes (Brishti et al., 2013; Cantos et al., 2002; Carrillo-lopez et al., 2000; Ergun & Satici, 2012; Tripathi & Dubey, 2004) and improve overall appearance of fruits (Tripathi & Dubey, 2004).

Lipid coating based on waxes and resin provide a good moisture barrier and improve the surface appearance of various foods (Baldwin et al., 2011; Bourtoom, 2008). In particular, wax coatings have been used to slow down the dehydration of citrus fruits (Guilbert et al., 1995). There are a variety of waxes derived from plants (e.g., carnauba, candelilla, and sugar cane waxes), animals (e.g., beeswax, lanolin, and wool grease) and petroleum (e.g., paraffin and microcrystalline waxes), that can be used as edible coating of fruits and vegetables. Petroleum-based waxes and oils such as paraffin wax, polyethylene wax, and mineral oil (Hernandez, 1994) and other synthetic waxes have been successfully used for extending the storage life of fruits (Bahnasawy & Khater, 2014). However, these petroleum-based waxes can only be used in edible coatings for fruits and nuts where the peel or shell is not ingested (Hernandez, 1994). Recently, there has been a shift in the consumer's preference for safe foods. Therefore, the use of natural waxes derived from plants and animals is gaining attention. Hassan et al. (2014) reported on the use of beeswax edible coatings on tangerine. Beeswax coating have also been used on oranges (Shahid & Abbasi, 2011), strawberries and apricot (Mladenoska, 2012), and plums (Gunaydin et al., 2017) with promising results.

Food additives such as antioxidants, antimicrobial agents, and nutraceuticals can also be incorporated to further improve the quality and storage life of fruits coated with edible materials (Rojas-Graü et al., 2007). Benzoic acid, sorbic acid and plant-derived secondary metabolites, such as essential oils are commonly used as antimicrobial agents in edible coatings (Porta et al., 2013). Anti-browning agents may also be incorporated into edible coating materials. Citric acid, an antimicrobial and anti-browning agent, has been used to inhibit browning of plant tissues and reduce losses in product appearance (Chiabrando, & Giacalone, 2012; Georgopoulou et al., 1994). These additives can impart functional, organoleptic and nutritional properties when incorporated into edible coatings.

Statement of the research problem

Eggplant fruits, like many other fresh fruits, are highly perishable and continues to be metabolically active even after harvest (Cortbaoui, 2015; Kader, 2004). Some changes that occur in eggplant fruits during storage and marketing include loss of colour, reduction in weight and shriveling. In addition, the biochemical and nutritional characteristics of fruits may change during storage due to the presence of brown pigments (Concellón et al., 2004). These changes reduce the economic value of the fruits. Unfortunately, there is limited research on improving the postharvest storage life and quality of the eggplant variety cultivated in Ghana.

Edible coatings have demonstrated a potential for use in preserving the quality and extending the storage life of fruits after harvest (Dhall, 2013). However, the benefit of this technology has not yet been derived in most developing countries mainly due to the high cost of the commercially available coating materials. There is, therefore, the need to develop cost effective edible coatings from locally available edible materials to help improve the quality and extend the storage life of eggplant fruits in Ghana. Reduction of post-harvest losses of eggplant fruits would increase the amount of food available for consumption and thus contribute to improving national food security.

Aims and objectives

The main objective of this work was to enhance the postharvest quality of eggplant fruits through the application of edible coatings. Therefore, this study investigated the effect of some inexpensive and locally available materials as potential edible coating materials to help improve the postharvest quality and storage life of eggplant fruits. Another objective of this work was to investigate whether the selected edible coatings can be applied to eggplant fruits without the use of antioxidant and antimicrobial agents.

To meet the main objectives of this thesis, the following sub-objectives were defined:

i. To investigate the effects of cassava starch, beeswax and Aloe vera coatings on the biochemical (total phenolic content, ascorbic acid and total antioxidant activity) and physical (weight losses, colour and firmness changes) quality of eggplant fruits during low temperature storage.
ii. To study the effects of incorporating citric acid, an antioxidant and antimicrobial agent, into cassava starch, beeswax and Aloe vera edible coatings on improving the quality of eggplant fruits during low temperature storage.
iii. To use Response Surface Methodology to optimize the coating conditions for cassava starch, beeswax and Aloe vera to improve the storage quality of eggplant fruits.

CHAPTER TWO

LITERATURE REVIEW

Economic and nutritional importance of eggplant fruits

Eggplant ranks as one of the most important crops in the world (Hurtado et al., 2012). The common eggplant (*Solanum melongena* L.), also known as aubergine, has been cultivated for centuries in Asia, Africa, Europe, and the Near East (Weese & Bohs, 2010). According to Weese & Bohs (2010), *S. melongena* is one of the many species of the Solanaceae or nightshade family that has been selected and developed as human food aside the new world crops (tomato, potato and chilli pepper). It is closely related to *Solanum aethiopicum* L. (African scarlet eggplant) and *Solanum macrocarpon* L. (Gboma eggplant) (Sękara et al., 2007).

S. aethiopicum, although native to Africa, was introduced into the West Indies and South America (Lester & Niakan, 1986). It differs from *S. melongena* in its small white corollas and mostly bright scarlet fruits (Weese & Bohs, 2010). The fruit is usually egg-shaped or globular and has a bright green calyx and firm texture (Gross et al., 2014; Jha & Matsuoka, 2002). Outside Africa, the dark purple eggplant is the most consumed variety (Zaro et al., 2014) and has gained considerable research attention. There is, therefore, the need to investigate the storage potential of the white type (*S. aethiopicum*) which is the most consumed eggplant variety in Ghana and many other African countries.

Production and economic importance of eggplant fruits

Eggplant fruit is considered to be among the 30 commonly produced and consumed horticultural crops worldwide (Concellon et al., 2007; Florkowski et al., 2014) and is best grown in the tropical and the sub-tropical regions

(Concellon et al., 2007; Cortbaoui, 2015; Loose et al., 2014). The global production of eggplant is around 50 million tonnes annually, with a net value of more than US$10 billion a year, making it the fifth most economically important solanaceous crop after potato, tomato, pepper, and tobacco (FAO, 2014; Taher et al., 2017).

The African scarlet eggplant, commonly known in Ghana as garden eggs, is one of the most important crops in West Africa (Norman, 1992; Owusu-Ansah et al., 2001). In Ghana, about 4,305 households from the coastal forest and savannah ecological zones are actively involved in the production of vegetables including eggplants (Asenso-Okyere et al., 2000). The fruit is consumed almost daily by both rural and urban families and also serves as a source of income for many households (Danquah-Jones, 2000; Owusu-Ansah et al., 2001). The national production of eggplant is estimated to be at around 30,000 tonnes, even though the availability of the fruit is seasonally based (Horna et al., 2007). Figure 2.1 shows the sources and fluctuations in the price of eggplant fruits within the Accra Metropolitan area. Generally, the price of eggplants peaks around April where the production is very low (Horna et al., 2007), which shows that although the fruit is an economically important fruit, its availability over the course of a year depends on the farming methods and the strategies used to enhance the storage life of the fruit after harvest.

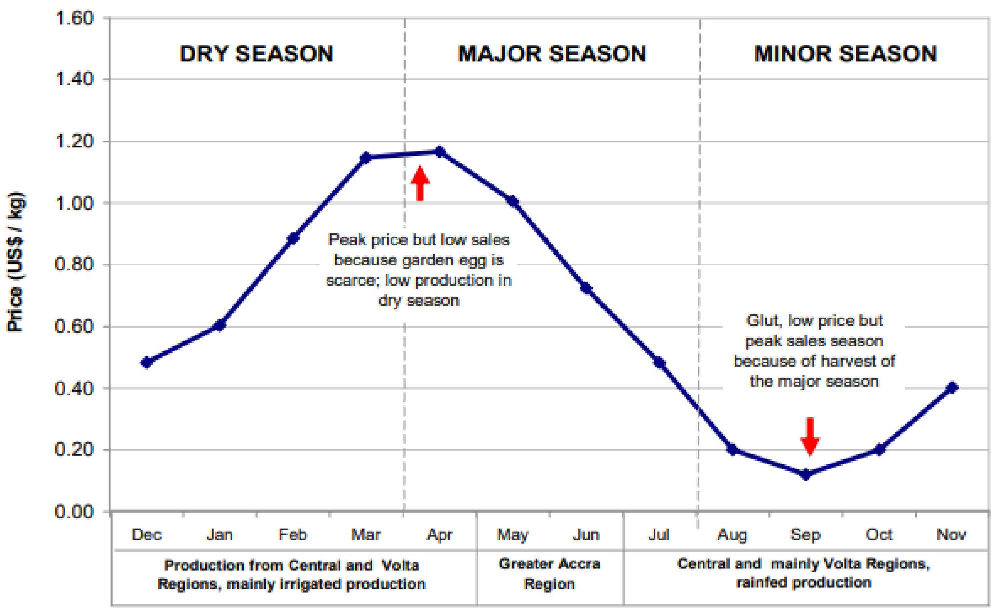

Figure 2.1: Eggplant fruit sources and price fluctuations in the markets of the Greater Accra region of Ghana (Horna et al., 2007).

Nutritional and health benefits of eggplant fruits

The eggplant fruit contains about 7 % dry matter, 1 % protein, and 4 % carbohydrates on fresh weight basis (Esteban et al., 1992). The fruit also contains vitamins B1, B2, B6 and C (Gajewski et al., 2009) and provides relevant quantities of P, K, and Cu to the diet (Raigón et al., 2008). The global mean values of P, K, and Cu in eggplant fruits are 26.6, 198.5 and 0.062 mg per 100 g of fresh weight fruits, respectively (Raigón et al., 2008). Kalloo (1993), reported that the total nutritional value of eggplant fruit is comparable to tomato. Water extracts of eggplant fruits have shown high antioxidant activity, high scavenging ability of superoxide radicals and the ability to inhibit hydroxyl radical generation (Kaneyuki et al., 1999; Noda et al., 2000). Boulekbache-Makhlouf et al. (2013), reported that the large number of polyphenols, vitamins and minerals content in eggplant fruits are responsible for the health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits.

Sudheesh et al. (1997), also reported that the consumption of eggplant fruits can decrease low-density lipoprotein levels and can help improve heart action. Additionally, eggplant fruits have been recommended for diabetic patients, and the roots for the treatment of asthma (Daunay & Janick, 2007).

Despite the health benefits and the nutritional importance of the eggplant fruit, its storage life after harvest is relatively short. Mohammed and Sealy (1988) reported that the eggplant fruit has a shelf life of about 4 days under ambient conditions, after which visible changes in quality such as shriveling, and softening become apparent. Proper postharvest handling and storage is therefore important to ensure that eggplant fruits are available all year round to be able to achieve the economic, nutritional and health benefits.

Postharvest storage of eggplant fruits

After eggplant fruits are harvested at an optimal physiological stage of maturity, appropriate storage procedures need to be used to preserve the shelf life and quality of the fruits. Various techniques have been developed to extend the postharvest storage life of eggplant fruits while maintaining acceptable market quality. Some of these techniques include low temperature storage which can be used in combination with controlled/modified atmosphere storage (CA) and the application of edible coating (Baldwin, 2003).

Low temperature storage

Temperature control is one of the major tools for extending postharvest storage life and refrigeration is the most widely used method (El-Ramady et al., 2015). Low temperature storage reduces the rate of respiration and ethylene production of fruits, resulting in reduced metabolic rate and an extended shelf life (Workneh & Osthoff, 2010). The importance of low temperature storage is underlined by the fact that for every 10 °C rise in storage temperature both metabolic and physiological reactions can double (Workneh & Osthoff, 2010). An increase in reaction rate will therefore hasten the spoilage of fruits. Eggplant fruits, under ambient conditions, have short storage life leading to visible changes in quality such as shriveling and softening (Mohammed and Brecht, 2003). However, at 10-12 °C, the storage life of eggplant fruits was reported to be about 10-15 days (Passam and Karapanos, 2008). When not properly managed, low temperature storage can cause damage to fruits. This is usually manifested as symptoms of chilling injury. Surface pitting and scald are among the external symptoms of chilling injury (Mccolloch, 1966), while browning of the flesh and seeds is a conspicuous internal symptom of chilling injury (Ryall & Lipton, 1979).

Fallik et al. (1995), reported that the quality of eggplant fruits during prolonged low temperature storage below 10 °C may be impaired by the susceptibility of the fruits to deterioration and chilling injury. Concellón et al. (2004), stored eggplant fruits at 0, 5 and 10 °C and reported that eggplant fruits stored at 10 °C were undamaged, whereas those kept at 0 and 5 °C experienced chilling injury from days 6 and 8 which was indicated by decrease in lightness (L* value) of pulp tissue. Therefore, Nunes (2003) reported that, some fruits and vegetable are not adaptable to long term low temperature storage because they are susceptible to chilling injury. Indeed, many fruits and vegetables of tropical and subtropical origin such as eggplants are susceptible to chilling injury (Wang, 1989). This usually limits the use of low-temperature storage to improve the shelf-life and quality of eggplants and other tropical fruits. The recommended storage temperature for eggplant fruits is between 10 and 12 °C

(Zamorano et al., 1994) combined with relative humidity between 90-95% (Gross et al., 2014).

Factors that affect the quality of eggplants and other fruits after harvest

Eggplants, like many other fruits, is highly perishable and remains metabolically active even after harvest (Kader, 2004). Postharvest losses of African eggplant fruit are estimated at 25 % depending on the stage of maturity at the time of harvesting and storage environment (Kader, 1986; Horna, 2007). Eggplant fruits are very sensitive to inappropriate postharvest handling as they can easily undergo colour change, shriveling and bruising (Kader, 1996). Among the factors that contribute to the perishability of the fruits after harvest are increased respiration rates, moisture loss and the activity of microorganisms (Kadar, 1992). Also, improper temperature storage and relative humidity control can contribute greatly to the deterioration of fruits (Azene et al. 2014).

Effect of respiration

Respiration is a major metabolic process that takes place in harvested produce. Respiration involves the breakdown of complex molecules (starch, sugars and organic acids) present in cells into simpler molecules (carbon dioxide and water), with the simultaneous release of energy and metabolites that can be used for synthetic reactions (Wills et al., 1989). Respiration can occur in the presence (aerobic) or absence (anaerobic) of oxygen. Under aerobic respiration, oxygen is consumed with the production of carbon dioxide. Anaerobic respiration can lead to the production of off-odour and off-flavour compounds such as acetaldehyde and ethanol which can negatively affect the quality of fruits (Howard & Dewi, 1995; Miller et al., 1983).

Based on their respiration pattern after harvest, fruits can be classified into two broad categories: these are climacteric and non-climacteric fruits. Climacteric fruits show a dramatic increase in respiration after harvest (Paul & Pandey, 2014). The climacteric pattern (Figure 2.2) involves an initial decline of respiration called the pre-climacteric minimum, followed by a sharp rise (climacteric rise) to a climacteric peak at the onset of ripening, and a gradual decline during a post-climacteric period (Biale, 1981). The climacteric rise in respiration reflects enhanced metabolic activity and occurs at the transition from the growth phase of the fruit to its senescence phase (Figure 2.2).

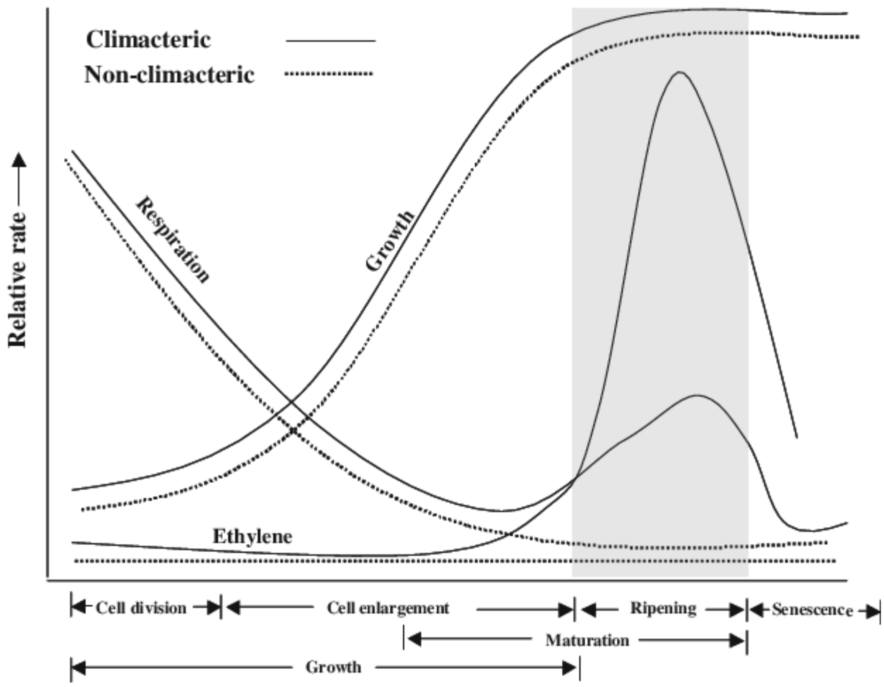

Figure 2.2: Respiration pattern of climacteric and non-climacteric fruits (Wills et al., 2007).

This coincides with changes associated with ripening such as colour changes, softening, increased tissue permeability and the development of a characteristic aroma (Kader & Saltveit, 2003). Non-climacteric fruits, however, exhibit a steady decline in respiration after harvest. Some examples of common climacteric and non-climacteric fruits are listed in Table 2.1.

Table 2.1: Some common examples of climacteric and non-climacteric fruits

Climacteric fruits	Non-climacteric fruits
Apple	Pepper
Apricot	Citrus fruits
Banana	Eggplant
Pear	Okra
Mango	Cucumber
Tomato	Grapes
Peach	Pineapple
Plum	Green bean
Fig	Summer Squash

(Adapted from Kader, 2002).

In addition to the effect of oxygen/carbon dioxide on fruits, another gas that plays a critical role in the storage of fruits and vegetables is ethylene. Harvested fruits and vegetables may be exposed to biologically active levels of ethylene which contributes to its biological activity (Salveit, 1999). Ethylene is the plant hormone that regulates and coordinates the different aspects of the ripening process and controls colour development, aroma production and texture (Klee & Giovannoni, 2011). Ethylene exposure could be beneficial (including ripening, development of colour) or detrimental (e.g. enhancing senescence and stimulating sprouting) to the fruits.

Eggplant is a non-climacteric fruit and the endogenous rate of ethylene synthesis falls from about 14 μL kg^{-1} h^{-1} after harvest to a low value of 1.4 μL kg^{-1} h^{-1} at commercial maturity (Rodriguez et al., 1999). Eggplant has a moderate to low sensitivity to ethylene exposure (Siller-Cepeda, 2004), implying that the exogenous application of ethylene to harvested eggplant fruits has no practical significance (Passam & Karapanos, 2008). Due to the effects of oxygen/carbon dioxide and ethylene on fruits, the control of respiration and ethylene metabolism is essential to improving the shelf life of harvested fruits (Mooz et al., 2012).

Storage temperature and relative humidity

According to Tano et al. (2007), most of the physiological, biochemical and microbiological activities contributing to the deterioration of fruits quality are largely dependent on temperature. Storage of fruits at relatively high temperature can trigger increased metabolic activities which can accelerate ripening and senescence (Workneh et al., 2011). Low temperature storage slows the rate of ripening and senescence of fruits as well as the activity of spoilage microorganisms. Tiwari et al. (2013) reported that the synthesis, retention, or breakdown of some plant-derived organic compounds are determined by temperature during transportation and storage. These compounds are unstable at higher temperatures (between 25 and 40 °C) but relatively stable at lower temperatures (between 4 and 10 °C) (Tiwari et al., 2013).

Postharvest water loss is a major cause of fruit quality deterioration. Once harvested, fruits continuously lose water to the surrounding air in the form of water vapour through transpiration (Baldwin, 2003). Transpiration involve the movement of water from cells to the surrounding atmosphere. Fruits lose water more rapidly when the relative humidity of the environment is low. Water loss usually results in weight loss and shriveling. Fresh fruits should, therefore, be stored under conditions of high relative humidity (90-98 %) to minimize water loss and thus prevent weight loss, and shriveling (Woods, 1990).

The effect of respiration, storage temperature and relative humidity on fruits means that these factors must be well controlled during the postharvest phase (Azene et al., 2014). Indeed, under commercial conditions most fruits are kept at low temperature to enhance their storage life.

Control and modified atmosphere storage

To further enhance the storage life and quality of fruits under low temperature, techniques that involve the modification of the gas composition around fruits (controlled and modified atmosphere) have been developed. This involves reducing oxygen and increasing carbon dioxide concentrations. Controlled and modified atmosphere packaging have been combined with low temperature to delay ripening, reduce physiological disorders, and suppress decay in many fresh fruits (Kader et al., 1989; Smith et al., 1987). Modified atmosphere packaging involves packaging of a perishable produce in an atmosphere which has been modified so that its composition is other than that of air whereas controlled atmosphere storage involves maintaining a fixed concentration of gas around the product by careful monitoring and addition of gases when necessary (Coles et al., 2003).

Kaynas et al. (1995) found that the storage life of eggplant fruits can be extended up to five to six weeks for 42 days when stored at 12 °C and 90-95 % RH using controlled atmosphere storage. Benitez et al. (2013), also, studied the effect of postharvest modified atmosphere packaging on the quality of eggplant fruits and found that modified atmosphere packaging was effective in delaying shriveling, reducing weight loss, improving visual quality, and extending shelf life.

Edible coatings

Edible coatings are materials applied to the surface of food to provide a barrier to moisture, oxygen, and other substances that can be exchanged between the food and the environment (Avena Bustillos et al., 1997; Guilbert et al., 1996; Mchugh & Senesi, 2000; Nisperos-Carriedo et al., 1991; Smith et al., 1987). An edible coating, according to the European Directive and USA regulations, can be classified as a food product, ingredient, additive, or packaging material (Dhall, 2013). Therefore, materials used for the preparation of edible coatings should be generally regarded as safe for consumption (Krochta & De Mulder-Johnston, 1997; Park et al., 1994) and must conform to the regulations that apply to the food product concerned (Guilbert et al., 1996). Edible coatings are usually produced from materials that are renewable and biodegradable and does not contribute to environmental pollution since the film can be consumed together with the product. These coatings are usually produced from materials with film forming ability (Bourtoom, 2008).

The use of edible coatings in food products has been in existence since the twelfth and thirteenth centuries, where oranges and lemons were dipped in wax to retard water loss (Hardenburg, 1967). During the sixteenth century, coating food products with fat (larding) was done to prevent the loss of moisture (Labuza & Contreras-Medellin, 1981). From the middle towards the late twentieth century, the application of edible coating to fresh produce gained significant attention (Table 2.2). Recently, there are several edible coatings that can be applied to help extend the storage life and improve the quality of fruits and vegetables (Table 2.3).

Table 2.2: Early application of edible coatings to fresh fruits and vegetables

Product	Coating	Benefit
Carrot	Vegetable waxes, petroleum mineral	Retard water loss and lower respiration
	Vegetable waxes, paraffin	Prolong shelf life
Cucumber	Paraffin wax or mineral oil	Retard water loss
	Carnauba, polyethylene	Retard water loss and chilling injury
Eggplant	Paraffin wax or mineral oil	Retard water loss and shrinkage
Melon	Paraffin wax	Reduce water loss
	Carnauba, paraffin wax	Delay decay
Pepper	Carnauba wax	Retard water loss and improve nutrition
	Mineral oil and Cellusoe	Retard water loss
Tomato	Vegetable wax	Retard water loss
	Chitosan	Prolong shelf life, reduce decay

(Adapted from Baldwin, 2003).

Table 2.3: Recent application of edible coatings and their primary functions on fruits and vegetables

Commodity	Coating material	Primary functions
Green bell Pepper	Lipid-based	$O_2/CO_2/H_2O$ barrier
Mushroom	Alginate	O_2/H_2O barrier
Citrus	Chitosan	$O_2/CO_2/H_2O$ barrier
Strawberry	Caseinate-whey protein	Microbial barrier
	Chitosan; HPMC	H_2O barrier; carrier (antimicrobial)
	Pullulan (bacterial polysaccharide from starch)	$O_2/CO_2/H_2O$ barrier
	Starch-based	H_2O barrier
	Wheat gluten-based	O_2/H_2O barrier
Cucumber	Guar Gum	H_2O barrier, Microbial barrier
Tomato	Guar Gum	Microbial barrier

(Adapted from Lin and Zhao, 2007).

Functional properties of edible coating

Edible coatings, when applied form a thin film on the surface of fruits. This film regulates the exchange of materials between the produce and the environment. Among the materials that can be exchanged between the produce and the environments include water, gases (including oxygen and carbon dioxide) and volatile components such as aroma substances. Edible coatings also serve as protective coatings for produce that are susceptible to oxidation (Baldwin et al., 2011). Figure 2.3 shows the functional properties of an edible coating on fresh fruits and vegetables.

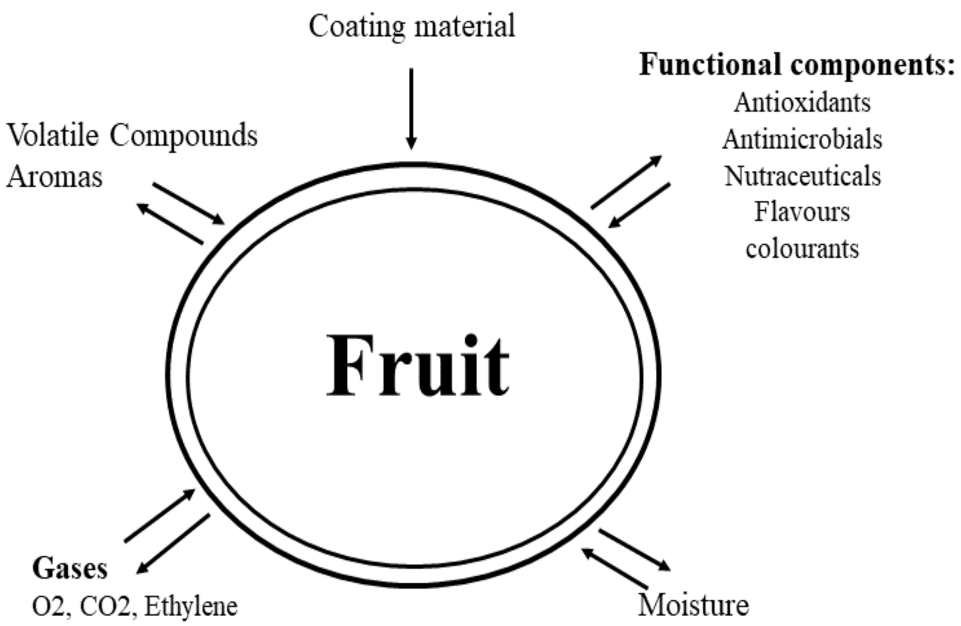

Figure 2.3: Functional properties of an edible coating on fresh fruits and vegetables (Adapted from Lin and Zhao, 2007).

Characteristics of edible coatings

Among the general properties that are considered before the selection of an edible coating for application on fruits are the water vapour and oxygen permeability, the thickness and sensory properties of the coating. It is generally expected that edible coatings will have low water vapour permeability in order to retard desiccation (De Azeredo, 2012; Garcia & Barrett, 2002). Fruits naturally have a waxy coating which may be removed or altered during washing (Hagenmaier & Baker, 1993). The removal of this waxy coating can result in increased water loss during storage (Baldwin, 2003). Therefore, edible coating can be used to control or limit water loss from fruits (Morillon et al., 2002). Edible coatings from lipid materials (wax and oil coatings) offer the most effective barrier to water loss while carbohydrate and protein-based coatings are the least effective due to their hydrophilic characteristics (Baldwin, 2003).

The exchange of gases such as oxygen and carbon dioxide between fruits, and the environment can be controlled using edible coatings (Mishra et al., 2010). Edible coatings generally have moderately to low permeability to oxygen and carbon dioxide. This helps to delay respiration and overall metabolic activity hence retarding ripening and its related changes (De Azeredo, 2012). However, a good edible coating must not reduce metabolic activity to a level that will create anaerobic conditions. Anaerobic conditions can promote physiological disorders and accelerate quality loss (De Azeredo, 2012; Kester & Fennema, 1986). A good edible coating should, therefore, regulate ripening in fruits by reducing oxygen penetration in the fruit rather than by decreasing carbon dioxide and ethylene evaporation (De Azeredo, 2012).

The thickness of an edible coating is an important characteristic since it contributes to the volume and weight of the produce (Embuscado & Huber, 2009). Thick coatings on fruits and vegetables surfaces can create an undesirable barrier between the external and internal atmosphere and restrict exchange of respiratory gases (Cisneros-Zevallos & Krochta, 2003). This can lead to fruits undergoing anaerobic respiration (Dhall, 2013). Park et al. (1994) reported that tomatoes coated with 2.6 mm zein film produced alcohol and off-flavors internally due to low oxygen and high carbon dioxide concentrations (Park et al., 1994).

Edible coatings are generally expected to be tasteless in order not to interfere with the flavour of the product to be coated (Labuza & Contreras-Medellin, 1981). They may however possess sensory properties compatible with those of the product. In this regard, fruit purees have been studied as potential edible coating materials (Mchugh et al., 1996; Senesi & Mchugh, 2002).

Types of edible coatings

Depending on their composition, edible coatings can be divided into three main categories. These are hydrocolloids (polysaccharides and proteins), lipids, and composites (Figure 2.4). Hydrocolloid films are hydrophilic in nature and generally have poor resistance to water vapour. According to Kester and Fennema (1986) hydrophilic films and coatings generally provide a good barrier to oxygen transfer. Lipid-based coatings generally have low water vapour permeability due to their apolar characteristics (Fabra et al., 2008).

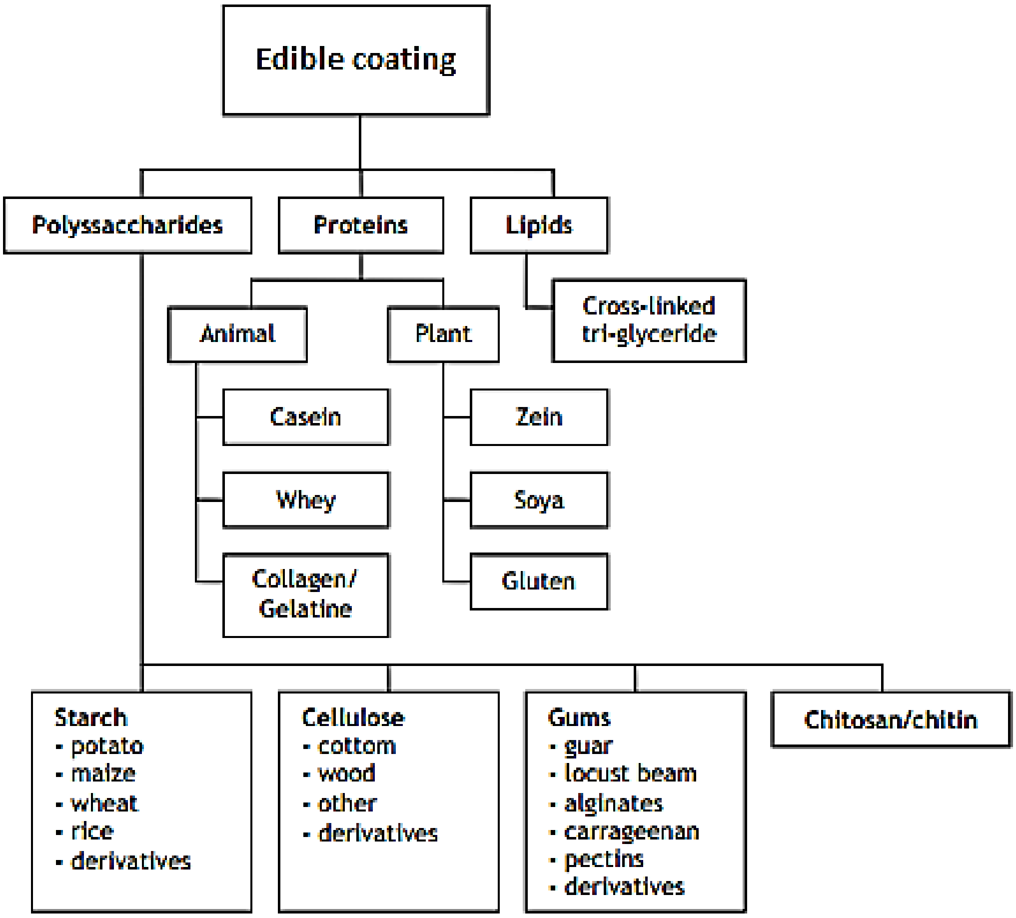

Figure 2.4: Schematic presentation of bio-based polymers based on their origin and method of production (Tuil et al., 2000).

Polysaccharides-based edible coatings

Polysaccharides are long-chain polymers formed from mono- or disaccharide repeating units. They are readily available and relatively inexpensive. Polysaccharide coatings have effective gas barrier properties and have the ability to retard respiration and ripening of fruits (Cha & Chinnan, 2004). However, most polysaccharide coatings have poor water vapour barrier properties (Park & Chinnan, 1995; Janjarasskul & Krochta, 2010). The main polysaccharides used as edible coatings include starch and modified starch, cellulose derivatives, chitosan, pectin, alginate and other gums (Hernandez-Izquierdo & Krochta, 2008; Tzoumaki et al., 2009).

Starch is an inexpensive, abundant, and biodegradable storage polysaccharide of plants. It is the most used material in the formulation of edible coatings (Galgano et al., 2015). Starch-based films are edible, transparent, odourless, tasteless, and colourless. These properties make starch an ideal material for the edible coating of fruits (Tang et al., 2015). Azwar and Hakkarainen (2012) have, however, reported that starch-based materials have inadequate mechanical properties. Starch based edible coatings can be prepared from different sources such as cassava, potatoes, corn, wheat and rice (Garcia et al., 1998).

Cellulose is the most abundant natural polymer. In its native state, cellulose is highly crystalline and insoluble in water (De Azeredo, 2012). The water solubility of cellulose can, however, be improved by etherification to yield water-soluble cellulose ethers which have good film-forming properties (Cha & Chinnan, 2004; Janjarasskul & Krochta, 2010). Cellulose films generally have poor water vapour barrier properties (Padua & Wang, 2012).

Chitosan is one of the most widely used natural compounds in edible coating preparations (Vieira et al., 2016). Chitosan is typically extracted from the exoskeleton of shellfish or the cell wall of some microorganisms (Hirano et al., 1976). Chitosan exhibits very good film-forming properties (Vargas et al., 2011). Several advantages of chitosan coatings have been reported. These include antimicrobial, antioxidant and emulsifying properties of the coating as well as the compatibility of chitosan with other coating biopolymers (Dutta et al., 2009; Elsabee & Abdou, 2013). Chitosan treatment have been observed to significantly reduce water loss and delay changes in colour, titratable acidity and ascorbic acid content of strawberry fruit (Petriccione et al., 2015). Additionally, chitosan has been observed to delay changes in total polyphenols, anthocyanins and flavonoids and the antioxidant capacity of fruits (Petriccione et al., 2015). Ali et al. (2011) and Lin et al. (2011) reported decreased respiration rate and prolonged shelf life after application of chitosan to papaya and litchi. Hong et al. (2012) also reported that chitosan treatment significantly reduced weight loss, delayed changes in chlorophyll and retarded changes in titratable acidity and ascorbic acid content during 12 days of guava storage.

Plant-based gums are solids consisting of mixtures of polysaccharides which are either water-soluble or absorb water and swell up to form gels when placed in water (Verbeken et al., 2003). Natural gums can be semi-synthetically modified to produce derivatives (Saha et al., 2017), which can be used as edible coatings. Examples of natural gums which are generally regarded as safe for use as edible coatings include gum arabic and gum acacia (Baldwin, 1999). Plant-based gums have many advantages such as being biodegradable, nontoxic, economical, and easily available. El-Anany et al. (2009), observed a significant delay in weight loss, firmness and other quality attributes of apple fruits coated with several gums (soybean, jojoba, Arabic). Furthermore, gum arabic was observed to delay ripening and increase the storage life of tomato fruits (Ali et al., 2010). Guar gum based edible coating have also been observed to increase the postharvest storage life of cucumbers (Saha et al., 2016) and Roma tomatoes (Ruelas-Chacon et al., 2017).

Protein-based edible coatings

Protein coatings are formed by denaturing the native structure of the protein followed by association of peptide chains in the protein through new intermolecular interactions (Janjarasskul & Krochta, 2010). Edible coatings obtained from proteins can exhibit markedly different characteristics because the composition and source of proteins can differ (Dhall, 2013). Protein coatings are generally hydrophilic and are therefore susceptible to moisture absorption. This implies that changes in relative humidity and temperature of the external environment can affect the functionality of protein coatings (Dhall, 2013).

Lipid-based edible coatings

Lipid based edible coatings are used primarily to block water vapour transport due to the relatively low polarity of lipids (Bourtoom, 2008). Guilbert et al. (1995), reported that lipid-based coatings, specifically wax coatings have been used to slow down the dehydration of citrus fruits since the 12th century in China. Lipid-based edible coatings are also widely applied to fresh fruits to provide glossy surface and to increase the shelf life of the product by decreasing respiration rate and water vapour transfer (Koyuncu & Savran, 2002).

Among the lipid-based coatings, petroleum-based waxes such as paraffin, polyethylene, and mineral oil have been used extensively to coat fruits

(Hernandez, 1994). The petroleum-based lipid coatings, are however, limited by the fact they can only be applied to produce where the peel or shell is not ingested (Hernandez, 1994). The limitation of petroleum lipids has raised interest concerning the use of natural lipids and waxes derived from plants and animals as edible coatings. Some natural waxes and lipids used as edible coatings include carnauba, candelilla, beeswax, lanolin and wool grease waxes (Rodrigues & Fernandes, 2012).

Composite coatings

Composite coatings consist of a mixture of polysaccharides, protein, and/or lipids (Bourtoom, 2008). Composite coatings therefore have the advantage of possessing the distinct functional characteristics of each class of coating (Kester & Fennema, 1986). The application of composite coatings can be carried out either by dispersion of the non-miscible constituents in successive layers (multilayer coating or films), or in the form of a solution in a common solvent (Bourtoom, 2008). Composite coatings can also be formulated in the form of an emulsion or suspension (Bourtoom, 2008; Guilbert et al., 1995).

Additives used with edible coatings

Food additives such as antioxidants, antimicrobials, and nutraceuticals can be incorporated to further improve the properties of edible coatings (Rojas-Graü et al., 2007). These additives can impart functional, organoleptic, and nutritional properties when incorporated into edible coatings. Among the commonly used additives for improving the antimicrobial properties of edible coatings include benzoic acid, sorbic acid and some plant-derived secondary metabolites such as essential oils (Porta et al., 2013). Anti-browning agents can also be added to edible coatings to inhibit browning reactions in certain fruits and vegetables. Some additives such as citric acid can serve the dual purpose of being both an antibrowning and an antimicrobial agent. Citric acid has been used to inhibit browning of plant tissues and reduce losses in product appearance. Gundidza and Gaza (1993) used citric acid as an additive in an edible coating to retard oxidation of lipids and also to inhibit microbial growth.

The mechanical properties of edible coatings can also be improved by the addition of plasticizers. Some commonly used plasticisers include polyethylene glycol, glycerol, acetylated monoglyceride and sucrose (Baldwin et al., 2011). However, the addition of plasticizers, if not properly carried out, can negatively alter the water vapour permeability and mechanical properties of edible coatings.

Some local sources of edible coatings

Cassava is an important source of starch worldwide. Cassava starch is one of the most suitable raw material for the production of starch based edible coating. This is due to the transparency and brightness of cassava starch (Cereda et al., 1992). Several studies on the use of cassava starch as a potential edible coating material for fruits have been done. Garcia et al. (2012) studied the effect of coating on minimally processed fruits and observed that cassava starch coating increased the water vapour resistance of strawberries. Freitas et al. (2017) evaluated the post-harvest characteristics of coating mombin fruits and observed cassava starch coating helped to improve the storage life of the fruits. Thomas et al. (2016) also studied the effect of cassava starch coating on the phytochemical content and antioxidant capacity of strawberry. Cassava starch has also been used as an edible coating of other fruits and vegetables with promising results (Bertuzzi et al., 2007; Castricini et al., 2012; Chillo et al., 2008; De Moraes et al., 2013; Márquez Cardozo et al., 2015; Souza et al., 2013; Veiga-Santos et al., 2008).

Aloe vera coating is mostly polysaccharide-based (Ni et al., 2004). The mucilage of Aloe vera consists of about 99.5% water (Eshun & He, 2004) as well as several vitamins, fatty acids, amino acids, sugars and minerals (Zafari et al., 2015). The Aloe vera gel, when used as an edible coating operates through a combination of mechanics (Serrano et al., 2006) including the formation of a protective layer against oxygen and moisture, and serving as an antimicrobial agent (Misir et al., 2014). Several reports have shown Aloe vera coating to prevent loss of moisture (Brishti et al., 2013; Ergun & Satici, 2012; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004), preserve firmness (Brishti et al., 2013), delay respiration (Ahmed et al., 2009; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004) delay colour changes (Brishti et al., 2013; Cantos et al., 2002; Carrillo-Lopez et al., 2000; Ergun & Satici, 2012; Tripathi & Dubey, 2004) and improve overall appearance of fruits (Tripathi & Dubey, 2004).

Beeswax is a naturally occurring wax produced by honeybees. Hassan et al. (2014) reported the use of beeswax coating to improve the quality of tangerine during storage. Beeswax coating have also been used to coat oranges (Shahid & Abbasi, 2011); strawberries and apricot, (Mladenoska, 2012) and plums (Gunaydin et al., 2017). The findings of these works show that the postharvest application of beeswax coating could be useful in maintaining fruit quality after harvest.

Advantages and disadvantages of edible coatings

Edible coating, when applied to fruits and vegetables can extend their storage life and improve quality (Robertson, 2005). Edible coating also helps to maintain the integrity of fruits and protect produce against bruising and tissue damage. During transportation and sorting, edible coatings can help protect fruits and vegetables against physical injury caused by impact, pressure, vibrations, and other mechanical factors (Palou et al., 2015). Additionally, edible coatings can help slow down gas and solute transport, and allow the preservation of organoleptic, nutritional, and mechanical properties (Garcia et al. (1997). Also, the incorporation of additives into edible coatings can help enhance the quality and even help improve the nutritional and sensory attributes of fruits (Rojas-Graü et al., 2009).

Edible coating may help improve the quality of fruits by minimizing water loss and chilling injury symptoms during storage (Valenzuela et al., 2017). The decreased metabolic activity provided by edible coatings has also been known to retard softening changes (Conforti & Zinck, 2002; Zhou et al., 2011), which result from the loss of turgor pressure and cell wall degradation, leading to a reduction in fruit brittleness and firmness (Zhou et al., 2008). Garcia et al. (1998) reported that starch-based coatings could be used to extend the storage life of refrigerated strawberries. Edible coatings have also been reported to have potential for retaining quality of pre-washed, ready-to-eat fresh blueberries under commercial storage conditions (Duan et al., 2011). These advantages have led to the development of several commercial edible coatings. A list of some available edible coatings, their main composition, and fresh produce to which they can be applied is shown in Table 2.4.

Table 2.4: Some commercially available edible coatings and their uses

Name	Main component	Uses
Freshseel^{TM}	Sucrose esters	Extending shelf life of melon

Fry Shield™	Calcium pectinate	Reduces fat uptake during frying fish, potatoes, and other vegetables
Nature Seal™	Calcium ascorbate	Apples, avocado, carrot, and other vegetables
Nutrasave™	*N,O*-Carboxymethyl chitosan	Reduces loss of water in avocado, retains firmness
Opta Glaze™	Wheat gluten	Replaces raw egg-based coating to prevent microbial growth
Seal gum, Spray gum™	Calcium acetate	Prevents darkening of potato during frying
Semperfresh™	Sucrose esters	Protect pome fruits from losing water and discolouration
ZCoat™	Corn protein	Extends shelf-life of nut, meats, pecan, and chocolate covered peanut

(Adapted from Pavlath and Orts, 2009).

Edible coatings have several advantages but the main factor limiting their use is the high cost of the commercial edible coatings. Furthermore, when applied to fruits and vegetables, some edible coatings may become permeable to water vapour and gases under conditions of high relative humidity (Baldwin, 2003). Additionally, when using lipid-based coatings, a primary problem that may be encountered is the development of off-flavours (Cohen et al., 1990; Cuquerella et al., 1982; Tewari et al., 1980). In addition, certain additives which might contain milk, soybeans, fish, peanuts, and wheat may elicit allergic reactions in consumers when incorporated into edible coatings (Dhall, 2013).

Edible coating application process

Coatings are applied directly on the surface of the fruits by dipping, spraying, or brushing (Guilbert et al., 1996; Krochta & De Mulder-Johnston, 1997; Mchugh & Senesi, 2000). The ability of edible coatings to preserve or improve the quality of fruits and vegetables depends on the manufacturer's method of coating formulation, the fruit's unique characteristics and the storage conditions of the fruits (Olivas et al., 2008). Industrial fruit coating consists mostly in keeping fruits in motion (e.g., by vibration or rolling) and simultaneously applying the coating dispersion so that the fruits are exposed to it. Spray coating is the most used technique for applying food coatings. In this process, spraying nozzles are used to deposit the coating dispersion on fruits pieces as they move over a conveyor roller (Debeaufort & Voilley, 2009), which drives them to a drying step. For coating dispersions with high viscosities, screw or drum coaters are the approved application methods (De Azeredo, 2012).

Physiological and biochemical changes in eggplant and other fruits during and after storage

Several physiological and biochemical changes occur in fruits and vegetables after harvest. A thorough understanding of these changes is important to help develop proper storage and transportation conditions for fruits and vegetables.

Physiological changes

The changes in overall quality of fruits has been attributed to physiological processes related to fruit ripening and ending with senescence, which subsequently determines the shelf life of a particular fruit (Valero & Serrano, 2010). The physical changes that occur in fruits after harvest include loss of weight, changes in firmness and changes in colour.

Loss of water and volatile substances during storage can lead to a reduction in weight of fruits and vegetables (Lin & Zhao, 2007). The quality of produce decreases when they lose weight causing consumers to reject such fruits. It has been reported that, eggplant calyx is the main pathway for weight loss and accounts for at least 60 % of fruit transpiration (Díaz-Pérez, 1998). Several researchers have reported increasing weight loss in other fruits during storage (Gao et al., 2015; Mencarelli et al., 1989; Moretti & Pineli, 2005; Singh et al., 2016).

Firmness is an important quality parameter that indicate the degree of hardness or softness of fruits. Most fruits and vegetables are firm when harvested and becomes relatively soft during storage. Softening of fleshy tissues is one of the key changes that occur during storage and influences consumer acceptability (Nunes, 2003). It is also one of the most noticeable changes occurring in fruits during prolonged storage (Chiabrando & Giacalone, 2015). Consequently, excessive softening is one of the main factors responsible for limiting the shelf life, storage, and marketability of fruits (Valero & Serrano, 2010). Decreases in firmness of eggplant fruits during storage has been reported by Singh et al. (2016), Gajewski (2002) and Moretti and Pineli (2005).

According to Britton and Hornero-Mendez (1996), colour changes is the first visual indication of ripening or spoilage and thus determine the eating quality of fruits. The changes in fruit colour are mainly due to the breakdown of chlorophyll, and changes in carotenoid and other pigments (Britton and Hornero-Mendez (1996). For climacteric fruits, the breakdown of chlorophyll usually occurs during the climacteric phase (Verma, 2017). The colour of fruits may also be altered through the action of light, temperature, oxygen and metal ions (Stintzing & Carle, 2004).

The colour of eggplant fruits (white-egg-shaped) changes to yellowish red during ambient storage. Horna et al. (2007) graded eggplants fruits on the

Ghanaian market based on colour. The different colour grades are the white colour for the unripe fruits, the yellow/orange colour for the ripe fruits, and the deep yellow/red colour for the aged and dehydrated fruits (Figure 2.5). This grading systems helps to determine the price of eggplant fruit. On the Ghanaian market the ripe fruits are usually sold at half the price of the unripe (Horna et al., 2007).

A B C

Figure 2.5: Grading of eggplant fruits on the Ghanaian local market based on colour. (A) Unripe fruits; (B) ripe fruits; and (C) aged and dehydrated fruits.

Biochemical changes

During storage, several biochemical changes can occur in fruits. These changes will ultimately affect the nutritional composition of fruits such as the total phenolic content, ascorbic acid levels and the total antioxidant capacity (Kays, 1991).

The total phenolic content of fruits can be affected by postharvest handling practices (Agarwal et al., 2012; Boulekbache-Makhlouf et al., 2013). Gao et al. (2015) observed a decrease in total phenolic content of eggplant fruits within the first 3 days of storage. A study involving four sweet cherry cultivars showed that the total phenolic content increased after six days of storage at ambient temperature (Valero & Serrano, 2010). The total phenolic content in dill and amaranth decreased during low temperature storage (Galani et al., 2017). According to Boo et al. (2011), decreases in total phenolic content during storage can be attributed to the possible degradation of polyphenol compounds by polyphenol oxidases (PPO) and peroxidases (POD).

Freshly harvested fruits and vegetables generally contain more ascorbic acid than those held in storage (Lee & Kader, 2000). However, increasing ascorbic acid levels were observed by Esteban et al. (1992) during the storage of eggplant fruits. Similarly, Silva et al. (2013) observed a significant increase in ascorbic acid levels during the storage of gabiroba fruits. The ascorbic acid levels were stable in some fruits and vegetables during storage (Kevers et al., 2007). However, Galani et al. (2017) reported decreases in ascorbic acid levels in dill, amaranth and pomegranate during low temperature storage.

Phenolic compounds and ascorbic acid contribute to the total antioxidant capacity of fruits (Van De Velde et al., 2013). The total antioxidant capacity of some selected fruits increased in the days following purchase (Kevers et al., 2007). Generally, fruits spoil before any significant antioxidant activity loss is observed (except in banana and broccoli) and, therefore, storage may not affect the total antioxidant capacity of most fruits (Kevers et al., 2007). However, decreases in total antioxidant capacity have been observed during storage of some selected fruits (Galani et al., 2017).

CHAPTER THREE

MATERIALS AND METHODS

Materials

Acquisition and handling of fruit samples

Freshly harvested eggplant fruits (*Solanum atheopicum* L.) were obtained from a farm at Mankessim in the Central Region of Ghana and cassava roots were purchased from a local market in Cape Coast, Ghana. Fresh Aloe vera leaves were obtained from the University of Cape Coast Parks and Gardens, Ghana. Beeswax was purchased from Honey Centre, a bee farm in Saltpond, and commercial cooking oil (Unilever Ghana Ltd., Frytol® Ghana) was purchased from the local market, all in Ghana. For each experiment, eggplant fruits were transported immediately after harvest in baskets from the farm to the laboratory at the University of Cape Coast. Unwholesome fruits were discarded, and sound fruits sorted based on their physical appearance. Wholesome fruits were immediately washed thoroughly with clean water and disinfected with 1 % sodium hypochlorite solution. Thereafter, the fruits were rinsed with sterile water and air dried at room temperature for 1 h before citric acid pre-treatment and coating.

Methods

Effect of coating on the physicochemical properties of eggplant fruits during storage

Preparation of beeswax coating

Beeswax coating (3 % w/v) was prepared by melting an appropriate amount of the beeswax in commercial cooking oil (Frytol) at low heat. The beeswax solution was cooled to room temperature and later used to coat the fruits.

Preparation of cassava starch coating

The preparation of starch from cassava roots was done using the wet method as described by Barimah and Mantey (2002) with some modification. Fresh cassava roots were washed thoroughly with clean water and peeled. The peeled roots were washed with distilled water and grated for easy grinding. 1 kg of the grated cassava roots was grinded into slurry with 4 L of distilled water using a kitchen blender. The slurry was then filtered through a cheese cloth to obtain a clear solution (filtrate). The residue was further washed with another 4 L of distilled water and filtered to obtain a second filtrate which was combined with the first and allowed to sediment for 6 h. The supernatant was discarded, and the wet starch was washed four times by adding 4 L of distilled water. This was allowed to settle before decanting. The clear starch obtained was then dried at 50 °C using a dehydrator until a constant weight was achieved. The dried starch was milled and sieved with a mesh of 75 μm pore size to obtain the powdered starch.

The cassava starch coating (2 % w/v) was prepared by dissolving an appropriate amount of powdered cassava starch in distilled water. The resulting solution was gelatinized by heating at 70 °C for 30 min. The gelatinized solution was cooled to room temperature before being used as a coating agent.

Preparation of Aloe vera coating

Fresh Aloe vera leaves were obtained from the plant and immediately washed with clean running water. The leaves were then disinfected with 1 % sodium hypochlorite solution. The Aloe vera gel was then separated from the core of the leaves using a sharp knife and blended using a kitchen blender. The gel then was sieved through 45 µm sieve and immediately applied on the fruits.

Coating and storage of eggplant fruits

Three edible coating treatments (*viz*. 2 % (w/v) cassava starch, 100 % (v/v) Aloe vera gel and 3 % (w/v) beeswax coating) were individually applied to eggplant fruits with or without citric acid pre-treatment. The control comprised of uncoated fruits (i.e. no coating or citric acid pre-treatment). Each treatment was applied in three replicates, with each replicate divided into two sub-samples; non-destructive (n=9) and destructive (n = 25; n = 35; and n = 55) fruits for each replicate of beeswax, cassava starch and Aloe vera coating experiments, respectively). The same number of fruits were designated for the control in each experiment.

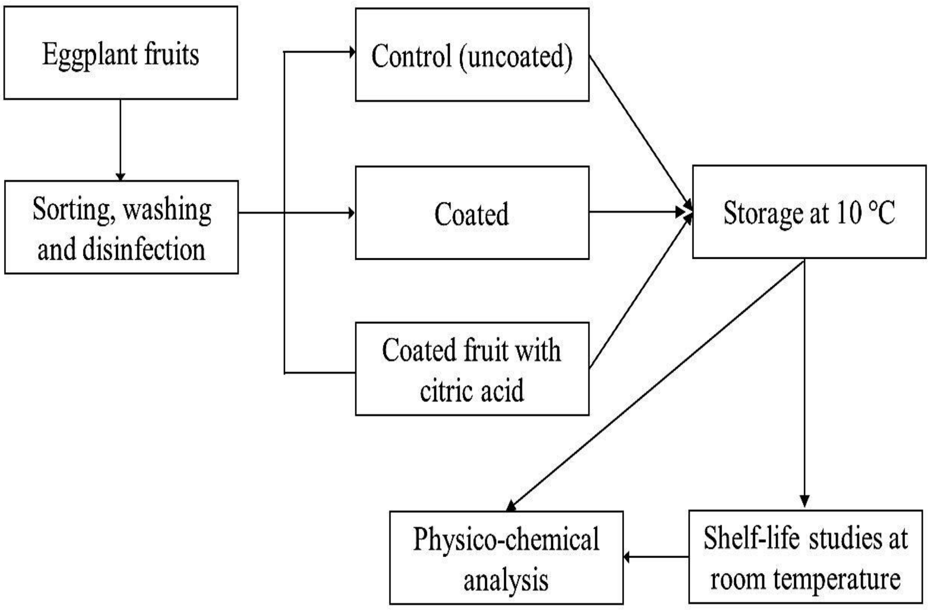

Figure 3.1: Experimental layout for the effect of cassava starch, Aloe vera and beeswax coating on the quality and storage life of eggplant fruits during low temperature storage.

Treatment was carried out by dipping the fruits (with or without citric acid pre-treatment) in the coating solution for 5 min, followed by air drying for 1 h. The citric acid pre-treated fruits were dipped in 1 % citric acid solution for 5 min, prior to coating. Uncoated fruits (without citric acid pre-treatment) were used as control. Coated and control fruits were later stored at low temperature (10 ± 1 °C and RH 90 ± 5%). After 14 days of low temperature storage, some fruits were transferred to room temperature for shelf life studies except for fruits coated with beeswax. The experimental layout for the different coating treatments, storage and shelf life is illustrated in Figure 3.1.

The fruits designated as non-destructive were distinguished by tagging for easy monitoring whereas the periodic selection of destructive fruits was done randomly. To determine the effect of the coating treatments on the physical attributes (weight loss, firmness and colour) of the fruits, the 9 non-destructive fruits were monitored throughout the experimental duration. Four (4) fruits (selected from the destructive set) were, however, used for the analysis of total phenolic content, total antioxidant capacity and ascorbic acid levels for each coating treatment and control.

On day 0 before coating and low temperature storage, 12 fruits were sampled randomly and analyzed to determine their physicochemical properties. During storage for all treatments, sampling was carried out periodically. For beeswax coating, sampling was done on days 3, 7, 10, 14 and 17. On days 2, 4, 6, 8, 10, 14 and 17, fruits were sampled for the starch coating batch, while fruits for Aloe vera coating batch, were sampled on days 2, 5, 8, 11, 14, 15, 16, 17 and 18. Also, fruits coated with starch in shelf life were sampled on day 17, whereas fruits coated with aloe vera in shelf life were sampled on days 15, 16, 17 and 18. The temperature and relative humidity of the storage environment were recorded and monitored using a temperature and relative humidity data logger (Dongguan Xintai Instrument Co. Ltd, China,HT-160-XINTEST).

Physicochemical Analysis

Physicochemical measurements were done on the fruits to understand the effect of the coating on the eggplant fruits during storage.

Determination of weight loss, colour and firmness

The initial weights of the fruits were measured at day 0 and each sampling time point using an analytical balance (VWR, Italy, ECN 611-2268). Cumulative weight loss was calculated as the difference between the initial weight at day 0 and the weight at the time of measurement. The weight loss of the fruits was expressed as g/kg.

The skin colour of the fruits was determined using a colour reader (CHN Spec, China, CS-10,) with an 8mm light path aperture, based on the CIELAB values. The instrument was calibrated with a standard white and black plate provided by the manufacturer. L*a*b* readings were measured from four opposite regions of the fruit and averaged to obtain mean values.

A digital fruit penetrometer (Tsingtao Tokyo Instruments Co., Ltd, China, GY- 4) was used to measure the firmness of the intact fruit (with slight peeling). The firmness values were obtained using a probe of 3.5 mm with an average speed of 15 mm/s. The probe was pushed downwards until it punctured the fruit. Four different measurements were carried out on opposite regions of the fruits and averaged for the mean firmness value. Firmness was measured in Newton (N).

Analysis of total phenolic content

Total phenolic content was assayed using the Folin Ciocalteau reagent in accordance with the method used by Meda et al. (2005). 1 g of homogenized sample (whole fruit) was weighed into a 25 mL centrifuge tube and 10 mL of 80 % methanol solution was added. Incubation was carried out for 2 h on a platform shaker. The samples were then centrifuged at 1790 x g for 20 min after which the supernatant was decanted into 4 mL vials. The samples were re-extracted under similar conditions and the supernatants combined for the total phenolic content assay. To 100 μL of the extract, 750 uL of 10 % Folin Ciocalteu reagent was added. After 10 min, 750 μL of 6 % sodium bicarbonate solution was added. The mixture was allowed to stand at room temperature for 90 min and absorbance was measured at 725 nm using a UV/VIS spectrophotometer (Bibby Scientific Ltd, UK, Jenway 6400,). The total phenolic content of the samples was expressed as Gallic acid equivalent in mg/kg of fresh fruit.

Determination of total antioxidant activity

Total antioxidant activity was determined using the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging method (Sánchez-Moreno et al., 1999). Methanolic extract of the eggplant fruits (100 μL) was mixed with 900 μL Tris-HCl buffer (50 mM, pH 7.4). DPPH solution (2 mL, 0.1 mM in methanol) was added and the solution incubated at room temperature for 30 min in the dark. DPPH solution without extract was used as control. The absorbance of the solution was measured at 517 nm against methanol blank. The DPPH radical scavenging activity was determined and the values expressed as Gallic acid equivalent in mg/kg of the fresh fruits.

Determination of ascorbic acid levels

Ascorbic acid was measured according to the method used by Kapur et al. (2012) with slight modification. 1 g of fruit sample was homogenized with 5 mL metaphosphoric-acetic acid solution in a total volume of 10 mL. The solution was filtered and centrifuged at 1790 x g for 15 min, after which the supernatant was used for spectrophotometric determination. To 1.54 mL of the supernatant, 90 µL of bromine water was added after which 50 µL of 10 % thiourea was added. Thereafter, 390 µL of 2,4-Dinitrophenylhydrazine (2 g in 100 mL 4.5 M H_2SO_4) solution was added and incubated at 37 °C for 3 h. After incubation, samples were cooled in an ice bath for 30 min. Chilled H_2SO_4 (85%, 1.93 mL) was later added with constant stirring. The absorbance of the solution was measured at 521 nm using a spectrophotometer. Standard curves were prepared using L-ascorbic acid and the ascorbic acid levels were expressed as mg/kg.

Optimization of process factors (coating concentration, citric acid concentration and coating duration) for the formulation of starch, Aloe vera and beeswax coating

Experimental design

A Response Surface Methodology (RSM) Box-Behnken Design (BBD) was employed to study the effect of three independent variables; coating concentration, [X_1 (% w/v)], citric acid concentration, [X_2 (% w/v)] and coating duration, [X_3 (min)] at three levels each on the physicochemical properties of eggplant fruits. Coating of the fruits were carried out according to the treatment combinations outlined in the experimental design presented in Table 3.1 The BBD arrangement for each coating experiment consisted of 17 experimental runs of different treatment combinations which included 5 replicated centre points as shown in Table 3.2. Coated fruits were stored for 17 d at 10 °C after which the physicochemical properties of the fruits were determined.

Table 3.1: Experimental range and levels of independent variables for cassava starch, Aloe vera and beeswax coating

Factors	Unit	Coded symbol	Levels		
			-1	0	+1
Coating concentration	% (w/v)	X_1	1*	3*	5*
Citric acid concentration	% (w/v)	X_2	1	3	5
Coating duration	min	X_3	3	6.5	10

*Levels for Aloe vera coating concentration (X_1); -1 (50), 0 (75) and +1 (100).

Table 3.2: RSM BBD for independent variables X_1 (coating concentration), X_2 (citric acid concentration), X_3 (coating duration), and their responses (Y) for starch, Aloe vera and beeswax coating

	Factors			
Run	X_1 % (w/w) *	X_2 (%w/v)	X_3 (min)	Responses (Y)**
1	5 (100)	1	6.5	
2	3 (75)	5	3	
3	1 (50)	3	3	
4	3 (75)	1	10	
5	5 (100)	3	10	
6	1 (50)	5	6.5	
7	3 (75)	5	10	
8	3 (75)	3	6.5	
9	3 (75)	3	6.5	
10	3 (75)	3	6.5	
11	1 (50)	3	10	
12	3 (75)	1	3	
13	3 (75)	3	6.5	
14	1 (50)	1	6.5	
15	5 (100)	3	3	
16	3 (75)	3	6.5	
17	5 (100)	5	6.5	

*X_1 (%w/v): the values in bracket represents the coating levels used for Aloe vera. **Response (Y): represents the measured physicochemical properties of the fruits (weight loss, colour, firmness, total phenolic content, ascorbic acid levels and total antioxidant capacity).

BBD experiments were carried out and quadratic polynomial equations were developed by RSM to predict the responses. Equation (Eqn.) 3.1 shows a generalized second-order polynomial model used in the response surface analysis.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i \le i \le j}^{k-1} \beta_{ij} x_i x_j \qquad \textbf{Eqn. 3.1}$$

Where Y is the predicted response, β_0 is the model constant, β_i, β_{ii}, β_{ij} represent the regression coefficients for linear, quadratic and interaction effects respectively. X_i, X_j...X_k are the input variables which affect the responses.

The fitted polynomial equation was then expressed in the form of three-dimensional (3D) response surface plots for two independent variables while fixing the remaining one at a coded zero level. This helped to illustrate the relationship between the responses and the experimental levels of each of the variables used in this study.

Prediction of optimized conditions and responses

The numerical optimization approach was carried out using the concept of overall desirability index (DI) to predict the ideal process conditions and their responses. The DI ranges between 0 and 1, with 0 being the least desirable while 1 is the most desirable. Maximization of DI value is the goal in optimization studies. The optimization process incorporates goals and priorities for the independent and dependent variables. In order to optimize the responses, the goals for the independent variables (coating concentration, citric acid concentration and the coating duration) were set at any level within the range of the design values. However, in the case of the response variables, the goals were minimization of weight loss, a* and b* values and maximization of L* value, firmness, total phenolic content, total antioxidant capacity and ascorbic acid levels.

Verification of optimized conditions and responses

To validate the predicted models, the optimized conditions of the input variables were tried in another experiment according to the previously described experimental procedure. A total of 12 fruits were used for each coating experiment. The fruits were stored for 17 d at 10° C after which the physicochemical properties were determined. Uncoated fruits were used as control. The verified optimized conditions and responses for beeswax, cassava starch and Aloe vera coated fruits were then compared to the control fruits to know the effectiveness of the coatings.

Statistical analysis

Effect of coating treatments on eggplant fruits during storage

Statistical analysis was performed using SPSS (IBM, SPSS Statistics 20). One-way Analysis of Variance (ANOVA) was first carried out to determine if the effect of the beeswax coating on the physicochemical properties of the eggplant fruits was significant. Afterwards, multiple comparison test using Tukey test was performed to determine which treatment means differed significantly. A two-way ANOVA was conducted to compare the mean differences between fruits transferred to room temperature for shelf life studies and fruits stored at 10° C. Test of significance was determined at a probability of 0.05.

Optimization of coating conditions using Response Surface Methodology

ANOVA was performed using Design-Expert® 11 Software (Stat-Ease Inc, MN, USA) to evaluate the adequacy of the model and to determine the regression coefficients of the individual and the interactive model parameters. Significant model terms were selected considering the p-value and the F-value. The statistical significance of each model term was verified at a probability of 0.05. The adequacy of the model to navigate the design space of the responses was determined using the coefficient of determination (R^2) and lack of fit test.

CHAPTER FOUR

RESULTS

EFFECT OF COATING ON THE PHYSICOCHEMICAL PROPERTIES OF EGGPLANT FRUITS DURING STORAGE

Effect of coating on weight loss of eggplant fruits

Effect of beeswax coating on weight loss of eggplant fruits

The effect of beeswax coating on the cumulative weight loss of eggplant fruits is shown in Figure 4.1. Weight loss of all fruits increased with elapsed storage time. After 3 d of storage at 10 °C, weight losses of 27.06, 13.14 and 4.96 g/kg were observed for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating, respectively. The rate of weight loss in control fruits were rapid compared to both coated fruits.

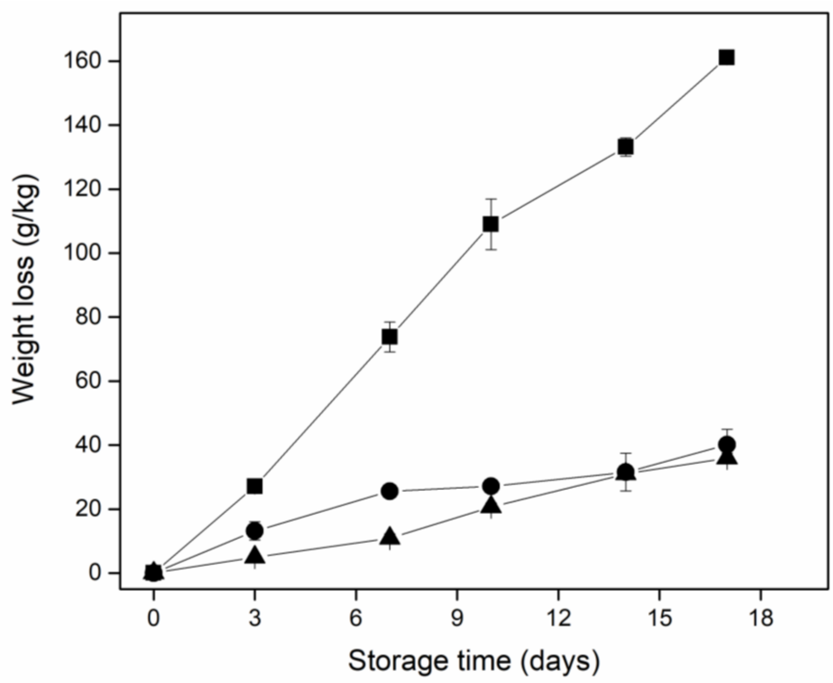

Figure 4.1: Weight loss of eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with beeswax alone (●); fruits dipped in citric acid before beeswax coating (▲). Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

Fruits coated with beeswax (with or without citric acid pre-treatment) maintained significantly lower weight losses compared to the control fruits throughout the storage period. Coating treatment and storage time significantly affected the weight loss of the fruits. Fruits coated with beeswax alone recorded significantly higher weight losses in the first 7 d of storage compared to fruits dipped in citric acid before coating with beeswax. However, after 7 d of storage, no significant difference in weight loss was observed between both coated fruits. At the end of the 17 d storage period, final weight losses of 161.11, 40.10 and 35.95 g/kg (Figure 4.1), representing 16.11, 4.01 and 3.60 % reduction in the weight were observed for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before coating with beeswax, respectively.

Effect of cassava starch coating on weight loss of eggplant fruits

The effect of starch coating on the weight loss of eggplant fruits is shown in Figure 4.2. Weight loss increased significantly for coated and uncoated fruits throughout the storage period. In the first two days of storage, weight losses of 26.04, 22.62, 20.70 g/kg were observed for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating, respectively. The control fruits exhibited higher weight losses than coated fruits throughout storage at 10 °C. However, weight losses of the control fruits were not significantly different from the fruits coated with starch alone throughout the storage period. On the other hand, significant differences were observed between the control fruits and fruits dipped in citric acid before starch coating only on days 6 and 17 (Figure 4.2). Fruits coated with starch alone recorded higher weight losses than the fruits dipped in citric-acid before starch coating, but a significant difference was observed only on day 17 (Figure 4.2). After 17 d of storage at 10 °C, the control, fruits coated with starch alone and fruits dipped in citric acid before starch coating recorded maximum weight losses of 215.28, 227.34 and 188.18 g/kg, respectively (Figure 4.2).

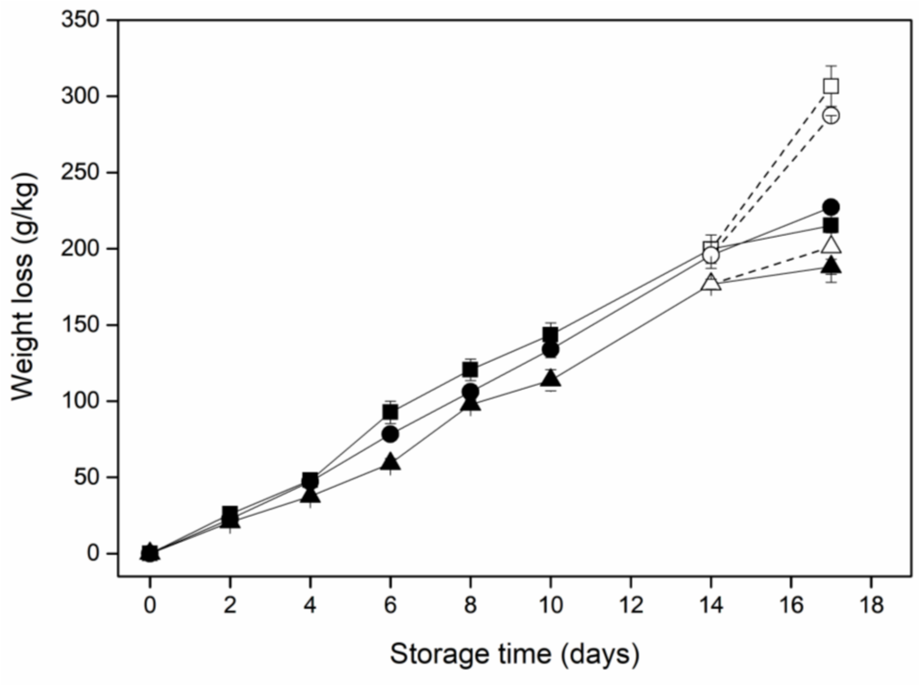

Figure 4.2: Weight loss of eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with starch alone (●); fruits dipped in citric acid before starch coating (▲); control fruits in shelf life (□); fruits coated with starch alone in shelf life (○); fruits dipped in citric acid before starch coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean

The transfer of the fruits from low temperature storage (10 °C) to room temperature storage (shelf life) resulted in an increase in weight loss of the fruits (Figure 4.2). Comparing fruits that were kept at 10 °C for 17 d and fruits in shelf life, a sharp increase in weight loss was observed in both the control fruits and fruits coated with starch alone but not fruits dipped in citric acid before starch coating. After 3 d in shelf life, the control fruits recorded the highest weight loss of 306.58 g/kg, followed by fruits coated with starch alone (287.35 g/kg) and fruits dipped in citric acid before starch coating (201.13 g/kg), respectively. A two-way ANOVA comparison of fruits in shelf life and fruits that were kept at 10 °C showed a significant effect of both storage temperature and coating treatment on the weight loss of the fruits.

Effect of Aloe vera coating on weight loss of eggplant fruits

Figure 4.3 shows the effect of Aloe vera coating on the weight loss of eggplant fruits during storage. Weight loss of both Aloe vera coated and control fruits increased with increasing storage time.

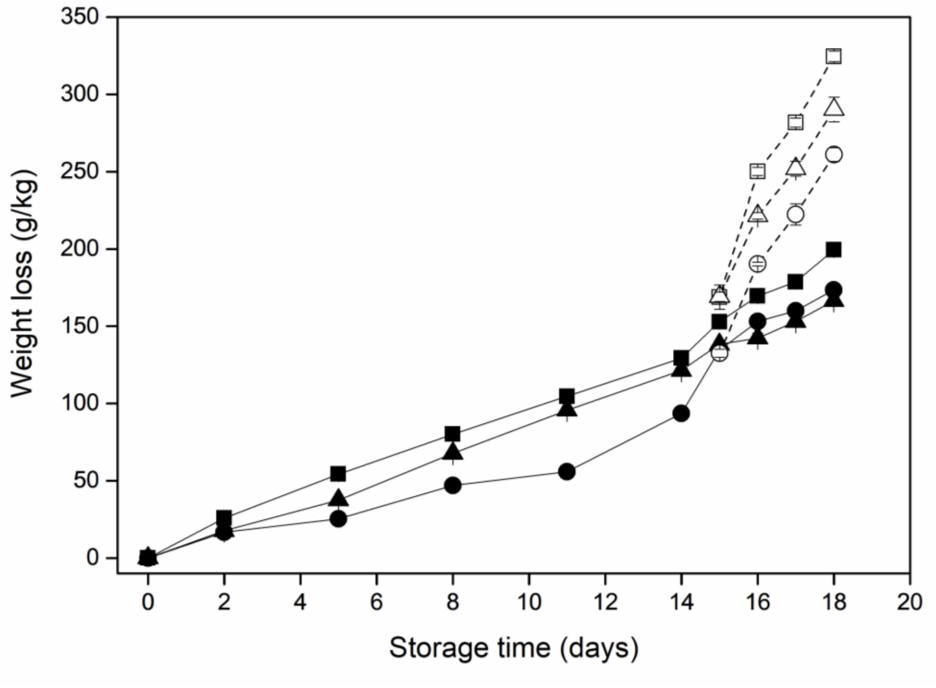

Figure 4.3: Weight loss of eggplant fruits during storage at 10 °C for 18 d. [control fruits (■); fruits coated with Aloe vera alone (●); fruits dipped in citric acid before Aloe vera coating (▲); control fruits in shelf life (□); fruits coated with Aloe vera alone in shelf life (○); fruits dipped in citric acid before Aloe vera coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

Storage time and coating treatment had significant effect on the weight loss of eggplant fruits throughout the storage period. Weight losses of 25.83, 16.71 and 17.60 g/kg were recorded after 2 d of storage for the control fruits,

fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating, respectively.

The control fruits recorded higher weight losses throughout the storage period. Significant differences were observed between the control fruits and the fruits coated with Aloe vera alone on all sampling days during storage at 10 °C. Additionally, there were significant differences in the weight losses observed between the control fruits and fruits dipped in citric acid before Aloe vera coating on all sampling days except on days 11 and 14. Generally, the fruits dipped in citric acid before Aloe vera coating recorded higher weight loss during the first 14 d of storage compared to the fruits coated with Aloe vera alone. A statistical comparison between fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating showed significant differences in weight loss only on days 5, 8, 11 and 14 during storage at 10 °C. The control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating recorded final weight losses of 199.39, 173.40 and 166.44 g/kg, representing weight losses of 19.94, 17.34 and 16.64 % after 18 d of storage at 10 °C, respectively (Figure 4.3).

The transfer from low temperature (10 °C) to room temperature storage resulted in an increase in the weight loss of both Aloe vera coated and control fruits (Figure 4.3). A two-way ANOVA showed that the effect of storage temperature and coating treatment, and the effect of the interaction between storage temperature and coating treatment on the weight loss was significant. Comparing weight loss of the fruits between the two storage temperatures, fruits in shelf life lost significantly higher weight on all sampling days except on day 15 compared to fruits in storage at 10 °C (Figure 4.3). In shelf life, the control fruits recorded significantly higher weight loss compared to both Aloe vera coated fruits with the exception of day 15 (Figure 4.3). Comparing both the Aloe vera coated fruits, significantly higher weight loss was observed in fruits dipped in citric acid before Aloe vera coating except on day 18. After 4 d of storage in shelf life, weight losses of 324.47, 261.02 and 290.11 g/kg were recorded for the control, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating, respectively.

Effect of coating on the firmness of eggplant fruits

Effect of beeswax coating on firmness of eggplant fruits

Figure 4.4 shows the effect of beeswax coatings on the firmness of eggplant fruits during storage. The firmness of the fruits generally decreased during storage for both coated and uncoated samples. At all sampling times, fruits coated with beeswax (with or without citric acid pre-treatment) recorded higher firmness values than the control fruits. The control fruits and fruits coated with beeswax alone showed significant differences on days 7, 14 and 17, whereas the control fruits and fruits dipped in citric acid before beeswax coating showed significant differences on all sampling days. However, no significant differences were observed between fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating. At the end of the 17 d storage period, the control fruits recorded the lowest firmness value of 25.73 N, while fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating recorded firmness values of 28.18 and 30.68 N, respectively (Figure 4.4).

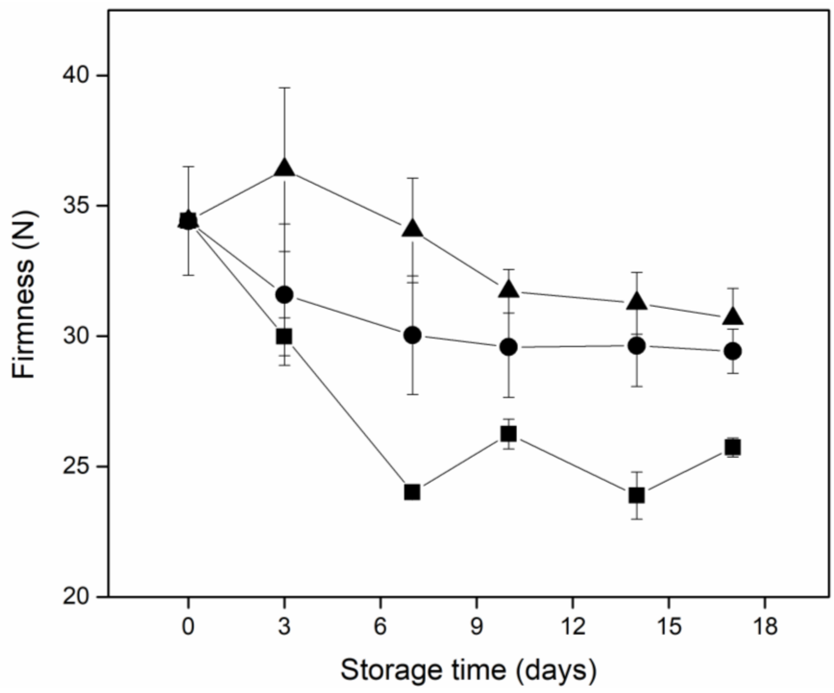

Figure 4.4: Firmness of eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with beeswax alone (●); fruits dipped in citric acid before beeswax coating (▲). Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

Effect of starch coating on firmness of eggplant fruits

Figure 4.5 shows the effect of starch coating on the firmness of eggplant fruits. The firmness of both coated and control fruits generally decreased during storage. Storage time significantly affected the firmness of eggplant fruits. Generally, no significant difference was found between fruits coated with starch alone and fruits dipped in citric acid before starch coating, except on day 14 and 17 where fruits dipped in citric acid before starch coating recorded significantly higher firmness than fruits coated with starch alone. After 17 d of storage at 10 °C, the control, fruits coated with starch alone and the fruits dipped in citric acid before starch coating recorded firmness values of 25.73, 22.59 and 26.51 N, respectively.

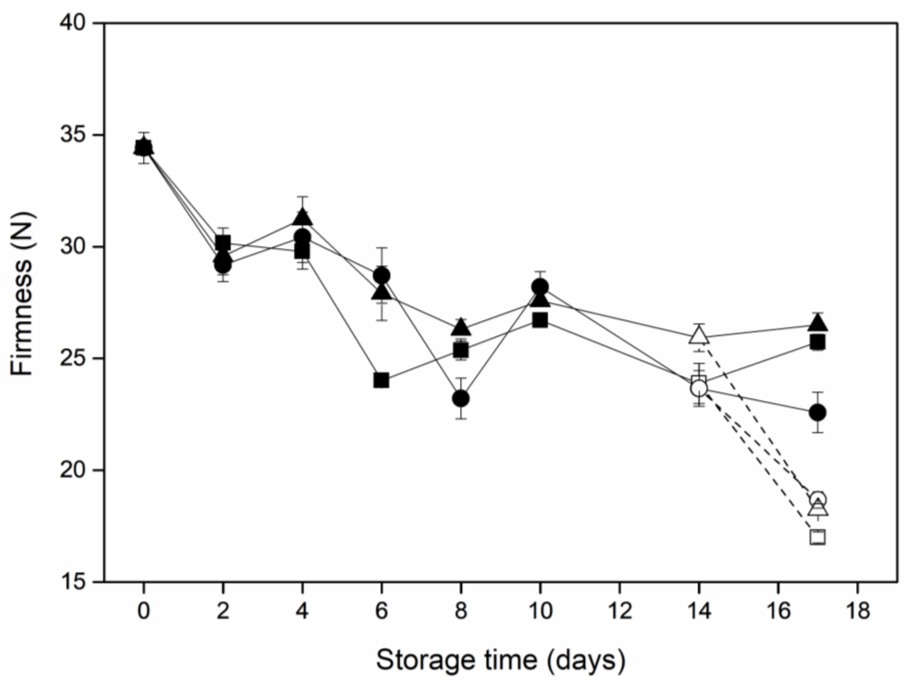

Figure 4.5: Firmness of eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with starch alone (●); fruits dipped in citric acid before starch coating (▲); control fruits in shelf life (□); fruits coated with starch alone in shelf life (○); fruits dipped in citric acid before starch coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

Transferring fruits from storage at 10 °C to room temperature storage (shelf life) caused a significant decrease in the firmness of the fruits. Fruits in shelf life recorded significantly lower firmness values than fruits that remained at low temperature storage. A two-way ANOVA showed that storage at 10 °C and coating treatment had significant effect on the firmness. The effect of the interaction between the coating treatment and temperature was also significant. Fruits coated with starch (with or without citric acid pre-treatment) recorded significantly higher firmness values than the control fruits in shelf life. However, no significant difference was observed between both coated fruits. The firmness of the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating, reduced to 17.0, 18.67 and 18.25 N, respectively after 3 d in shelf life.

Effect of Aloe vera coating on firmness of eggplant fruits

The effect of Aloe vera coating on the firmness of eggplant fruits is illustrated in Figure 4.6. The firmness of all fruits (coated and uncoated) decreased with increasing storage time. Storage period and coating treatment significantly affected the firmness of the fruits. The control fruits recorded lower firmness throughout the storage period compared to the coated fruits. Also, the firmness of fruits coated with Aloe vera alone were higher than the fruits dipped in citric acid before Aloe vera coating. Significant differences in firmness were observed between the control fruits and fruits coated with Aloe vera alone throughout the storage period except on days 2 and 18. However, the control fruits and the fruits dipped in citric acid before Aloe vera coating showed significant differences only on days 11 and 17. Fruits coated with Aloe vera (with or without citric acid pre-treatment) showed no significant differences except on day 14, where fruits coated with Aloe vera alone, recorded a significantly higher firmness value. Final firmness values of 27.34, 28.43 and 28.53 N were recorded for the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating, respectively after 18 d of storage at 10 °C (Figure 4.6).

When fruits were transferred from low temperature to room temperature storage for shelf life studies, the firmness continued to decrease but was not significant between treatments (Figure 4.6). A two-way ANOVA comparing fruits in shelf life and fruits kept at 10 °C showed that the effect of storage temperature and the coatings were significant. The effect of the interaction between the storage temperature and coating was, however, significant only on day 17.

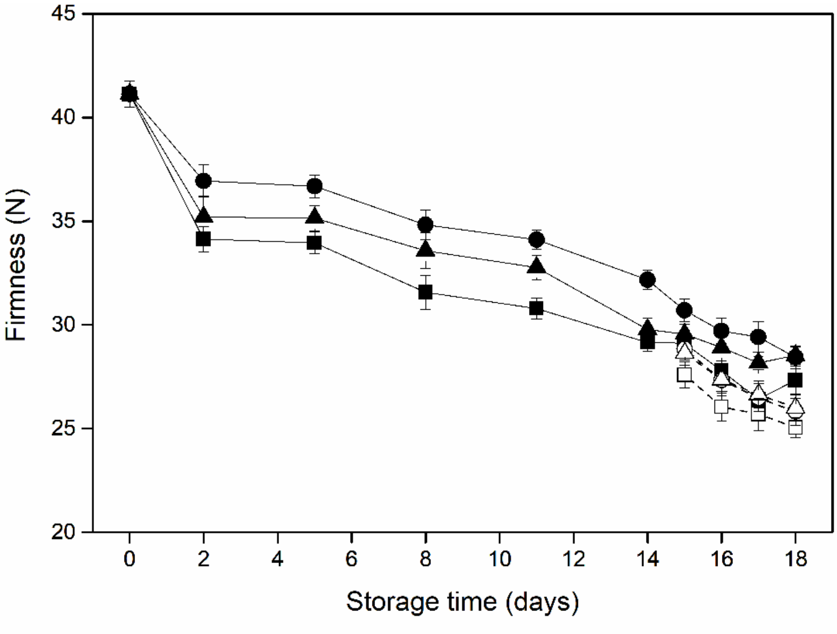

Figure 4.6: Firmness of eggplant fruits during storage at 10 °C for 18 d. [control fruits (■); fruits coated with Aloe vera alone (●); fruits dipped in citric acid before Aloe vera coating (▲); control fruits in shelf life (□); fruits coated with Aloe vera alone in shelf life (○); fruits dipped in citric acid before Aloe vera coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

Effect of coating on the colour of eggplant fruits

Effect of beeswax coating on colour of eggplant fruits

Figure 4.7 shows the effect of beeswax coating on the colour (L*a*b*) of eggplant fruits. The colour of fruits coated with beeswax did not change significantly during storage. Generally, the L* values for fruits coated with beeswax (with or without citric acid pre-treatment) slightly increased during storage, although the effect of storage time and the coating treatment were not significant. Contrary to the observation made in the coated fruits, the L* values of the control fruits decreased gradually during the first 10 d of storage but the decreases were not significant. Significant decreases in the control fruits were observed on days 10 and 14. After 10 d of storage, the coated fruits recorded higher L* values than the control fruits (Figure 4.7). Significant differences were observed between fruits coated with beeswax alone and the control fruits only on day 17. A similar observation was made between fruits dipped in citric acid before beeswax coating and the control fruits. Final L* values recorded after 17 d of storage for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating were 76.74, 79.27 and 81.84, respectively.

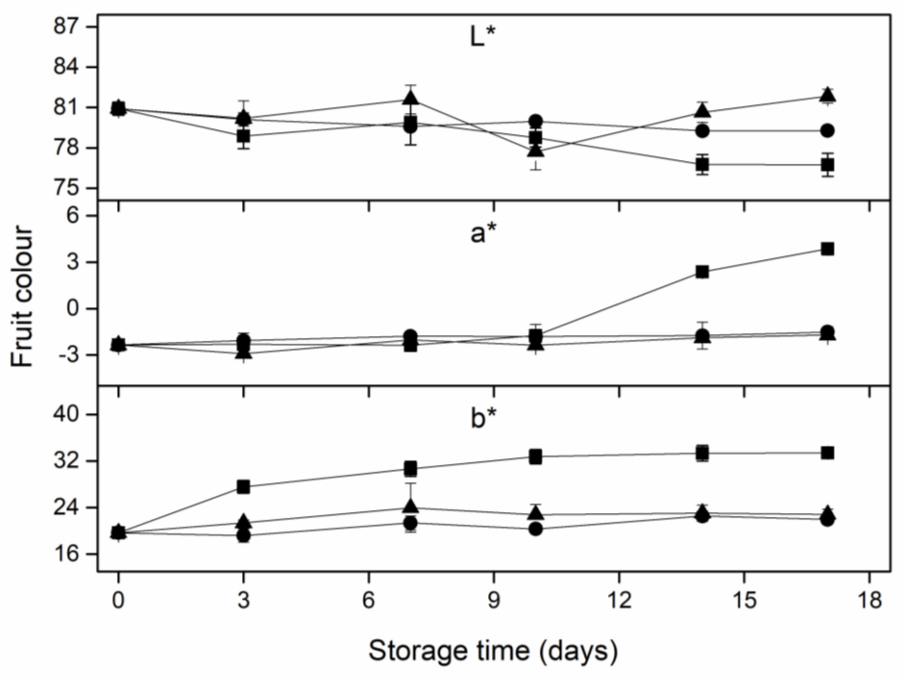

Figure 4.7: Colour changes (L*a*b*) in eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with beeswax alone (●); fruits dipped in citric acid before beeswax coating (▲). Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

The a* values were fairly constant during the first 10 d of storage for all the treatments. After 10 d however, a* value increased rapidly for the control fruits (Figure 4.7). For the fruits coated with beeswax (with or without citric acid pre-treatment), the a* values were generally constant throughout the storage period. The a* values were significantly affected by the storage time, coating treatment, and their interactions after 10 d of storage. The control fruits recorded significantly higher a* values than both beeswax coated fruits on days 14 and 17. The beeswax coated fruits (with and without citric acid pre-treatment) showed no significant differences on all sampling days. The a* values recorded for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating after the 17 d storage period were 3.87, -1.51 and -1.72, respectively.

The b* values of both beeswax-coated fruits generally, remained constant throughout the storage period (Figure 4.7). However, the b* values of the control fruits increased gradually during storage. Storage time and coating treatment had a significant effect on the b* values. Generally, the control fruits recorded significantly higher b* values than both beeswax coated fruits during storage. There were no significant differences between both beeswax coatings. Final b* values obtained after storing eggplant fruits for 17 d at 10 °C were 33.39, 21.96 and 22.83 for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating, respectively.

Effect of starch coating on colour of eggplant fruits

The effect of cassava starch coating on colour changes of eggplant fruits are shown in Figure 4.8. The L* values of fruits coated with starch (with or without citric acid pre-treatment) and the control fruits decreased gradually throughout storage (Figure 4.8). Storage time and coating treatment significantly affected the L* values, but the interaction between storage time and coating treatment did not significantly affect L* values. Generally, no significant difference was observed between the treatments throughout the storage period. Final L* values after the 17 d storage at 10 °C were 76.74 for control fruits and 74.15 for both starch-coated fruits.

When the fruits were transferred from 10 °C to room temperature after 14 d, L* values decreased (Figure 4.8). A two-way ANOVA between fruits in shelf life and fruits that remained at 10 °C showed that temperature had a significant effect on the L* values but the effect of the coating and the interaction between the coating and storage temperature were not significant. In shelf life, fruits dipped in citric acid before starch coating recorded the highest L* value followed by fruits coated with starch alone and the control, although the differences were not significant. After three (3) days in shelf life, L* values of 65.93, 67.57, and 69.12 were observed for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating, respectively.

The a* values increased gradually throughout storage at 10 °C for the starch coated and control fruits (Figure 4.8). The effect of storage time and coating treatment and the interaction between storage time and coating treatment on the a* values were not significant. In the first 10 d of storage, a* values increased from -1.72 on day 0 to -0.96, -0.51 and -0.69 for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating. There was no significant difference between both starch coated fruits or between the control and starch coated fruits throughout storage period. Similar to the a* values, b* values increased gradually throughout the storage period (Figure 4.8). No significant difference was observed between fruits under the different coating treatments. The final b* values obtained after the 17 d storage period were 33.90, 33.14 and 33.09, respectively for the control fruits,

fruits coated with starch alone and fruits dipped in citric acid before starch coating.

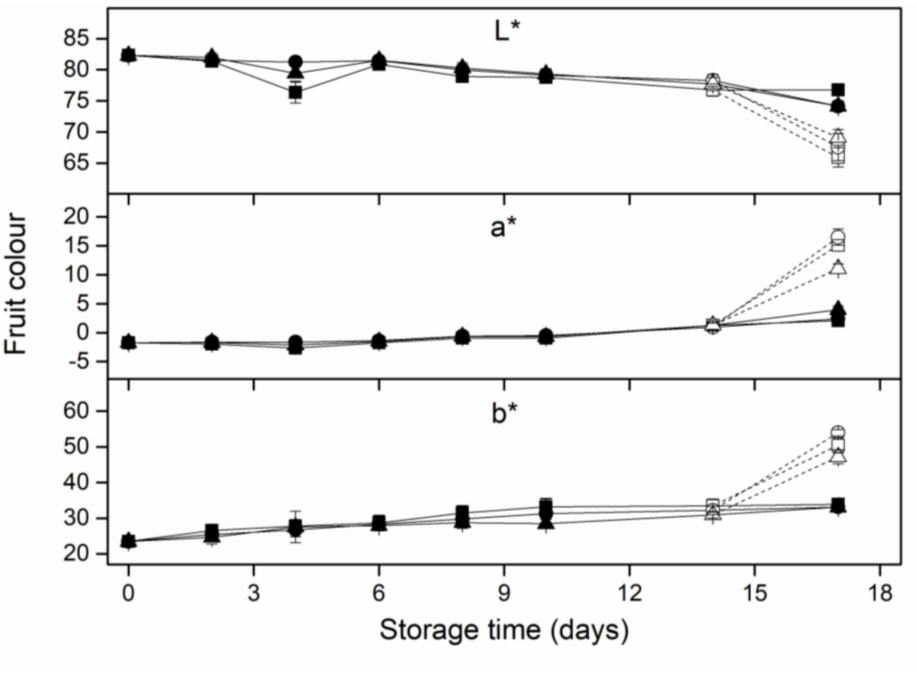

Figure 4.8: Colour changes (L*a*b*) in eggplant fruits during storage at 10 °C for 17 d. [control fruits (■); fruits coated with starch alone (●); fruits dipped in citric acid before starch coating (▲); control fruits in shelf life (□); fruits coated with starch alone in shelf life (○); fruits dipped in citric acid before starch coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

After three days in shelf life, a* and b* values increased significantly. A two-way ANOVA comparing fruits in shelf life and those that remained at 10 °C after the transfer showed that temperature affected the a* and b* values in magnitude but not the coating treatment. There was no interaction effect between the storage temperature and coating treatment significant. No significant differences were observed in the a* and b* values between fruits coated with starch alone and the control fruits. Fruits dipped in citric acid before starch coating recorded lower a* and b* values compared to the control fruits. Fruits coated with starch alone recorded higher a* and b* values compared to fruits dipped in citric acid before starch coating. The control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating recorded a* values of 15.10, 16.50 and 11.06, and b* values of 50.44, 53.91 and 47.19, respectively, after three days in shelf life.

Effect of Aloe vera coating on colour of eggplant fruits

The colour changes observed in fruits coated with Aloe vera (with or without citric acid pre-treatment) and the control fruits during storage are shown in Figure 4.9. Aloe vera coating and storage time had significant effect on the colour of eggplant fruits. The L* values decreased gradually for both coated and control fruits as storage time increased (Figure 4.9). Sharper decreases were observed in the control fruits after 5 days of storage while the decreases observed in the coated fruits (with or without citric acid pre-treatment) were gradual throughout the storage period.

Fruits coated with Aloe vera alone measured significantly higher L* values than the control fruits on all sampling days except days 2 and 5. Similarly, fruits dipped in citric acid before Aloe vera coating recorded significantly higher L* values compared to the control fruits except on day 2. Comparing both coated fruits, fruits coated with Aloe vera alone generally recorded higher L* values than the fruits dipped in citric acid before Aloe vera coating, but significant differences were observed only on days 5, 15 and 18. In shelf life, the control fruits recorded significantly lower L* values compared with both Aloe vera-coated fruits on all sampling days. There was however, no significant differences between both coated fruits on all sampling days in shelf life.

At the end of the storage period at 10 °C, L* values for the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating reached 71.82, 79.57 and 77.31, while the corresponding values were 67.13, 74.43 and 72.83 after 4 d in shelf life, respectively (Figure 4.9). A two-way ANOVA showed that the effect of storage temperature on L* values was significant on days 16, 17 and 18 while the effect of the coating was significant throughout the shelf life period. There was, however, no interaction effect between storage temperature and coating treatment.

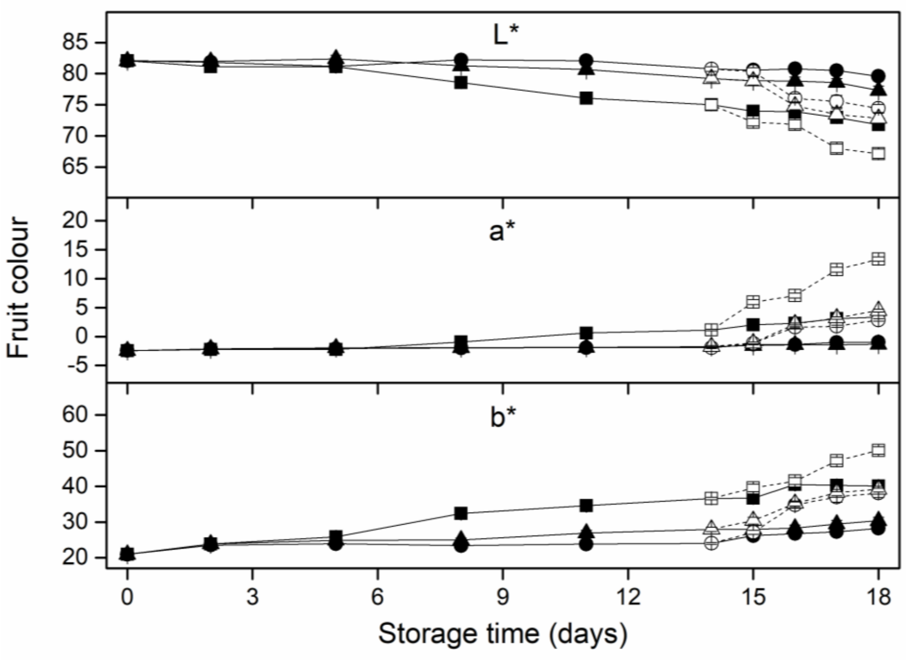

Figure 4.9: Colour changes (L*a*b*) in eggplant fruits during storage at 10 °C for 18 d. [control fruits (■); fruits coated with Aloe vera alone (●); fruits dipped in citric acid before Aloe vera coating (▲); control fruits in shelf life (□); fruits coated with Aloe vera alone in shelf life (○); fruits dipped in citric acid before Aloe vera coating in shelf life (Δ)]. Each data point is the mean of nine (9) replicates and the error bars are the standard error of the mean.

The a* values were fairly constant for both Aloe vera coated and the control fruits in the first 8 days of storage at 10 °C. However, the a* values for the control fruits increased after 8 d of storage (Figure 4.9). The control fruits recorded significantly higher a* values than fruits coated with Aloe vera (with or without citric acid pre-treatment) from day 8 until the end of storage. However, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating generally showed no significant differences throughout the storage period. At the end of storage at 10 °C, a* values of the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating were 3.43, -0.99 and -1.33, respectively (Figure 4.9).

The transfer of fruits from low temperature (10 °C) to room temperature storage resulted in further increases in the a* values, with fruits in shelf life having higher a* values compared to fruits kept at 10 °C (Figure 4.9). The control fruits recorded significantly higher a* values compared to both coated fruits throughout the shelf life period. However, there was no significant difference between both coated fruits. On day 18 in shelf life, the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before Aloe vera coating recorded a* values of 13.37, 2.90 and 4.49 respectively (Figure 4.9). The effect of temperature and coating on a* values was significant throughout shelf life. The interaction effect between the coating treatment and storage temperature was also significant on all sampling days in shelf life.

The b* values also increased significantly throughout the storage period and is shown in Figure 4.9. The b* values of the eggplant fruits were significantly affected by storage time, coating treatment, and their interaction. A rapid increase in b* value was observed in the control fruits after 5 d of storage and continued until the end of storage. The increases observed in the coated fruits were however gradual compared to the control fruits. The control fruits measured significantly higher b* values compared to both coated fruits except on days 2 and 5. The differences in b* values between the coated fruits (with or without citric acid pre-treatment) were, however, only significant on days 11 and 14, where fruits dipped in citric acid before Aloe vera coating recorded significantly higher b* values than fruits coated with Aloe vera alone. The final b* values obtained at the end of storage at 10 °C were 40.13, 28.23 and 30.36, respectively, for the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before coating (Figure 4.9). When fruits were transferred from 10 °C to shelf life, the b* values continued to increase. The control fruits in shelf life recorded significantly higher b* values than both Aloe vera coated fruits. However, no significant differences were observed between the coated fruits (with or without citric acid pre-treatment). The b* values were also significantly affected by temperature and coating treatments on all sampling days in shelf life. However, the effect of the interaction between the storage temperature and coating treatment was only significant on day 16.

Effect of coating on the total phenolic content of eggplant fruits

Effect of beeswax coating on total phenolic content of eggplant fruits

The effect of beeswax coating on the total phenolic content of eggplant fruits is presented in Table 4.1A. Total phenolic content decreased slightly for the control fruits but remained fairly constant for fruits coated with beeswax (with or without citric acid pre-treatment) within the initial 3 d of storage.

Table 4.1A: Total phenolic content of eggplant fruits coated with beeswax during storage.

Days	Total Phenolic Content (mg/kg)		
	Control	Beeswax alone	Citrate-dipped-beeswax
0	230.72 ± 3.19^{A}	-	-
3	214.26 ± 6.99^{aAB}	229.45 ± 11.35^{aA}	235.98 ± 7.78^{aA}
7	261.15 ± 3.09^{aC}	245.81 ± 5.25^{aA}	173.24 ± 6.87^{bB}
10	222.43 ± 2.34^{aA}	224.00 ± 2.61^{aA}	204.12 ± 12.98^{aA}
14	247.50 ± 1.68^{aAB}	221.27 ± 10.72^{aA}	118.33 ± 17.96^{bB}
17	153.23 ± 5.88^{aB}	232.48 ± 4.73^{bA}	161.96 ± 17.33^{aB}

Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test (p<0.05). The data values represent the mean of four replicates.

Fruits dipped in citric acid before beeswax coating generally recorded lower total phenolic content compared to the control fruits and fruits coated with beeswax alone. No significant difference was observed between the control fruits and fruits coated with beeswax alone, except on day 17 (Table 4.1A). At the end of the storage period, the highest total phenolic content of 224.91 mg/kg was recorded for fruits coated with beeswax alone, while the control and fruits dipped in citric acid before beeswax coating recorded 153.24 and 136.47 mg/kg, respectively.

Effect of starch coating on total phenolic content of eggplant fruits

The effect of starch coating on the total phenolic content of eggplant fruits is presented in Table 4.1B. Generally, total phenolic content decreased within the first two days of storage, from 401.40 mg/kg to 272.35, 181.18 and 135.59 mg/kg for the control, fruits coated with starch alone and fruits dipped in citric acid before starch coating, respectively.

Table 4.1B: Total phenolic content of eggplant fruits coated with starch during storage.

Days	Total Phenolic Content (mg/kg)		
	Control	Starch alone	Citrate-dipped-starch
0	401.40 ± 27.63^{A}	-	-
2	272.35 ± 3.12^{aD}	181.18 ± 1.04^{bB}	135.59 ± 2.08^{cB}
4	479.71 ± 27.51^{aC}	517.94 ± 29.12^{aC}	469.41 ± 32.24^{aC}
6	465.00 ± 2.08^{aC}	344.41 ± 22.88^{bAD}	312.06 ± 2.08^{bDC}
8	363.04 ± 5.16^{aABC}	317.21 ± 9.17^{bD}	383.38 ± 9.17^{aAD}
10	360.59 ± 1.04^{aAB}	410.59 ± 11.44^{bA}	445.88 ± 13.52^{bC}
14	263.53 ± 10.70^{aD}	302.50 ± 9.18^{bD}	301.03 ± 11.41^{bADC}
17	140.00 ± 8.10^{aE}	260.10 ± 16.13^{bD}	182.65 ± 2.08^{cBC}
17*	154.22 ± 7.25^{a}	165.98 ± 2.25^{a}	156.18 ± 8.05^{a}

* Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

Storage time had a significant effect on the total phenolic content but the effect of the coating and the interaction between storage time and coating were not significant. After a general increase in total phenolic content observed on the 4th day of storage, total phenolic content decreased again until the end of storage. Fruits coated with starch alone recorded higher total phenolic content of 517.94 mg/kg on day 4 but was not significantly different from the control fruits and fruits dipped in citric acid before starch coating. The control fruits had higher total phenolic content of 465.00 and 363.04 mg/kg on days 6 and 8, respectively compared to 344.41 and 317.21 mg/kg for fruits coated with starch alone (Table 4.1B). However, from day 10 to 17, fruits coated with starch alone recorded significantly higher values compared to the control fruits. Similarly, fruits dipped in citric acid before starch coating recorded significantly higher total phenolic content than the control fruits after 8 d of storage. After 17 d of storage at 10 °C, fruits coated with starch alone recorded the highest total phenolic content of 260.1 mg/kg while the control fruits and the fruits dipped in citric acid before starch coating recorded 140 and 182.65 mg/kg, respectively (Table 4.1B).

When the fruits were transferred from 10 °C to room temperature, the total phenolic content of control fruits increased while the content observed for both starch coated fruits decreased but the differences were not significant (Table 4.1 B). A two-way ANOVA comparing fruits transferred to shelf life and fruits kept at 10 °C showed that temperature and coatings had a significant effect on the total phenolic content of eggplant fruits. Similarly, the effect of the interaction between temperature and coating was also significant.

Effect of Aloe vera coating on total phenolic content of eggplant fruits

The effect of Aloe vera coating on the total phenolic content of eggplant fruits is presented in Table 4.1C. The total phenolic content decreased slightly for control fruits and fruits dipped in citric acid before Aloe vera coating, but increased for fruits coated with Aloe vera alone, within the first two days of storage, remained fairly constant up to day 14, followed by an increase until the end of storage. The total phenolic content of the fruits were significantly influenced by the storage time, coating treatment and their interaction. Generally, the control fruits recorded higher total phenolic content than the fruits coated with Aloe vera alone, but significant differences were observed only on days 11 and 16. A similar observation was made between the control fruits and fruits dipped in citric acid before Aloe vera coating, with significant differences observed on days 8, 11 and 18.

Table 4.1C: Total phenolic content of eggplant fruits coated with Aloe vera during storage.

Days	Total Phenolic Content (mg/kg)		
	Control fruits	Aloe vera alone	Citrate-dipped-Aloe vera
0	220.48 ± 4.24^{A}	-	-
2	214.87 ± 2.22^{aA}	247.88 ± 0.68^{bA}	199.49 ± 4.34^{aA}
5	261.35 ± 2.04^{aB}	214.23 ± 2.72^{aA}	241.15 ± 9.47^{aA}
8	241.79 ± 4.00^{aAB}	256.54 ± 1.36^{aA}	207.82 ± 8.72^{bA}
11	322.88 ± 6.12^{aB}	254.62 ± 5.44^{bA}	261.03 ± 6.55^{bA}
14	280.58 ± 11.56^{aB}	227.69 ± 5.44^{aB}	274.49 ± 8.72^{aAB}
15	347.88 ± 6.12^{aB}	323.85 ± 5.44^{aC}	308.46 ± 8.65^{aB}
16	342.44 ± 5.80^{aB}	241.15 ± 3.85^{bA}	343.08 ± 10.58^{aB}
17	308.46 ± 7.49^{aB}	317.12 ± 12.92^{aC}	281.06 ± 8.65^{aB}
18	357.98 ± 3.71^{aB}	333.46 ± 2.72^{aD}	246.92 ± 7.26^{bA}
15*	375.29 ± 11.56^{aA}	342.12 ± 3.40^{aA}	308.46 ± 4.08^{aA}
16*	376.73 ± 25.06^{aA}	439.23 ± 6.93^{aB}	443.08 ± 9.17^{aB}
17*	364.71 ± 18.31^{aA}	373.85 ± 12.24^{aA}	401.73 ± 7.48^{aBC}
18*	365.19 ± 26.33^{aA}	493.08 ± 6.73^{bC}	368.08 ± 8.65^{aC}

* Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

The total phenolic content of the fruits coated with Aloe vera alone were significantly higher than those dipped in citric acid before Aloe vera coating on days 2, 8 and 18. After 18 d at 10 °C, the highest total phenolic content of 357.98 mg/kg was recoreded in the control fruits followed by fruits coated with Aloe vera alone (333.46 mg /kg) and fruits dipped in citric acid before Aloe vera coating (246.92 mg/kg) (Table 4.1C).

In shelf life, the total phenolic content of fruits generally increased significantly for fruits coated with Aloe vera (with or without citric acid pre-treatment) but decreased slightly (p>0.05) for control fruits after 4 d in shelf life. Generally, higher total phenolic content was observed for the coated fruits compared to the control fruits (Table 4.1C). Also, the total phenolic content of the fruits were generally higher in shelf life than fruits kept at 10 °C. There was no significant difference between the coating treatments, except on day 18, where fruits coated with Aloe vera alone recorded significantly higher value (493.08 mg/kg) than fruits dipped in citric acid before Aloe vera coating (368.08 mg/kg) and the control fruits (339.23 mg/kg) (Table 4.1C). The effect of storage temperature, coating treatment, and the interaction between storage temperature and coating treatmnet on the total phenolic content were all significant.

Effect of coating on the ascorbic acid levels of eggplant fruits

Effect of beeswax coating on ascorbic acid levels of eggplant fruits

The effect of beeswax coating on the ascorbic acid levels of eggplant fruits during storage is shown in Table 4.2A. Storage time, beeswax coating and the interaction between storage time and beeswax coating significantly affected the ascorbic acid content of the eggplant fruits. The levels of ascorbic acid increased for the control fruits but decreased for the beeswax-coated fruits (with or without citric acid pre-treatment) during storage. Thus, the control fruits measured significantly higher ascorbic acid levels compared to beeswax coated fruits throughout the storage period, although on day 3, fruits dipped in citric acid before beeswax coating was not significantly different from the control fruits. Comparing both beeswax coated fruits, no significant difference was observed. Ascorbic acid levels recorded at the end of the 10 °C storage period were 162.98, 72.32 and 63.58 mg/kg, respectively, for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating, respectively (Table 4.2A).

Table 4.2A: Ascorbic acid levels of eggplant fruits coated with beeswax during storage.

Days	Ascorbic Acid Levels (mg/kg)		
	Control fruits	Beeswax alone	Citrate-dipped-beeswax
0	127.88 ± 2.22^{A}	-	-
3	135.44 ± 2.79^{aB}	98.57 ± 7.30^{bB}	120.52 ± 15.70^{abA}
7	144.09 ± 2.69^{aB}	114.88 ± 6.82^{bB}	110.43 ± 5.40^{bB}
10	156.33 ± 3.46^{aB}	93.15 ± 3.37^{bB}	92.14 ± 2.53^{bB}
14	167.91 ± 4.48^{aC}	92.01 ± 1.29^{bB}	88.46 ± 5.06^{bB}
17	162.98 ± 4.91^{aBC}	72.32 ± 2.06^{bC}	63.58 ± 4.14^{bC}

Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

Effect of starch coating on ascorbic acid content of eggplant fruits

The effect of starch coating on the ascorbic acid levels of eggplant fruits during storage is shown in Table 4.2B. Ascorbic acid levels generally increased during storage. In the first two days of storage, ascorbic acid levels increased significantly from 212.83 on day 0 to 330.76, 290.30 and 343.86 mg/kg for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating, respectively (Table 4.2B). The ascorbic acid levels were significantly affected by storage time, starch coating and the interaction between storage time and starch coating. The control fruits recorded significantly higher values than fruits coated with starch alone throughout the storage period except on days 2 and 4. The highest ascorbic acid content was recorded by fruits dipped in citric acid before starch coating on day 17 (476.62 mg/kg), although it was not significantly different from the fruits coated with starch alone (Table 4.2B).

Table 4.2B: Ascorbic acid levels of eggplant fruits coated with starch during storage.

Days	Ascorbic Acid Levels (mg/kg)		
	Control	Starch alone	Citrate-dipped-starch
0	212.83 ± 4.26^{A}	-	-
2	330.76 ± 13.74^{aB}	290.30 ± 6.99^{aB}	343.86 ± 6.83^{aB}
4	380.87 ± 12.94^{aBC}	335.24 ± 3.17^{bB}	425.59 ± 20.24^{aC}
6	288.46 ± 13.38^{aB}	404.90 ± 10.00^{bC}	296.05 ± 12.25^{aC}
8	421.10 ± 0.98^{aD}	320.41 ± 13.65^{bB}	417.83 ± 2.78^{aC}
10	432.60 ± 1.00^{aC}	438.00 ± 2.68^{aC}	319.26 ± 4.50^{bB}
14	468.92 ± 7.32^{aD}	393.17 ± 6.58^{bC}	455.24 ± 12.11^{aC}
17	431.45 ± 3.90^{aC}	429.15 ± 14.36^{abC}	476.62 ± 10.12^{bD}
17*	388.69 ± 10.24^{a}	420.87 ± 7.28504^{a}	258.69 ± 7.07107^{b}

* Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

The transfer of fruits from low temperature to room temperature resulted in a decrease in the ascorbic acid levels of the fruits, although the decrease observed in fruits coated with starch alone was not significant (Table 4.2B). There was no significant difference between the control fruits and fruits coated with starch alone in shelf life. Fruits coated with starch alone recorded significantly higher ascorbic acid content than the fruits dipped in citric acid before starch coating. Likewise, the control fruits recorded significantly higher ascorbic acid content than fruits dipped in citric acid before starch coating. There was, however, no significant differences between the control and both starch coated fruits. The effect of temperature, coating and the interaction effect between storage temperature and starch coating were also significant. After 3 d in shelf-life, the ascorbic acid levels were 388.68, 420.87 and 258.69 mg/kg respectively for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating (Table 4.2B).

Effect of Aloe vera coating on ascorbic acid content of eggplant fruits

The effect of Aloe vera coating on the ascorbic acid levels of eggplant fruits during storage is shown in Table 4.2C. The ascorbic acid levels of the control and both Aloe vera coated fruits exhibited a general increase in the first 14 d of storage (Table 4.2C). Storage time, Aloe vera coating and the interaction effect between storage time and Aloe vera coating significantly affected the ascorbic acid levels. A general decrease in ascorbic acid levels was observed on days 15 and 16, followed by an increase until the end of storage. The highest ascorbic acid level (325.64 mg/kg) was observed in the control fruits on day 17 (Table 4.2 C). However, after 18 d of storage, fruits coated with Aloe vera alone recorded a significantly higher ascorbic acid level of 288.31mg/kg compared to the control fruits (249.38 mg/kg), and the fruits dipped in citric acid before Aloe vera coating (251.82 mg/kg) (Table 4.2 C).

The transfer of fruits from storage at 10 °C to room temperature storage resulted in a general decrease in the ascorbic acid levels (Table 4.2 C). No significant differences were observed between the control fruits and the fruits coated with Aloe vera alone in shelf life. Fruits dipped in citric acid before Aloe vera coating, however, recorded higher ascorbic acid levels than the control fruits, and were significant on days 15 and 16.

Table 4.2C: Ascorbic acid levels (mg/kg) of eggplant fruits coated with Aloe vera during storage

Days	Ascorbic Acid Levels (mg/kg)		
	Control	Aloe vera alone	Citrate-dipped-Aloe vera
0	248.78 ± 3.58^{A}	-	-
2	278.85 ± 13.33^{aA}	227.39 ± 4.35^{bA}	255.88 ± 1.67^{aA}
5	294.90 ± 4.66^{aAB}	268.89 ± 7.52^{aB}	201.91 ± 8.87^{bB}
8	266.69 ± 0.96^{aA}	256.10 ± 1.95^{aA}	282.06 ± 2.27^{bAC}
11	277.16 ± 8.12^{aA}	236.11 ± 3.70^{abA}	207.45 ± 5.53^{bB}
14	239.32 ± 9.56^{aA}	199.63 ± 8.24^{aA}	303.29 ± 7.20^{bBC}
15	132.91 ± 7.17^{aB}	114.66 ± 4.03^{abB}	152.50 ± 6.98b^{cB}
16	227.84 ± 6.44^{aA}	148.11 ± 2.63^{bB}	154.70 ± 11.11^{bB}
17	325.64 ± 6.57^{aB}	213.31 ± 10.03^{bA}	214.83 ± 7.76^{bC}
18	249.38 ± 24.96^{aA}	288.31 ± 9.32^{aB}	251.82 ± 7.17^{aA}
15*	90.42 ± 8.12^{aA}	124.23 ± 0.76^{aA}	183.24 ± 15.53^{bA}
16*	102.08 ± 6.97^{aA}	129.19 ± 2.15^{abA}	151.66 ± 6.81^{bA}
17*	99.57 ± 9.88^{aA}	100.81 ± 2.62^{aA}	112.75 ± 7.27^{aB}
18*	124.46 ± 6.93^{aA}	145.97 ± 8.14^{aB}	141.69 ± 5.35^{aA}

*Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

Also, fruits dipped in citric acid before Aloe vera coating measured higher ascorbic acid levels in shelf life compared to fruits treated with Aloe vera coating alone, showing significant differences only on day 15. Ascorbic acid levels measured in shelf life were relatively lower than values recorded at 10 °C (Table 4.2 C). Temperature and coating had a significant effect on ascorbic acid levels. The interaction effect between the storage temperature and the coating treatment was also significant.

Effect of coating on the total antioxidant capacity of eggplant fruits

Effect of beeswax coating on total antioxidant capacity of eggplant fruits

Table 4.3A shows the effect of beeswax coatings on the total antioxidant capacity of eggplant fruits. An increase in the total antioxidant capacity was observed in the control and both beeswax coated fruits in the first 3 d of storage.

Table 4.3A: Total antioxidant capacity of eggplant fruits coated with beeswax during storage

Days	Total Antioxidant Capacity (mg/kg)		
	Control	Beeswax alone	Citrate-dipped-beeswax
0	122.07 ± 0.73^{A}	-	-
3	147.16 ± 3.65^{abB}	138.83 ± 1.50^{bA}	152.6 ± 0.86^{aB}
7	129.51 ± 3.68^{aA}	144.73 ± 3.00^{abA}	144.64 ± 2.76^{bcB}
10	137.51 ± 4.10^{aA}	136.06 ± 0.48^{aA}	168.53 ± 2.46^{bC}
14	131.02 ± 4.35^{aA}	152.45 ± 1.15^{bB}	131.02 ± 2.01^{aA}
17	136.61 ± 6.20^{aA}	147.26 ± 0.61^{aA}	139.34 ± 1.17^{aAB}

Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test (P<0.05). The data values represent the mean of four replicates.

Storage time, beeswax coating treatment and the interaction between storage time and beeswax coating significantly affected the total antioxidant capacity of the fruits. The total antioxidant capacity recorded for the control fruits, fruits coated with beeswax alone and fruits dipped in citric acid before beeswax coating, within the first 3 d of storage were 147.16, 138.83 and 152.60 mg/kg, respectively (Table 4.3A).

Generally, no significant difference was observed between the control fruits and fruits coated with beeswax alone, except on day 14, where fruits coated with beeswax alone recorded significantly higher total antioxidant capacity than the control fruits. Fruits dipped in citric acid before beeswax coating also recorded significantly higher total antioxidant capacity than the control fruits on days 7 and 10. The total antioxidant capacity of fruits dipped in citric acid before beeswax coating was significantly higher than fruits coated with beeswax alone only on days 3 and 10. Highest total antioxidant capacity (168.53 mg/kg) was observed by fruits dipped in citric acid before beeswax coating on day 10 (Table 4.3A). However, at the end of the 17 d storage period at 10 °C, no significant differences were observed between the different coating treatments. The total antioxidant capacity recorded at the end of the storage period were 136.61, 147.26 and 139.34 mg/kg for the control fruits, fruits coated with beeswax and fruits dipped in citric acid before beeswax coating, respectively (Table 4.3A).

Effect of starch coating on total antioxidant capacity of eggplant fruits

Table 4.3B shows the effect of starch coating on the total antioxidant capacity of eggplant fruits. The total antioxidant capacity generally increased within the first 4 d of storage from 600.80 mg/kg to 634.34, 676.05 and 631.0 mg/kg for the control fruits, fruits coated with starch alone and fruits dipped in citric acid before starch coating, respectively. After 4 d of storage, the total antioxidant capacity generally remained constant until the end of storage. The fruits coated with starch alone recorded significantly higher total antioxidant capacity (676.05 mg/kg) than the control fruits and the fruits dipped in citric acid before starch coating on day 4 (Table 4.3B). Total antioxidant capacity for the control, fruits coated with starch alone, and fruits dipped in citric acid before starch coating reached 620.65, 621.76 and 616.59 mg/kg at the end of the 10 °C storage period (Table 4.3B). The transfer of fruits from 10 °C to room temperature did not affect the total antioxidant capacity of the fruits. No significant differences were observed between the coating treatments after the transfer. A two-way ANOVA showed that the effect of temperature, coating and the interaction effect between temperature and coating on total antioxidant capacity were not significant.

Table 4.3B: Total antioxidant capacity of eggplant fruits coated with starch during storage

Days	Total Antioxidant Capacity (mg/kg)		
	Control	Starch alone	Citrate-dipped-starch
0	600.8 ± 7.29^{A}	-	-
2	635.01 ± 2.56^{aB}	615.09 ± 7.55^{bA}	596.24 ± 2.75^{bA}
4	634.34 ± 2.79^{aB}	676.05 ± 6.35^{bB}	631 ± 1.08^{aB}
6	611.28 ± 2.31^{aA}	607.49 ± 1.87^{aA}	602.15 ± 3.39^{aA}
8	629.29 ± 2.99^{aBC}	622.06 ± 1.15^{aAC}	619.93 ± 3.48^{aB}
10	626.81 ± 1.98^{aBC}	628.58 ± 2.91^{aAC}	625.98 ± 2.02^{aB}
14	621.52 ± 3.27^{aBC}	632.85 ± 4.30^{aC}	616.22 ± 2.39^{aB}
17	620.65 ± 1.93^{aC}	621.76 ± 2.42^{aAC}	616.59 ± 5.55^{aB}
17*	625.88 ± 2.42^{a}	621.76 ± 1.46^{a}	619.42 ± 2.71^{a}

* Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($P<0.05$). The data values represent the mean of four replicates.

Effect of Aloe vera coating on total antioxidant capacity of eggplant fruits

The effect of Aloe vera coating on the total antioxidant capacity of eggplant fruits during storage is presented in Table 4.3C. The total antioxidant capacity of both coated fruits and control fruits increased significantly during storage. The effect of the Aloe vera coating treatment was only significant on days 11 and 15. The interaction effect between storage time and coating treatment on the total antioxidant capacity of the eggplant fruits was significant.

Table 4.3C: Total antioxidant capacity of eggplant fruits coated with Aloe vera during storage

Days	Total Antioxidant Capacity (mg/kg)		
	Control	Aloe vera alone	Citrate-dipped-Aloe vera
0	495.41 ± 3.29^{A}	-	-
2	502.23 ± 7.27^{aA}	502.82 ± 2.56^{aA}	507.8 ± 2.98^{aA}
5	512.66 ± 4.50^{aA}	508.51 ± 5.09^{aA}	511.95 ± 4.97^{aA}
8	502.27 ± 6.86^{aA}	508.63 ± 1.78^{aA}	511 ± 3.04^{aA}
11	524.08 ± 2.50^{aA}	509.62 ± 1.79^{bA}	517.5 ± 1.91^{aA}
14	543.17 ± 1.67^{aB}	544.03 ± 2.67^{aB}	544.71 ± 6.55^{aB}
15	582.75 ± 8.65^{aBC}	550.35 ± 3.08^{bB}	568.22 ± 6.88^{aB}
16	562.26 ± 5.57^{aBC}	575.11 ± 4.91^{aB}	574.18 ± 11.37^{aB}
17	559.83 ± 5.25^{aBC}	569.1 ± 7.63^{aB}	578.65 ± 3.32^{aB}
18	578.84 ± 8.13^{aC}	590.4 ± 5.65^{aB}	569.34 ± 1.15^{aB}
15*	539.71 ± 4.22^{aA}	555.11 ± 5.33^{aA}	561.51 ± 2.64^{aA}
16*	574.24 ± 1.67^{aB}	553.13 ± 5.80^{aA}	578.84 ± 2.90^{aA}
17*	561.33 ± 7.11^{aA}	573.25 ± 5.80^{aA}	578.09 ± 7.03^{aA}
18*	592.26 ± 1.84^{aB}	577.72 ± 1.62^{aA}	587.78 ± 3.95^{aA}

* Fruits transferred to room temperature for shelf life studies. Means not sharing the same lower-case letters in a row for coating treatment or upper-case letters in a column for storage days are significantly different by Tukey multiple comparison test ($p<0.05$). The data values represent the mean of four replicates.

The total antioxidant capacity of fruits coated with Aloe vera alone was lower than both the control fruits and fruits dipped in citric acid before Aloe vera coating on days 11 and 15. After 18 d of storage at 10 ° C, total antioxidant capacities of 578.84, 590.40 and 569.34 mg/kg were recorded for the control fruits, fruits coated with Aloe vera alone and fruits dipped in citric acid before

Aloe vera coating, respectively (Table 4.3C). The highest total antioxidant capacity of 590.40 mg/kg was determined in fruits coated with Aloe vera alone on day 18 day of storage at 10 ° C.

Upon transfer to room temperature storage, the total antioxidant capacity of the fruits increased (Table 4.3C). However, no significant differences were observed between the control fruits and both Aloe vera coated fruits throughout the shelf life period. Similarly, no significant differences were observed between both Aloe vera coated fruits. The effect of temperature on the total antioxidant capacity of the fruits was significant on days 15 and 16, while the effect of coating was significant on days 16 and 17. The interaction effect between storage temperature and the coating treatment was also found to be significant.

OPTIMIZATION OF PROCESS CONDITIONS FOR THE PREPARATION OF EDIBLE COATINGS FOR APPLICATION ON EGGPLANT FRUITS USING RESPONSE SURFACE METHODOLOGY

Fitting and validation of the beeswax, starch and Aloe vera coating models

Tables 4.4, 4.5 and 4.6 shows the response data for beeswax, starch and Aloe vera coating, respectively after the Response Surface Methodology (RSM) Box Behnken design (BBD) experiments were carried out. The model fitting for weight loss, colour (L*a*b*), firmness, total phenolic content, ascorbic acid level and total antioxidant capacity were carried out using the experimental data presented in Tables 4.4 to 4.6. During the model fitting, run 10 for total phenolic content of the beeswax coating was eliminated from the analysis after a diagnostic test revealed it was an outlier (Table 4.4).

Table 4.4: Response surface methodology Box-Behnken design of experiment for process factors (X) and their responses (Y) for beeswax coating

Run	Factor*			Response (Y)**							
	X_1	X_2	X_3	WL	L*	a*	b*	F	TPC	AA	AOA
1	5	3	10	31.68	78.69	-1.7	25.3	32.86	133.53	98.34	131.55
2	5	1	6.5	26.96	80.84	-2.13	23.63	33.14	137.45	113.74	135.70
3	3	5	10	36.13	79.35	-2.05	28.32	33.45	146.60	143.21	136.37
4	3	3	6.5	35.95	81	-2.16	23.63	31.58	132.22	110.27	133.96
5	1	1	6.5	52.97	81.16	0.45	30.31	32.34	154.12	89.24	131.26
6	3	3	6.5	31.47	81.29	-2.32	23.21	31.5	132.88	95.09	133.39
7	1	3	3	52.90	81.19	-1.72	22.83	32.07	131.57	63.58	139.36
8	5	3	3	31.54	80.04	-1.98	25.12	32.57	161.63	89.07	129.05
9	3	3	6.5	31.54	81.77	-2.03	23.16	31.28	137.45	98.01	130.69
10	3	5	3	38.78	77.98	-1.72	28.45	33.49	-	66.06	131.26
11	3	1	3	41.37	80.69	-1.47	22.76	33.13	161.96	130.13	150.74
12	3	3	6.5	31.40	81.4	-2.04	23.87	31.21	137.45	110.27	134.54
13	1	3	10	46.63	80.54	-2.19	26.68	33.14	151.18	69.21	117.86
14	3	1	10	31.22	80.56	-1.76	26.04	33.67	104.12	98.51	121.53
15	1	5	6.5	39.08	80.38	-1.98	25	33.27	128.95	80.85	123.94
16	5	5	6.5	31.35	78.61	0.74	32.99	33.28	130.59	82.45	121.53
17	3	3	6.5	35.95	81.57	-2.03	23.16	31.55	132.22	115.89	134.73

*Factor: X_1 (coating concentration, %w/v), X_2 (citric acid concentration, %w/v), and X_3 (coating duration).
**Response (Y): Weight loss, WL (g/kg), Firmness, F (N), Colour (L*a*b* values), Total phenolic content, TPC (mg/kg), Ascorbic acid, AA (mg/kg) and Total antioxidant capacity, TOA (mg/kg).

Table 4.5: Response surface methodology Box-Behnken design of experiment for process factors (X) and their responses (Y) for starch coatings

Run	Factors*			Responses (Y)**							
	X_1	X_2	X_3	WL	L*	a*	b*	F	TPC	AA	AOA
1	1	1	6.5	216.53	80.12	0.48	26.36	30.81	171.95	49.97	134.39
2	3	1	3	231.08	77.94	-0.7	33.92	30.92	239.84	119.05	127.11
3	5	1	6.5	257.10	79.51	-1.22	31.2	36.61	224.39	69.56	97.61
4	3	3	6.5	218.11	78.43	-0.88	32.26	33.52	224.39	72.6	96.8
5	3	3	6.5	225.91	78.31	-0.88	30.97	33.14	203.25	78.68	120.45
6	1	3	10	222.38	80.36	0.85	29.68	30.37	162.2	69.56	87.1
7	5	3	3	257.90	78.52	-1.51	31	34.23	134.96	74.07	102.86
8	3	3	6.5	225.02	78.1	-0.81	31.4	33.54	195.12	61.45	124.69
9	3	1	10	236.01	80.15	-0.8	30.54	36.21	239.02	114.16	94.07
10	5	5	6.5	212.06	77.61	-1.3	31.06	33.51	153.66	65.28	109.73
11	5	3	10	212.94	80.11	-1.01	29.24	36.49	208.13	114.32	117.01
12	3	5	3	234.60	76.88	-1.25	35.39	33	221.95	88.31	119.03
13	1	3	3	210.70	80.1	0.56	27.75	30.99	180.49	77.16	148.94
14	3	3	6.5	217.98	78.54	-0.86	31.15	33.04	234.15	62.64	124.39
15	3	5	10	198.85	76.43	0.21	38.55	31.06	278.05	158.24	125.3
16	3	3	6.5	220.00	78.3	-0.85	32.09	33.51	208.13	67.53	121.35
17	1	5	6.5	212.69	77.62	0.92	33.04	31.55	221.95	57.06	129.84

*Factor: X_1 (coating concentration, %w/v), X_2 (citric acid concentration, %w/v), and X_3 (coating duration).
**Response (Y): Weight loss, WL (g/kg), Firmness, F (N), Colour (L*a*b* values), Total phenolic content, TPC (mg/kg), Ascorbic acid, AA (mg/kg) and Total antioxidant capacity, TOA (mg/kg).

Table 4.6: Response surface methodology Box-Behnken design of experiment for process factors (X) and their responses (Y) for Aloe vera coatings

Run	Factors*			Responses (Y)**							
	X_1	X_2	X_3	WL	L*	a*	b*	F	TPC	AA	AOA
1	50	1	6.5	205.71	77.59	-0.79	29.26	32.39	200	76.31	134.79
2	75	3	6.5	211.78	78.59	0.21	30.12	32.46	193.9	66.69	108.93
3	75	3	6.5	211.84	78.98	0.18	30.19	32.12	198.78	67.03	111.75
4	100	3	10	180.87	80.55	-0.84	29.11	32.91	182.93	67.2	111.35
5	75	3	6.5	216.71	78.86	0.26	29.15	32.31	219.51	67.53	114.38
6	100	5	6.5	203.59	80.67	-1.01	28.47	34.83	152.44	57.51	106.5
7	100	1	6.5	195.34	79.52	-0.85	28.92	33.37	193.9	64.92	133.18
8	75	1	10	228.19	78.83	-1.35	26.41	32.57	228.46	73.28	115.39
9	75	5	3	247.82	79.49	-0.06	28.63	31.71	233.33	59.99	119.84
10	75	3	6.5	219.55	78.74	0.2	29.73	32.13	201.22	64.16	110.14
11	100	3	3	185.54	79.73	-1.08	28.54	34.97	221.95	58.92	121.05
12	75	1	3	220.66	77.73	1.19	34.61	32.45	226.83	69.22	126.81
13	75	3	6.5	206.76	78.83	0.2	29.83	32.99	212.2	65.39	117.41
14	75	5	10	217.63	80.42	0.61	29.5	33.52	180.49	64.66	105.89
15	50	3	3	196.47	77.48	0.98	35.26	29.93	211.38	66.86	120.45
16	50	3	10	194.57	78.92	-1.21	26.41	32.26	203.25	73.39	114.38
17	50	5	6.5	211.90	78.59	0.8	31.97	30.62	173.17	65.68	114.69

*Factor: X_1 (coating concentration, %w/v), X_2 (citric acid concentration, %w/v), and X_3 (coating duration).
**Response (Y): Weight loss, WL (g/kg), Firmness, F (N), Colour (L*a*b* values), Total phenolic content, TPC (mg/kg), Ascorbic acid, AA (mg/kg) and Total antioxidant capacity, TOA (mg/kg).

The model fitting for the beeswax coating is summarized in Table 4.7. Quadratic models were used for fitting all the responses of the beeswax coatings. However, in order to improve the adequacy of the models, some insignificant model terms were eliminated to obtain reduced quadratic models.

Table 4.7: Response surface methodology Box-Behnken design model fitting statistics for beeswax coating

Model	p-value	Lack of fit	R-Squared	Adj. R-Squared	Pred. R-Squared	Adequate precision
Weight loss	<0.0001*	0.39 NS	0.92	0.88	0.73	15.54
Firmness	<0.0001*	0.13 NS	0.95	0.91	0.75	13.6
L* value	0.0008*	0.06 NS	0.82	0.74	0.48	10.14
a* value	<0.0001*	0.12 NS	0.97	0.95	0.84	20.31
b* value	<0.0001*	0.08 NS	0.98	0.96	0.85	26.09
Total phenolic content	0.0005*	0.05 NS	0.93	0.87	0.55	15.99
Ascorbic acid	0.0002*	0.44 NS	0.87	0.81	0.66	12.12
Total antioxidant capacity	<0.0001*	0.11 NS	0.93	0.88	0.72	20.36

*Significant NS Not significant

A significant model (p<0.0001) and an insignificant lack of fit (p=0.39) was obtained for weight loss (Table 4.7). The model for firmness was also significant (p<0.0001) and did not present a lack of fit (p=0.13). The weight loss and firmness models had R-squared values of 0.92 and 0.95, respectively (Table 4.7). The L* value model was also significant (p=0.0008), had an insignificant lack of fit (p=0.06) and an R-squared value of 0.82. Similarly, the model for a* value was significant (p<0.0001), with an insignificant lack of fit (p=0.12) and an R-squared value of 0.97. The fitting of the b* value response also resulted in a significant model ($p<0.0001$) with an insignificant lack of fit ($p=0.08$) and an R-squared value of 0.98.

The total phenolic content, ascorbic acid level and total antioxidant capacity models were all significant with p values of 0.0005, 0.0002 and <0.0001, and insignificant lack of fit with p values of 0.05, 0.44 and 0.11, respectively (Table 4.7). Total phenolic content, ascorbic acid and total antioxidant capacity had R-squared values of 0.93, 0.87 and 0.93, respectively.

Generally, the predicted and the adjusted R-squared values for all the beeswax coating models were in reasonable agreement since the differences were less than 0.2 (Table 4.7). The correlation between the predicted and the actual response for the varying conditions are shown in Figure 4.10.

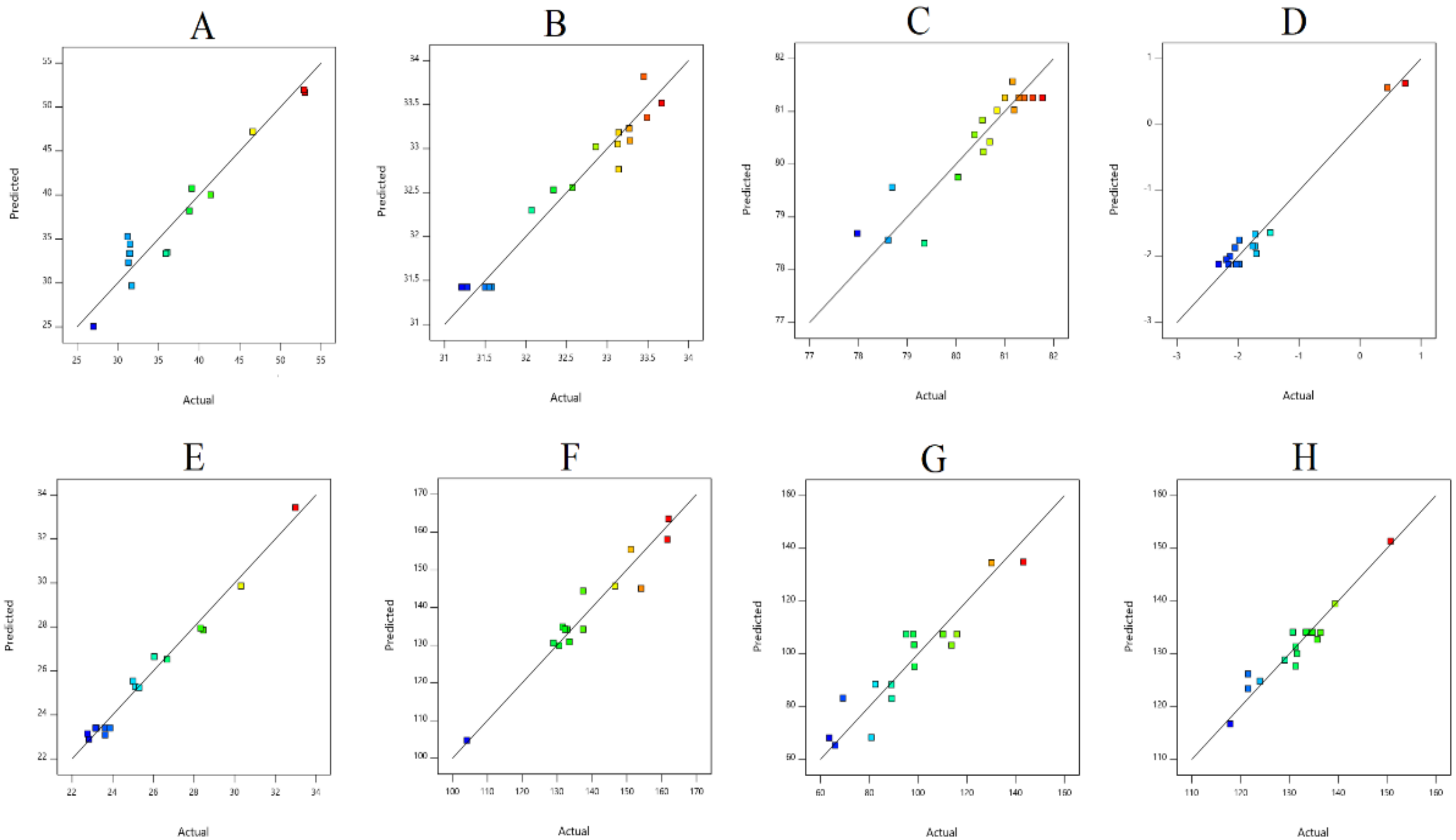

Figure 4.10: Correlation between predicted and actual values for (A) Weight loss (g/kg); (B) Firmness (N); (C) L* value; (D) a* value; (E) b* value; (F) Total phenolic content (mg/kg); (G) Ascorbic acid (mg/kg) and (H) Total antioxidant capacity (mg/kg) of beeswax coatings.

Table 4.8 is a summary of the model fitting statistics for the responses of starch coating. Quadratic models were used in fitting the weight loss and firmness models of starch coating. A significant model (p<0.0001), an insignificant lack of fit (p=0.53) and an R-squared value of 0.96 was obtained for weight loss. The firmness model was also significant (p<0.0001) and had an insignificant lack of fit (0.1). The weight loss and firmness models had R-squared values of 0.96 and 0.97, respectively (Table 4.8).

Table 4.8: Response surface methodology Box-Behnken design model fitting statistics for starch coating

Response	p-value	Lack of fit	R-Squared	Adj. R-Squared	Pred. R-Squared	Adequate precision
Weight loss	<0.0001*	0.53 NS	0.96	0.94	0.91	24.79
Firmness	<0.0001*	0.10 NS	0.97	0.91	0.90	23.54
L* value	<0.0001*	0.18 NS	0.99	0.97	0.86	23.67
a* value	<0.0001*	0.01 *	1.00	0.99	0.93	40.92
b* value	<0.0001*	0.45 NS	0.98	0.96	0.84	27.23
Total phenolic content	<0.0017*	0.80 NS	0.94	0.86	0.73	13.55
Ascorbic acid	0.0001*	0.45 NS	0.97	0.93	0.76	18.89
Total antioxidant capacity	<0.0001*	0.85 NS	0.79	0.67	0.4598	10.02

*Significant NSNot significant

The colour (L*a*b*) responses of the starch coatings were also fitted using quadratic models (Table 4.8). ANOVA showed that the models were all significant ($p < 0.0001$). Insignificant lack of fit with p values of 0.18 and 0.45 were obtained for the L* and b* models but the lack of fit observed for the a* value model was significant (p=0.01). R-squared values of 0.99, 1.00 and 0.98 were observed for the L*, a* and b* models, respectively (Table 4.8).

The quadratic model was best for fitting the total phenolic content data as well as the ascorbic acid level data. However, the total antioxidant capacity was best fitted with the two-factor interaction model (2FI) model. Fitting data for total phenolic content, ascorbic acid and total antioxidant capacity produced significant models ($p = 0.0009$, $p < 0.0001$ and $p = 0.0055$) and did not present any lack of fit with p values of 0.55, 0.51 and 0.85, respectively (Table 4.8). R-squared values of 0.94, 0.97 and 0.79 were observed for the total phenolic content, ascorbic acid level and total antioxidant capacity models respectively (Table 4.8). The correlations between the predicted and the experimental responses for the varying conditions are shown in Figure 4.11.

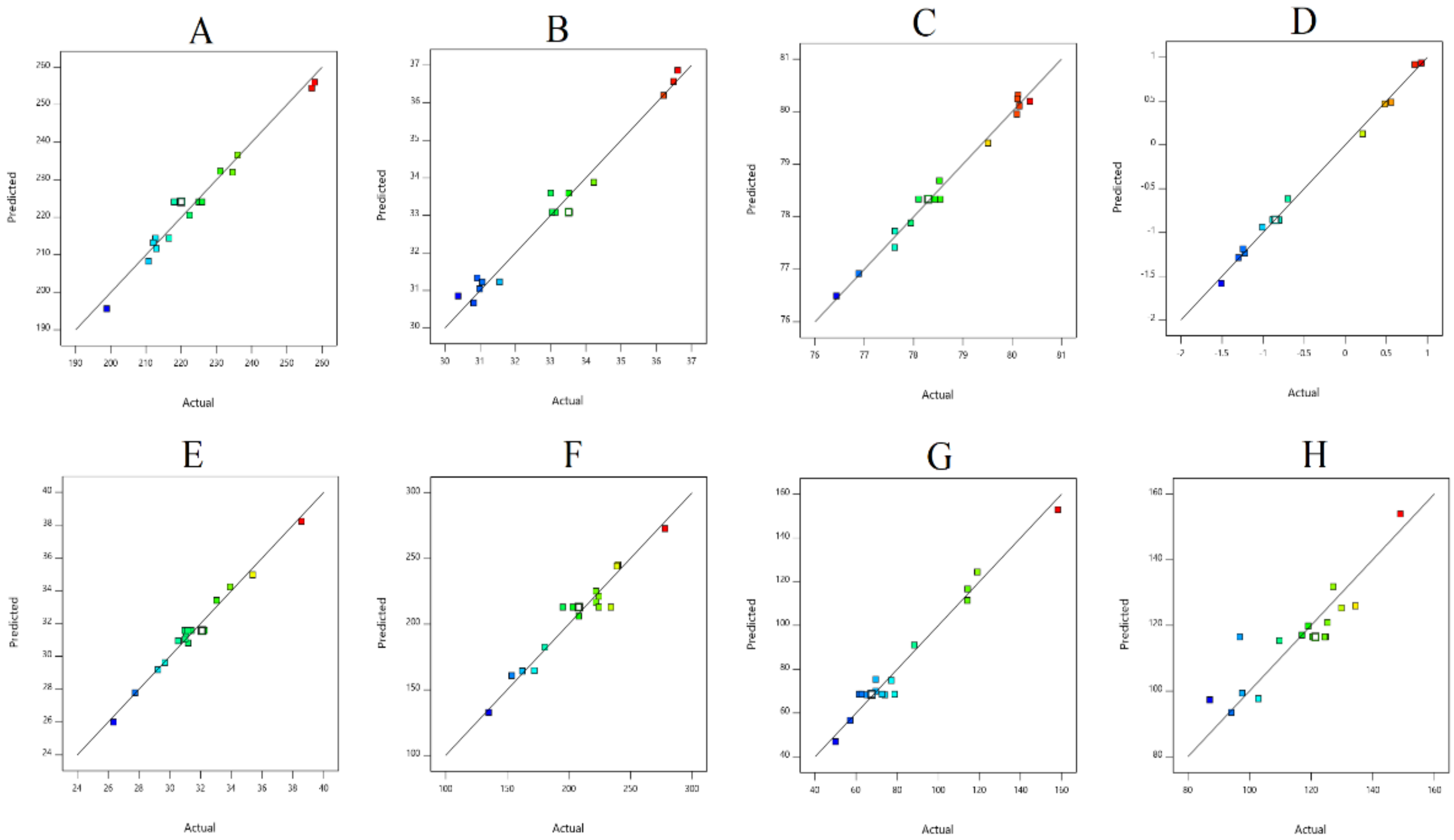

Figure 4.11: Correlation between predicted and actual values for (A) Weight loss (g/kg); (B) Firmness (N); (C) L* value; (D) a* value; (E) b* value; (F) Total phenolic content (mg/kg); (G) Ascorbic acid (mg/kg) and (H) Total antioxidant capacity (mg/kg) of starch edible coatings.

Table 4.9 shows the Aloe vera coating fit statistics. Weight loss, a* value and total phenolic content were best fitted with quadratic models while the b* value and firmness were fitted with 2FI models. The quadratic models were reduced by removing insignificant model terms in order to improve the various models. Linear models were, however, most suitable for fitting the L* value, the ascorbic acid and the total antioxidant capacity responses. The weight loss, firmness, L*, a* and b*, total phenolic content, ascorbic acid level and total antioxidant capacity models were all significant with p values ranging from 0.0032 to <0.0001 (Table 4.9). As shown in Table 4.9, the lack of fit for all models describing the responses were all not significant except that of a* value (Table 4.9). Also, apart from the total antioxidant capacity model which had a relatively low R-squared value of 0.64, the rest of the models obtained R-squared values ranging from 0.86-0.99 (Table 4.9). The predicted R-squared values observed were also in close agreement with the adjusted R-squared values. Overall, the models obtained for Aloe vera coating were deemed adequate to be used to navigate the design space. The correlation between the predicted and the experimental (actual) values for weight loss, colour (L*a*b*), firmness, total phenolic content, ascorbic acid and total antioxidant capacity are illustrated in Figure 4.12.

Table 4.9: Response surface methodology Box-Behnken design model fitting statistics for Aloe vera coating

Response	p-value	Lack of fit	R-Squared	Adj. R-Squared	Pred. R-Squared	Adequate precision
Weight loss	<0.0001*	0.92 NS	0.97	0.95	0.91	27.32
Firmness	<0.0001*	0.51 NS	0.95	0.92	0.84	21.36
L* value	<0.0001*	0.12 NS	0.95	0.93	0.91	28.2
a* value	<0.0001*	0.005*	0.99	0.98	0.94	33.17
b* value	<0.0001*	0.13 NS	0.95	0.92	0.79	22.71
Total phenolic content	0.0008*	0.57 NS	0.86	0.78	0.59	10.85
Ascorbic acid	0.0001*	0.66 NS	0.95	0.94	0.91	28.43
Total antioxidant capacity	0.0032*	0.12**	0.64	0.56	0.37	9.61

*Significant NSNot significant

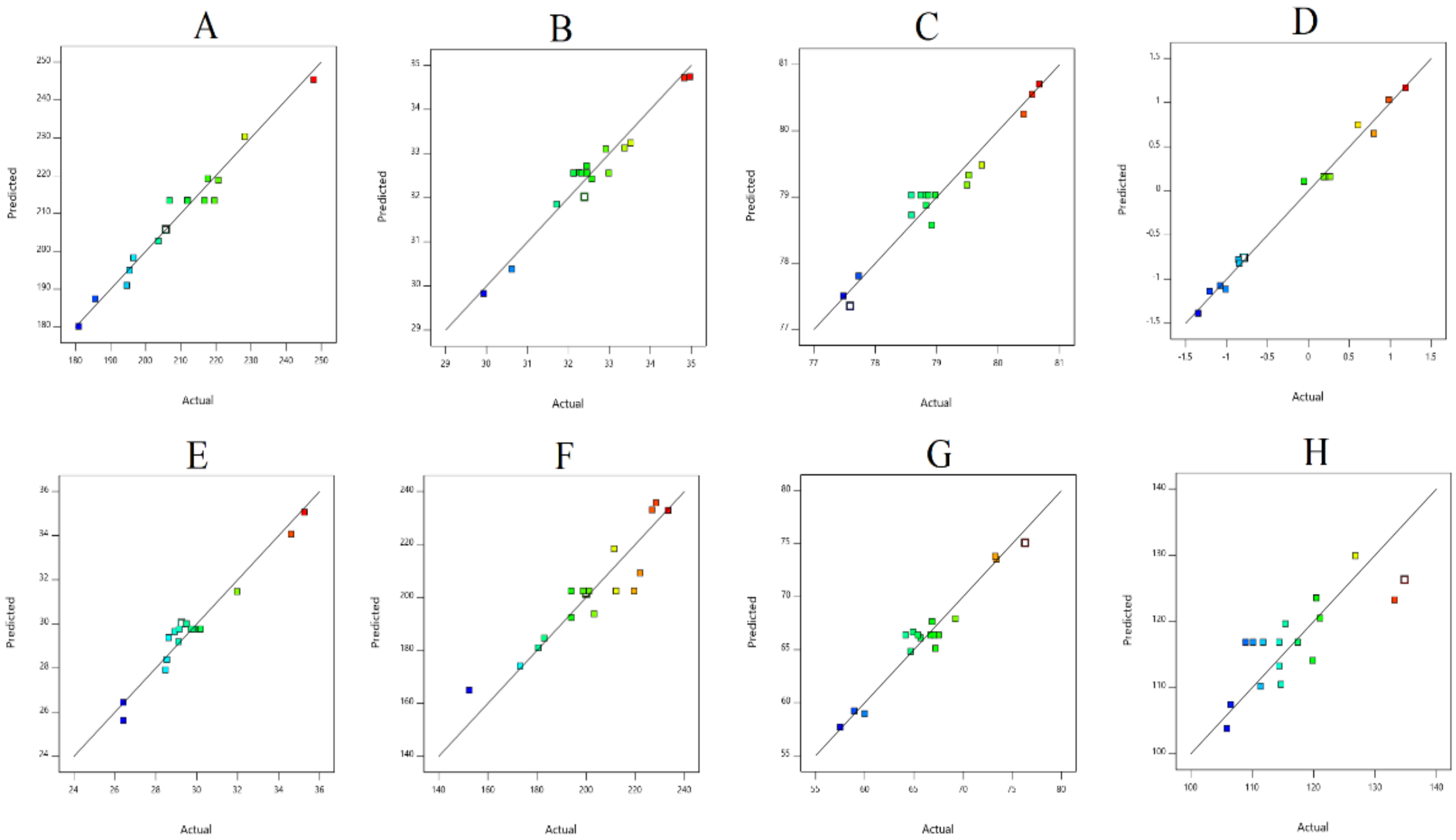

Figure 4.12: Correlation between predicted and actual values for (A) Weight loss (g/kg); (B) Firmness (N); (C) L* value; (D) a* value; (E) b* value; (F) Total phenolic content (mg/kg); (G) Ascorbic acid (mg/kg) and (H) Total antioxidant capacity (mg/kg) of Aloe vera edible coatings

Effect of process conditions on the weight loss of eggplant fruits

Effect of process conditions on the weight loss of eggplant fruits coated with beeswax

Weight loss of the eggplant fruits coated with beeswax varied from 26.96 to 52.97 g/kg. Insignificant model terms (X_1X_3, X_2X_3 and X_2^2) were eliminated to obtain a reduced quadratic model (Equation 4.1). The regression coefficients in Equation 4.1 were compared to determine the relative impact of the factors. The significance of the main, interaction and quadratic effects are shown in Appendix 1.

$$Weight\ loss\ (g/kg) = 33.36 - 8.76X_1 - 0.91X_2 - 2.38X_3 + 4.55X_1X_2 + 4.09X_1^2 + 3.37X_3^2 \qquad \textbf{Eqn. 4.1}$$

From Equation 4.1, the main effect of coating concentration (X_1) showed the highest regression coefficient of 8.76, implying that coating concentration had the highest effect on weight loss. Weight loss decreased significantly when coating concentration was increased. Also increasing citric acid concentration (X_2) and coating duration (X_3) resulted in a decrease in weight loss, although the effect of the citric acid concentration was not significant (Appendix 1). A significant increase in weight loss was, however, noticed with the interaction between coating concentration and citric acid concentration. The quadratic effect of coating concentration and coating duration also had a significant increasing effect on weight loss (Appendix 1).

Effect of process conditions on the weight loss of eggplant fruits coated with starch

Equation 4.2 describes the effect of starch coating on the weight loss of eggplant fruits. Weight loss of the starch coated eggplant fruits ranged from 198.85 to 257.90 g/kg.

$$Weight\ loss\ (g/kg\ ) = 224.11 + 9.71X_1 - 10.31X_2 - 8.01X_3 - 10.30X_1X_2 - 14.16X_1X_3 - 10.17X_2X_3 \qquad \textbf{Eqn. 4.2}$$

From Equation 4.2, weight loss increased significantly with increasing coating concentration (X_1). However, high citric acid concentration (X_2) and coating duration (X_3) resulted in a significant reduction in weight loss. Considering the main effects, citric acid concentration had the highest regression coefficient, implying that it had the most significant effect on weight loss. Figure 4.13 shows the interactive effect of coating concentration and citric acid concentration (X_1X_2), coating concentration and coating duration (X_1X_3), and citric acid concentration and coating duration (X_2X_3) on the weight loss of starch coated fruits. All three interactions resulted in significant reduction in weight loss. The most significant interactive effect observed was that of coating concentration and coating duration. The significance of each model term is given in Appendix 2.

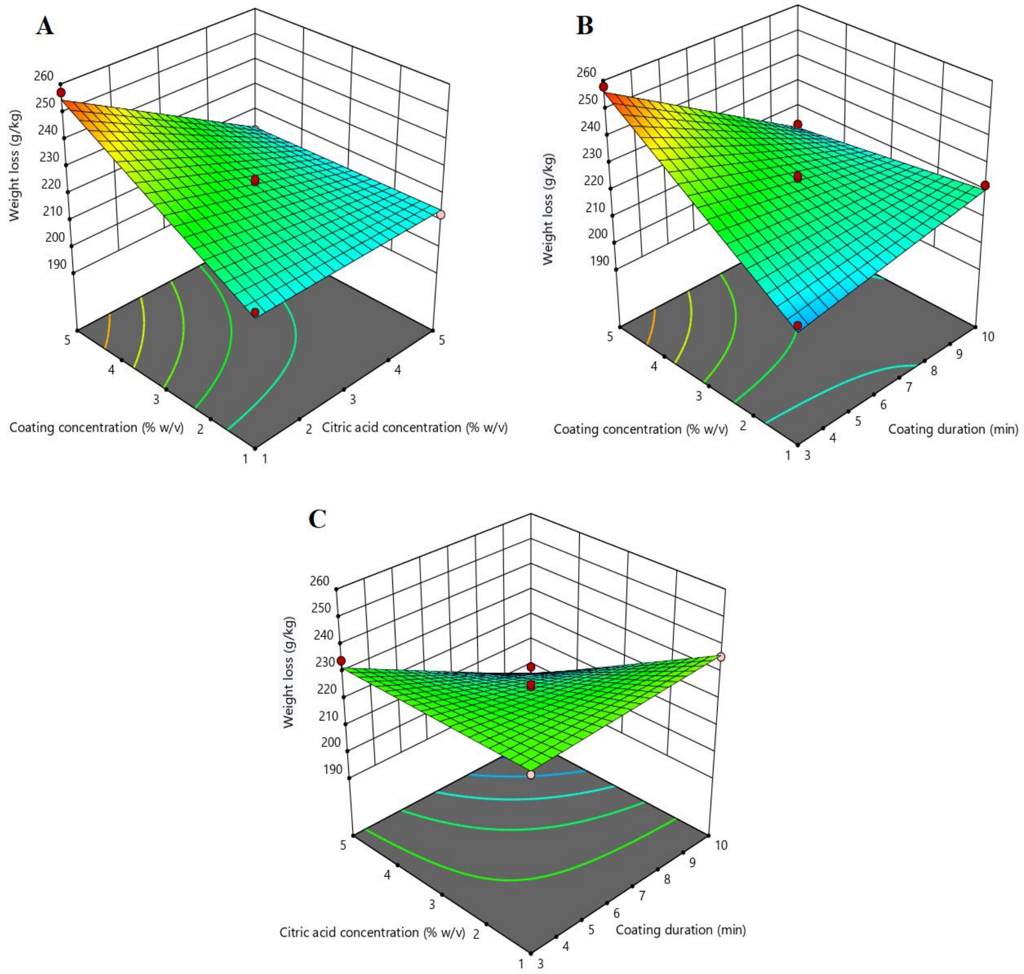

Figure 4.13: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3); and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on weight loss of starch coated eggplant fruits after 17 d of storage at 10 °C.

Effect of process conditions on the weight loss of eggplant fruits coated with Aloe vera

Coating of eggplant fruits with Aloe vera resulted in weight loss ranging from 180.87 to 247.82 g/kg. The effect of Aloe vera coating on weight loss was explained using a reduced quadratic model as shown in Equation 4.3.

$$Weight\ loss\ (g/kg) = 213.43 - 5.41X_1 + 3.88X_2 - 3.65X_3 - 9.43X_2X_3 - 24.19X_1^2 + 15.02X_2^2$$ **Eqn. 4.2**

Weight loss decreased significantly when the Aloe vera coating concentration (X_1) and the coating duration (X_3) were increased. Coating concentration had the highest effect on weight loss. High citric acid concentration (X_3), however, caused a significant increase in the weight loss. The interaction effect between citric acid concentration and coating duration (X_2X_3), significantly decreased weight loss (Figure 4.14). The quadratic effect of coating concentration reduced weight loss while that of citric acid concentration increased weight loss significantly. The ANOVA for the resulting reduced quadratic model is shown in Appendix 3.

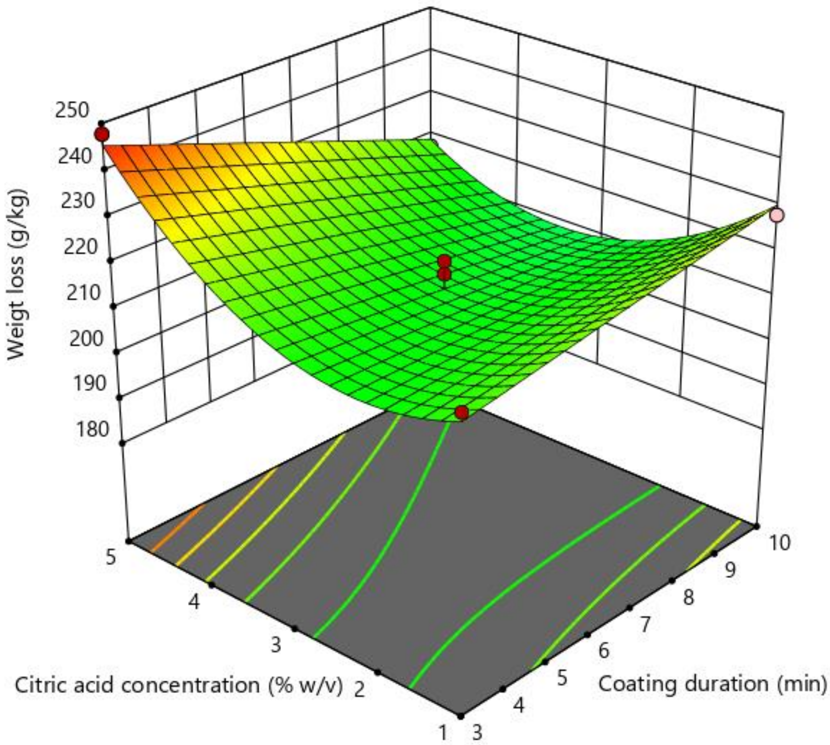

Figure 4.14: Effect of citric acid concentration (X_1) and coating duration (X_3) on weight loss of Aloe vera coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the firmness of eggplant fruits

Effect of process conditions on the firmness of eggplant fruits coated with beeswax.

The firmness of fruits coated with the different beeswax coating treatments ranged from 31.21 to 33.67 N. According to Equation 4.4, there is a tendency for firmness to increase when coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) increases. However, only the effect of coating duration was significant (Appendix 4).

$$Firmness\ (N) = 31.42 + 0.1288X_1 + 0.1513X_2 + 0.2325X_3 - 0.1975X_1X_2 + 0.4042X_1^2 + 1.18X_2^2 + 0.8318X_3^2$$ **Eqn. 4.3**

The interaction effect between coating concentration and citric acid concentration (X_1X_2) resulted in firmness increasing up to a point, followed by a slight decrease ($p>0.05$) as illustrated in Figure 4.15. The quadratic effect of coating concentration, citric acid concentration and coating duration, all increased firmness significantly (Appendix 4).

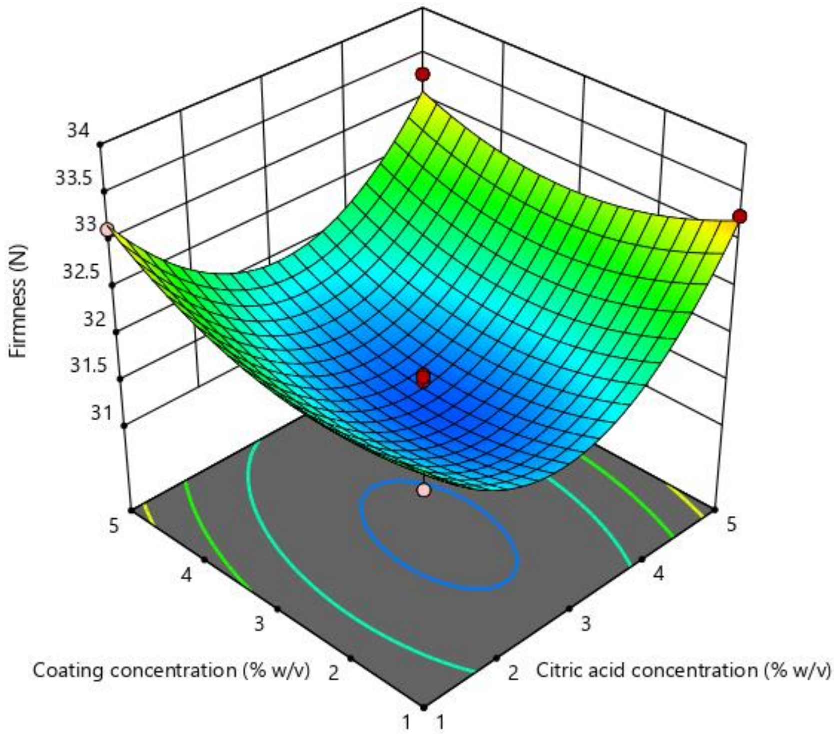

Figure 4.15: Effect of coating concentration (X_1) and citric acid concentration (X_2) on firmness of beeswax coated fruits after 17 d storage period at 10 °C.

Effect of process conditions on the firmness of eggplant fruits coated with starch

The firmness of the starch coated eggplant fruits varied from 30.37 to 36.61 N. The 2FI model expressed in Equation 4.1 was used to predict the firmness response.

$$Firmness\ (N) = 33.09 + 2.14X_1 - 0.6783X_2 + 0.6244X_3 - 0.9584X_1X_2 + 0.7196X_1X_3 - 1.81X_2X_3 \quad \textbf{Eqn. 4.4}$$

It was observed that coating concentration (X_1) had the highest positive impact on the firmness of the starch coated fruits and was significant. Coating duration (X_3) also increased the firmness of the fruits. However, citric acid concentration (X_2) had a decreasing effect on the firmness of the fruits. The effect of the coating concentration, citric acid concentration and coating duration were all significant (Appendix 5).

A further decrease in firmness was observed due to the interaction between coating concentration and citric acid concentration (X_1X_2) (Figure 4.16A). A similar observation was made with the combined effect of citric acid concentration and coating duration (X_2X_3) (Figure 4.16C). However, firmness increased as a result of the interaction between coating concentration and coating duration (X_1X_3) (Figure 4.16B).

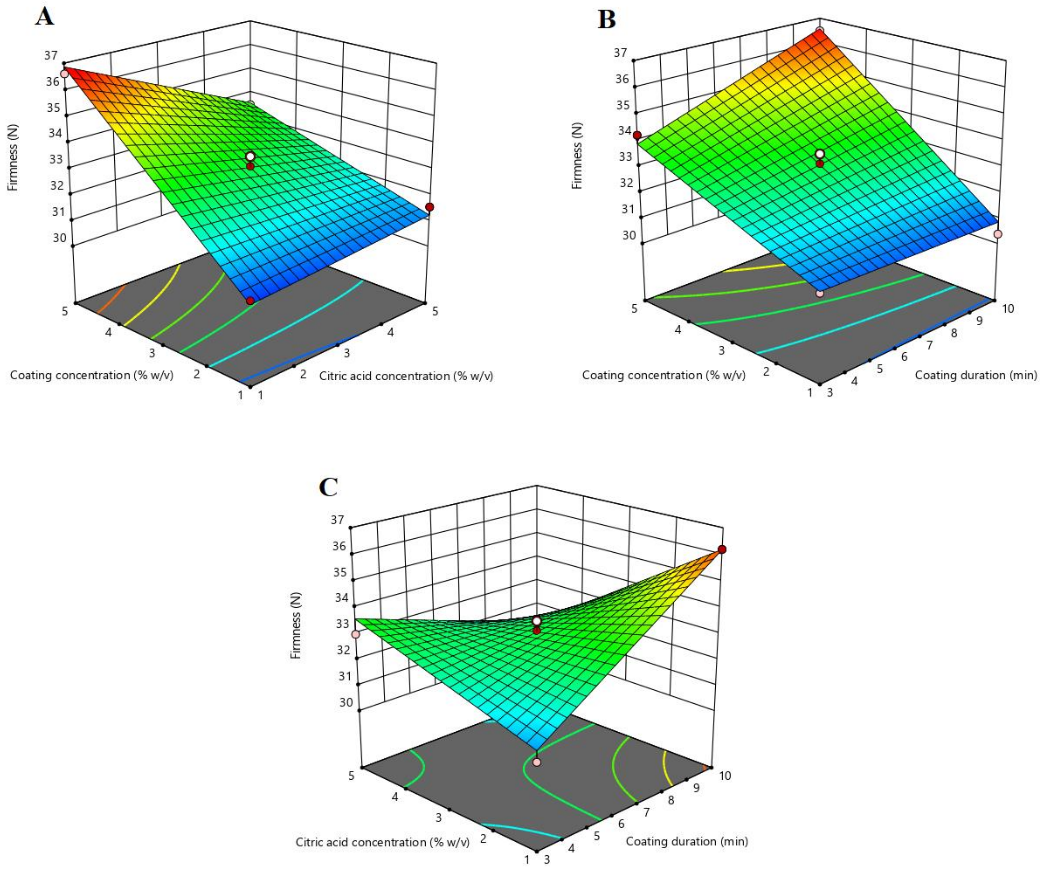

Figure 4.16: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration and coating duration (X_3) on the firmness (N) of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the firmness of Aloe vera coated eggplant fruits

The firmness of eggplant fruits coated with Aloe vera was described using the 2FI model as shown in Equation 4.6. Coating concentration (X_1) and coating duration (X_3) increased the firmness of the fruits, but only coating concentration was significant (Appendix 6).

$$Firmness\ (N) = 32.56 + 1.36X_1 - 0.0129X_2 + 0.2753X_3 + 0.8074X_1X_2 - 1.09X_1X_3 + 0.4206X_2X_3$$ **Eqn. 4.5**

Citric acid concentration (X_2), on the other hand, decreased the firmness of the fruits, although it was not significant. Considering the regression coefficient, coating concentration exhibited the highest positive effect on firmness of Aloe vera coated fruits. The interaction between coating concentration and citric acid concentration (X_1X_2), resulted in a significant increase in the firmness of the fruits (Figure 4.17A). This observation was similar to the interaction effect observed between citric acid concentration and coating duration (X_2X_3) (Figure 4.17C). However, the effect of the interaction between coating concentration and coating duration (X_1X_3) resulted in a significant decrease in firmness (Figure 4.17B). The significant levels of the main and interaction effect are shown in Appendix 6.

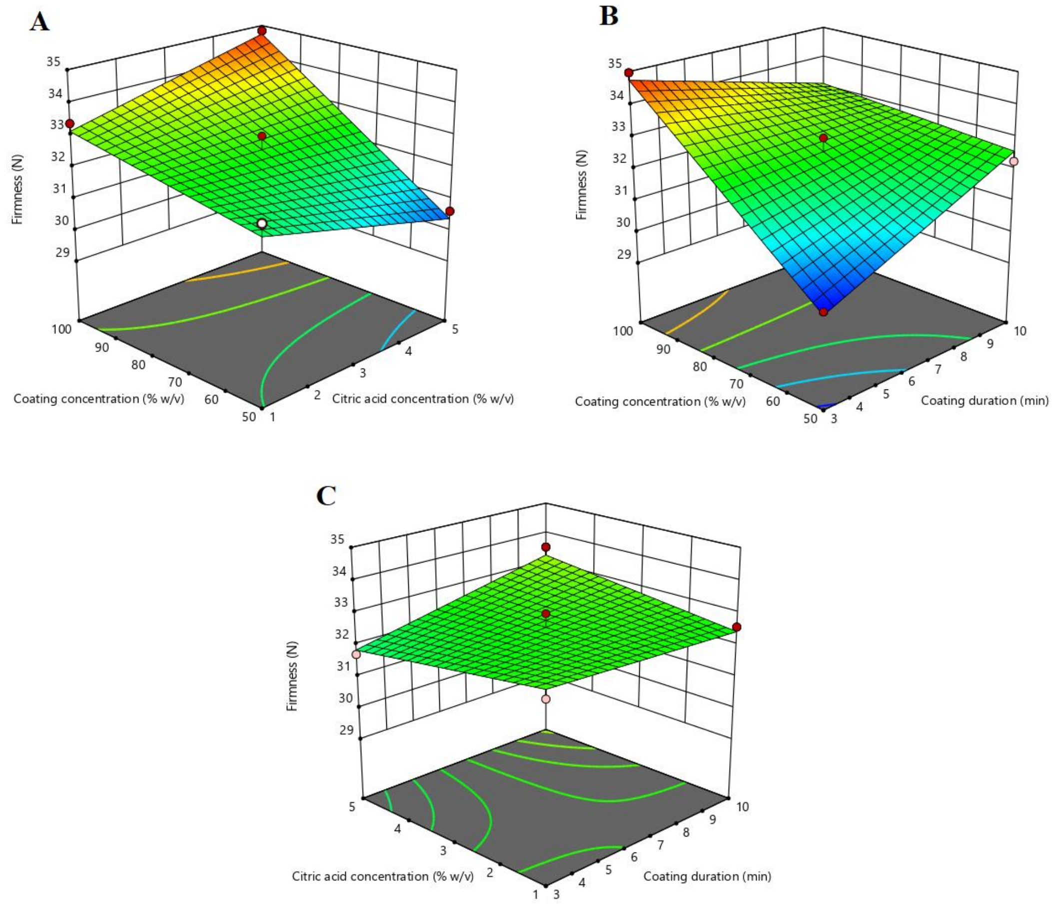

Figure 4.17: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration (X_2) and coating duration (X_2) on firmness of Aloe vera coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the L* values of eggplant fruits

Effect of process conditions on the L* values of eggplant fruits coated with beeswax

Eggplant fruits coated with beeswax had L* values ranging from 77.98 to 81.77. The reduced quadratic model expressed in Equation 4.7 was used for the prediction of the L* value response.

$$L^{*}value = 81.26 - 0.6363X_1 - 0.8663X_2 - 0.0950X_3 - 0.8324X_1^2 - 0.9649X_3^2 \quad \textbf{Eqn. 4.6}$$

From the model Equation, the main effect of coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) had negative regression coefficients, which imply that increasing these factors will decrease the L* values. The decreasing effect exhibited by coating concentration and citric acid concentration were significant but that of coating duration was not significant (Appendix 7). The quadratic effect of coating concentration and coating duration also had significant negative effect on the L* values. The significant levels of the model terms are presented in Appendix 7.

Effect of process conditions on the L* values of eggplant fruits coated with starch.

L* values of starch coated eggplant fruits varied from 76.43 to 80.36 after 17 days of storage. Equation 4.8 was developed to make prediction about the L* value response.

$$L^{*}\ value = 78.34 - 0.3053X_1 - 1.14X_2 + 0.4501X_3 + 0.1509X_1X_2 + 0.3292X_1X_3 - 0.6633X_2X_3 + 1.15X_1^2 - 0.7699X_2^2 + 0.2864X_3^2 \qquad \textbf{Eqn. 4.7}$$

The model Equation shows that coating concentration (X_1) and citric acid concentration (X_2) had a decreasing effect on L* values of eggplant fruits but the citric acid concentration had the most significant effect. However, increasing the coating duration (X_3) increased the L* values significantly. ANOVA for the L* value quadratic model is presented in Appendix 8. Figure 4.18 shows the 3D surface plots generated to illustrate the interaction effect of the independent variables on L* values. It was observed that the combined effect of coating concentration and citric acid concentration (X_1X_2) slightly increased the L* values (Figure 4.18A) but was not significant. The interaction between coating concentration and coating duration (X_1X_3) also increased the L* value

(Figure 4.18B) significantly (Appendix 8). However, the interaction effect between citric acid concentration and coating duration (X_2X_3), caused a significant reduction in the L* value (Figure 4.18C). The quadratic effect of coating concentration and coating duration increased L* values significantly but that of citric acid concentration caused a significant decrease (Appendix 8).

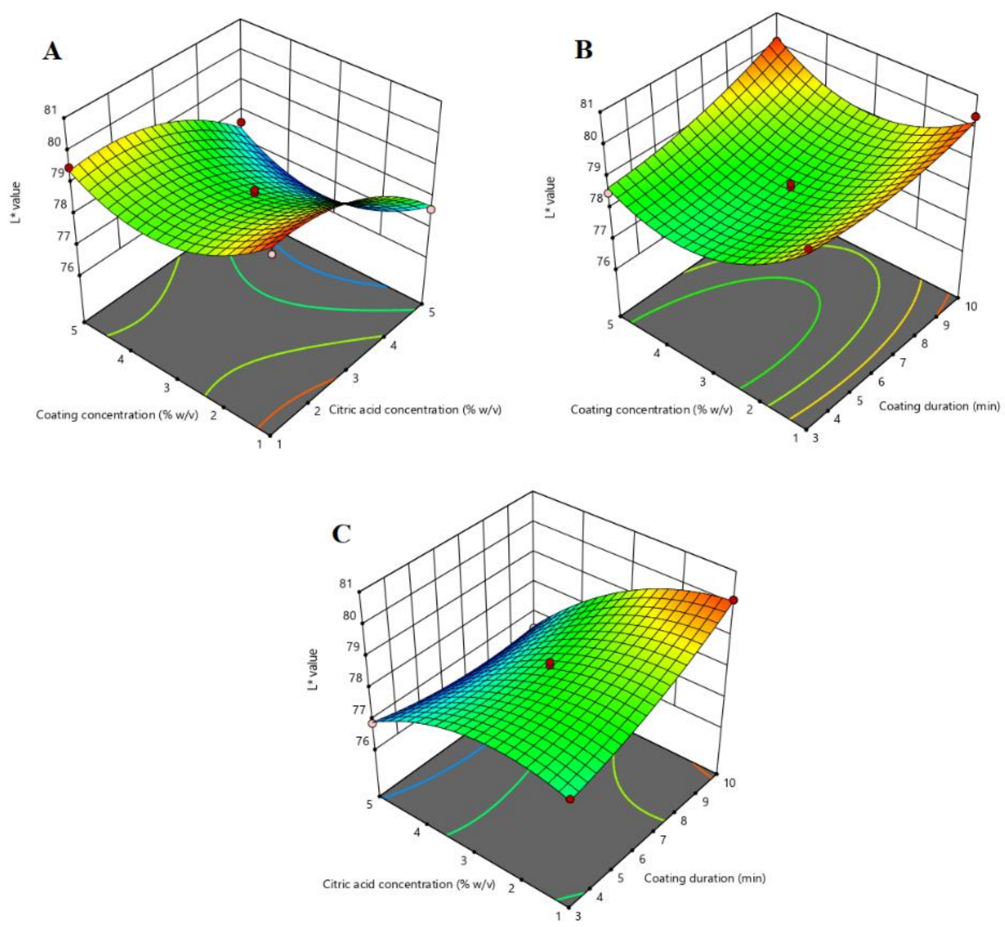

Figure 4.18: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3); and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on L* values of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the L* values of eggplant fruits coated with Aloe vera

The L* values of fruits coated with Aloe vera ranged from 77.48 to 80.67. A Linear model (Equation. 4.9) was used to describe the L* value response since none of the interaction or quadratic terms was significant.

$$L^{*}value = 79.83 + 0.9880X_1 + 0.6871X_2 + 0.5349X_3 \qquad \textbf{Eqn. 4.8}$$

From Equation 4.9, coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) had a positive impact on L* values as shown by positive regression coefficients. The increasing effect observed for the linear factors on the L* value were all significant (Appendix 9).

Effect of process conditions on the a* values of eggplant fruits

Effect of process conditions on the a* values of eggplant fruits coated with beeswax.

The a* values of eggplant fruits coated with beeswax ranged from -2.32 to 0.45. The a* value response was predicted using Equation 4.10.

$$a^{*}\ value = -2.12 + 0.0463X_1 - 0.0125X_2 - 0.1012X_3 + 1.33X_1X_2 + 0.6193X_1^2 + 0.7667X_2^2 - 0.4008X_3^2 \quad \textbf{Eqn. 4.9}$$

It was observed that at high coating concentration (X_1), a* values increased but was not significant (Appendix 10). On the other hand, high citric acid concentration (X_2) and coating duration (X_3) caused a reduction in the a* values, but both effects were not significant (Appendix 10).

Figure 4.19 shows that the interaction between coating concentration and citric acid concentration (X_1X_2) resulted in an increase in the a* value. Another observation made was that the quadratic terms of coating concentration and citric acid concentration resulted in a significant increase in the a* values, while that of coating duration decreased a* values significantly (Appendix 10).

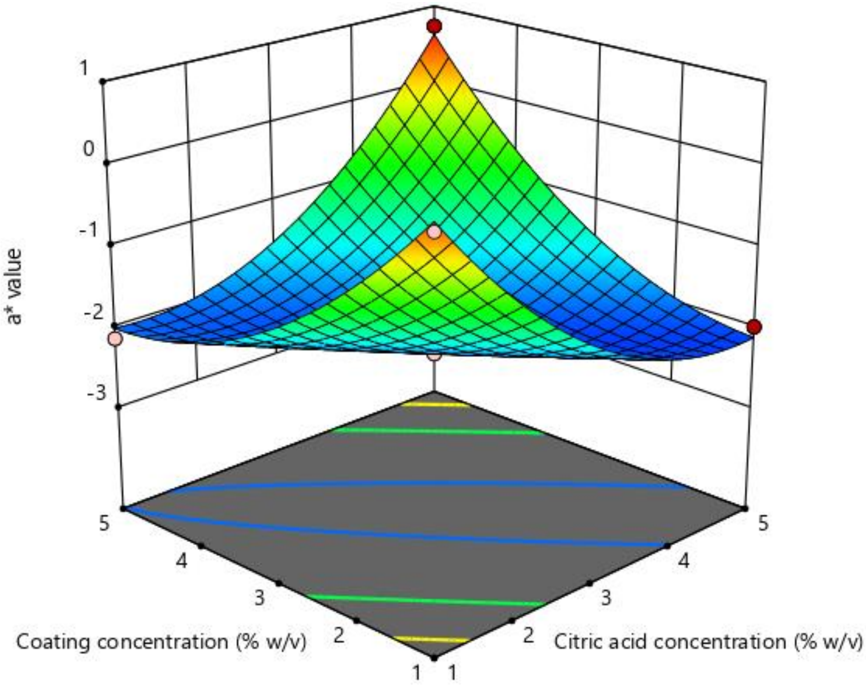

Figure 4.19: Effect of coating concentration (X_1) and citric acid concentration (X_2) on a* value of beeswax coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the a* values of starch coated eggplant fruits.

The a* values of the starch coated fruits ranged from -1.51 to 0.92. The model Equation (Equation 4.11) shows that coating concentration reduced a* values while the citric acid concentration and coating duration increased a* values of the starch coated fruits and all were significant (Appendix 11).

$$a^{*}\ value = -0.8559 - 0.9820X_1 + 0.1039X_2 + 0.2679X_3 - 0.1304X_1X_2 + 0.0532X_1X_3 + 0.3895X_2X_3 + 0.4655X_1^2 + 0.1103X_2^2 + 0.1112X_3^2$$

Eqn. 4.10

Figure 4.20 shows the effect of the interaction between the process factors on the eggplant fruits. The interaction effect of coating concentration and citric acid concentration (X_1X_2) significantly decreased a* values (Figure 4.20 A). However, the interaction due to coating concentration and coating duration (X_1X_3) increased the a* values but was not significant (Appendix 11).

A similar observation was made for the interaction between citric acid concentration and coating duration (X_2X_3) (Figure 4.20 B), although the effect of this interaction was significant (Appendix 11). The quadratic effect of coating concentration, citric acid concentration and coating duration increased a* values, with coating concentration showing the most significant effect (Appendix 11).

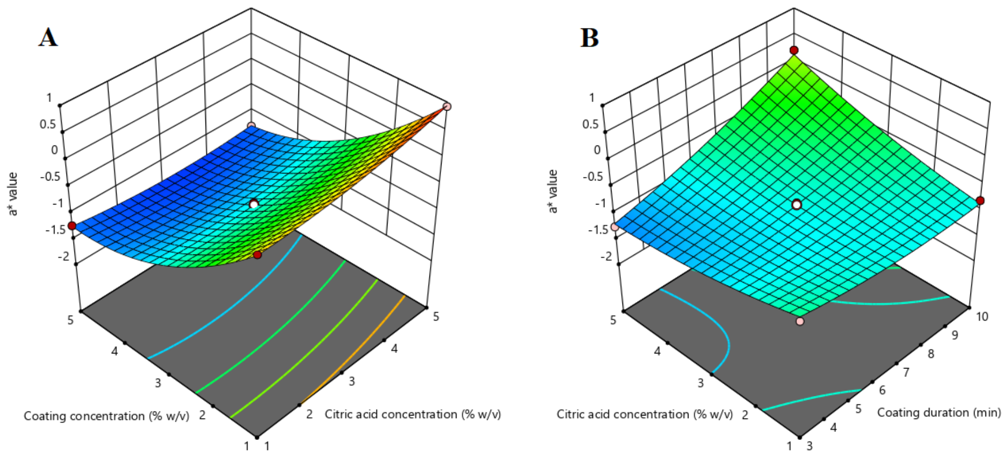

Figure 4.20: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) on a* values of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the a* values of eggplant fruits coated with Aloe vera

The a* values of fruits coated with Aloe vera ranged from -1.35 to 1.19. Equation 4.12 was used to explain the effect of the process factors on the a* values.

$$a^{*}value = 0.1605 - 0.4465X_1 + 0.2682X_2 - 0.4788X_3 - 0.4356X_1X_2 + 0.6057X_1X_3 + 0.7984X_2X_3 - 0.6603X_1^2 \quad \textbf{Eqn. 4.11}$$

The model Equation shows that high Aloe vera coating concentration (X_1) and coating duration (X_3) reduced the a* values while high citric acid concentration increased a* values. The effect of the interaction between coating concentration and citric acid concentration (X_1X_2) decreased a* value significantly (Figure 4.21 A). However, the combined effect of coating concentration and coating duration (X_1X_3), and that of citric acid concentration and coating duration (X_2X_3) increased the a* values (Figure 4.21 B) significantly. Appendix 12 shows the significant levels of the main, interaction and quadratic effects. 3D surface plots representing the effect of the interactions are shown in Figure 4.21.

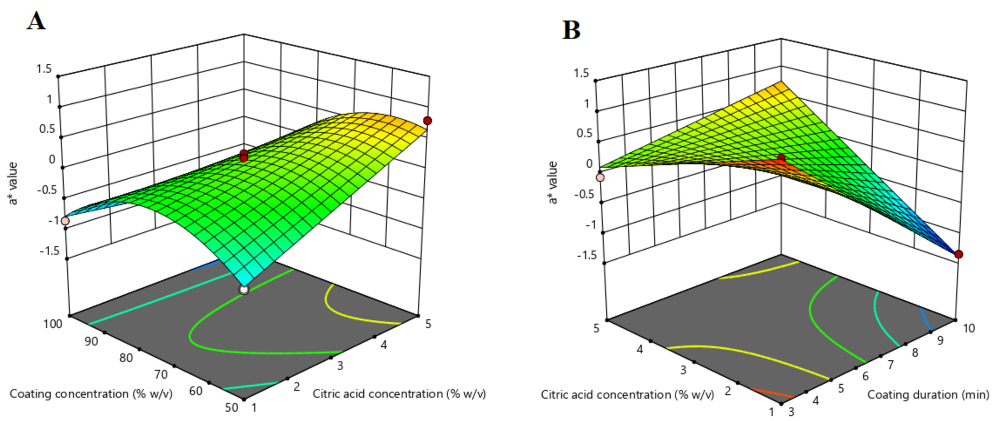

Figure 4.21: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2) and (B) Effect of citric acid concentration (X_2) and coating duration (X_3) on a* value of Aloe vera coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the b* values of eggplant fruits

Effect of process conditions on the b* values of eggplant fruits coated with beeswax

The b* values of fruits coated with beeswax ranged from 22.76 to 32.99. Equation 4.13 represents the model used to predict the b* value response for the beeswax coating.

$$b^*\,value = 23.40 + 0.2775X_1 + 1.50X_2 + 0.8975X_3 + 3.67X_1X_2 - 0.9175X_1X_3 - 0.8525X_2X_3 + 1.58X_1^2 + 2.99X_2^2$$ **Eqn. 4.12**

The beeswax coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) increased b* values as the factor levels increased. The effect of citric acid concentration and coating duration were significant but that of coating concentration was not significant (Appendix 13).

In Figure 4.22, it was observed that the b* values increased significantly due to the interaction between coating concentration and citric acid concentration (X_1X_2) (Figure 4.22A). However, the combined effect of coating concentration and coating duration (X_1X_3) as well as citric acid concentration and coating duration (X_2X_3) caused a decrease in the b* values as shown in Figure 4.22B and 4.21C, respectively. The quadratic effect of coating concentration and citric acid concentration caused a significant increase in the b* values (Appendix 13).

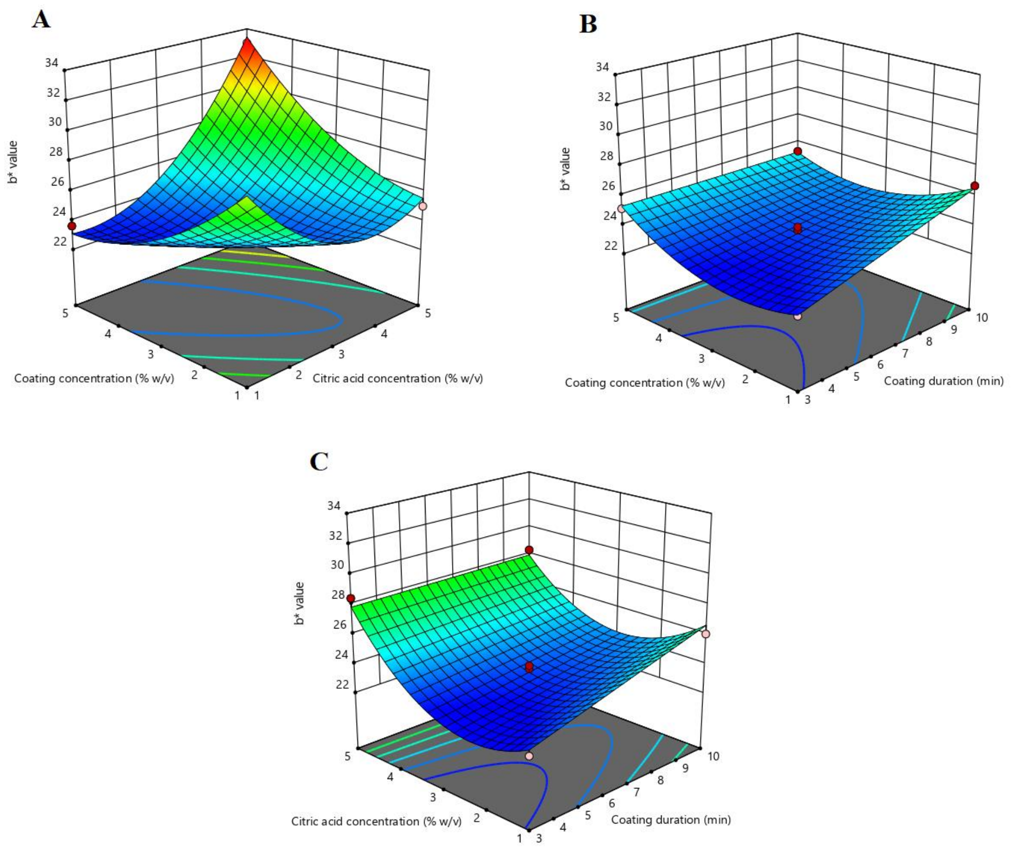

Figure 4.22: Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on b* values of beeswax coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the b* values of eggplant fruits coated with starch.

The b* value of starch coated fruits ranged from 26.26 to 38.55. Equation 4.14 shows the model Equation used to make predictions for the b* value. The significance of the model terms are shown in Appendix 14.

$$b^*\ value = 31.57 + 0.7078X_1 + 2.00X_2 - 0.0061X_3 - 1.71X_1X_2 - 0.9228X_1X_3 + 1.64X_2X_3 - 3.17X_1^2 + 2.01X_2^2 + 1.01X_3^2$$

Eqn. 4.13

From Equation 4.14, it can be seen that increasing the coating concentration (X_1) and citric acid concentration (X_2) increased the b* value of the fruits while increasing the coating duration (X_3) decreased the b* value but only the former was significant. Also, the effect of the interaction between the coating concentration and the citric acid concentration (X_1X_2) caused a significant reduction in the b* values of the fruits (Figure 4.23A). Similarly, the effect of the interaction between coating concentration and coating duration (X_1X_3) caused the b* values to decrease significantly (Figure 4.23B). The interaction between the citric acid concentration and the coating duration (X_2X_3), however, increased the b* values as shown in Figure 4.23C. Although the main effect of coating concentration increased the b* values, the quadratic term decreased b* values significantly. Also, the quadratic effect of citric acid concentration and coating duration on the other hand increased the b* values significantly (Appendix 14).

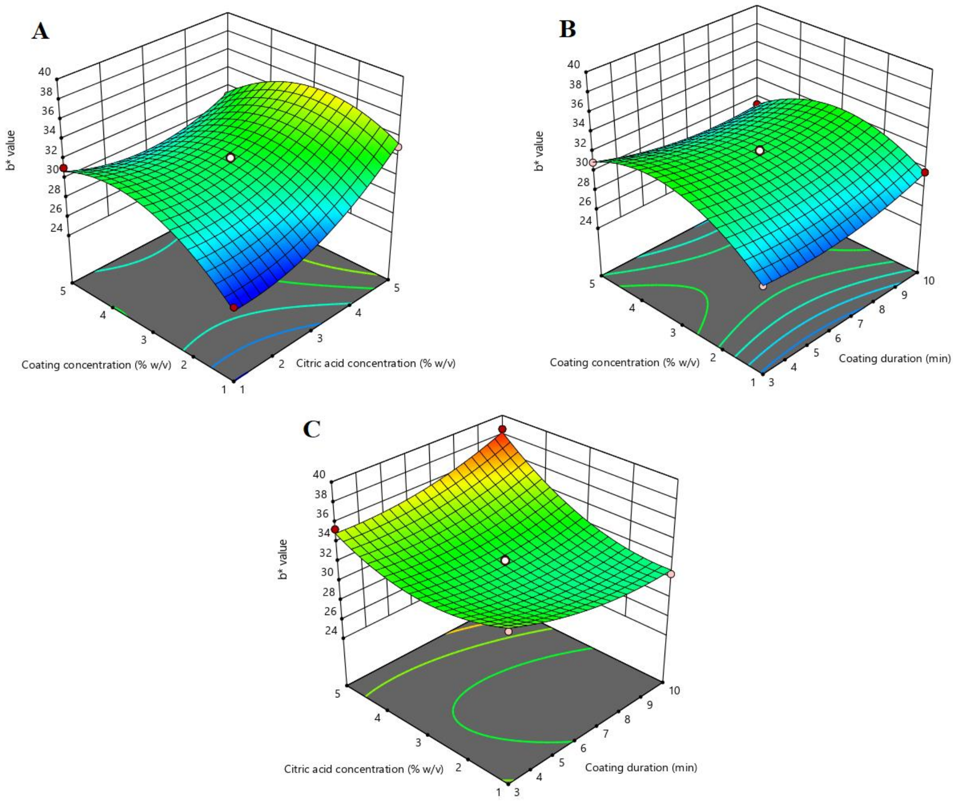

Figure 4.23: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration(X_2) and coating duration (X_3) on b* values of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the b* values of eggplant fruits coated with Aloe vera

Eggplant fruits coated with Aloe vera had b* values varying from 26.41 to 35.26. The 2FI model presented in Equation 4.15 was identified as best for fitting the b* value response data since there was no significant quadratic term.

$$b^{*}value = 29.77 - 0.9822X_1 - 0.0782X_2 - 1.95X_3 - 0.7917X_1X_2 + 2.36X_1X_3 + 2.27X_2X_3 \quad \textbf{Eqn. 4.14}$$

From Equation 4.15, the regression coefficient for the main effects, it can be said that high levels of Aloe vera coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) could decrease b* values of eggplant fruits. The decreasing effect of coating concentration and coating duration were significant, but that of citric acid concentration was not significant (Appendix 15). Also, the negative regression coefficient observed for the interaction between coating concentration and citric acid concentration (X_1X_2) implies that such interaction can decrease the b* values. However, the effect of the interaction between coating concentration and coating duration (X_1X_3), and citric acid concentration and coating duration (X_2X_3) caused a significant increase in the b* values. Figure 4.24 illustrates these interactions and the significance of the model terms are given in Appendix 15.

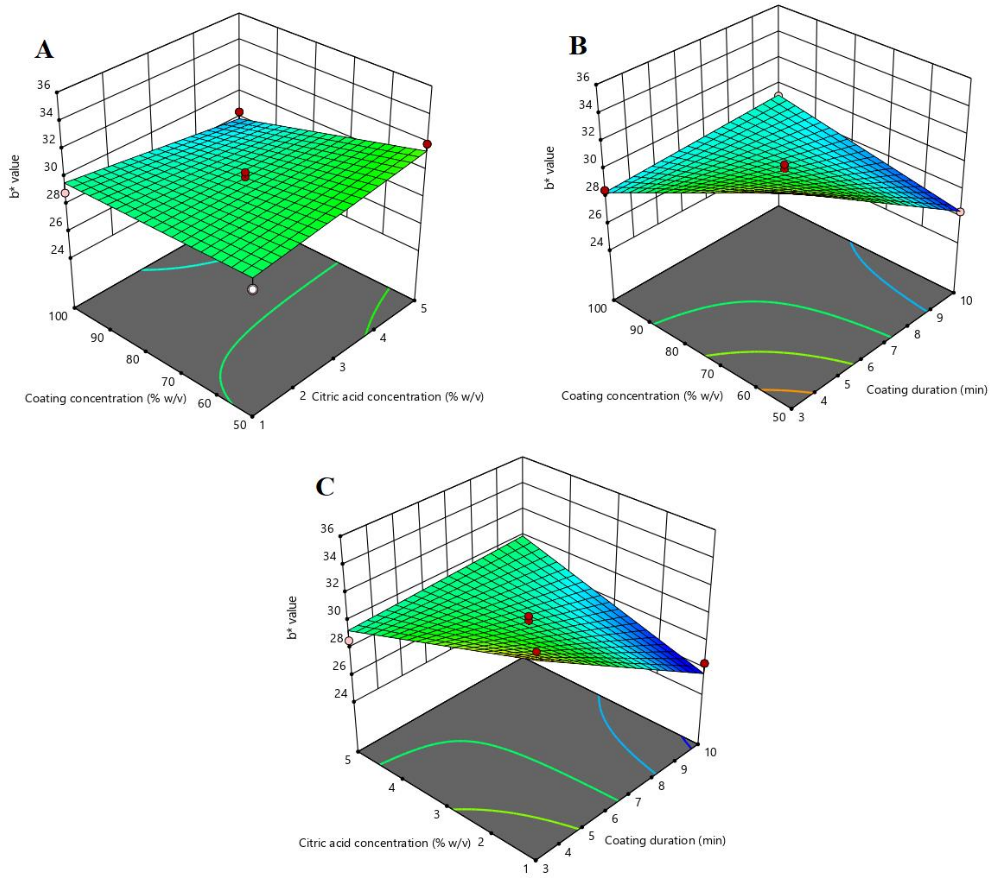

Figure 4.24: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration and coating duration and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on b* value of Aloe vera coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the total phenolic content of eggplant fruits

Effect of process conditions on the total phenolic content of eggplant fruits coated with beeswax

The total phenolic content of beeswax coated fruits ranged from 104.12 to 161.96 mg/kg. A reduced quadratic model was best for predicting the response and is expressed in Equation 4.16. The negative regression coefficients observed for coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) imply that increasing these factors will negatively affect the total phenolic content of eggplant fruits coated with beeswax. However, only the effect of citric acid concentration was significant as given in Appendix 16.

$$Total\ phenols\ (mg/kg\ ) = 134.20 - 0.3273X_1 - 7.24X_2 - 1.66X_3 - 11.93X_1X_3 + 27.71X_2X_3 + 10.59X_1^2 - 7.32X_2^2 \quad \textbf{Eqn. 4.15}$$

The combined effect of coating concentration and coating duration (X_1X_3) resulted in a significant decrease in the total phenolic content (Eqn. 4.16). However, the effect of the interaction between citric acid concentration and coating duration (X_2X_3) (Figure 4.25) resulted in a higher increase in the total phenolic content, although the individual factors had a negative effect on total phenolic content. The quadratic effect of coating concentration increased total phenolic content while citric acid concentration caused a decrease. The significance of the model terms are given in Appendix 16.

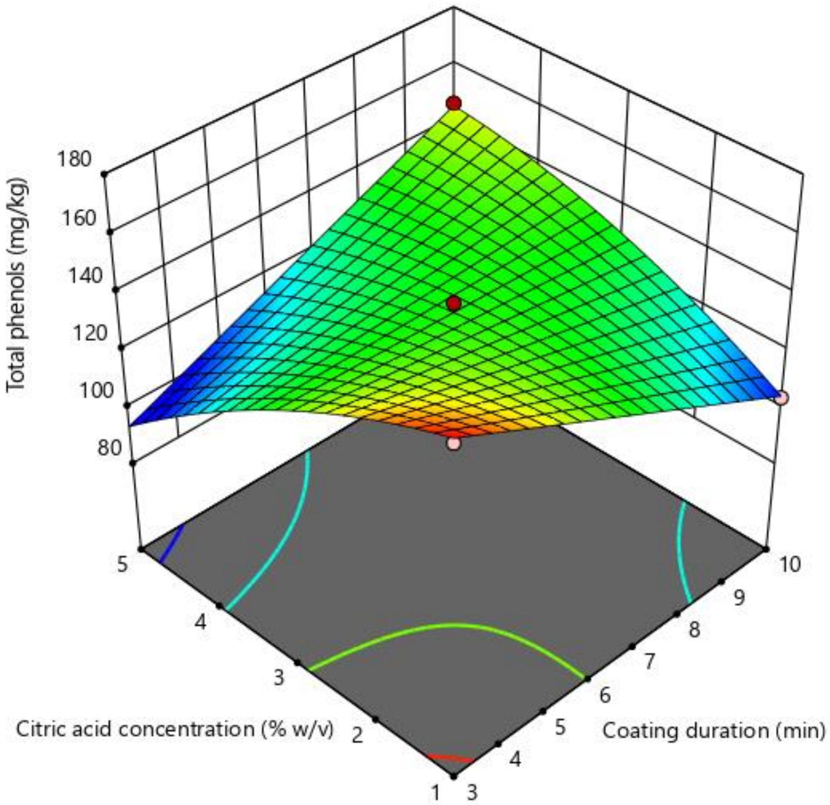

Figure 4.25: Effect of citric acid concentration (X_2) and coating duration (X_3) on total phenolic content of beeswax coated fruits after 17 d storage period at 10 °C.

Effect of process conditions on the total phenolic content of eggplant fruits coated with starch

The total phenolic content of the starch coated fruits ranged from 153.66 to 278.05 mg/kg. Equation 4.17 shows that total phenolic content decreased at high starch coating concentration (X_1), but increased when citric acid concentration (X_2) was increased, although, the effect of both factors on the total phenolic content were not significant (Appendix 17).

$$Total\ phenols\ (mg/kg) = 213.01 - 1.93X_1 + 0.0508X_2 + 13.77X_3 - 30.18X_1X_2 + 22.87X_1X_3 + 14.23X_2X_3 - 46.38\ X_1^2 - 26.89X_2^2 + 5.08X_3^2$$

Eqn. 4.16

Coating duration (X_3) which gave the highest main effect (Equation 4.17), significantly increased the total phenolic content of the starch coated fruits (Appendix 17). As shown in Figure 4.26, a significant decrease in the total phenolic content was observed due to the interaction between coating concentration and citric acid concentration (X_1X_2). However, the effect of the interaction between coating concentration and coating duration (X_1X_3) and that between the citric acid concentration and coating duration (X_2X_3) produced a positive effect, although only the former was significant. The quadratic effect of coating concentration and citric acid concentration, however, caused a significant decrease in the total phenolic content while coating duration enhanced the levels of total phenolic content, but was not significant (Appendix 17).

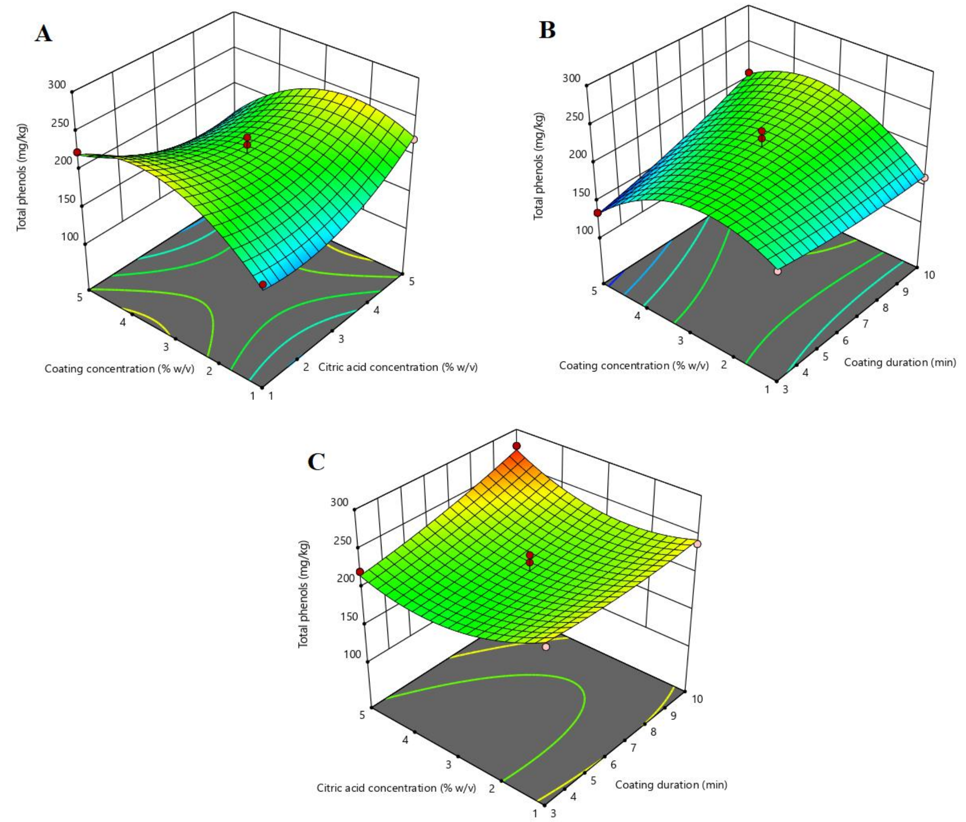

Figure 4.26: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on total phenolic content of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the total phenolic content of eggplant fruits coated with Aloe vera

The total phenolic content of eggplant fruits coated with Aloe vera ranged from 152.44 to 233.33 mg/kg. Equation 4.18 was used to predict the total phenolic content response. The significance of the model terms are expressed in Appendix 18.

$$Total\ phenols\ (mg/kg) = 202.42 - 4.57X_1 - 13.72X_2 - 12.30X_3 - 13.62X_2X_3 - 19.16X_1^2 + 18.24X_3^2 \quad \textbf{Eqn. 4.17}$$

From Equation 4.18, the main effect of coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_3) all caused a decrease in the total phenolic content of Aloe vera coated fruits. The decreasing effect observed for coating concentration was not significant but citric acid concentration and coating duration were significant (Appendix 18). Figure 4.27 shows that the effect of the interaction between citric acid concentration and coating duration can cause a significant decrease in the total phenolic content of eggplant fruits. While the quadratic effect of coating concentration decreased the total phenolic content, that of coating duration resulted in an increase and both were significant (Appendix 18).

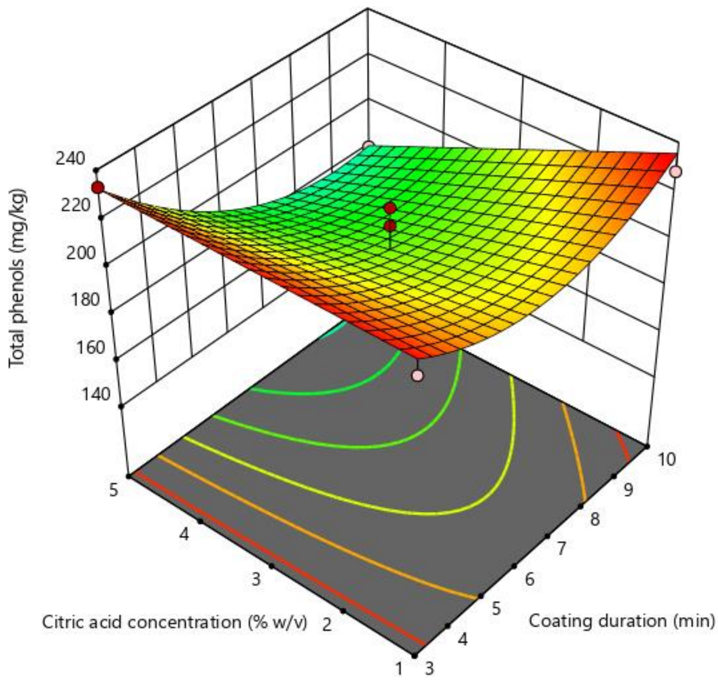

Figure 4.27: Effect of citric acid concentration (X_1) and coating duration (X_2) on total phenolic content of Aloe vera coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the ascorbic acid levels of eggplant fruits

Effect of process conditions on the ascorbic acid levels of eggplant fruits coated with beeswax

Ascorbic acid levels of the beeswax coated fruits varied from 63.58 to 143.21 mg/kg. Equation 4.19 was used to explain the effect of the variables and to predict the ascorbic acid response.

$$Ascorbic\ acid\ (mg/kg) = 107.49 + 10.09X_1 - 7.38X_2 + 7.55X_3 + 27.19X_2X_3 - 21.68X_1^2$$ **Eqn. 4.18**

The main effect of coating concentration (X_1) and coating duration (X_3) increased ascorbic acid levels while citric acid concentration (X_2) decreased the ascorbic acid levels. Figure 4.28 shows that the combined effect of citric acid concentration and coating duration (X_2X_3) caused a significant increase in ascorbic acid levels. However, the quadratic effect of citric acid concentration caused a significant decrease in the ascorbic acid levels. The significance of the model terms can be seen in Appendix 19.

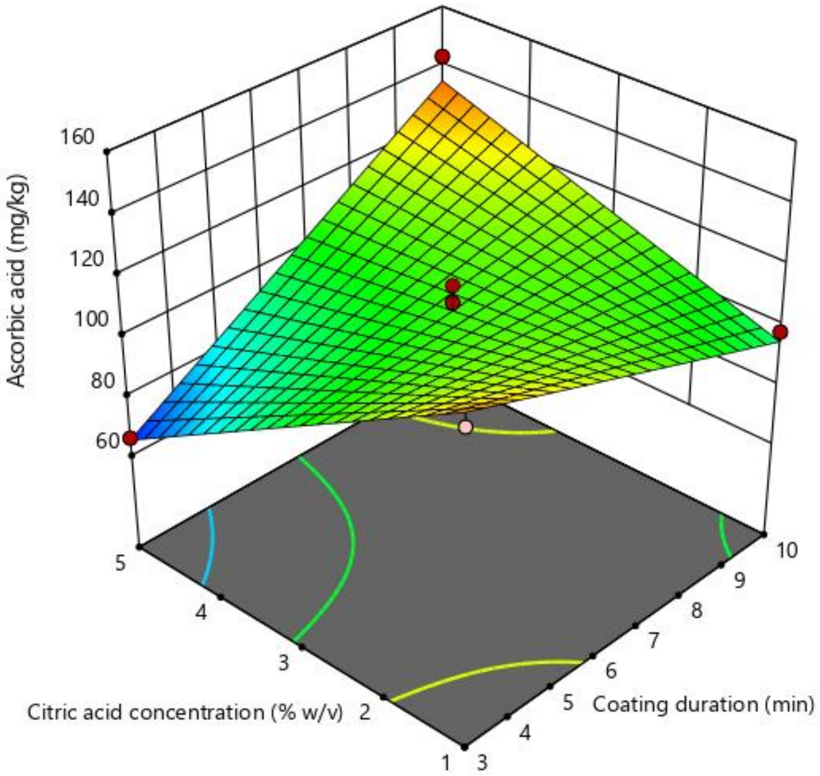

Figure 4.28: Effect of citric acid concentration (X_2) and coating duration (X_3) on ascorbic acid levels of beeswax coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the ascorbic acid levels of starch coated eggplant fruits.

The starch coated fruits recorded ascorbic acid levels that varied from 49.97 to 158.24 mg/kg. From Equation 4.20, the ascorbic acid levels increased when all the linear factors were increased. Appendix 20 presents the significance of the model terms. Coating duration (X_3) had the highest regression coefficient followed by coating concentration (X_1) and both factors had significant effect on the ascorbic acid levels on starch coated fruits. The effect of citric acid concentration (X_2) was, however, not significant.

$$Ascorbic\ acid\ (mg/kg) = 68.58 + 8.69X_1 + 2.02X_2 + 12.21X_3 - 2.84X_1X_2 + 11.97X_1X_3 + 18.71X_2X_3 - 22.14X_1^2 + 14.02X_2^2 + 37.34X_3^2$$

Eqn. 4.19

Further significant increases were observed as a result of the interaction between coating concentration and coating duration (X_1X_3) (Figure 4.29 A). Furthermore, in Figure 4.29 B, it was observed that the combined effect of citric acid concentration and coating duration (X_2X_3) caused a significant increase in ascorbic acid levels. The quadratic effect of coating concentration significantly decreased the ascorbic acid levels whereas that of citric acid concentration and coating duration caused a significant increase with coating duration showing the highest effect. ANOVA showing the levels of significance for the ascorbic acid model and model terms are shown in Appendix 20.

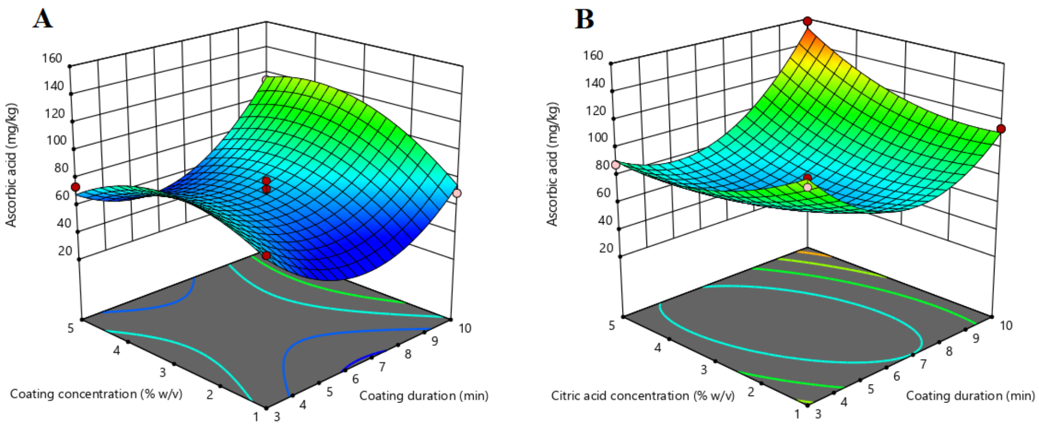

Figure 4.29: (A) Effect of coating concentration (X_1) and coating duration (X_3); (B) Effect of citric acid concentration (X_2) and coating duration (X_3) on ascorbic acid levels of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the ascorbic acid levels of eggplant fruits coated with Aloe vera

Aloe vera coated fruits measured ascorbic acid levels ranging from 57.51 to 76.31 mg/kg. A linear model was used to predict the ascorbic acid response using Equation 4.21. Ascorbic acid levels decreased when coating concentration (X_1) and citric acid concentration (X_2) increased. The ascorbic acid levels however increased as the coating duration (X_3) increased. All the factors had a significant effect on ascorbic acid levels (Appendix 21).

$$Ascorbic\ acid\ (mg/kg) = 66.40 - 4.21X_1 - 4.49X_2 + 2.94X_3 \quad \textbf{Eqn. 4.21}$$

Effect of process conditions on the total antioxidant capacity of eggplant fruits

Effect of process conditions on the total antioxidant capacity of eggplant fruits coated with beeswax

The reduced quadratic model expressed in Equation 4.22 was used for predicting the total antioxidant capacity response for the fruits coated with beeswax.

$$Total\ antioxidant\ activity\ (mg/kg) = 134.13 + 0.6748X_1 - 3.27X_2 - 5.39X_3 + 6.00X_1X_3 + 8.58X_2X_3 - 5.35X_1^2 \quad \textbf{Eqn. 4.20}$$

It was observed that increasing coating concentration (X_1) increased the total antioxidant capacity of the fruits but was not significant. On the other hand, increasing citric acid concentration (X_2) and coating duration (X_3) significantly decreased the total antioxidant capacity. The effect of the interaction between coating concentration and coating duration (X_1X_3) significantly increased the total antioxidant capacity of the eggplant fruits (Figure 4.30A). Similarly, the interactive effect between citric acid concentration and coating duration (X_2X_3) increased total antioxidant capacity significantly (Figure 4.30B). The quadratic effect of coating concentration decreased total antioxidant capacity. Appendix 22 shows the levels of significance of the total antioxidant capacity model and the model terms.

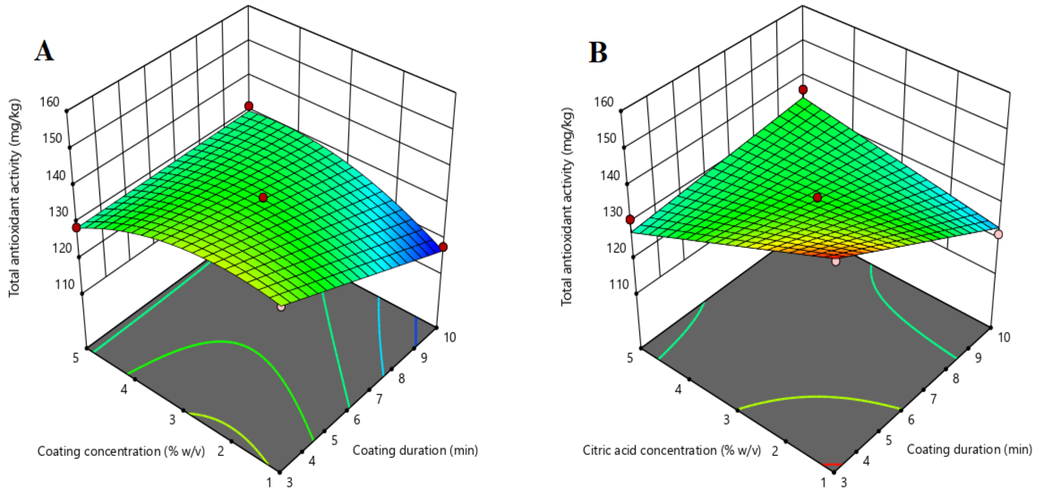

Figure 4.30: (A) Effect of coating concentration (X_1); and coating duration (X_3) and (B) Effect of citric acid concentration (X_2) and coating duration (X_3) on the total antioxidant capacity of beeswax coated eggplant fruits stored for 17 d at 10 °C.

Effect of process conditions on the total antioxidant capacity of eggplant fruits coated with starch

The effect of the process factors on the total antioxidant capacity of starch coated fruits was explained using the reduced quadratic model summarized in Equation 4.23.

$$Total\ antioxidant\ activity\ (mg/kg) = 116.51 - 9.13X_1 + 3.84X_2 - 9.31X_3 + 4.17X_1X_2 + 19.00X_1X_3 + 9.83X_2X_3 \quad \textbf{Eqn. 4.21}$$

The total antioxidant capacity of the starch coated fruits ranged from 87 to 148.94 mg/kg. Equation 4.23 shows that the total antioxidant capacity decreased when the coating concentration (X_1) and coating duration (X_3) increased and the observed increases were significant (Appendix 23). The total antioxidant capacity however increased when citric acid concentration (X_2) increased, although, the effect was not significant (Appendix 20).

The effect of the interactions between coating concentration and citric acid concentration (X_1X_2) (Figure 4.31A), and citric acid concentration and coating duration (X_2X_3) (Figure 4.31C) increased the total antioxidant capacity but were not significant as shown in Appendix 23. Similarly, the interactions between coating concentration and coating duration (X_1X_3) increased the total antioxidant capacity (Figure 4.31B) and was significant (Appendix 23).

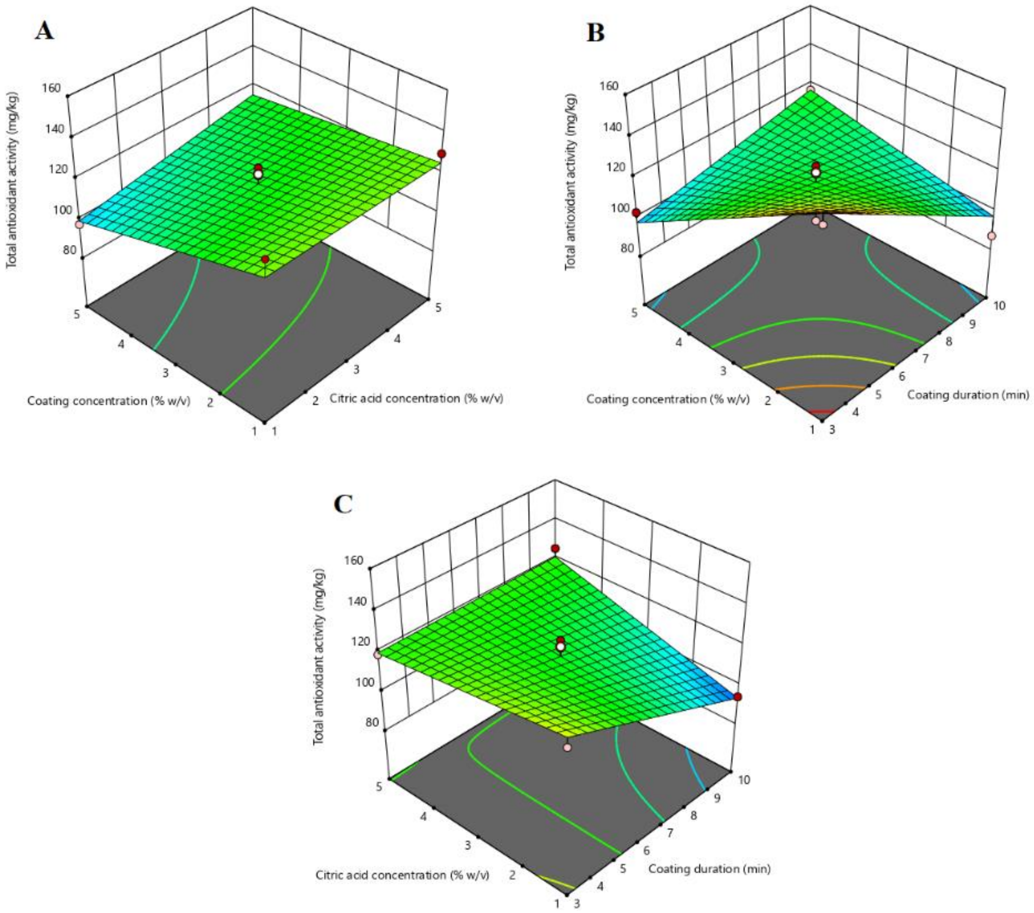

Figure 4.31: (A) Effect of coating concentration (X_1) and citric acid concentration (X_2); (B) Effect of coating concentration (X_1) and coating duration (X_3) and (C) Effect of citric acid concentration (X_2) and coating duration (X_3) on the total antioxidant capacity (mg/kg) of starch coated eggplant fruits after 17 d storage period at 10 °C.

Effect of process conditions on the total antioxidant capacity of eggplant fruits coated with Aloe vera

The total antioxidant capacity of eggplant fruits coated with Aloe vera was described using the linear model presented in Equation 4.24. It was observed that increasing coating concentration (X_1), citric acid concentration (X_2) and coating duration (X_2) decreased the total antioxidant capacity of the fruits eggplant fruits, but the effect of the coating concentration was not significant (Appendix 24). No significant interaction effect or quadratic effect on total antioxidant capacity of the fruits was observed.

$$Total\ antioxidant\ acitivy\ (mg/kg) = 116.88 - 1.53X_1 - 7.91X_2 - 5.14X_3$$ **Eqn. 4.22**

Prediction and verification of optimized conditions and responses

The predicted coating conditions and responses as well as the measured physicochemical properties obtained after verification experiment are presented in Table 4.10. The optimized process conditions gave an overall desirability of 0.883, 0.712, 0.658 for beeswax, starch and Aloe vera coating, respectively.

The experimental (measured) values of weight loss, firmness, colour (L*a*b*) and total antioxidant activities of beeswax-coated fruits were close to the predicted values. However, the total phenolic content measured was higher while ascorbic acid level was lower than predicted. The weight loss, firmness and colour of starch based coated fruits were also well predicted by the models since the experimental values were close to the predicted. However, the total phenolic content, ascorbic acid level and total antioxidant capacity measured were higher than the predicted values. The models for the Aloe vera coatings were also adequate in predicting the weight loss firmness and colour (L*a*b*) responses. High total phenolic content, ascorbic acid level and total antioxidant capacity were however observed experimentally compared to the predicted values. Figure 4.32 shows a plot of the predicted and measured data. A good correlation was observed between the predicted and the measured physicochemical properties with an R-squared value of 0.87.

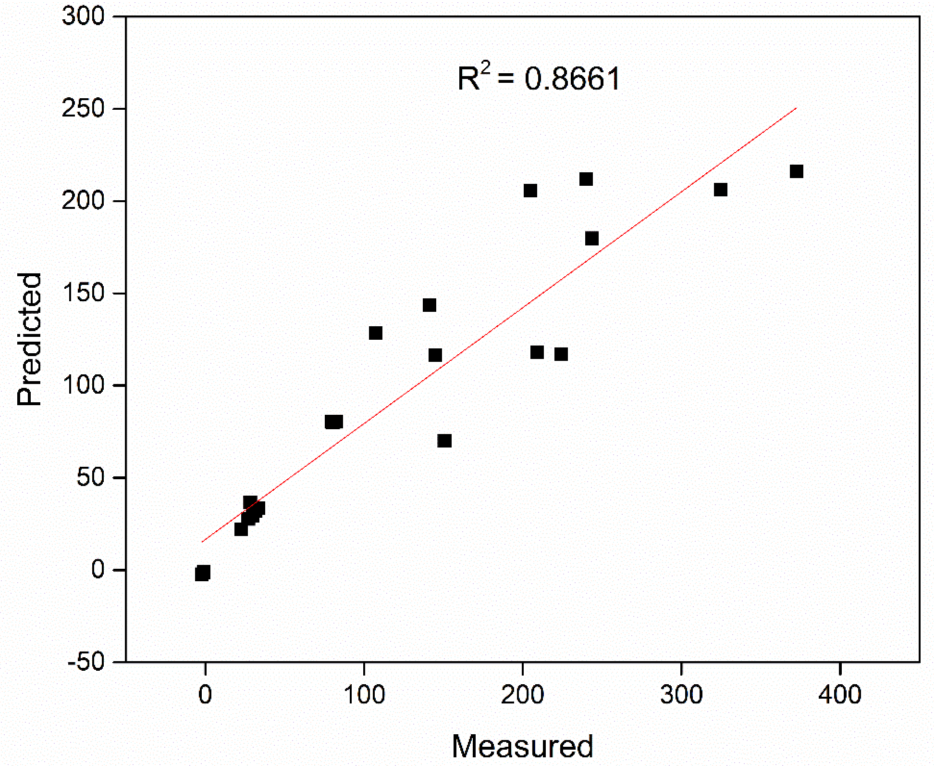

Figure 4.32: Correlation between predicted and measured physicochemical responses for beeswax, starch and Aloe vera coatings.

Table 4.10: Predicted optimized coating conditions and verified responses for beeswax, starch, and Aloe vera

Predicted coating conditions	Predicted responses							
	Weight loss (g/kg)	Firmness (N)	L*	a*	b*	Total phenolic content (mg/kg)	Ascorbic acid levels (mg/kg)	Total antioxidant Capacity (mg/kg)
Beeswax (4.62 % X_1, 1 % X_2, 3 min X_3)	31.93	33.58	80.2	-2.27	22.18	179.78	128.51	143.57
Starch (4.99 % X_1, 2.98 % X_2, 10 min X_3)	211.99	36.61	80.26	-0.94	29.17	206.33	116.44	116.87
Aloe (96.92 % X_1, 1.07 % X_2, 10 min X_3)	205.82	31.99	79.77	-1.35	27.58	216.04	69.98	118.04
Coating	**Verification (Measured physicochemical parameters)**							
	Weight loss (g/kg)	**Firmness (N)**	**L***	**a***	**b***	**Total phenolic content (mg/kg)**	**Ascorbic acid levels (mg/kg)**	**Total antioxidant Capacity (mg/kg)**
Beeswax	31.94± 2.15^{a}	33.71± 1.26^{a}	82.4± 0.77^{a}	-2.06 ± 0.28^{a}	22.47 ± 1.82^{a}	243.90 ± 10.35^{a}	107.31 ± 14.34^{a}	141.36 ± 5.93^{a}
Starch	240.14± 4.12^{b}	28.33± 1.77^{b}	79.8± 1.41^{b}	-0.94 ± 0.53^{b}	29.82 ± 2.97^{b}	324.91 ± 14.14^{b}	144.84 ± 12.56^{a}	224.26 ± 3.87^{b}
Aloe	205.03± 4.75^{c}	30.36± 1.43^{c}	80.4± 1.41^{ab}	-1.14 ± 0.30^{b}	27.14 ± 1.67^{b}	372.48 ± 13.4^{c}	150.66 ± 20.77^{a}	209.28 ± 5.18^{c}
Control	239.27± 14.26^{b}	26.21± 0.13^{b}	73.2± 2.11^{c}	3.48 ± 0.23^{c}	37.02 ± 2.60^{c}	308.46 ± 14.98^{b}	330.79 ± 11.93^{b}	559.83± 10.50^{d}

*X_1 (Coating concentration, %w/v), X_2 (Citric acid concentration, %w/v), and X_3 (Coating duration).
* Means in the same row not sharing the same letter are significantly different.

The optimized coating conditions for the beeswax, starch and Aloe vera coating were compared using mean comparison test at p = 0.05 significance level. Fruits coated with beeswax significantly minimized weight loss compared to those coated with starch and Aloe vera. Fruits coated with starch recorded significantly higher weight loss compared to Aloe vera coated fruits. Significant differences in firmness were also observed between the various coatings. The highest firmness value of 33.71 N was determined in fruits coated with beeswax while fruits coated with Aloe vera and starch had 30.36 N and 28.33 N, respectively (Table 4.10).

Fruits coated with beeswax had significantly higher L* values than fruits coated with starch. However, no significant difference was observed between fruits coated with beeswax and fruits coated with Aloe vera. Fruits coated with Aloe vera and starch also did not show any significant differences. Among the coatings, beeswax obtained the highest L* values of 82.48 (Table 4.10). Fruits coated with beeswax had significantly lower a* values compared to fruits coated with starch and Aloe vera. However, no significant difference in a* value was observed between fruits coated with starch and Aloe vera. Similar observations were made with the b* values.

Fruits coated with beeswax had the lowest total phenolic content of 243.90 mg/kg while fruits coated with Aloe vera had the highest value of 372.48 mg/kg (Table 4.10). Among the coatings, Aloe vera coated fruits had the highest ascorbic acid level of 150.66 mg/kg followed by the starch coated fruits with a value of 144.84 mg/kg but were not significantly different (Table 4.10). Beeswax coated fruits had the lowest ascorbic acid level of 107.31 mg/kg, although, it not significantly different from the levels recorded for the starch and Aloe vera coated fruits (Table 4.10). Among the coatings, the starch coated fruits obtained the highest total antioxidant capacity of 224.26 mg/kg and was significantly different from the values obtained for beeswax and Aloe vera coated fruits (Table 4.10). Fruits coated with beeswax recorded the lowest total antioxidant capacity of 141.36 mg/kg (Table 4.10).

The coatings were further compared to the control fruits to know their effectiveness after the optimization Table 4.10. It was observed that weight loss of the control was significantly higher ($p<0.05$) than fruits coated with beeswax and Aloe vera but not fruits coated with starch. Firmness loss of the eggplant fruits was also significantly reduced by the coatings compared to the control fruits ($p<0.05$), except for starch coated fruits which did not differ significantly from the control. The L* values of the control fruits were significantly lower than the fruits coated with beeswax, starch or Aloe vera. For the a* and b* values, control fruits recorded significantly higher values compared to the coated fruits, irrespective of the type of coating. Total phenolic content of fruits coated with Aloe vera had significantly higher value while fruits coated with beeswax had significantly lower values compared to the control fruits. No significant difference in the total phenolic content was observed between fruits coated with starch and the control fruits. However, ascorbic acid levels and total antioxidant capacity of control fruits were significantly higher than the values determined in coated fruits.

CHAPTER FIVE

DISCUSSION

Effect of coating on the physicochemical properties of eggplant fruits during storage

Eggplant fruits, like many other fruits go through physiological and biochemical changes after harvest resulting in loss of quality. In this study, the effect of beeswax, cassava starch and Aloe vera coating on some physicochemical properties of eggplant fruits during storage were monitored over a period of time.

Effect of coating on the weight loss of eggplant fruits

Weight loss increased throughout the storage period irrespective of the coating treatment. The increasing weight loss was due to water loss driven by active metabolic processes, such as transpiration and respiration (Abbasi et al., 2011). Bora and Narain (1997) reported that loss of water during storage is one of the main causes of deterioration as it results in loss of fruit weight. The increasing weight loss over time agrees with other findings on the weight loss of eggplant fruits during storage (Gao et al., 2015; Mencarelli et al., 1989; Moretti & Pineli, 2005; Singh et al., 2016).

Beeswax coating significantly minimized weight loss of eggplant fruits compared to the control fruits. Similarly, beeswax coatings were effective in reducing weight loss of oranges (Shahid & Abbasi, 2011a), strawberries and apricot (Mladenoska, 2012), plums (Gunaydin et al., 2017) and cucumber (Bahnasawy & Khater, 2014). The weight retention property exhibited by the beeswax coating could be due to the fact that lipid-based coatings are good barriers to water vapour due to their hydrophobic nature (Ball, 1997;

Lerdthanangkul & Krochta, 1996). Bourtoom (2008) reported that the primary function of lipid coating is to block the transport of moisture due to their relative low polarity. Prevention of weight loss by the beeswax coating is a major improvement in the preservation of eggplant fruits since weight loss is one of the primary reasons why eggplant fruits become unsuitable for sale.

Starch coating (without citric acid pre-treatment) did not reduce weight loss of eggplant fruits significantly as compared to the control fruits during storage. This may be due to the fact that starch coatings are not good barriers against water vapour due to their hydrophilic characteristics (Baldwin, 2003). However, pre-treatment with citric acid before starch coating helped to minimize weight loss, even though citric acid has a dehydrating effect on fruits. As reported by Chiumarelli et al. (2010), it is possible that the cassava starch coating hindered the dehydrating effect caused by citric acid, resulting in the lower weight losses observed in fruits dipped in citric acid before starch coating. The citric acid exhibited a similar combined effect with starch coating after the transfer of the fruits to room temperature for shelf life studies. Additionally, the higher weight losses observed for fruits in shelf life compared to those kept at low temperature may be due to the higher temperature in shelf life. This observation is in agreement with the report of Freitas and Mitcham (2013) on the effect of storage temperature on pitaya fruits. Low temperature reduces respiration and metabolic processes which slows down the rate at which fruits lose weight during storage (Wills et al., 1989). Guelfat-Reich (1970) also reported that low temperature storage caused the least weight loss of loquat fruits.

Aloe vera coating (with or without citric acid pre-treatment) improved weight retention in the eggplant fruits compared to the control fruits throughout the storage period. It is possible that Aloe vera coating formed a protective barrier around the fruits, blocking the stomata and guard cells, retarding respiration, transpiration and some active metabolic processes in the eggplant fruits. Similar reduction in weight loss due to Aloe vera coating was reported for papaya fruits (Brishti et al., 2013). Aloe vera coatings have been reported to prevent moisture loss in fruits and vegetables (Brishti et al., 2013; Ergun & Satici, 2012; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004). Misir et al., (2014) reported that Aloe vera increased the barrier properties of the coating and thereby, restricting water transfer.

Overall, the control fruits exhibited higher weight losses as compared to the coated fruits. Among the coating treatments the starch coated fruits showed the highest weight loss while the beeswax coated fruits recorded the least weight loss. The differences in weight loss between the different coating treatments could be attributed to their hydrophilic properties.

Effect of coating on firmness of eggplant fruits during storage

The firmness of the eggplant fruits generally decreased throughout the storage period irrespective of the coating treatment. This is consistent with the reports by Singh et al. (2016) and Moretti and Pineli (2005), who observed decreases in the firmness of eggplant fruits during storage. Softening of fruits has been found to generally increase with the progression of ripening due to the depolymerization of pectin substances (Yaman & Bayoındırlı, 2002). Bai et al. (2002) also reported that water loss and or weight loss can cause shrinkage, softening of the flesh, ripening, senescence through ethylene production, and other metabolic changes. According to Mohebbi et al. (2014) edible coatings can inhibit the degradation of pectin caused by pectin enzymes. The firmness of eggplant fruits obtained in this study were higher than the 3.57-8.56 N reported by Singh et al. (2016) for eggplant coated with carnauba wax, but lower than the 40-130 N reported for $CaCl_2$ and 1-MCP-treated eggplant fruits stored for a period of 10 days at 12 °C (Moretti & Pineli, 2005). They were however close to 29.0-40.42 N reported for fertilizer treated-eggplant fruits (Alves Dias et al., 2016). The variations in firmness values could be due to varietal differences.

The fruits coated with beeswax showed higher firmness compared to the control fruits. The barrier created by the beeswax coating may have inhibited pectin-degrading enzymes, like polygalacturonases, by reducing the rate of metabolic processes that induce these enzymes during senescence (Ball, 1997). Furthermore, fruits coated with beeswax might have developed resistance against compositional changes in cell wall and moisture loss, thereby resulting in higher firmness (Ullah et al., 2017). Lower firmness values of the control fruits compared to fruits coated with beeswax could also be due to the relatively higher weight losses observed in the control fruits. Water loss leading to weight loss during storage may sometimes result in wilting and firmness loss (Bora & Narain, 1997). Shahid and Abbasi (2011b) reported that 5 % beeswax coatings preserved the firmness of sweet oranges compared to uncoated fruits.

Generally, starch coating did not reduce the loss in firmness of eggplant fruits during storage. This may be due to the fact that starch coating promoted water loss from the fruits due to their hydrophilic characteristics, resulting in weight loss, wilting and loss of firmness. The transfer from low temperature storage to shelf life caused significant reduction in the firmness of the fruits. This could be due to the high temperature in shelf life. Increasing temperature has been reported to decrease the firmness of fruits and vegetables (Lownds et al., 1994; Miccolis & Saltveit, 1995). The lower firmness observed in shelf life could also be due to the increased weight loss (due to water loss) at the higher temperature of storage. Weight loss could result in a decrease in turgidity which could subsequently cause fruit softening.

Aloe vera coating was effective in maintaining eggplant fruit firmness compared to the control. Similarly, Aloe vera coating has been shown to delay firmness loss in table grapes (Valverde et al., 2005), strawberry (Vahdat et al., 2009), 'Arctic Snow' nectarine (Ahmed et al., 2009) and bell peppers (Ullah et al., 2017). This may be due to the effect of Aloe vera on the reduction of α-galactosidase, polygalacturonase, and pectin methyl-esterase activities (Valverde et al., 2005). Alberio et al. (2015) reported that treatment of table grapes with Aloe vera significantly reduced activity of β-galactosidase. Fruits coated with Aloe vera alone had higher firmness retention than those dipped in citric acid before Aloe vera coating. The acidic condition, created by the citric acid may have increased fruit softening during ripening due to hydrolysis of pectin (Verma, 2017). It is also possible that the citric acid increased the hydrophilic properties of the Aloe vera. Generally, fruits coated with Aloe vera recorded relatively higher firmness in shelf life compared to the control fruits.

Effect of coating on colour of eggplant fruits during storage

The eggplant variety used in the current work has a whitish-cream colour at harvest, however, the colour changes to yellowish-red as storage time progresses. This was indicated in the increasing a* and b* values as well as the decreasing L* values observed in the starch and Aloe vera coated fruits. The increasing trend observed in the a* and b*values could be as a result of the breakdown of chlorophyll which results in degreening of plant organs during ripening and senescence (Gong & Mattheis, 2003).

The beeswax coating slightly increased the lightness (L* value) of eggplant fruits while maintaining the redness (a* value) and yellowness (b* value) of the fruits. The higher L* values observed for beeswax coated fruits may be due to the ability of the coating to delay the breakdown of chlorophyll and synthesis of carotenoids (Ullah et al., 2017). Similarly, Mladenoska (2012) observed that beeswax coating containing coconut oil improved the appearance of strawberry fruits. The barrier formed by the wax may hinder oxygen and carbon dioxide diffusion, thus reducing respiration rate (Banks, 1984; Waks et al., 1985), which could delay ripening and colour changes.

The cassava starch coatings (with or without citric acid pre-treatment) were not effective in delaying colour changes throughout storage at 10 °C. Garcia et al. (1998) however, reported that 3 % cassava starch coatings slowed the ripening rate and facilitated the maintenance of colour in strawberry fruits during the first eight days of storage at 0 °C. Castricini et al. (2012) also reported that papaya fruits coated with 3 and 5 % of cassava starch maintained the green colour of the fruits for a longer period. In this study, it is possible that the starch coating was not effective in regulating gas exchange between the eggplant fruit and the environment. This may have increased respiration and ripening of the fruits. The transfer of fruits from low temperature storage to shelf life resulted in rapid colour changes compared to fruits stored under low temperature storage for 17 days. This rapid change in colour could be attributed to the increase in temperature upon transfer of the fruits. Nunes and Emond (2003) reported that temperature has a direct effect on colour changes in fruits during storage. With increasing temperature, respiration and other processes which lead to fruit senescence are increased leading to faster deterioration of fruits. In shelf life however, the fruits dipped in citric acid before starch coating delayed colour changes from green to red as compared to the control fruits and fruits coated with cassava starch alone.

Aloe vera coating (with or without citric acid pre-treatment) delayed the colour changes in eggplant fruits during storage at 10 °C. This observation could be attributed to the modified atmosphere created by the Aloe vera coating which possibly reduced ripening caused by high respiration rate, by slowing down the rate of interchange of carbon dioxide and oxygen between the environment and coated fruits (Chrysargyris et al., 2016; Valverde et al., 2005). Several reports have shown that Aloe vera delayed respiration (Ahmed et al., 2009; Martínez-Romero et al., 2006; Tripathi & Dubey, 2004), colour changes (Brishti et al., 2013; Cantos et al., 2002; Carrillo-lopez et al., 2000; Ergun & Satici, 2012; Tripathi & Dubey, 2004) and improved the overall appearance of fruits (Tripathi & Dubey, 2004). When Aloe vera-coating was applied on mature unripe tomato fruits, ripening was delayed by 4 days (Ankita et al., 2016). Also, Aloe vera coating significantly suppressed the green colour loss of 'Granny Smith' apples (Ergun & Satici, 2012).

Effect of coating on the total phenolic content of eggplant fruits during storage

The total phenolic content of the fruits generally decreased in the first few days of storage irrespective of the coating treatment. A similar decrease in total phenolic content in the initial stages of storage of eggplant fruits treated with 24-epibrassinolide has been reported (Gao et al., 2015). Galani et al. (2017)

also reported that the total phenolic content in dill and amaranth decreased during low temperature storage at 4 °C. This decrease could be due to the possible degradation of polyphenol compounds by polyphenol oxidases and peroxidases during storage.

Large variations in total phenolic content have been cited among different varieties and cultivars of eggplant fruits. Tripathi et al. (2014) reported total phenol content of 793.3 - 1,034.2 mg/kg for the round eggplant variety and 843.2 - 951.8 mg/kg for the long variety. Relatively lower values of 509.8 - 914.2 mg/kg and 328.9 - 391.2 mg/kg were reported by Boubekri et al. (2015) and Kandoliya et al. (2015) respectively. Gao et al. (2015) also reported values ranging from 250 - 300 mg/kg fresh weight. The total phenolic content of the fruits ranged from 131.57 - 517.94 mg/kg. In this work, the total phenolic content recorded for the beeswax coated fruits were significantly lower than the starch and Aloe vera coated fruits. The beeswax coating might have created a modified atmosphere (low oxygen and high carbon dioxide levels) around the fruits, leading to anaerobic respiration and possible degradation of phenolic compounds (Schink et al., 2000) and or decreased synthesis of some secondary plant metabolites like phenolic compounds. Moussaid et al. (2004) reported that waxing reduced the total phenolic content of oranges.

The total phenolic content of starch coated fruits fluctuated along the storage period. Fluctuations of total phenolic content of fresh fruits and vegetables during storage has been reported (Kevers et al., 2007). Fruits coated with starch alone recorded the highest total phenolic content on day 4 and at the end of the storage period. Accumulation of phenolic compounds in fresh fruits can occur with the application of edible coatings (Frusciante et al., 2007) due to the fact that edible coatings may cause respiratory stress and consequently, increase ethylene production with subsequent phenolic compounds biosynthesis. The decrease in the total phenolic content of the fruits in shelf life is probably due to the degradation of polyphenolic compounds due to the rise in temperature. Higher total phenolic content observed at low temperature storage could be due to low polyphenol oxidase activity leading to reduced oxidation of phenolic substrates to quinones (Cantos et al., 2002; Lattanzio et al., 2008).

There were also fluctuations in the total phenolic content of Aloe vera coated fruits experienced fluctuations during storage at 10 °C. The increase in total phenolic content observed following the general decrease in the first 14 days may be due to enzymatic hydrolysis or biodegradation of previously unextractable bound phenolic compounds. Total phenolic content of fruits were generally higher in shelf life than the fruits that remained at 10 °C. This is contrary to the observation made in the starch coated fruits. However, warmer temperatures have been observed to increase the total phenolic content of cranberry fruits (Khoo & Falk, 2014). Total phenolic content can be influenced by many factors like genotype, harvest time and growing location (Madiwale et al., 2011; Rumbaoa et al., 2009).

Effect of coating on the ascorbic acid levels of eggplant fruits during storage

Ascorbic acid is a plant metabolite with strong antioxidant activity and is involved in numerous biochemical reactions including neutralizing the effects of reactive oxygen species (Barry & Giovannoni, 2007). Generally, the ascorbic acid content obtained in the current work were significantly higher compared with previous reports. Prohens et al. (2007) observed low levels of ascorbic acid

(10.0-22.6 mg/kg) among 69 eggplant varieties and hybrids. Ascorbic acid levels from 94.3-167.5 mg/kg were also reported by Kandoliya et al. (2015) for eggplant fruits.

Beeswax coating of eggplant fruits increased ascorbic acid loss during storage. Wang (1977) determined that high levels of carbon dioxide (resulting from lipid-based coatings) inhibited ascorbic acid synthesis in peppers stored at 13° C. Shiri et al. (2011) also reported a decreasing pattern for ascorbic acid levels in fruits coated with beeswax. The uncoated eggplants fruits had higher ascorbic acid levels than coated fruits. Similarly, Ball (1997) reported that uncoated bell peppers had higher ascorbic acid content than lipid-coated fruits. The increasing trend observed in the control fruits may be due to the synthesis of ascorbic acid during storage, since the natural atmosphere of control fruits were not modified with coating. Ascorbic acid synthesis has been reported in some fruits and vegetables during postharvest storage (Silva et al., 2013: Esteban et al., 1992).

The increasing ascorbic acid levels for starch coated fruits within the first 6 days of storage is consistent with the work done by Esteban et al. (1992) on eggplant fruits during storage. Additionally, Silva et al. (2013) reported a significant increase in ascorbic acid levels during storage of gabiroba fruits. Thomas et al. (2016) also observed an increase in ascorbic acid levels of strawberry fruits coated with propolis-incorporated cassava starch coating during storage. In this work, the effect of the coating (with or without citric acid pre-treatment) on ascorbic acid levels was not clear due to the fluctuations that occurred during the storage period. Relatively higher levels of ascorbic acid were observed for fruits that remained at low temperature compared to the fruits that were transferred to room temperature. This observation is similar to the results obtained by Lee & Kader (2000). Nunes et al. (1998) reported that low ascorbic acid levels of fruits observed in shelf life could be attributed it to the combined effect of temperature and water loss. Similarly, a decrease in ascorbic acid levels was observed in broccoli florets when transferred from low to room temperature storage for 24 h (Paradis et al., 1996).

The fruits coated with Aloe vera exhibited a general increase in the ascorbic acid levels in the first 14 days of storage, and this may be due to ascorbic acid synthesis in the eggplant fruits. However, the ascorbic acid levels decreased on days 15 and 16. The observed decrease towards the end of the storage period could be due to the fact that the synthesized ascorbic acid was used as an antioxidant compound in response to oxidative stress caused by the low-temperature storage (Galani et al., 2017) or the coating application.

Effect of coating on the total antioxidant capacity of eggplant fruits during storage

Phenolic compounds and ascorbic acid have been reported to contribute to the total antioxidant capacity of fruits (Kandoliya et al., 2015). Generally, the total antioxidant capacity of the fruits was not negatively affected during storage, irrespective of the coating treatment. This agrees with previous reports that showed that total antioxidant capacity of fruits was steady or increased during storage (Castricini et al., 2012; Gao et al., 2015; Kevers et al., 2007). Kevers et al. (2007) reported increases in the antioxidant capacity of some selected fruits and vegetables in the days following purchase. Decreases in total antioxidant capacity has, however, been observed during storage of some selected fruits and vegetables (Galani et al., 2017).

Significantly lower total antioxidant capacity was recorded for beeswax coated fruits compared to starch and Aloe vera coated fruits. The lower total antioxidant capacity recorded for fruits coated with beeswax may be due to the relatively lower total phenolic content and significantly lower ascorbic acid levels observed. On the other hand, the relatively high ascorbic acid levels observed in the starch and Aloe vera coated fruits during storage may be responsible for the high total antioxidant capacity recorded.

Optimization of process conditions for the preparation of edible coatings for application on eggplant fruits using Response Surface Methodology

Fitting of the models

Model fitting helps to select the highest order polynomial where the additional terms of the model are significant, and the model is not aliased (Design-Expert® 11 Software, Stat-Ease Inc, MN, USA). The lack of fit test measures a variation of data around the fitted model. A significant lack of fit is undesired because it implies that the model did not fit the data. Additionally, a good model should have high R-squared value and an adequate precision greater than 4. The adequate precision measures the signal to noise ratio. A ratio higher than 4 indicates an adequate signal and therefore a good model.

Generally, all the model possessed p value less than 0.05 (i.e. significant) and the lack of fit test showed p values greater than 0.05 (i.e. not significant), which implies that the models were good and adequate to navigate the design space. All the models (irrespective of the type of coating) had higher adequate precisions (greater that 4), also indicating they were good models. The predicted and adjusted R-squared for all models were in a reasonable agreement having a difference of less than 0.2, except the predicted and adjusted R-squared values of the L* value and total antioxidant capacity models for the beeswax and Aloe vera coating, respectively.

Effect of process conditions on weight loss of eggplant fruits coated with beeswax, starch and Aloe vera.

The high negative regression coefficient observed for beeswax coating concentration implies that higher beeswax concentration has the tendency to decrease weight loss of eggplant fruits.

Contrary to the observation made in the beeswax coating regarding weight loss, high starch coating concentration promoted higher weight loss in the eggplant fruits. Additionally, high citric acid concentration minimized weight loss of fruits coated with starch. The interaction effect of citric acid and coating concentration minimized weight loss significantly. Hence, the hydrophilic effect of starch coating can be minimized by the addition of citric acid, while the dehydrating effect of citric acid can be inhibited by combining it with starch coating.

High Aloe vera concentration decreased the weight loss of eggplant fruits but citric acid concentration at high levels promoted higher weight losses. When coating duration increased, the dehydrating effect of the citric acid was minimized, thereby reducing weight loss. The high R-squared values of 0.92, 0.96 and 0.97 observed for the beeswax, starch and Aloe vera weight loss models, respectively, implies that the models could explain 92, 96 and 97 % of all variance in the weight loss data.

Effect of process conditions on the firmness of eggplant fruits coated with beeswax, starch and Aloe vera.

The application of high beeswax coating concentration can help improve the firmness of the eggplant fruits. The retention of weight with increasing coating concentration may have decreased turgor loss in the fruits, increasing the firmness. When fruits were dipped in the beeswax coating for a longer period, a similar increasing effect on firmness was observed. However, the interaction effect between beeswax coating concentration and citric acid concentration caused a decrease in firmness. The increase in weight loss observed for the interaction between beeswax coating concentration and citric acid concentration may be responsible for the loss of firmness.

High starch coating concentration increased the firmness of eggplant fruits. This observation was unexpected since higher starch coating concentrations increased weight loss of the eggplant fruits. Once weight loss increases, it is generally expected that fruits will shrink and soften (Bai et al., 2002). Therefore, the retention of firmness with high starch coating concentration could be attributed to the thickness of the coating rather than retention of fruit weight.

The firmness of eggplant fruits increased when Aloe vera concentration increased. According to Valverde et al. (2005), high Aloe vera concentration can inhibit pectic enzymes involved in the softening of tissues of fruits. Also, high concentrations may have delayed ripening, which is another contributing factor for retention of firmness. The use of high citric acid concentration, however resulted in a decrease in firmness. This may be due to the fact that increasing citric acid concentration increased the weight loss of the fruits coated with Aloe vera, which resulted in shriveling and loss of firmness. The beeswax, starch and Aloe vera firmness models had high R-squared values of 0.95, 0.97 and 0.95, respectively, showing that the models could explain 95 to 97 % of all variances in the firmness data.

Effect of process conditions on the colour (L*a*b*) in eggplant fruits coated with beeswax, starch and Aloe vera.

Waxing of fruits and vegetables have been found to delay respiration, ripening and colour changes (Shahid & Abbasi, 2011a). In this work, beeswax coating was found to slightly increase L* values of eggplant fruits during storage at 10 °C for 17 d. However, in the optimization experiment, it was observed that high beeswax coating concentration decreased the L* values of the eggplant fruits. It is possible that high concentration of beeswax can promote anaerobic condition due to the modification of the internal gas composition of the fruit by the beeswax coating. Anaerobic conditions can promote physiological disorders and accelerate quality loss (de Azeredo, 2012; Kester & Fennema, 1986). The ripening due to anaerobic respiration may have caused the decrease in the L* values as well as the increase in the a* values and b* values of the fruits when coating concentration was increased. Additionally, the interaction between coating concentration and citric acid concentration accelerated colour changes in the fruits. This implies that higher beeswax coating and citric acid concentration may lead to undesirable colour changes in eggplant fruits.

High starch coating concentration can lead to a decrease in the L* value of eggplant fruits due to possible increase in respiration and transpiration which can accelerate ripening. Hence, the application of starch coating can lead to decreased L* value and increased a* and b* values. Although, starch coating concentration and citric acid concentration had a negative effect on colour of the eggplant fruits, their interaction caused an increase in the L* value and a decrease in the a* and b* values. This may be as a result of a synergistic effect produced by the interaction between starch coating and citric acid, to reduce, respiration and ripening in the eggplant fruits. R-squared values of 0.99, 1.00 and 0.98 obtained for the L*a*b* models implied the models were deemed adequate to explain 99, 100 and 98 % of all variances in the L*a*b* response data for starch coating, respectively.

Aloe vera coating was effective in preserving the colour of eggplant fruits. At high Aloe vera coating concentration, the L* values increased while the a* values and b* values decreased. This could be attributed to the fact that high concentrations of Aloe vera decreased the rate of respiration and delayed ripening of the fruits. Morillon et al. (2002) reported a reduction in the rate of respiration when Aloe vera was applied on the arils of pomegranate. High citric acid concentration also helped to improve L* value and reduce the b value in the eggplant fruits. The L*a*b* models of the Aloe vera coating also had high R-squared values of 0.95, 0.99 and 0.95, respectively.

Effect of process conditions on total phenolic content, ascorbic acid and total antioxidant capacity of eggplant fruits coated with beeswax, starch and Aloe vera.

Generally, higher coating concentration (irrespective of the coating treatment) decreased the total phenolic content of eggplant fruits. Higher coating concentration may have resulted in thicker coating which may have hindered the fruit's exposure to oxygen leading to anaerobic conditions and causing possible degradation of phenolic compounds (Schink et al., 2000). The significant increase in total phenolic content observed with the interaction between citric acid concentration and coating duration may be due to the citric acid inhibiting the anaerobic degradation of the phenolic compounds.

Lower ascorbic acid levels were observed during storage of fruits coated with beeswax at 10 °C. It was however observed that, increasing the beeswax coating concentration tends to increase the ascorbic acid levels. Higher coating concentration might have produced a thicker coating, reducing oxygen exposure around the fruits. Although, low oxygen does not favour ascorbic acid synthesis, it possibly inhibited oxidation of ascorbic acid already present in the fruits. Similarly, Pardede (2009) observed good preservation of ascorbic acid in strawberries at higher beeswax concentration. Ascorbic acid levels increased when starch coating concentration increased. However, when Aloe vera coating concentration increased, ascorbic acid levels decreased. This observation could be due to differences in the characteristics of the coating.

Higher beeswax coating concentration could increase the total antioxidant capacity of eggplant fruits. This may be attributed to the high ascorbic acid content observed at higher beeswax coating concentration. The interaction between the citric acid concentration and coating duration also resulted in an increase in total antioxidant capacity of the fruits as well as the total phenolic content. This confirms the report that phenolic compounds and ascorbic acid are responsible for the total antioxidant capacity of fruits (Kandoliya et al., 2015).

Optimization of process conditions using desirability function

Generally, the models for the beeswax, cassava starch and Aloe vera were good and could predict the weight loss, firmness and colour changes in the eggplant fruits, since the experimental values were in close agreement with the predicted values. Similarly, RSM was used to adequately predict the weight loss, firmness and respiration rate of gellan and alginate-based minimally processed pineapples (Azarakhsh et al., 2012). The predictions for the total phenolic content, ascorbic acid level and total antioxidant capacity were generally not very close to the experimental values compared to the predictions for the weight loss, firmness and colour. This observation could be due to some specific preharvest factors such as, time of harvest, fertilizer application, mode of harvesting which may account for the differences in biochemical properties of the fruits. The cassava starch coating recorded the highest weight loss while beeswax coating recorded the least. The reduction of weight in fruits coated with beeswax helped with the retention of firmness in the fruits. Beeswax coatings was most effective in delaying colour changes. Starch and Aloe vera coating comparatively preserved the total phenolic content and ascorbic acid levels which may have resulted in the relatively high total antioxidant capacity compared with fruits coated with beeswax. Similarly, Ball (1997) observed that lipid-coated green bell pepper recorded significantly lower ascorbic acid levels than uncoated samples.

Comparing the optimized coatings to the control, beeswax significantly reduced weight loss, while starch coating did not prevent weight loss. Generally, the coatings (irrespective of the type) preserved firmness and delayed colour changes in the eggplant fruits compared to the control. Ascorbic acid levels and total antioxidant capacity were generally lower in coated fruits compared to the control fruits, but total phenolic content of control fruits did not differ from the control fruits.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This study sought to investigate the effect of some inexpensive and locally available materials as potential edible coating materials to help improve the postharvest quality and storage life of eggplant fruits. Another aim of this work was to investigate whether the selected edible coatings could be applied to eggplant fruits without the use of citric acid as an antioxidant and/or antimicrobial agent. Coated and uncoated (control) fruits were stored at 10 °C for 17 d for beeswax and starch coating and 18 d for Aloe vera coating. After 14 d of storage at 10 °C, some fruits from the starch and Aloe vera batch were transferred to room temperature for shelf life studies. Response Surface Methodology Box Behnken Design was further used to study the effect of the coating concentration (beeswax, starch and Aloe vera), citric acid concentration and coating duration on the physicochemical properties of eggplant fruits and also to optimized the coating conditions that can help improve the storage quality of eggplant fruits.

Summary of key findings

Beeswax coating was the most effective in reducing weight loss of eggplant fruits while starch coating was the least effective. Aloe vera coating also minimized weight loss of eggplant fruits during storage at 10 °C and in shelf life. Generally, the rate of weight loss in shelf life was higher than at 10 °C, due to the high temperature in shelf life.

Firmness loss during storage was expected due to the increasing weight loss along the storage period. Generally, the coatings studied reduced the loss of firmness in eggplant fruits, except the starch coating. Beeswax coating was the most effective in reducing firmness loss.

Colour (L*a*b*) changes in eggplant fruits during storage at 10 °C were significantly delayed by beeswax coating, followed by Aloe vera coating and then the starch coating. In all cases, however, the coatings delayed colour changes. The high temperature in shelf life further promoted colour changes in the fruits.

The total phenolic content of the eggplant fruits was least preserved with beeswax coating. Beeswax coating also promoted ascorbic acid losses while starch and Aloe vera coatings enhanced ascorbic acid levels of the eggplant fruits during storage. The total antioxidant capacity of the fruits was generally not affected during storage at 10 °C, irrespective of the coating treatment. Generally, low total antioxidant capacity was observed for fruits coated with beeswax compared to fruits coated with starch and Aloe vera. Higher temperature in shelf life generally caused a decrease in the ascorbic acid levels of the fruits (irrespective of the coating treatment).

The pre-treatment of eggplant fruits with citric acid solution before starch coating contributed to a reduction in weight loss during storage at 10 °C and in shelf life. Also, citric acid pre-treatment improved firmness retention in beeswax coated fruits.

RSM BBD was successfully used to optimize the coating conditions for the storage of eggplant fruits. The optimized coating conditions were; 4.6 % (w/v) coating concentration, 1% (w/v) citric acid concentration and 3 min coating duration for beeswax coating; 4.99 % (w/v) coating concentration, 2.98 % (w/v) citric acid concentration and 10 min coating duration for starch coating;

and 96.92 % (v/v) coating concentration, 1.07 % (w/v) citric acid concentration and 10 min coating duration for Aloe vera coating. The validation experiment showed a good correlation between the predicted and the experimental values with an R-squared value of 0.87.

Conclusions

The coatings studied showed varying effects on the post-harvest quality of eggplant fruits. The effect of beeswax coating was mostly on reducing weight loss, maintaining firmness and delaying colour changes during storage at 10 °C. Generally, beeswax coating did not improve the biochemical quality of the fruits. Aloe vera coating minimized weight loss, reduced firmness loss and delayed colour changes during low temperature storage and in shelf life. Starch coating did not prevent weight loss, colour changes and firmness loss of the fruits compared to beeswax and Aloe vera coating. Citric acid pre-treatment before starch coating minimized weight loss in eggplant fruits during storage at 10 °C and in shelf life. Response surface methodology was effectively used to optimize beeswax, cassava starch and Aloe vera coating conditions and could be an effective tool in predicting the physicochemical changes in eggplant fruits during storage.

Recommendations

To further enhance the quality of eggplant fruits,

1. The effect of incorporating plasticizers in starch coatings should be studied.
2. Future research can focus on the use of composite coatings containing both hydrophobic and hydrophilic materials in order

to provide a synergistic effect obtained from the unique functional characteristics of the individual polymers.

3. A sensory study should be conducted to determine if the coatings have any significant effect on the sensory attributes such as taste, flavour, texture and visual appearance.
4. Future work should also consider measurement of internal gas composition and measurement of respiration rate in coated eggplant fruits during storage.
5. The beeswax, cassava starch and the Aloe vera coatings can be characterized to understand their coating properties better.

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APPENDICES

Appendix 1: ANOVA table for reduced quadratic weight loss model of beeswax coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	874.45	6	145.74	20.02	< 0.0001*
X_1	614.25	1	614.25	84.36	< 0.0001*
X_2	6.66	1	6.66	0.91	0.3614 NS
X_3	45.13	1	45.13	6.20	0.0320*
X_1X_2	82.81	1	82.81	11.37	0.0071*
X_1^2	70.79	1	70.79	9.72	0.0109*
X_3^2	47.94	1	47.94	6.58	0.0281*
Residual	72.81	10	7.28		
Lack of Fit	49.22	6	8.20	1.39	0.3909 NS
Pure Error	23.59	4	5.90		
Cor Total	947.26	16			

*Significant NSNot significant

Appendix 2: Two factor interaction (2FI) ANOVA for weight loss model of starch coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3758.93	6	626.49	43.49	<0.0001*
X_1	754.53	1	754.53	52.38	<0.0001*
X_2	850.95	1	850.95	59.07	<0.0001*
X_3	513.55	1	513.55	35.65	0.0001*
X_1X_2	424.28	1	424.28	29.45	0.0003*
X_1X_3	801.99	1	801.99	55.67	<0.0001*
X_2X_3	413.63	1	413.63	28.71	0.0003*
Residual	144.06	10	14.41		
Lack of Fit	86.16	6	14.36	0.99	0.5282NS
Pure Error	57.91	4	14.48		
Cor Total	3902.99	16			

*Significant NSNot significant

Appendix 3: Reduced quadratic model ANOVA for weight loss of Aloe vera coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	4080.07	6	680.01	49.11	< 0.0001*
X_1	234.29	1	234.29	16.92	0.0021*
X_2	120.37	1	120.37	8.69	0.0146*
X_3	106.83	1	106.83	7.72	0.0195*
X_2X_3	355.51	1	355.51	25.67	0.0005*
X_1^2	2470.90	1	2470.9	178.45	< 0.0001*
X_2^2	952.58	1	952.58	68.79	< 0.0001*
Residual	138.46	10	13.85		
Lack of Fit	40.55	6	6.76	0.28	0.9216 NS
Pure Error	97.91	4	24.48		
Cor Total	4218.54	16			

*Significant   NS Not significant

Appendix 4: ANOVA for reduced quadratic firmness model of beeswax coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	11.26	7	1.61	24.42	< 0.0001*
X_1	0.13	1	0.13	2.01	0.1896 NS
X_2	0.18	1	0.18	2.78	0.1299 NS
X_3	0.43	1	0.43	6.57	0.0306*
X_1X_2	0.17	1	0.17	2.37	0.1582 NS
X_1^2	0.69	1	0.69	10.45	0.0103*
X_2^2	5.86	1	5.86	88.90	< 0.0001*
X_3^2	2.91	1	2.91	44.22	< 0.0001*
Residual	0.59	9	0.07		
Lack of Fit	0.48	5	0.10	3.41	0.1288 NS
Pure Error	0.11	4	0.03		
Cor Total	11.85	16			

*Significant   NS Not significant

Appendix 5: ANOVA for 2FI firmness model of starch coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	62.27	6	10.38	61.67	< 0.0001*
X_1	36.63	1	36.63	217.69	< 0.0001*
X_2	3.68	1	3.68	21.87	0.0009*
X_3	3.12	1	3.12	18.53	0.0015*
X_1X_2	3.67	1	3.67	21.83	0.0009*
X_1X_3	2.07	1	2.07	12.31	0.0056*
X_2X_3	13.09	1	13.09	77.78	< 0.0001*
Residual	1.68	10	0.17		
Lack of Fit	1.45	6	0.24	4.12	0.0959 NS
Pure Error	0.23	4	0.06		
Cor Total	63.95	16			

*Significant NSNot significant

Appendix 6: ANOVA for 2FI firmness model of Aloe vera coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	23.52	6	3.92	30.54	< 0.0001*
X_1	14.80	1	14.80	115.31	< 0.0001*
X_2	0.001	1	0.001	0.01	0.9212 NS
X_3	0.61	1	0.61	4.72	0.0548 NS
X_1X_2	2.61	1	2.61	20.31	0.0011*
X_1X_3	4.79	1	4.79	37.35	0.0001*
X_2X_3	0.71	1	0.71	5.51	0.0408*
Residual	1.28	10	0.13		
Lack of Fit	0.78	6	0.13	1.02	0.5146 NS
Pure Error	0.51	4	0.13		
Cor Total	24.81	16			

*Significant NS Not significant

Appendix 7: ANOVA for reduced quadratic L value model of beeswax coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	16.57	5	3.31	10.22	0.0008*
X_1	3.24	1	3.24	9.99	0.0091*
X_2	6.00	1	6.00	18.51	0.0012*
X_3	0.07	1	0.07	0.22	0.6462 NS
X_1^2	2.93	1	2.93	9.02	0.0120*
X_3^2	3.93	1	3.93	12.12	0.0051*
Residual	3.57	11	0.32		
Lack of Fit	3.23	7	0.46	5.46	0.0601 NS
Pure Error	0.33	4	0.08		
Cor Total	20.14	16			

*Significant NSNot significant

Appendix 8: ANOVA for L value quadratic model for starch coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	23.23	9	2.58	58.19	< 0.0001*
X_1	0.75	1	0.75	16.81	0.0046*
X_2	10.49	1	10.49	236.39	< 0.0001*
X_3	1.62	1	1.62	36.55	0.0005*
X_1X_2	0.09	1	0.09	2.05	0.1949 NS
X_1X_3	0.43	1	0.43	9.77	0.0167*
X_2X_3	1.76	1	1.76	39.68	0.0004*
X_1^2	5.57	1	5.57	125.58	< 0.0001*
X_2^2	2.50	1	2.50	56.26	0.0001*
X_3^2	0.35	1	0.35	7.79	0.0269*
Residual	0.31	7	0.04		
Lack of Fit	0.20	3	0.07	2.46	0.2021 NS
Pure Error	0.11	4	0.03		
Cor Total	23.54	16			

*Significant NSNot significant

Appendix 9: ANOVA for L value linear model for Aloe vera coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	13.87	3	4.62	77.27	< 0.0001*
X_1	7.81	1	7.81	130.47	< 0.0001*
X_2	3.78	1	3.78	63.09	< 0.0001*
X_3	2.29	1	2.29	38.25	< 0.0001*
Residual	0.78	13	0.06		
Lack of Fit	0.69	9	0.077	3.56	0.1169 NS
Pure Error	0.09	4	0.022		

*Significant NSNot significant

Appendix 10: ANOVA for a value reduced quadratic model for beeswax coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	11.88	7	1.7	43.72	< 0.0001*
X_1	0.02	1	0.02	0.44	0.5233 NS
X_2	0.001	1	0.001	0.03	0.8616 NS
X_3	0.08	1	0.08	2.11	0.1800 NS
X_1X_2	7.02	1	7.02	180.93	< 0.0001*
X_1^2	1.61	1	1.61	41.6	0.0001*
X_2^2	2.48	1	2.48	63.78	< 0.0001*
X_3^2	0.68	1	0.68	17.42	0.0024*
Residual	0.35	9	0.04		
Lack of Fit	0.29	5	0.06	3.56	0.1213 NS
Pure Error	0.06	4	0.02		
Cor Total	12.23	16			

*Significant NSNot significant

Appendix 11: ANOVA for a value quadratic model for starch coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	10.14	9	1.13	174.91	< 0.0001*
X_1	7.71	1	7.71	1197.97	< 0.0001*
X_2	0.09	1	0.09	13.41	0.0081*
X_3	0.57	1	0.579	89.19	< 0.0001*
X_1X_2	0.07	1	0.07	10.57	0.0140*
X_1X_3	0.01	1	0.01	1.76	0.2261 NS
X_2X_3	0.61	1	0.61	94.24	< 0.0001*
X_1^2	0.91	1	0.91	141.69	< 0.0001*
X_2^2	0.05	1	0.05	7.95	0.0258*
X_3^2	0.05	1	0.05	8.08	0.0250*
Residual	0.05	7	0.006		
Lack of Fit	0.04	3	0.014	13.82	0.0141*
Pure Error	0.004	4	0.0010		
Cor Total	10.18	16			

*Significant NS Not significant

Appendix 12: ANOVA for reduced quadratic model of a value for Aloe vera coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	10.63	7	1.52	120.48	< 0.0001*
X_1	1.59	1	1.59	126.56	< 0.0001*
X_2	0.58	1	0.58	45.67	< 0.0001*
X_3	1.83	1	1.83	145.56	< 0.0001*
X_1X_2	0.76	1	0.76	60.24	< 0.0001*
X_1X_3	1.47	1	1.47	116.44	< 0.0001*
X_2X_3	2.55	1	2.55	202.37	< 0.0001*
X_1^2	1.85	1	1.85	146.53	< 0.0001*
Residual	0.11	9	0.01		
Lack of Fit	0.11	5	0.02	22.91	0.0048*
Pure Error	0.004	4	0.001		
Cor Total	10.74	16			

*Significant NS Not significant

Appendix 13: ANOVA for reduced quadratic model of b value for beeswax coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	135.98	8	17	55.21	< 0.0001*
X_1	0.62	1	0.62	2.00	0.1949 NS
X_2	18.06	1	18.06	58.67	< 0.0001*
X_3	6.44	1	6.44	20.93	0.0018*
X_1X_2	53.8	1	53.8	174.77	< 0.0001*
X_1X_3	3.37	1	3.37	10.94	0.0107*
X_2X_3	2.91	1	2.91	9.44	0.0153*
X_1^2	10.58	1	10.58	34.37	0.0004*
X_2^2	37.82	1	37.82	122.86	< 0.0001*
Residual	2.46	8	0.31		
Lack of Fit	2.04	4	0.51	4.80	0.079 NS
Pure Error	0.42	4	0.10		
Cor Total	138.44	16			

*Significant NS Not significant

Appendix 14: ANOVA for b value quadratic model for starch coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	122.44	9	13.60	39.63	< 0.0001*
X_1	4.01	1	4.01	11.68	0.0112*
X_2	32.13	1	32.13	93.59	< 0.0001*
X_3	0.0003	1	0.0003	0.0009	0.9774 NS
X_1X_2	11.64	1	11.64	33.91	0.0006*
X_1X_2	3.41	1	3.41	9.92	0.0161*
X_2X_3	10.70	1	10.70	31.18	0.0008*
X_1^2	42.36	1	42.36	123.40	< 0.0001*
X_2^2	17.04	1	17.04	49.64	0.0002*
X_3^2	4.33	1	4.33	12.62	0.0093*
Residual	2.40	7	0.34		
Lack of Fit	1.09	3	0.36	1.10	0.4452 NS
Pure Error	1.31	4	0.33		
Cor Total	124.84	16			

*Significant NS Not significant

Appendix 15: Two factor interaction (2FI model) ANOVA for b value of Aloe vera coating*

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	83.53	6	13.92	33.22	< 0.0001*
X_1	7.72	1	7.72	18.42	0.0016*
X_2	0.05	1	0.05	0.12	0.7397 NS
X_3	30.47	1	30.47	72.72	< 0.0001*
X_1X_2	2.51	1	2.51	5.98	0.0345*
X_1X_3	22.19	1	22.19	52.96	< 0.0001*
X_2X_3	20.59	1	20.59	49.13	< 0.0001*
Residual	4.19	10	0.42		
Lack of Fit	3.51	6	0.58	3.43	0.1263 NS
Pure Error	0.68	4	0.17		
Cor Total	87.72	16			

*Significant NSNot significant

Appendix 16: ANOVA for reduced quadratic model of total phenolic content for beeswax coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2861.51	7	408.79	15.13	0.0005*
X_1	0.8567	1	0.8567	0.0317	0.8631 NS
X_2	300.41	1	300.41	11.12	0.0103*
X_3	15.89	1	15.89	0.5880	0.4652 NS
X_1X_3	569.06	1	569.06	21.06	0.0018*
X_2X_3	1714.59	1	1714.59	63.46	< 0.0001*
X_1^2	398.80	1	398.80	14.76	0.0049*
X_2^2	183.69	1	183.69	6.80	0.0313*
Residual	216.15	8	27.02		
Lack of Fit	185.74	4	46.44	6.11	0.0538 NS
Pure Error	30.41	4	7.60		
Cor Total	3077.66	15			

*Significant NSNot significant

Appendix 17: ANOVA for total phenolic content quadratic model for starch coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	19787.04	9	2198.56	12.14	0.0017*
X_1	29.83	1	29.83	0.16	0.6970 NS
X_2	0.02	1	0.02	0.0001	0.9918 NS
X_3	1516.97	1	1516.97	8.38	0.0232*
X_1X_2	3644.04	1	3644.04	20.13	0.0028*
X_1X_3	2091.39	1	2091.39	11.55	0.0115*
X_2X_3	809.70	1	809.70	4.47	0.0723 NS
X_1^2	9161.60	1	9161.60	50.60	0.0002*
X_2^2	2985.03	1	2985.03	16.49	0.0048*
X_3^2	108.71	1	108.71	0.60	0.4638 NS
Residual	1267.47	7	181.07		
Lack of Fit	252.21	3	84.07	0.33	0.8046 NS
Pure Error	1015.27	4	253.82		
Cor Total	21054.52	16			

*Significant NSNot significant

Appendix 18: ANOVA for response surface reduced quadratic model of total phenolic content of Aloe vera coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	6423.75	6	1070.62	10.37	0.0008*
X_1	167.31	1	167.31	1.62	0.2319 NS
X_2	1505.8	1	1505.8	14.58	0.0034*
X_3	1209.68	1	1209.68	11.71	0.0065*
X_2X_3	741.79	1	741.79	7.18	0.0231*
X_1^2	1549.87	1	1549.87	15.01	0.0031*
X_3^2	1404.6	1	1404.6	13.6	0.0042*
Residual	1032.75	10	103.28		
Lack of Fit	594.32	6	99.05	0.90	0.5667 NS
Pure Error	438.43	4	109.61		
Cor Total	7456.5	16			

*Significant NSNot significant

Appendix 19: ANOVA for response surface reduced quadratic model of the ascorbic acid levels of beeswax coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	6655.82	5	1331.16	14.42	0.0002*
X_1	814.46	1	814.46	8.82	0.0127*
X_2	435.86	1	435.86	4.72	0.0525 NS
X_3	456.47	1	456.47	4.94	0.0481*
X_2X_3	2957.73	1	2957.73	32.03	0.0001*
X_1^2	1991.30	1	1991.30	21.56	0.0007*
Residual	1015.79	11	92.34		
Lack of Fit	698.69	7	99.81	1.26	0.4352 NS
Pure Error	317.10	4	79.28		
Cor Total	7671.62	16			

*Significant NSNot significant

Appendix 20: ANOVA for response surface reduced quadratic model of the ascorbic acid levels of starch coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	12357.75	9	1373.08	25.68	0.0001*
X_1	603.47	1	603.47	11.28	0.0121*
X_2	32.64	1	32.64	0.6104	0.4602 NS
X_3	1192.95	1	1192.95	22.31	0.0021*
X_1X_2	32.34	1	32.34	0.6048	0.4622 NS
X_1X_3	572.65	1	572.65	10.71	0.0136*
X_2X_3	1399.92	1	1399.92	26.18	0.0014*
X_1^2	2063.58	1	2063.58	38.59	0.0004*
X_2^2	828.15	1	828.15	15.49	0.0056*
X_3^2	5869.16	1	5869.16	109.75	< 0.0001*
Residual	374.33	7	53.48		
Lack of Fit	168.87	3	56.29	1.10	0.4475 NS
Pure Error	205.46	4	51.37		
Cor Total	12732.08	16			

*Significant NSNot significant

Appendix 21: ANOVA for response surface reduced quadratic model of the ascorbic acid levels of Aloe vera coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	372.16	3	124.05	77.95	< 0.0001*
X_1	141.91	1	141.91	89.17	< 0.0001*
X_2	161.01	1	161.01	101.17	< 0.0001*
X_3	69.24	1	69.24	43.51	< 0.0001*
Residual	20.69	13	1.59		
Lack of Fit	13.17	9	1.46	0.78	0.6552 NS
Pure Error	7.52	4	1.88		
Cor Total	392.85	16			

*Significant NS Not significant

Appendix 22: ANOVA for response surface reduced quadratic model of the total antioxidant capacity of beeswax coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	880.97	6	146.83	20.90	< 0.0001*
X_1	3.64	1	3.64	0.5185	0.4880 NS
X_2	85.32	1	85.32	12.14	0.0059*
X_3	232.12	1	232.12	33.03	0.0002*
X_1X_3	144.06	1	144.06	20.50	0.0011*
X_2X_3	294.46	1	294.46	41.91	< 0.0001*
X_1^2	121.37	1	121.37	17.27	0.0020*
Residual	70.27	10	7.03		
Lack of Fit	59.51	6	9.92	3.69	0.1135 NS
Pure Error	10.75	4	2.69		
Cor Total	951.23	16			

*Significant NSNot significant

Appendix 23: ANOVA for total antioxidant capacity 2FI model for starch coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3378.02	6	563.00	6.38	0.0055*
X_1	667.24	1	667.24	7.56	0.0205*
X_2	117.96	1	117.96	1.34	0.2744 NS
X_3	693.33	1	693.33	7.86	0.0187*
X_1X_2	69.50	1	69.50	0.7880	0.3956 NS
X_1X_3	1443.68	1	1443.68	16.37	0.0023*
X_2X_3	386.31	1	386.31	4.38	0.0628 NS
Residual	882.07	10	88.21		
Lack of Fit	330.90	6	55.15	0.4002	0.8482 NS
Pure Error	551.17	4	137.79		
Cor Total	4260.09	16			

*Significant NS Not significant

Appendix 24: ANOVA for total antioxidant capacity reduced quadratic model for Aloe vera coating

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	730.34	3	243.45	7.77	0.0032*
X_1	18.69	1	18.69	0.5962	0.4539 NS
X_2	500.21	1	500.21	15.96	0.0015*
X_3	211.44	1	211.44	6.74	0.0221*
Residual	407.53	13	31.35		
Lack of Fit	360.94	9	40.1	3.44	0.123 NS
Pure Error	46.6	4	11.65		
Cor Total	1137.88	16			

*Significant NS Not significant