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EXTENDING THE SHELF-LIFE OF SLICED FRUITS BY DEVELOPING EDIBLE PACKAGING WITH APPLE POMACE EXTRACT

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1. INTRODUCTION

Preparation and cutting activities of fresh-cut fruits negatively impact their integrity. Despite being fresh and offering convenience to consumers, their shelf-life is much shorter than that of the whole fruit (Yousuf and Qadri, 2020). Fresh-cut products are comprised of fruits that are washed, peeled, sliced, and shredded (Francis *et al.*, 2012). The main sensory attributes affected in fresh-cut fruits include colour, flavour, and texture. Peeling, slicing, shredding, and chopping fruits induce stress and consequently result in increased respiration, resulting in biochemical deterioration characterized by browning, off-flavour, and loss of texture. Browning results from tissue injury induced in the fresh-cut product during processing, raising physiological activities causing enzymatic browning. Texture loss is mainly due to shrinkage. (Yousuf *et al.*, 2020).

Apple and pears are amongst the most utilised fruits in the production of fresh-cut products (Najafi Marghmaleki *et al.*, 2021). Apples (*Malus domestica*) and pears (*Pyrus communis*) are seasonal but cold storage makes it possible for all-year-round availability, fruits with cold-storage (refrigeration) tolerance are suitable for fresh-cut fruit processing. Apple and pears are subject to browning due to the activity of Polyphenol Oxidase on phenolic compounds present in the fruit which are released during cutting. Softening is also another negative quality attribute that affects fresh-cut apples and pears (Amiot *et al.*, 1995; Soliva-Fortuny and Martín-Belloso, 2020).

To extend the shelf-life of fresh-cut fruits, cold storage, and various packaging methods such as Modified Atmosphere Packaging and the use of edible coatings are utilised (Yousuf and Qadri, 2020). Edible coatings when applied as a thin layer, function well to prevent moisture loss and prevent oxidation of fresh-cut fruits from the time of production to consumption (Treviño-Garza *et al.*, 2017). Apples and pears have their shelf-life increased using edible coatings since the edible coatings can regulate transpiration, respiration, and physiological disorders. The edible coatings are carriers of bioactive compounds that bear antioxidant and antimicrobial properties consequently extending the shelf-life of fresh-cut apples and pears (Soliva-Fortuny and Martín-Belloso, 2020). Edible biopolymers comprising polysaccharides, for example, alginate, lipids, and proteins are used in making edible coatings and films (Salgado *et al.*, 2015). Alginate is an effective edible coating due to its ability to create strong gels when polyvalent metal ions such as calcium are available (Featherstone, 2015). Citric acid and ascorbic acid have proven to be

effective in preventing browning in fresh-cut fruits such as apples (Chiabrando and Giacalone, 2012).

Furthermore, by-products from the food industry such as seeds, peels, and pomace contain bioactive compounds, for example, plant-based cellulose starch and proteins, which may be utilised to produce edible coatings. Despite research data supporting the use of food industry by-products, few studies have been carried out using food industry by-products in the production of edible coatings (Perez-Vazquez *et al.*, 2023). Apple pomace is a by-product of apple processing, comprising apple seeds (2-4%) and apple peels (95%), calyx, and stem (1%). There is a lot of interest in the utilization of apple pomace in producing bioplastics, (Perussello *et al.*, 2017; Asma *et al.*, 2023). Apple pomace presents a challenge of disposal. Apple pomace has the potential to form harmful substances when it is poorly disposed of due to high amounts of moisture and nutrients. Additionally, the utilisation of apple pomace represents a hopeful and suitable approach for adding value to agroindustry residues (Zhang *et al.*, 2021).

When used in edible film manufacture, apple pomace extract demonstrated antimicrobial and antioxidant properties (Lan *et al.*, 2021). Apples and their by-products bear high phenolic compound content. Apple peels comprising 95% apple pomace have been found to contain higher amounts of phenolic compounds than other apple parts. These compounds contribute to high antioxidant and bioactive activities (Kruczek *et al.*, 2017; Raudone *et al.*, 2017; De La Rosa *et al.*, 2019; Cömert, Mogol and Gökmen, 2020).

In this study, an evaluation of the effectiveness of apple pomace extract in extending the shelf-life of sliced ‘Idared’ apples and ‘Conference’ pear varieties was done. Quality assessment of browning, colour parameters, weight loss, and texture was conducted during the storage period of five days at 4^0C±1, to investigate the effect of the different edible coating solutions utilized. The apple pomace extract was used in two different edible coating solutions: one containing citric acid, sodium alginate, and glycerol, and in the other ascorbic acid replacing citric acid. Additionally, the effect of the apple pomace extract was also compared to that of a control sample containing distilled water and three other edible coating solutions containing different combinations of citric acid, ascorbic acid, glycerol, and sodium alginate.

2. AIMS AND OBJECTIVES

This study aims to provide a new perspective on extending the shelf-life of sliced apple and pear fruits by utilising apple pomace extract obtained from apple pomace, an apple industry by-product, The general objective was contributing to food preservation advancement, minimisation of food waste, and provision of access to wholesome and nutritious sliced apple and pear fruits to consumers through the utilisation of apple pomace extract as an edible coating.

For the achievement of the main objective of extending the shelf-life of sliced apple ('Idared' variety) and Pear ('Conference' variety) by utilising apple pomace extract obtained from the 'Idared' apple variety, the specific objectives are as follows:

1. To evaluate the effect of five different edible coating solutions with varying concentrations of apple pomace extract, sodium alginate salt, citric acid, acetic acid, and glycerol on the texture of coated sliced apples and sliced pears.
2. To evaluate % weight loss of coated sliced apples and pears with an edible coating containing varying concentrations of apple pomace extract, sodium alginate salt, citric acid, acetic acid, and glycerol.
3. To determine the effect on the colour parameters (L*, a*, and b*) by five different edible coating solutions with varying concentrations of apple pomace extract, sodium alginate salt, citric acid, acetic acid, and glycerol on coated sliced apples and sliced pears.
4. To evaluate the effect of five different edible coating solutions with varying concentrations of apple pomace extract, sodium alginate salt, citric acid, acetic acid, and glycerol on the browning index of coated sliced apples and sliced pears.

3. LITERATURE REVIEW

3.1 Sliced Fruits as a Type of Fresh-cut Produce

Sliced fruits alongside washed, peeled, and shredded fruits are classified as Fresh-cut products (Francis *et al.*, 2012). Consumption of fresh-cut produce offers numerous advantages including convenience since they are ready-to-eat and require low preparation time and they also offer good sensory and nutritional value (Yousuf *et al.*, 2020). Fresh sliced fruits are more prone to deterioration due to wounding whilst being prepared, unlike whole fruits (Mantilla *et al.*, 2013; Zambrano-Zaragoza *et al.*, 2017). The preparation activities of fresh-cut fruits lead to a rise in respiration which consequently results in negative quality defects such as browning, likelihood of microbial growth, off-flavours, and texture loss. In apples and pears browning defect is a very typical quality defect.

3.2 Apples (*Malus domestica*) and pears (*Pyrus communis*) as Fresh-cut Products

Apples (*Malus domestica*) and pears (*Pyrus communis*) are among the fruits that are hugely utilised in the production of fresh-cut products (Najafi Marghmaleki *et al.*, 2021). Their tolerance to refrigeration temperatures makes apples and pears ideal for producing fresh-cut produce. Browning is a common quality defect in apples and pears it is a result of the activities of the enzyme polyphenol oxidase on phenolic compounds resulting in quinones which are then polymerized to melanin that are responsible for the brown, black, and red colour in the fruits. Softening is also another negative quality attribute that affects fresh-cut apples and pears (Amiot *et al.*, 1995; Soliva-Fortuny and Martín-Belloso, 2020; Yousuf *et al.*, 2020).

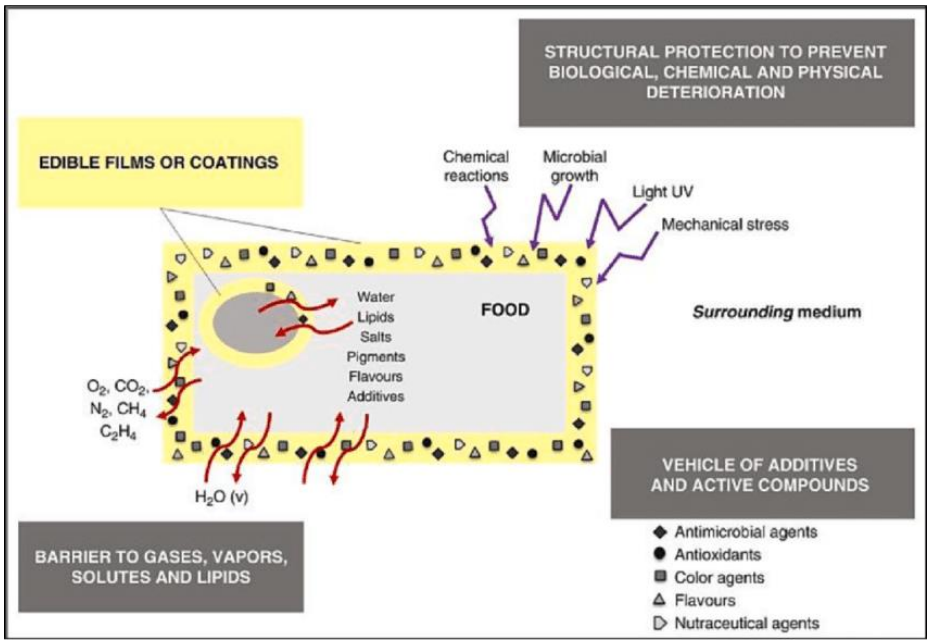
Peeling and cutting activities result in water loss that causes loss of texture in fresh-cut fruits. To determine the texture quality of products, a Texture Profile Analyser is used to acquire information on textural parameters such as hardness and springiness (Liu, Cao and Liu, 2019).

3.3 Shelf-life Extension of Sliced Fruits

Packaging methods utilised in extending the shelf-life of fresh-cut fruits include modified atmosphere packaging (prevents senescence, cold storage, controlled atmosphere packaging, use of ozone gas (Yousuf et al., 2018), biopreservation (Denoya, Vaudagna and Polenta, 2015), and use of edible coatings a process which is of high interest in the food industry (Khan *et al.*, 2014). The use of edible packaging in the food industry provides various advantages and functional

properties which include acting as a physical barrier to mechanical injuries, moisture loss, oxygen, and light exposure and acting as a carrier of bioactive compounds such as phenolic compounds which bear antioxidant and antimicrobial activities (Aayush *et al.*, 2022). The roles and advantages are illustrated in Figure 1 below.

Figure 1: Roles of Edible Coatings and Films, *(Source: Salgado et al., 2015)*



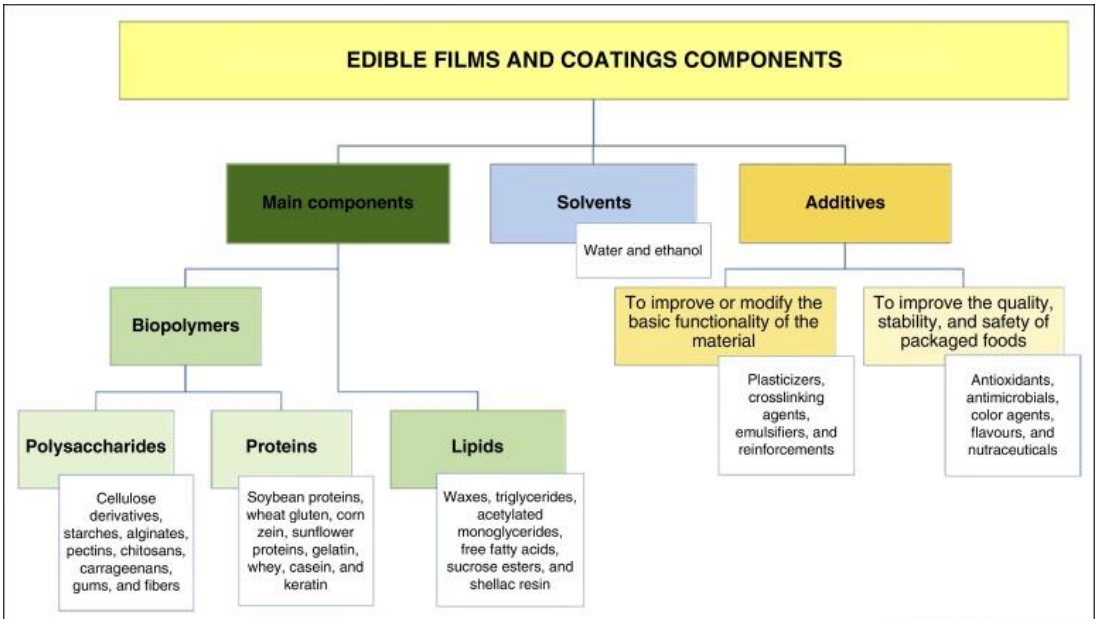
3.4 Edible Coatings

Edible packaging is packaging obtained from edible substances, for example, natural polymers. The edible packaging is made into films or coatings, coatings are placed on food surfaces and consumed with the foods, while the films are used to make pouches, bags, casings, wraps, or capsules (Aguirre-Joya *et al.*, 2018). During the selection of edible packaging, the main determinant of the packaging to be used is the product to be packaged, other determinants include sensory compatibility with food, processing technique, and material's composition (Restrepo *et al.*, 2018).

3.4.1 Natural Extracts in Edible Packaging

Biodegradable polymers which are utilized by bacteria, fungi, and algae during composting are used in the manufacture of environmentally friendly packaging, these biopolymers are classified into edible and non-edible biopolymers (Nur Hanani, Roos and Kerry, 2014). Edible coatings and films are made from edible biopolymers comprising polysaccharides, lipids, and proteins (Salgado *et al.*, 2015). The edible biopolymers and additives used in edible coating manufacturing are demonstrated in Figure 2 below. Biocompatibility, gas and/or moisture barriers, non-toxicity, and non-polluting qualities are some of the merits presented by the use of the aforementioned polymers (Mellinas *et al.*, 2016).

Figure 2: Edible Coatings and Film Components*(Source: Salgado et al., 2015)*



3.4.2 Edible Polysaccharide Biopolymers

Chitosan, gums, pectin, alginate, cellulose, and starch are utilized in edible coating manufacture, these polysaccharide coatings when used in fruits prevent texture, moisture, and color loss (Pedro *et al.*, 2022). A major disadvantage of their use is their hydrophilic nature resulting in low moisture barrier properties (Hassan *et al.*, 2018). Polysaccharide films exhibit selective permeability to oxygen and carbon dioxide, along with resilience to oils (Costa *et al.*, 2015). These films also enhance the edible packaging's properties by providing attributes like hardness, crispness, compactness, viscosity, adhesiveness, and the ability to form gels (Sánchez-Ortega *et al.*, 2014).

3.4.3 Edible Protein Biopolymers

Wheat gluten and soy protein, and zein corn proteins are sourced from plants. In contrast, casein, whey protein, gelatin, casein, and keratin are sourced from animals and used in edible packaging manufacture (Chiralt *et al.*, 2020; Aayush *et al.*, 2022). Mechanical stability is provided by these polymers. Oils, beeswax, and other hydrophobic substances are combined with protein biopolymers to counter the challenge of water permeability in protein biopolymers. Plasticizers are also used to increase the protein's network flexibility (Costa *et al.*, 2015).

3.4.4 Edible Lipid/ Fat Biopolymers

In the production of edible coating, phospholipid, mono-di, and triacylglycerol lipids are used (Aayush *et al.*, 2022). Phospholipids, triglycerides, antioxidants, and polyphenols are contained in vegetable oils (Sources: muster, olive, sunflower seed, and corn) which are potential raw materials for edible coatings (Yousuf, Sun and Wu, 2022)**.** Paraffin wax, carnauba wax, beeswax, and candelilla wax are examples of waxes used in edible coat manufacture (De Oliveira Filho *et al.*, 2021)**.** Lipid biopolymers bear water loss barrier properties, however, their hydrophobic nature causes brittleness and thicker characteristics necessitating the need for blending with proteins and or polysaccharide biopolymers (Hassan *et al.*, 2018).

3.4.5 Other Additives Used in Edible Packaging Manufacture.

Plasticizers are used in edible films to increase the mechanical properties and make them flexible. Commonly used plasticizers include polyols, for example, glycerol, lipids, monosaccharides, and oligosaccharides (Sothornvit and Krochta, 2005; Xie *et al.*, 2014; Regubalan *et al.*, 2018).

Emulsifiers, for example, sugar esters, glycerol monooleate, sodium lauryl sulfate, lecithin, polysorbates, acetylated monoglyceride, glycerol monopalmitate, glycerol mono-stearate, sorbitan monooleate, sorbitan monostearate, and sodium stearoyl lactylate are used (Mendes *et al.*, 2020). The emulsifiers function to improve surface wettability, increase anti-microbial activity (sugar esters and glycerol monooleate), and ensure lipid particles in composite emulsion films are well distributed and also that the coated surface adheres or is correctly distributed (Taarji *et al.*, 2020).

Texture enhancers are used to improve the film's strength. Salts (mostly calcium salts) form linkages with carboxylated polymers consequently improving the film's strength (Vasile, 2018).

3.4.6 Plant (Vegetable and Fruits) Use in Edible Packaging Manufacture

Food industry by-products such as seeds, peels, and pomace contain biopolymers such as plant-based proteins, cellulose, and starch, which are utilized in edible coating manufacture (Chiralt *et al.*, 2020; Karimi Sani *et al.*, 2023). Other than environmental conservation, the use of plants and or plant residues offers excellent sensory and nutritional properties. Previous research for example shows how edible packaging may be developed from apple peels and carboxymethylcellulose polymeric (Shin *et al.*, 2014). In edible film production, pomaces obtained from fruit manufacture and value addition are added into edible films or used in the manufacture of edible films. Apple pomace extract demonstrated optimal antimicrobial, antioxidant, increased PH sensitivity, and increased mechanical characteristics when used in edible film manufacture (Lan *et al.*, 2021).

3.5 Apple Pomace as a Potential Raw Material in Edible Package Manufacture

In the world today, among the most produced fruits is apples with China being the highest apple producer in the world, the European Union falls in second, and the United state of America the third-largest producer (Wang et al., 2016). As of 2015, 2.27 million hectares of land in China were used for apple cultivation and 40.92 million tons of apples were exported from China (Z. Zhu et al., 2018). Jonagold, Golden Delicious, Red Delicious, and Fuji apple varieties are the most known out of the available 7,500 varieties (Wu et al., 2017). ‘‘Idared’ ’, ‘Red Delicious’, and ‘Gala’ apple varieties are the most common varieties grown within the European Union (Dashboard, 2024).

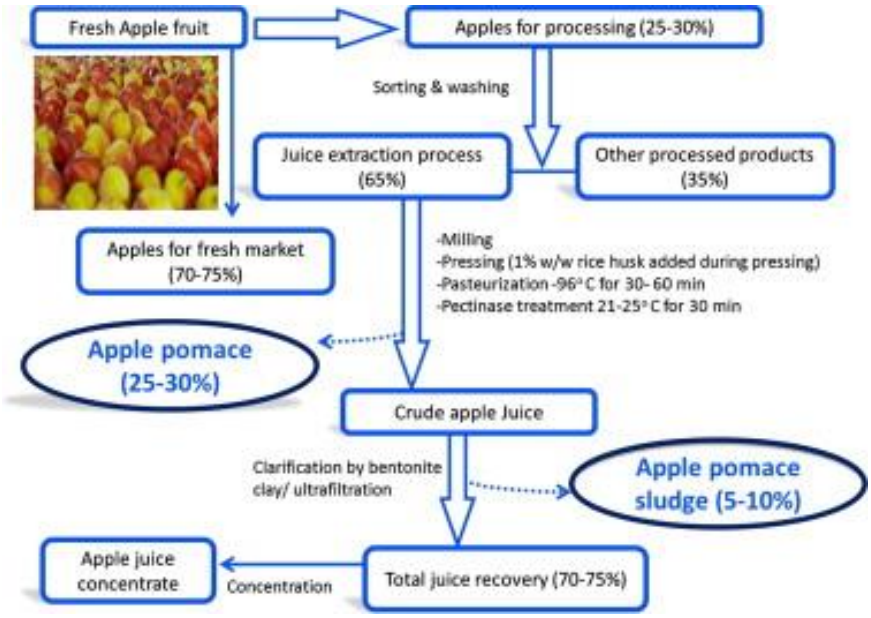
3.5.1 Apple Products

There is a need to process apples into various value-added products despite more than 57 billion tons of apples being consumed fresh globally (Al Daccache *et al.*, 2020). To increase the shelf life of the apples, they are processed into value-added products such as juices, apple vinegar, apple pastries, condiments, apple chips, and preserves. Among all the apple products, most processors produce apple juice consequently making it the highest-produced product with 65% productivity (Lyu *et al.*, 2020).

3.5.2 Apple Processing by-products

From the value addition and processing of the various products a lot of by-products are generated which include apple seeds (2-4%) and apple peels (95%) which comprise the apple pomace, other components of apple pomace include calyx and stem (1%) (Perussello *et al.*, 2017; Asma *et al.*, 2023). Apple pomace constitutes 25% of the apple's fresh weight (O'Shea, Arendt and Gallagher, 2012) and 5-10% of apple pomace sludge (Dhillon, Kaur and Brar, 2013). Figure 3 below shows an illustration of how apple pomace is obtained from the use of apples in the production of various products.

Figure 3: Flow chart showing the production of Apple Pomace during fruit juice production (*Source: Dhillon et al., 2013)*



3.5.3 Apple Pomace's Proximate Composition

Apples pomace contains various nutrients example minerals, carbohydrates, vitamins, phenolic compounds, and 74% dietary fiber (Dhillon, Kaur and Brar, 2013; Rana *et al.*, 2015). Soluble saccharides such as mono-, di-, oligosaccharides, starch, and pectin and insoluble ones (also known as lignocellulosic materials) including cellulose (7-44% dry weight), hemicellulose (4-24% dry weight), lignin (15-25% dry weight) make up carbohydrates found in apple pomace. On a dry basis, 46.8% carbon, 43.6% oxygen, 6.4% hydrogen, 0.6% nitrogen, and 0.3% Sulphur comprise

the apple pomace's chemical composition (Dhillon, Kaur and Brar, 2013; Costa *et al.*, 2022). The proximate composition of apple pomace is presented in Table 1 below.

Table 1: Proximate Composition of Apple Pomace (Dry Weight Basis *(Source: (Dhillon, Kaur and Brar, 2013)*

Biomass Components	**Composition (Dry Weight Basis)**	**Micronutrients**	**Composition (Dry Weight Basis) mg/kg otherwise mentioned**
Initial PH	3.5±0.1	Ca	0.06- 0.1(%)
Total Nitrogen	6.8(g/kg)	Cu	1.1
Total Carbon	127.9 (g//kg)	Fe	31.8- 38.3
Cellulose	7.2-43.6 (%w/w)	K	0.4- 1.0 %
Hemicellulose	4.26-24.40 (%w/w)	Mg	0.02- 0.36%
Lignin	15.3-23.5 (%w/w)	Mn	3.96- 9.0
Pectin	3.5-14.32 (%w/w)	Na	0.2(%)
Total Carbohydrates	48.0-83.8(%w/w)	P	0.07- 0.0076(%)
Fiber	4.7-51.10 (%w/w)	Zn	15
Protein	2.9-5.7 (%w/w)		
Lipids (ether extracts)	1.20-3.9 (%w/w)		
Reducing Sugars	10.8-15.0 (%w/w)		
Glucose	22.7		
Fructose	23.6		
Sucrose	1.8		
Arabinose	14-23		
Galactose	6-15		
Xylose	1.1		

Studies on apple pomace's nutritional composition have also been carried out and reported based on fresh weight. There is 2.27% fat, 9.0%moisture, 1.6% ash, 2.37% protein, 84.7% carbohydrates, 54.2% total sugar, and 5.6% starch in apple pomace (fresh weight basis). Calcium (126.5 mg/100ml), iron (0.84 mg/100ml), zinc (0.17 mg/100ml), magnesium (12.6 mg/100ml), and potassium (253.1 mg/100ml) are minerals with high concentrations in apple pomace (fresh weight basis) (O'Shea *et al.*, 2015).

3.5.4 Bioactive Compounds with Antioxidant Properties in Apple Pomace

Flavonoids, phenolic compounds, and vitamins are examples of natural antioxidants that work well as reducing agents, chelating pro-oxidant metal ions, and scavengers of free radicals (Agati *et al.*, 2007). To increase the shelf life of foods antioxidants are used, which prevent the formation of free radicals (Ribeiro *et al.*, 2019).

Apples have been found to contain more than sixty phenolic compounds (Da Silva *et al.*, 2021). Studies have suggested that apples are comprised of two classes of phenolic compounds, phenolic acids and flavonoids (Asma *et al.*, 2023). Due to high phenolic compound content apples and their by-products consequently bear high antioxidant and bioactive capabilities (Raudone *et al.*, 2017; De La Rosa *et al.*, 2019; Cömert, Mogol and Gökmen, 2020). Garlic acid and vanillic acid are examples of hydroxybenzoic acids, a classification of phenolic acids available in apples. Caffeic acid and quinic acid are examples of hydroxycinnamic acids in apples (Da Silva *et al.*, 2021). Apple peels making up 95% of apple pomace have been found to bear a high amount of phenolic compounds compared to other apple parts (Kruczek *et al.*, 2017).

Four types of flavonoids in apples have been documented, flavanols (71–90%), flavanols-3-ols (1–11%), anthocyanins (1-3%), and chalcones/dihydrochalcones (2–6%). Quercetin glycosides are the most available flavonoids in apples, whereas in apple peels and pulp catechins and epicatechins are the highest available types of flavan-3-ols flavonoids (Bondonno *et al.*, 2017). High amounts of flavonoids are found in apple pomace and apple seeds, however, not in a free form but are linked to sugars in the fruit (Jakobek and Barron, 2016). Table 2 below shows some phenolic compounds identified in apple pomace by research carried out by (Li *et al.*, 2020).

Table 2: Various Phenolic Compounds in Apple Pomace *(Source: Li et al., 2020)*

Phenolic Compound (microwave-assisted apple pomace extracts using ethanol)	Polyphenol content (mg/100g DW)	Phenolic Compounds (in aqueous acetone and ethyl acetate extracts of apple pomace)	Polyphenol content (mg/100g DW)
Caffeic acid	8.37	Epicatechin	14-19
Procyanidin B2	21.9	Quercetin glycosides	52-68
Chlorogenic acid	6.28	Catechin	0.8-1.4
Cinnamic acid	8.37	Quercetin	0.35-2.3
Syringin	0.43	Chlorogenic acid	3.3- 7.9
Quercetin	0.61	Procyanidin B2	9.3- 1.6
Phlorizin	0.28	Phloretin	0.04-0.14

Vitamin content in apples is high, research has shown that apples contain vitamins C and E. Vitamin D, and Vitamin B12 are also contained in apples but in trace quantities. Research by (Pieszka *et al.*, 2015) on dried apple, pomace revealed that it bears 5.5mg/ 100g Vitamin E and 22.4mg/100g Vitamin C. Vitamin C and E have been demonstrated to have an antioxidant effect with a free radical-scavenging activity of EC50 =0.35 and EC50 = 0.30 respectively (Skinner *et al.*, 2018).

3.6 Applications of Apple Pomace

3.6.1 Apple Pomace Application in Agriculture and Livestock

Due to environmental concerns, apple pomace is no longer placed in landfills (Shalini and Gupta, 2010). Apple pomace is used as an animal feed with the main aim of acting as an energy substitute source (Perussello *et al.*, 2017). Current research shows the merits of using dried apple pomace for feeding animals. Some of the merits include daily growth improvement, increased meat yield, organ mass, and improved health. The research further suggests that apple pomace in animal feed is between 5-20% (Maslovarić *et al.*, 2017).

Apple pomace is also used in composting, research has also shown that applying modified apple pomace compost in zinc-deficient soil may improve the production levels of Chinese cabbage.

Apple pomace helps improve the retainment of nitrogen in compost and the quality of fertilizer (Mao *et al.*, 2017).

3.6.2 Bioactive Compounds Production

Examination of dried apple pomace has revealed that it contains 36.8% water-soluble and insoluble fiber (Issar et al., 2017). From apple pomace fiber extracts such as pectin, lignin, and cellulose are acquired and utilized in various applications such as in food (Lyu et al., 2020). Studies suggest that pectin is the most significant fiber in apple pomace (Kammerer et al., 2014). Apple pomace is utilized in the production of pectin, a research carried out (Wang, Chen and Lü, 2014), shows how pectin can be extracted from apple pomace using subcritical water and the results revealed that an optimal yield of 16.68% was obtained. Other methods of obtaining pectin from apple pomace include the use of acids such as acetic acid (Le Deun *et al.*, 2015), the use of fungi or enzymes (biological methods) (Lee *et al.*, 2014) , and the use of microwave or ultrasound (green technologies) (Dranca and Oroian, 2019; Dranca, Vargas and Oroian, 2020). Pectin obtained from apple pomace can further be processed into ethanol, ethanol may be obtained using autoclaving, acid, and alkali chemical treatment, enzymatic hydrolysis, and microbial fermentation (Solid State Fermentation) (Magyar *et al.*, 2016).

From apple pomace, enzymes are also obtained through fermentation. Polygalacturonase a pectinase enzyme can be obtained through the use of apple pomace as a fermentation (solid-state-fermentation) substrate and *Penicillum epansum* as the culture (Zhu *et al.*, 2018). Using a culture comprised of both *Bacillus subtilis* and *Bacillus pumilus* pectinase enzyme was obtained from apple pomace (Kuvvet, Uzuner and Cekmecelioglu, 2019).

From apple pomace, obtaining other bioactive compounds such as vitamins, dietary fiber, and polyphenols has been documented (Pan *et al.*, 2018). Polyphenols have been utilized in the drug and pharmaceutical industry (Costa *et al.*, 2022). Organic acids are also obtained from apple pomace which acts as a substrate for Solid- State Fermentation, research has shown that citric acid can be produced from apple pomace (combined with arginine) as a substrate using *Aspergillus ornatus* and *Alternaria alternate* (Ali *et al.*, 2016).

Apple pomace has proven to be a good substrate for utilization in the production of biofuels, for example, methane and hydrogen. Despite the challenges presented by the use of apple pomace which include difficulty in utilization of pectin, cellulose, and hemicellulose macromolecules

leading to the requirement of pretreatment of apple pomace and some pretreatment methods such as the use of pyrolysis (400ºC) leading to methane transformation to hydrogen during methane production (Guerrero *et al.*, 2016; Silva *et al.*, 2018), successful production of biofuels has been reported. Research carried out by (Sato *et al.*, 2015) led to the production of 14.5mmol of hydrogen/L.h using *Clostridium beijerinckii.*

3.6.3 Food Industry Application of Apple Pomace

In the food industry, various uses of apple pomace have been recorded as illustrated in Figure 4 below. Apple pomace powder has been shown to reduce the fermentation period, raise the gelation period, and formation of a harder and more uniform yogurt gel during its storage in a cold room (Wang, Kristo and LaPointe, 2019). Apple pomace extract (3%) has been proven to enhance the phenolic content (by 2 times more) and antioxidant (by 3 times more) activity of probiotic yogurt resulting in the prevention of oxidation (Fernandes *et al.*, 2019; Ahmad *et al.*, 2020).

To prevent fat and protein oxidation in fish and fish products, apple extracts (phenolic compounds) are utilized. Research carried out on rainbow trout and surimi a fish product revealed that there is reduced formation of Thiobarbituric acid-reactive substances, a lipid oxidation product (Sun *et al.*, 2017).

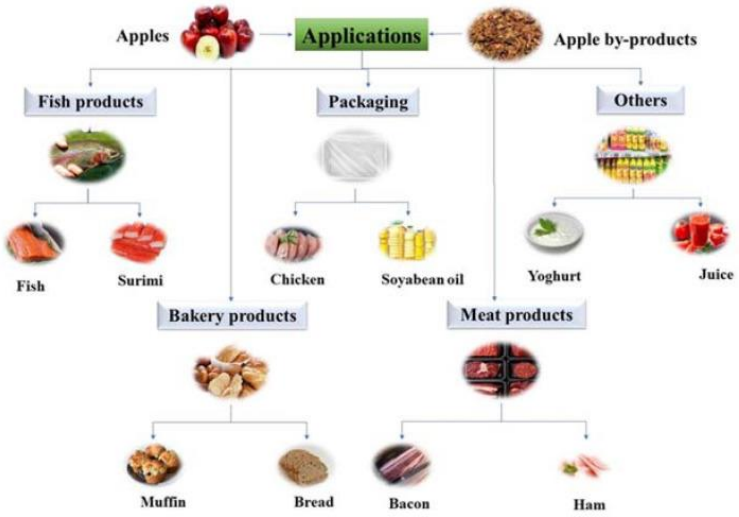
In meat, apple pomace application in bacon reduced lipid and protein oxidation, in research carried out (Deng, Shi and Xia, 2022), showed that there was reduced Thiobarbituric acid and protein carbonyl, which are products of lipid oxidation and protein oxidation respectively.

In the baking industry, by use of apple pomace, there is increased acceptable sensory qualities, total antioxidant capacity, and total phenolic content, this was demonstrated in research where muffins were prepared using 20% apple pomace(Jung, Cavender and Zhao, 2015; Sudha *et al.*, 2016). Apple pomace is used as an additive in wheat flour to aid in fermentation using baker's yeast and *Fructilactobacillus florum* (Martău *et al.*, 2021). To enhance the yield of functional bread, lactic acid bacteria immobilized in apple pomace is used (Bartkiene *et al.*, 2017). The application of apple pomace in short dough biscuits leads to higher dietary fiber composition consequently leading to a lowering of the glycemic index according to research by (Alongi, Melchior and Anese, 2019).

Apple pomace may also be utilized as an ingredient in food products, application of apple pomace extract obtained from the 'Idared' apple variety when used in bakery jam to substitute pectin, the results revealed that apple pomace powder can substitute pectin up to 40% and that there was good stability over the period (12 months) (Szabó-Nótin *et al.*, 2014).

Cellulose, lignin, and hemicellulose comprising lignocellulosic materials, are utilized in the production of edible films (Gustafsson *et al.*, 2019). There is great interest in the use of apple pomace in the production of bioplastics (Perussello *et al.*, 2017). According to research carried out by (Gaikwad, Lee and Lee, 2016), apple pomace powder (1 to 10%w/w) integrated into polyvinyl alcohol and used in storing soybean oil at 23- 60^0 C resulted in the presence of antioxidant activity, slowdown of lipid oxidation in the oil and the packaging, increased tensile strength, increased thermal stability, raised amount of total phenolic content, enhanced film's antioxidant capabilities.

Figure 4: Apple and Apple Pomace Applications *(Source: Asma et al., 2023)*



3.7 Antimicrobial and antifungal Properties of Apple Pomace

Apple pomace contains phytochemicals which include phenolic acids, polyphenols, and triterpenoids. Research has suggested that phytochemicals have anti-inflammatory, antifungal, and antimicrobial properties (Karantonis *et al.*, 2023). The phytochemicals interact with proteins necessary for microbial and fungal growth, hence preventing their proliferation. Phenolic acids: chlorogenic acid and ellagic acid have shown high binding affinity against fungi and gram-positive bacteria respectively. Polyphenols: rutin demonstrated high binding affinity to target proteins (Skinner *et al.*, 2018).

Apple pomace obtained from the golden delicious apple variety bears phenolic compounds, which upon being researched demonstrated that phenolic compounds extracted from the apple pomace using ethyl acetate (flavonoids had the highest concentration) had excellent inhibitory effects against *Staphylococcus aureus* and *Escherichia coli* with a minimum inhibition concentration of 1.25mg/ml and 2.50mg/ ml respectively (Zhang *et al.*, 2016).

In an attempt to use phenolic compounds and pectin extracts from apple pomace (Spanish origin) to prepare a hydrogel, it was observed that hydroethanolic extracted phenolic compounds showed excellent antimicrobial activity against *Propionibacterium acnes, Proteus mirabilis, Pseudomonas aeruginosa,* and Methicilin- resistant *Staphylococcus aureus* (Arraibi and Barreira, 2018).

Apple pomace extruded with a biodegradable starch film made from cassava extracts (4% and 8%) demonstrated microbial inhibition against *Salmonella thyphimurium*, *Staphylococcus aureus*, and *Escherichia coli* at the lowest concentrations of 12.5mg/ ml. Starch films from cassava into which apple pomace was added during extrusion also demonstrated antioxidant activity, which was quantified through Ferric Reducing Antioxidant Power assay and radical-scavenging activity on 2,2-Diphenyl-1-picrylhydrazy (DPPH) and 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid). The sample containing 8% apple pomace demonstrated higher total phenolic compound concentration and antioxidant inhibition effect compared to the film containing 4%, indicating that the amount of phenolic compounds increases with the amount of apple pomace addition (Carpes *et al.*, 2021).

3.8 Methods of Applying Edible Coatings on Fruits

3.8.1 Dipping

The dipping process begins with submersion and retainment of the product to be coated into the solution to be used for coating, followed by deposition and finally evaporation (Andrade, Skurtys, and Osorio, 2012; Costa, Conte, and Del Nobile, 2014). The goal of retainment is to ensure that there is maximal interaction between the product and the coating solution (Valdés *et al.*, 2017). The purpose of the disposition step is the removal of surplus coating solution from the product's surface therefore ensuring thin layer formation (Costa, Conte, and Del Nobile, 2014). The last step is evaporation through heating and drying, evaporation facilitates the removal of the solvent and additional liquid from the food product's surface (Andrade, Skurtys, and Osorio, 2012). According

to research by (Settier-Ramírez *et al.*, 2022) the dipping method was utilised production of apple pomace coating.

3.8.2 Spraying

To obtain a coat on a polymeric surface, the solution used to form a film may be sprayed onto its surface, and the film-forming solution settles on the surface in the form of droplets. Less drying period is attained since the solvent used during dispersion evaporates after exiting the sprayer's nozzle (Espitia *et al.*, 2014). Different spraying methods are presented in Table 3 below.

Table 3: Spraying Techniques of Coating Food *(Source: Suhag et al., 2020)*

Method	Working Principle	Reference
Air Spray Atomization	Atomization is caused by friction and disruption due to the fluid exiting the nozzle being encircled by compressed air at high speed.	(Valdés *et al.*, 2017)
Pressure atomization	Surrounding air outside the nozzle causes fragmentation plus formation of droplets due to its friction with the fluid that is emitted from the nozzle at high pressure	(Peretto *et al.*, 2017)
Air-assisted airless atomization	Air spraying and airless methods are incorporated into this method. A concentrated airflow is incorporated to improve the regulation of droplet formation.	(Andrade, Skurtys and Osorio, 2012)

3.8.3 Panning and Fluidized Bed Method

This method comprises a pan into which the food product to be coated is placed and a gun that discharges the coating solution. Once the coating process is done, drying is accomplished through the use of hot air (Kumar *et al.*, 2022).

One of the most popular methods for covering particles is fluidized bed coating. In the process of fluidized bed coating, coarse particles in the reactor are fluidized by hot air passing through a distributor. The dense phase zone has one or more nozzles mounted upon it from which slurry or

solution is sprayed to meet the inventory particles. The precipitated solute sticks to the surface of the particles when the water evaporates after colliding with them (Zhang, Wang and You, 2022).

3.9 Application of Edible Coatings in Shelf-life Extension of Sliced Fruits

A summary of various applications of edible coatings on fresh-cut fruits is provided in Table 4 below:

Table 4: Applications of Edible Coatings *(Source: Suhag et al., 2020; Yousuf and Qadri, 2020)*

Polymers and Coating Method	**Food Product**	**Functions/ Results**	**Reference**
Alginate- Dipping	Fresh-cut watermelon	PH and Brix maintenance, minimal weight loss, texture maintenance, antimicrobial effect against psychrotrophic, coliforms, yeasts, and molds	(Sipahi *et al.*, 2013)
Ag-Chitosan	Melons	Reduced respiration rate improved textural properties.	(Ortiz-Duarte *et al.*, 2019)
Chitosan, pectin, alginate, gellan	Cantaloupe	Extended shelf-life, retained quality (texture, PH, titratable acidity, phenolic content)	
Alginate- Dipping	Fresh- cut Mango	The reduced microbial count below 6 log CFU/g at 4°C, PH retainment, reduced color, and total solid content	(Salinas-Roca *et al.*, 2016)
Konjac glucomannan-dipping	Rose apple	Reduced browning in the fresh-cut apples.	(Supapvanich, Prathaan and Tepsorn, 2012)
Sodium alginate and pectin-dipping	Apple	Increased shelf-life without noticeably lowering the fruit's nutritional value, leading to a decrease in microbiological spoiling and good preservation of most quality indices during 12-day storage.	(Guerrero *et al.*, 2016)

Whey protein- Dipping	Apples	Retardation of total phenolic content, browning, and weight loss	(Feng *et al.*, 2018)
Chitosan – Dipping	Pears (Huangguan variety)	Chitosan when combined with pure oxygen and rosemary extracts lead to low browning and softening rates. Reduced weight loss and L* values.	(Xiao *et al.*, 2010)
Sodium Alginate- Dipping	Apple	When sodium alginate was combined with citric and ascorbic acid, the texture was maintained (hardness and chewiness), reduced weight loss, colour change, and browning.	(Najafi Marghmaleki *et al.*, 2021)
Gellan gum- Dipping	Fresh- cut Strawberries	Increase microbial stability (against yeast, molds, psychrophilic bacteria) and loss of texture (firmness)	(Tomadoni *et al.*, 2018)
Sodium alginate, konjac glucomannan, and starch-dipping	Goji	Increased shelf-life for up to around 4 days, reduced weight loss and rate of rotting.	(Fan *et al.*, 2019)

4. MATERIALS AND METHODS

4.1 Material Acquisition

Sodium alginate salt (Alginate E401) was procured from Naturguru Ltd. Glycerol from Molar Chemicals Kft, ethanol from Thomasker Finomvegyszer Budapest, Ascorbic Acid from Chem Lab NV, and Citric Acid Monohydrate G.R was purchased from Reanal Laborvegyszer Ltd. The distilled water and apple pomace powder were prepared in the Fruits and Vegetables laboratory.

The apple ('Idared' variety) and Pear ('Conference' variety) were purchased from SPAR supermarket.

4.2 Machine and Equipment

An A&D weighing FX 3000I Toploading balance (Korea, Republic of (South)) was used for weighing, and the bandelin Sonorex ultrasonic bath (RK 52) by Bandelin Electronic GmbH % Co.KG (Germany) was used for ultrasonication. The Thermo Scientific Megafuge 8 small benchtop series centrifuge by Thermo Fisher Scientific (United States of America) was used for centrifugation. Chroma Meter CR-400 Series with version 1.11 released between 2002 and 2006 by Konica Minolta Sensing Inc (Japan) was used for colour determination. Texture Profile analysis was determined using the TMS PRO texture analyzer and the Texture Lab (TL) Pro v1.18- 408 software (by the Food Technology Corporation (FTC) in the United States).

4.3 Apple Pomace Extract Preparation

Apple pomace powder from the 'Idared' apple variety was used to prepare the apple pomace extract. The apple pomace powder had been previously prepared in the fruits and vegetables department laboratory by drying apple pomace at 80°C to a moisture content of 3% (Gonelimali, Szabó-Nótin and Máté, 2021). The dried apple pomace powder was subsequently sieved through a sieve with a mesh size of 200µm. 50g of dried apple pomace powder was weighed using an A&D weighing FX 3000I Toploading balance (Korea, Republic of (South)), subsequently, it was mixed with 150ml 80% ethanol. The mixture of ethanol and apple pomace powder was then subjected to ultrasonication at 20 kHz, 25°C for 25 minutes using a bandelin Sonorex ultrasonic bath (RK 52) manufactured by Bandelin Electronic GmbH % Co.KG (Germany). Following ultrasonication, centrifugation at 4500 rpm for 5 minutes was done using a Thermo Scientific Megafuge 8 small

benchtop series centrifuge (Thermo Fisher Scientific- United States of America). The supernatant obtained from centrifugation was filtered through filter paper No.1 (Najafi Marghmaleki *et al.*, 2021). The filtrate was then dried in the laboratory oven drier at 80°C for 102 minutes to fully evaporate the solvent. The obtained extract was then redissolved in 100 ml distilled water and refrigerated for use in coating preparation.

4.4 Edible Coating Solution Preparation

Five edible coating solutions and a 6th control solution consisting of distilled water were prepared. The composition of the 5 edible coating solutions is presented in the table below.

Table 5: Edible Coating Solution Components *(Source: Own Work)*

Solution	Components
1	1% Sodium Alginate salt, 1.5% glycerol
2	1% Sodium Alginate salt, 1.5% glycerol, 1% citric acid
3	1% Sodium Alginate salt, 1.5% glycerol, 0.5% ascorbic acid
4	1% Sodium Alginate salt, 1.5% glycerol, 1% citric acid, 5% apple pomace extract
5	1% Sodium Alginate salt, 1.5% glycerol, 0.5% ascorbic acid, 5% apple pomace extract

The preparation of the solutions was carried out as follows. To prepare the 1st solution, 1000 ml of distilled water was heated to 70°C into which 1% Sodium alginate salt was added, cooling was then carried out to below room temperature (22 °C) after which 1.5% glycerol was added obtaining a final solution with 1%w/v Sodium alginate concentration and 1.5%w/v glycerol. The 2nd solution was prepared by adding 1% sodium alginate to 1000 ml distilled water at 70°C, cooling was done to room temperature after which 1.5% glycerol and 1% citric acid were added obtaining a solution with 1%w/v sodium alginate, 1.5%w/v glycerol, and 1%w/v citric acid. To prepare the 3rd solution, sodium alginate was added to 1000 ml distilled water at 70°C, cooling was done to room temperature after which 1.5% glycerol and 0.5% ascorbic acid were added to obtain a solution with 1%w/v sodium alginate, 1.5%w/v glycerol, and 0.5%w/v ascorbic acid (source prof's article). In the 4th solution, sodium alginate was added to 950 ml distilled water at 70°C, cooling was done

to room temperature after which 1.5% glycerol and 1% citric acid, and 5% apple pomace extract were added to obtain a solution with 1%w/v sodium alginate, 1.5%w/v glycerol and 1%w/v citric acid and 5%v/v apple pomace extract. To prepare the 5th solution, 1% sodium alginate was added to 950ml distilled water at 70°C, cooling was done to room temperature after which 1.5% glycerol and 0.5% ascorbic acid were added to obtain a solution with 1%w/v sodium alginate, 1.5%w/v glycerol and 0.5%w/v ascorbic acid and 5%v/v apple pomace extract. For control, distilled water was used.

4.5 Coated Apple and Pear Slices Preparation

The apples and pears were cleaned, peeled, and sliced into equal cubes. Subsequently, the sliced apple cubes were dipped into the respective edible coating solutions for two minutes, drained for one minute, and dipped into the 2% Calcium Chloride solution for one minute. The treated cubes were then placed in a white tray, dried out in the air for 30 minutes, and stored in a refrigerator at 4°C ±1 for quality assessment.

4.6 Quality Attributes Determination

4.6.1 Weight Loss Determination

To determine the weight loss of the sliced apple and pear cubes, the weight of the samples was determined using an A&D weighing FX 3000I Toploading balance (Korea, Republic of (South)). The initial weight was determined on day 0, this measurement was done immediately after dipping the sliced apple and pear cubes into the edible coating solutions. The measurement was repeated on days 3,5 and 7 for the refrigerated samples stored at 4°C. The weight during storage was compared with the initial weight on day 0 and the results provided as % weight loss (Najafi Marghmaleki *et al.*, 2021).

4.6.2 Browning Index and Colour Parameter Determination

The following formula according to (Subhashree *et al.*, 2017) was used to determine the browning index:

$$BI = \frac{100(x - 0.31)}{0.17} \quad (1)$$

To determine the value of x the following formula was used:

$$x = \frac{\mathrm{a}* + 1.75\mathrm{L}*}{5.65\mathrm{L}* + \mathrm{a}* - 3.012\mathrm{b}*} \quad (2)$$

To determine the L* (lightness), a* (red and green), and b* (blue and yellow) parameters of the coated sliced apple and pear cubes, the Chroma Meter CR-400 Series with version 1.11 released between 2002 and 2006 by Konica Minolta Sensing Inc (Japan) was used(Rhim and Hong, 2011). The procedure used for the analysis was as follows: Before the colour measurements, the Chroma Meter was calibrated using a white tile. The Chroma Meter was then placed above the surface of the sliced fruit sample to be tested, the measurement was then done to obtain the a*, b*, and L* values, which were recorded.

4.6.3 Texture Profile Analysis

A texture analyzer was used for texture profile analysis (Liu et al., 2019). The TMS PRO texture analyzer and the Texture lab (TL) Pro v1.18- 408 software (by the Food Technology Corporation (FTC) in the United States) were used to determine the texture, adhesiveness, stringiness, and hardness of the apple and pear samples. A cylindrical probe was used. 5 parallel measurements were done for each apple and pear cube sample. Each randomly selected sliced cube apple and pear samples from each edible coating solution were individually placed on the texture analyzer's platform. Subsequently, using the Texture Lab software, the arm was gradually lowered compressing the sample, while the load cell fitted in the arm recorded the acquired deformation. The obtained load and time information was then processed in the TL Pro v.1.12-408 software to establish the adhesiveness, stringiness, and hardness characteristics of the coated apple and pear sliced cubes.

4.7 Data Analysis

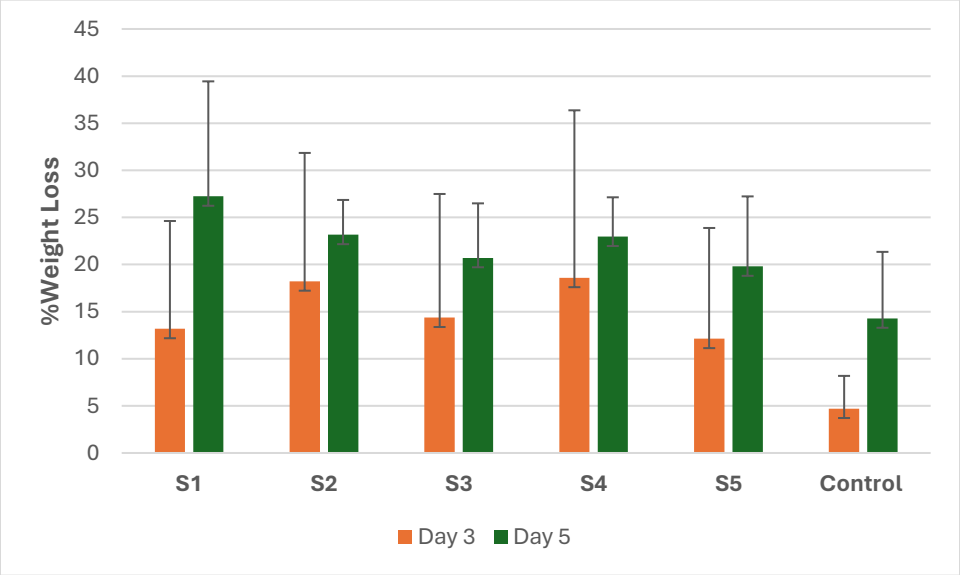
Data obtained from colour, browning Index, and texture analysis was analysed using Microsoft Excel Version 2403 and Infostat Statistical Software version 2020d. Significant differences among the treatments were determined using ANOVA and HSD Turkey test at 95% Confidence Interval level.

5. RESULTS AND DISCUSSION

5. 1 Sliced Apple % Weight Loss

Throughout the 5-day storage period at 4^0C±1, an increase in % weight loss was observed in both the coated and the control sliced apple samples as illustrated in Figure 5 below.

Figure 5:%Weight Loss in control and coated sliced apples during 5-day Storage at 4^0C±1. S1- 1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract Error bars represent ±SD*(Source: Own Work)*



In each solution, there was a significant increase in weight loss. The lowest amount of % water loss (14%) was observed in the control sample, this may be attributed to the ability of injured or wounded apples to form a layer of lignin and polyphenols on their surface gradually in 24 hours, the cells in the hypodermis become lignified and this results in reduced moisture loss. (Zhang *et al.*, 2020).

% Weight loss was highest in solution 1 (Na-alginate/glycerol) compared to the other edible coating solutions. Sodium alginate being hydrophilic formed a hydrogel in solution 1 through the traditional external gelling method, where Ca^+ ions are introduced to sodium alginate resulting in

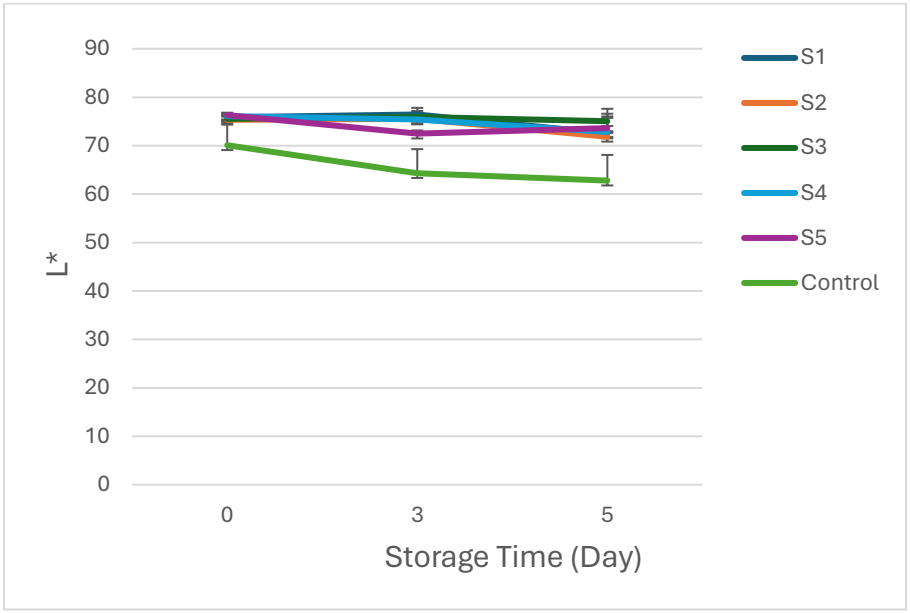
the formation of a hydrogel as a result of the Ca^{+} ions reacting with guluronic acid ions. In contrast, the internal gelling method which involves reducing PH through the use of organic acids that contain gelling ions results in more uniform gelling compared to the traditional method and this can be attributed to why there was a reduced % weight loss in the edible coating solutions (2- sodium alginate/glycerol/citric acid, 3- alginate/glycerol/ascorbic cid/,4-/ apple pomace extract, sodium alginate/glycerol/citric acid,5- apple pomace extract/ sodium alginate/glycerol/ascorbic acid) containing citric acid and ascorbic acid (Senturk Parreidt, Müller and Schmid, 2018).

The reduced % weight loss in edible coating solutions 4 and 5 containing apple extract may be attributed to the high content of pectin in the apple pomace. Pectin has gelling abilities, and when Ca^{+} ions are available, it forms a flexible gel network (Freitas *et al.*, 2021).

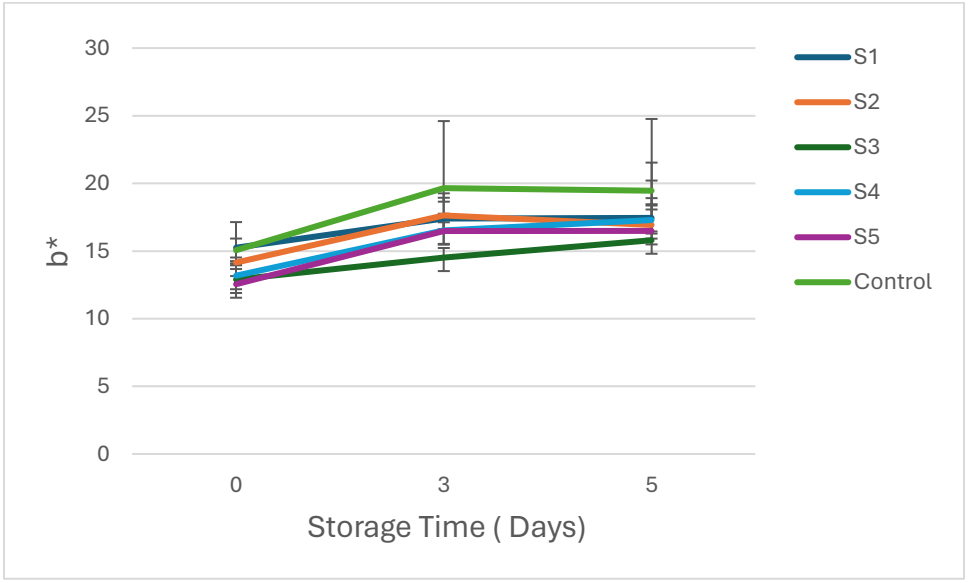
5.2 Sliced Apple Samples Colour

The browning index is an indicator of the amount of pigments produced by sliced fruits during storage (Kuwar, Sharma and Tadapaneni, 2015). To provide a detailed effect of the edible coating solutions on the change in surface browning of the sliced apple samples, (a*_ green- red; b*_ yellow- blue; and L*- lightness) were evaluated in the coated and control sliced apple samples during the 5-day storage at $4^{0}C\pm1$. From the a*, b*, and L* the browning index was obtained through calculation. Changes in the a*, b*, L*, and Browning Index are illustrated in Figure 6 below.

Figure 6: Colour Values (a*,b*, L*) and Browning Index in control and coated sliced apples during 5-day Storage at 4^0C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD. *Source(Own Work)*



(a)



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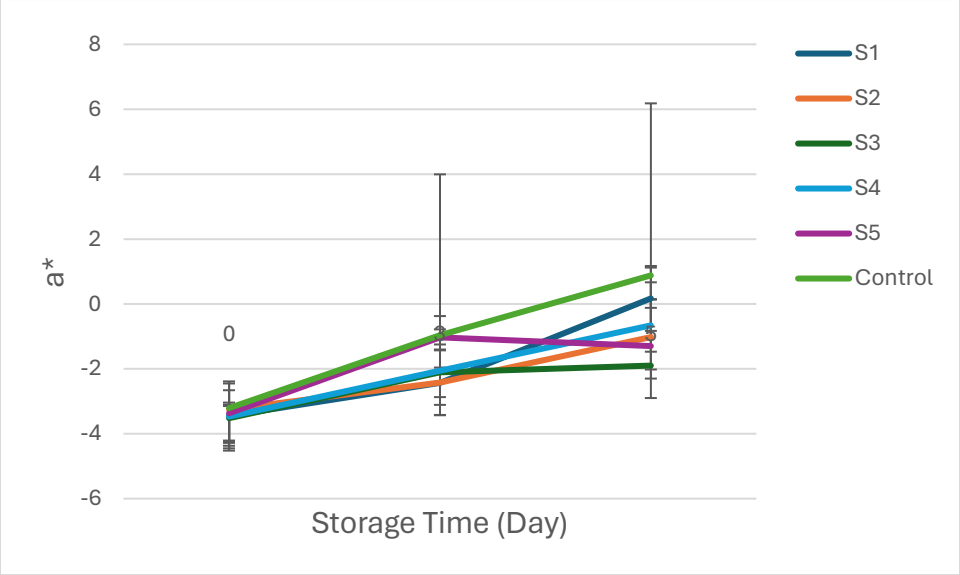

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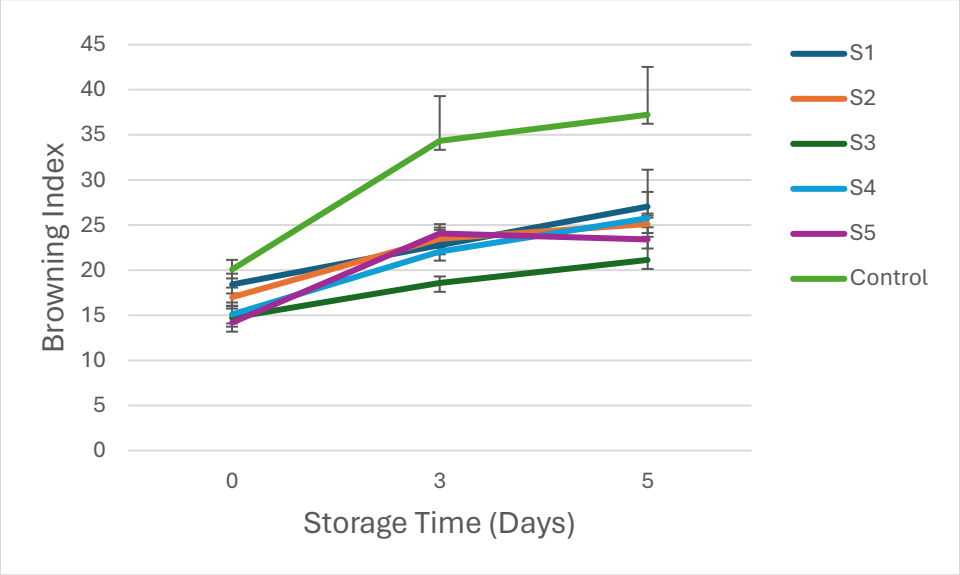


(d)

There was a decrease in the lightness (L*) value in all sliced apple samples dipped in the different solutions during the seven-day storage period at 4^0C±1. The rate of change is illustrated in Figure 6a above. Notably, there was a significant difference ($p< 0.05$) in the L* parameters of all 5 edible coating solutions from the control solution, which had the highest decrease in the L*- lightness

value. However, no significant difference was observed between the means of the 5 edible solutions ($p>0.05$), and lightness remained constant from the initial to final storge day.

An increase in b* values was observed during the 5-day storage period at $4^0C\pm1$ of the sliced apples with the highest change being on day 3 of storage, as illustrated in Figure 6b above. Solutions 1,2, 3, and the control significantly differed from all other solutions ($p>0.05$). The highest increase in b* was observed in the control sample indicating more yellowness and the least in solution 3. Solutions 4 and 5 were not significantly different from each other but were significantly different from the other solutions, this may be attributed to the presence of apple pomace extract in the edible coating solutions.

There was an increase in a* value of the sliced apple slices dipped in the various edible coating solutions and the control solutions during the 5-day storage at $4^0C\pm1$, as illustrated in Figure 6c above. The control sample exhibited the highest increase (0.88), followed by S1 (0.17 and the least was S3. However, the changes observed in all the edible coating solutions were not significantly different from each other or the control sample ($p>0.05$).

An increase in the browning index of the sliced apple samples was observed during the 5-day storage at $4^0C\pm1$ with the highest increase occurring on the third day. The browning index of the edible coating solutions was significantly different from the control sample (37.2%) showing the effectiveness of the edible coating solutions in reducing the browning index in sliced apples. Among the edible coating solutions, S1 had the highest level of browning and S3 the least, However, there was no significant difference in the browning index among all the edible coating solutions ($p>0.05$). This is illustrated in Figure 6d above.

The ability of apple pomace extract in an edible coating solution to contribute to reduced browning and a*,b*, L* value of sliced apples may be attributed to a high phenolic compound with excellent free radical scavenging activity, consequently resulting in high antioxidant capabilities (Lu and Yeap Foo, 2000). Enzyme Polyphenol oxidase bears a copper ion which is chelated by citric acid preventing oxidation while ascorbic acid reduces the formation of brown-coloured quinones to colourless ones (Ali et al., 2014). Sodium alginate solution's antioxidant ability is attributed to it being a barrier against oxygen and the presence of chloride ions from the calcium chloride solution to inhibit the activity of polyphenol oxidase by interacting with the copper at its active site (Barrett and Garcia, 2002; Najafi Marghmaleki *et al.*, 2021). Despite the edible coating solutions reducing

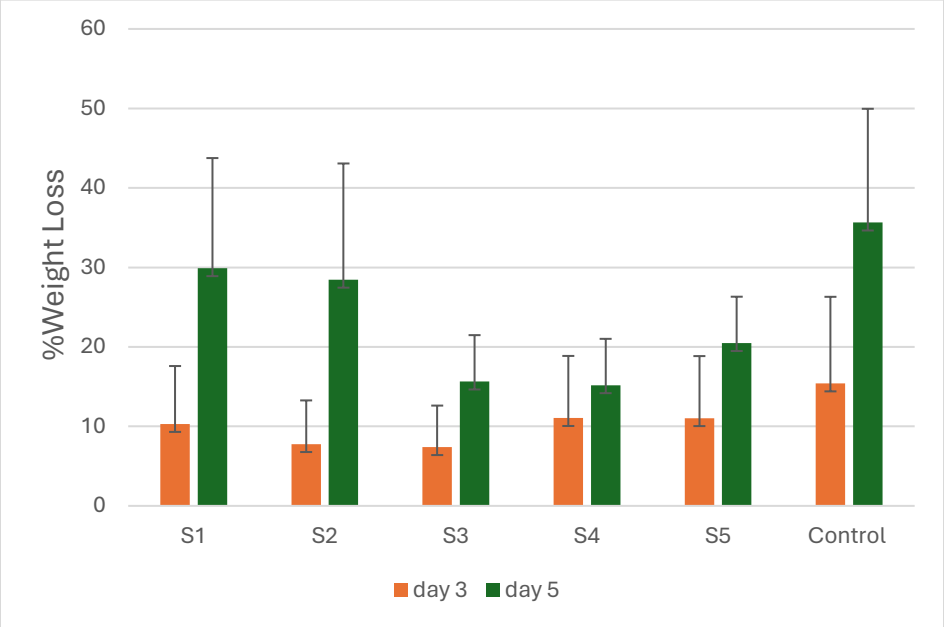
the browning index, they were not able to prevent the browning problem fully as seen in Figure 7 below.

Figure 7: Sliced Apple Samples on Day 5 of Storage. S1-1%Sodium Alginate+ 1.5% glycerol; S2-1%Sodium Alginate+ 1.5% glycerol+ 1% Citric acid; S-3 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid; S4- 1% Sodium Alginate+ 1.5% glycerol+ 1% Citric acid+ 5%Apple Pomace Extract; S5- 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5% Apple Pomace Extract.*(Source: Own Work)*

5.2 %Weight Loss Pear Samples

There was an increased % weight loss in the sliced pear samples from the initial to the final day, typical of fresh-cut refrigerated fruits (Kumar *et al.*, 2018) as illustrated in Figure 8 below. The control had the highest % weight loss (35.6%) due to the disruption of the cells during the slicing period causing loss of moisture in vapor form into the air (Radi *et al.*, 2017).

Figure 8: %Weight Loss in control and coated sliced apples during 5-day Storage at 4^0C±1. S1- 1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD. *(Source: Own Work)*



The increased % weight loss in solution 1 containing only sodium alginate and glycerol, can be attributed to the hydrophilic nature of sodium alginate. In this solution, a hydrogel was formed through the traditional external gelling method, where Calcium ions are introduced to sodium alginate resulting in the formation of a hydrogel due to the reaction of calcium ions with guluronic acid ions. However, this method is less effective compared to the internal gelling method, which involves reducing PH through the use of organic acids that contain gelling ions. Solutions 2,3,4 and 5 which contained organic acids, exhibited reduced % weight loss attributed to why there was a reduced % weight loss, this is because the internal gelling method results in more uniform gelling compared to the traditional method in the edible coating compared to the traditional method (Senturk Parreidt, Müller and Schmid, 2018).

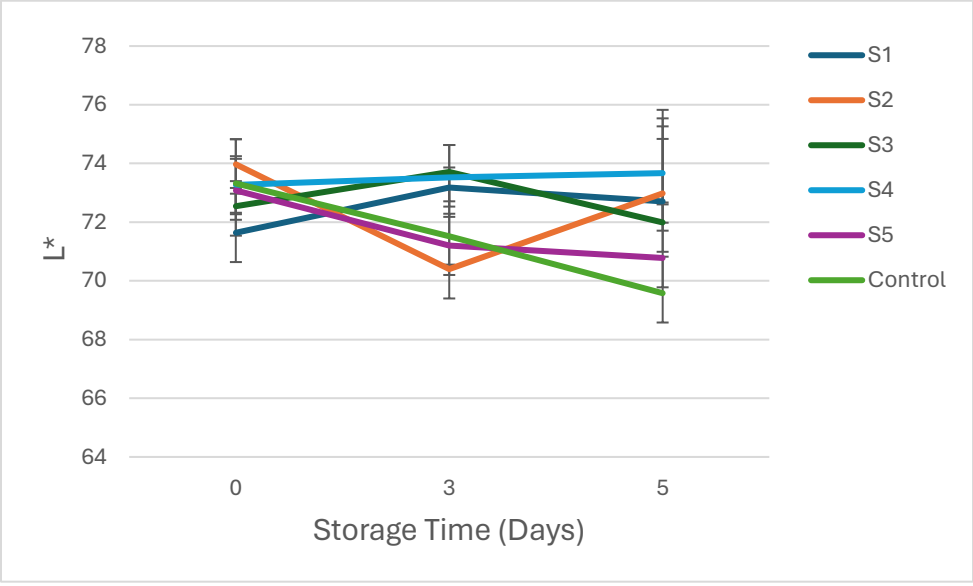
Solution 4 had the lowest % weight loss (15.18%) among all samples. This may be attributed to the combined effect of the organic acid and the pectin in the apple pomace extract contributing to

the formation of a flexible gel network in the presence of Ca^{+} ions (Freitas *et al.*, 2021). Despite the % weight loss variations in the samples from different solutions, the changes in the % weight loss were not statistically significantly different from the control ($p>0.05$) indicating that the edible coatings were not fully effective in preventing weight loss in the sliced pear.

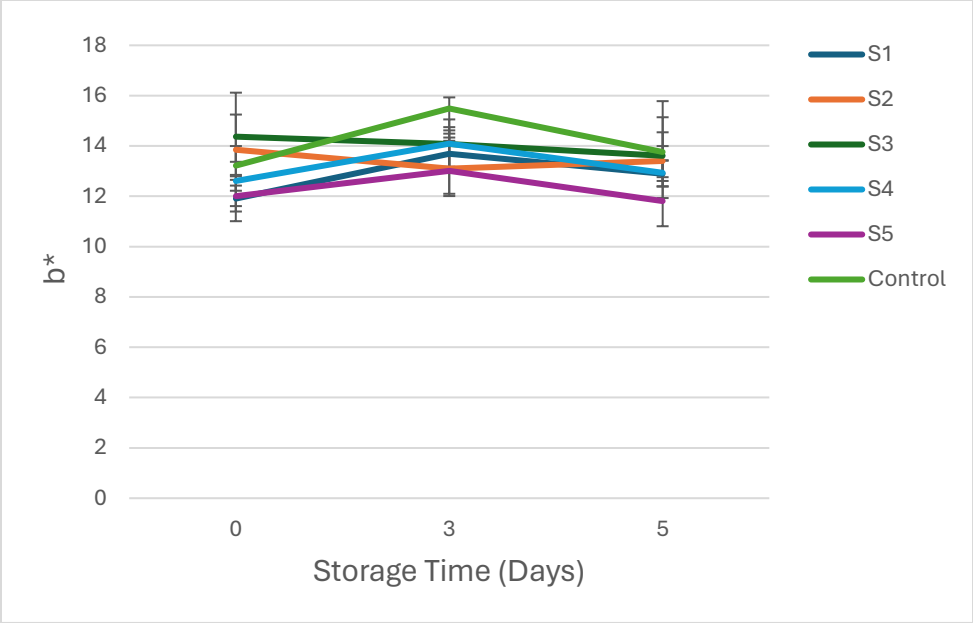
5.3 Sliced Pears Samples Colour Results

Similar to the sliced apple samples, the colour change in the sliced pear samples was assessed during the 5-day storage period at $4^0C\pm1$, to assess the effect of the edible coating solutions as illustrated in Figure 9 below. The a* (green-red), b*(yellow-blue), and L* (lightness), were assessed and the browning index was determined by calculation.

Figure 9: Colour Values (a*,b*, L*) and Browning Index in control and coated sliced pear during 5-day Storage at $4^0C\pm1$. S1-1% Sodium Alginate+ 1.5% glycerol; S2- 1% Sodium Alginate+ 1.5% glycerol+ 1% Citric acid; S-3 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid; S4- 1% Sodium Alginate+ 1.5% glycerol+ 1% Citric acid+ 5% Apple PomaceExtract; S5- 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5% Apple Pomace Extract. Error bars represent ±SD. *(Source: Own Work)*



(a)


18
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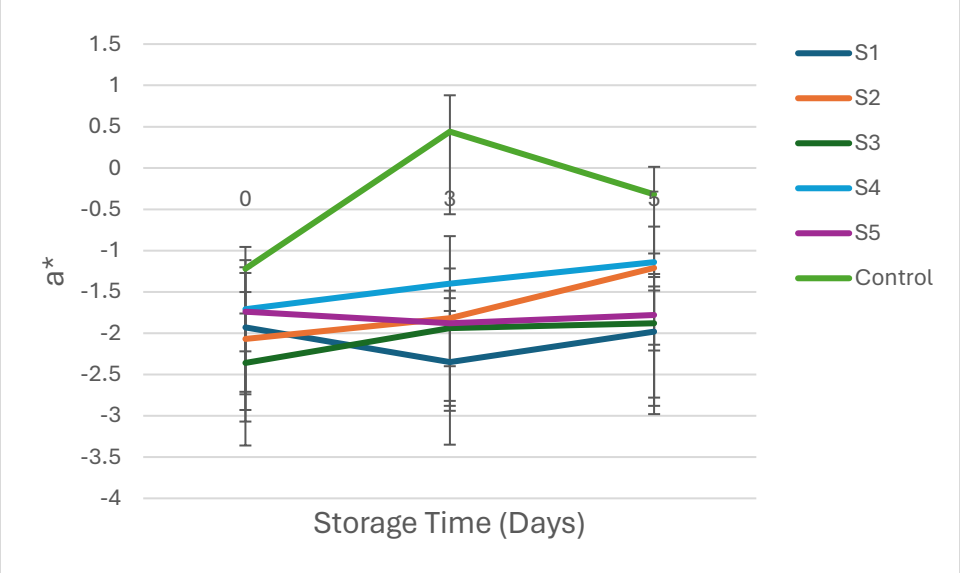
(b)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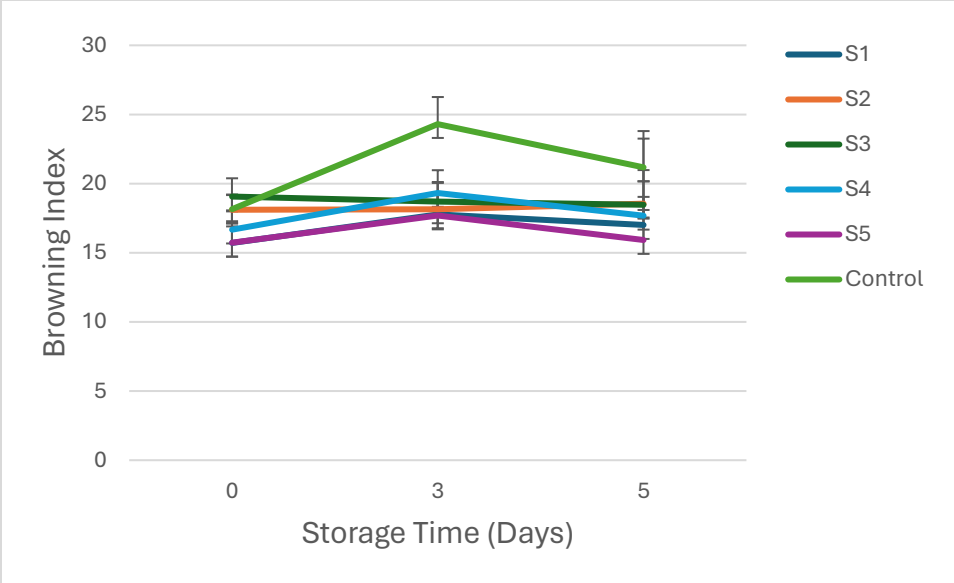


(d)

In the sliced pear samples, the lightness (L*) was maintained from the initial day of storage to the seventh day at 4^0C in all the samples as illustrated in Figure 9a above. There was no significant difference observed between the means of the edible coating solutions and the control samples ($p>0.05$) despite the control samples showing a sharp decrease in the L*.

A positive b* value indicates yellowness (Ly *et al.*, 2020). There was a significant difference in the b* value obtained from the sliced pears ($p<0.05$), among the various edible coating solutions and when compared to the control sample. Specifically, solution 5 showed a significant difference ($p<0.05$) from the other 4 edible coating solutions. Solution 5 (Sodium alginate/ glycerol/ ascorbic acid/ apple pomace extract) had the lowest b* value compared to the other edible coating solutions while the control sample had the highest b* value. This is illustrated in Figure 9b above.

An increase in the* value was observed in the sliced pear samples from the initial a* value indicating a shift of surface colour from blue to red as illustrated in Figure 9c above. When comparing the edible coatings to the control sample, a significant difference was observed ($p<0.05$), suggesting that edible coating solutions can reduce reddening on the surface of sliced pear. Solution 4 (1% sodium alginate/ 1.5% glycerol/ 1% citric acid/5% apple pomace) showed a significant difference ($p>0.05$) on the* compared to the other edible coating solutions. It had the highest a* value among the edible coating solutions suggesting that the combination of apple pomace and citric acid is less effective in preventing an increase in a* value.

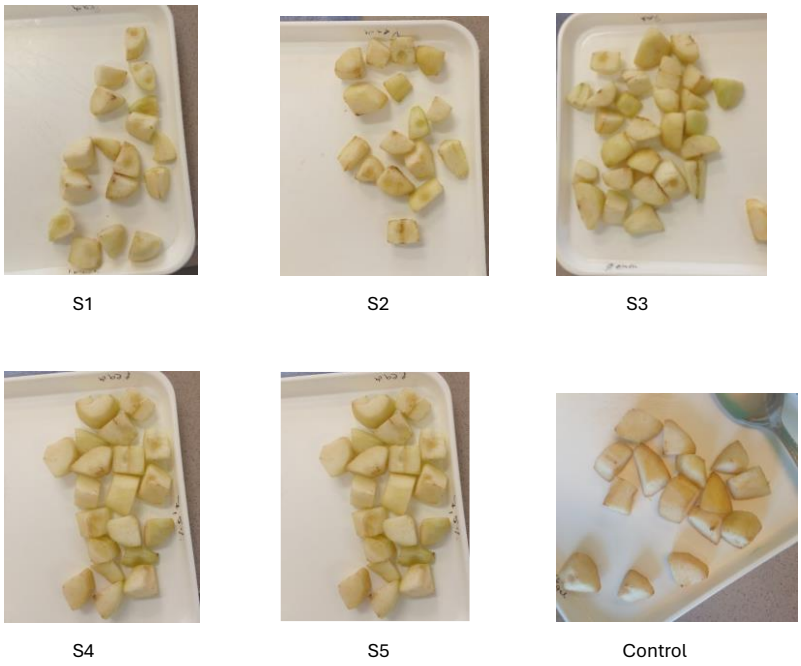
Furthermore, Solutions 1 and 5 maintained the same a* value in the pear samples as the original samples suggesting that the solutions can successfully prevent reddening of the apple samples.

During the 5-day storage period, an increase in the browning index from the initial to the final day was observed as illustrated in Figure 9d above. The edible coatings exhibited a significant effect on browning when compared to the control solution. The control sample had the highest browning index, which can be ascribed to the activity of the enzyme polyphenol oxidase (EC1.14.18.1) in catalysing the oxidation reaction. In pear, the effect of enzyme peroxidase when Hydrogen Peroxide causes oxidation has been documented (Richard-Forget and Gauillard, 1997). Notably, the edible coatings, Solutions 5 and 1 were not significantly different ($p<0.05$), both solutions demonstrated higher browning index values compared to other solutions. Solutions 4, 2, and 3 were also not significantly different from each other ($p<0.05$).

The reduced browning, L*, a*,b* of sliced pears in the presence of apple pomace extract in an edible coating solution may be because of its high phenolic compound, which has strong free radical scavenging activity, leading to potent antioxidant capabilities (Lu and Yeap Foo, 2000). Additionally, citric acid, inactivates the copper ion in the enzyme polyphenol oxidase, thus preventing oxidation, while ascorbic acid converts brown-coloured quinones into colourless forms (Ali *et al.*, 2014). The antioxidant ability of sodium alginate solution is attributed to its ability to act as a barrier against oxygen, and the chloride ions present in the calcium chloride solution inhibit the activity of polyphenol oxidase by interacting with the copper at its active site (Barrett and Garcia, 2002; Najafi Marghmaleki *et al.*, 2021).

The edible coating solutions including solutions 4 and 5 into which apple pomace extracts were utilised, demonstrated the ability to reduce browning, however, it could not prevent surface colour change and browning fully in pear samples as observed in Figure 10 below.

Figure 10: Colour Values (a*,b*, L*) and Browning Index in control and coated sliced apples during 5-day Storage at 4^0C±1. S1-1% Sodium Alginate+ 1.5% glycerol; S2- 1% Sodium Alginate+ 1.5% glycerol+ 1% Citric acid; S-3 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid; S4- 1% Sodium Alginate+ 1.5% glycerol+ 1% Citric acid+ 5% Apple Pomace Extract; S5- 1% Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5% Apple Pomace . *(Source: Own Work)*



5.4 Texture Results

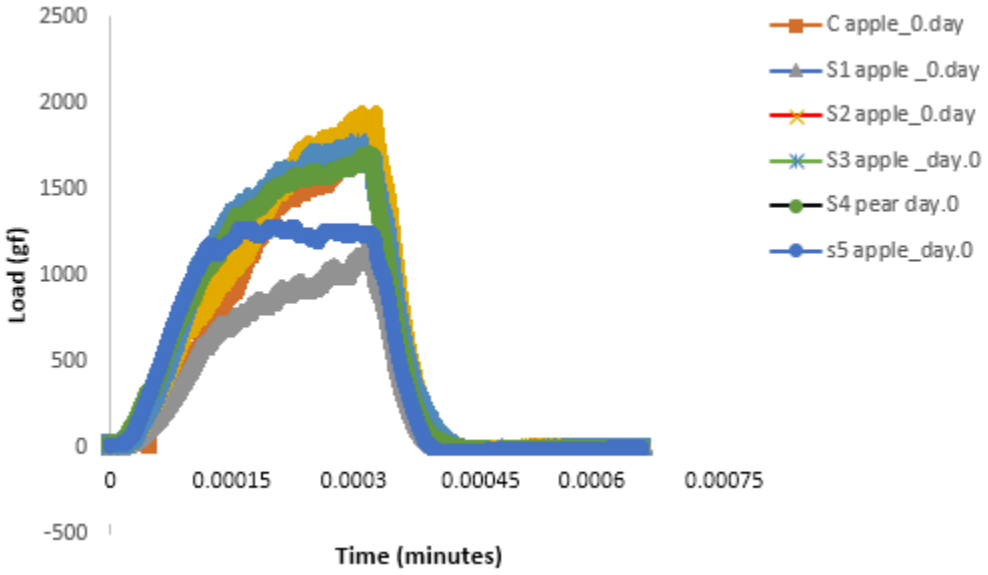
Texture Profile analysis was carried out on the apples to determine the texture of the sliced apples and pears during storage. From the texture profile analysis, the load vs time graph was obtained from which the hardness, adhesiveness, and stringiness are determined (Liu, Cao and Liu, 2019). Hardness, a measure of the amount of force needed to compress an item or product to a given degree, and springiness which reflects how well a product regains its shape from deformation are the texture parameters that were tested. Adhesiveness also known as stickiness, which is a measure of the extent to which a sample product adheres to teeth after chewing was also determined (Pascua, Koç and Foegeding, 2013).

5.4.1 Sliced Apple Texture

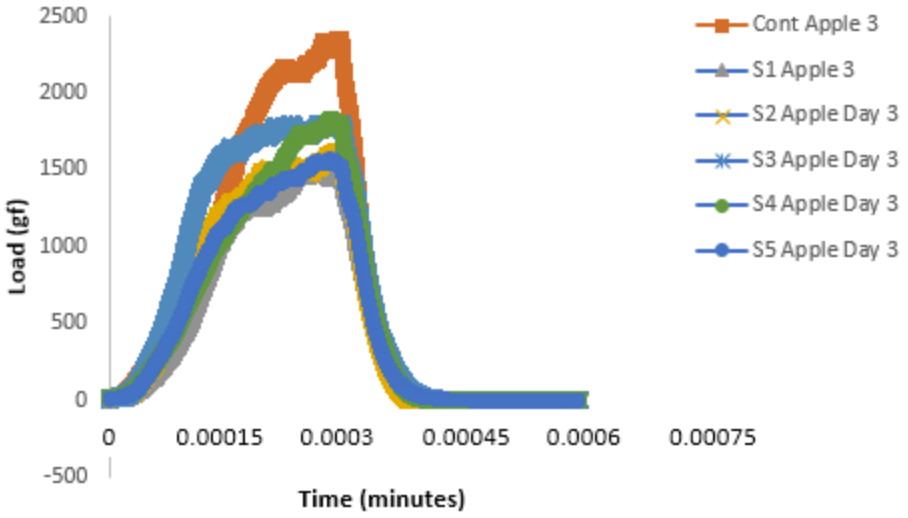
Figure 11 below shows the load vs time diagrams of sliced apple samples on day 0 (11a), day 3 (11b) to day 5 (11c). From the diagram, the highest peak in the curve which is the maximum

amount of force required to compress the sample is observed. The load (gf) of the control sample continuously increased while in the edible coated samples, it continuously decreased corresponding to increased hardness and reduced hardness respectively.

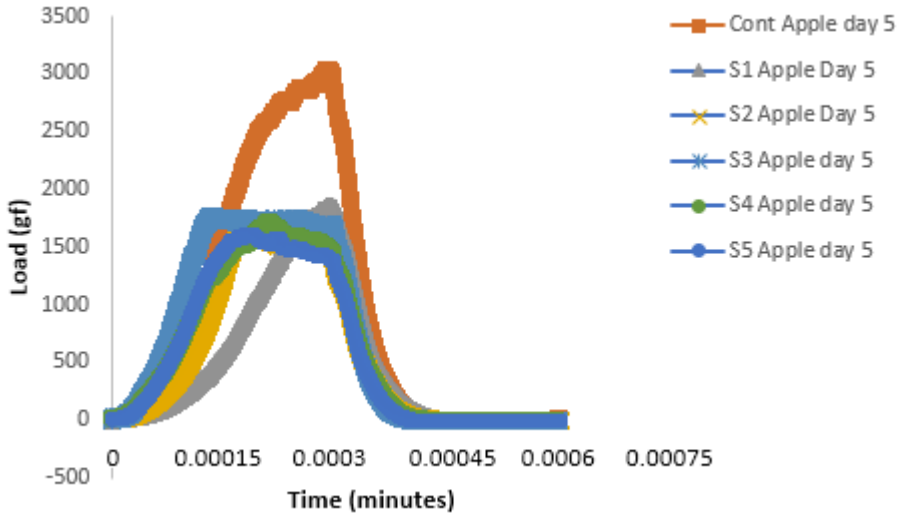
Figure 11. Load vs Time graph for control and coated sliced apples during 5-day Storage at 40C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. *(Source Own Work)*



(a)



(b)

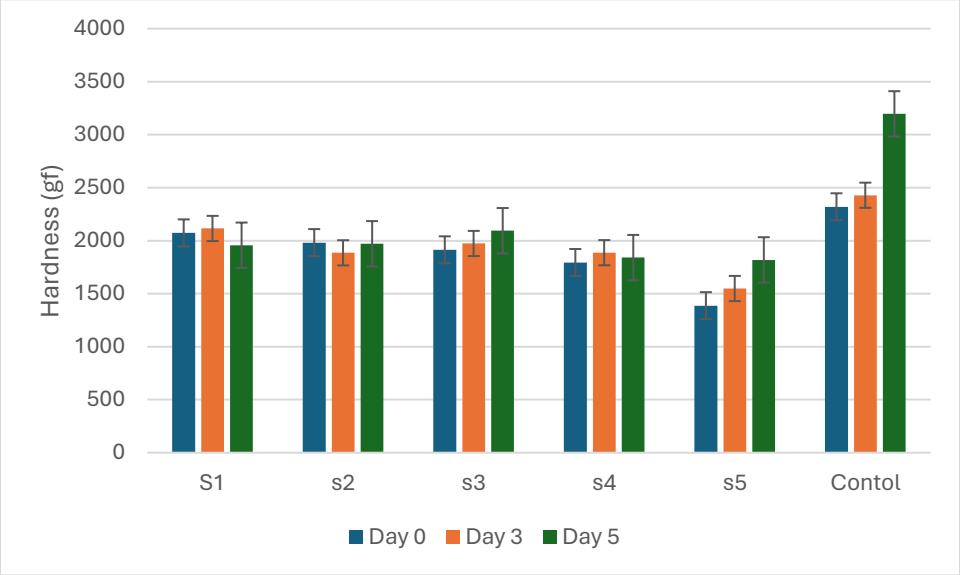


(c)

During the 5-day storage in the refrigerator, the hardness of the control sliced apples increased as illustrated in Figure 12 below. There was a significant difference between the control sample ($p < 0.05$) and the coated apple slices. The high level of hardness in the control samples may be attributed to the wound healing mechanism that occurs at 4^0C, of sliced apples which results in the building up of a lining layer on the surface of slices (Wu *et al.*, 2017). The control apple slices

were also dipped in calcium chloride solution, and research has shown that the presence of calcium ions, contributes to cell wall stability through cross-linking with pectin (Willats *et al.*, 2001).

Figure 12. Hardness (gf) in control and coated sliced apples during 5-day Storage at 4^0C±1. S1- 1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD. *(Source: Own Work)*

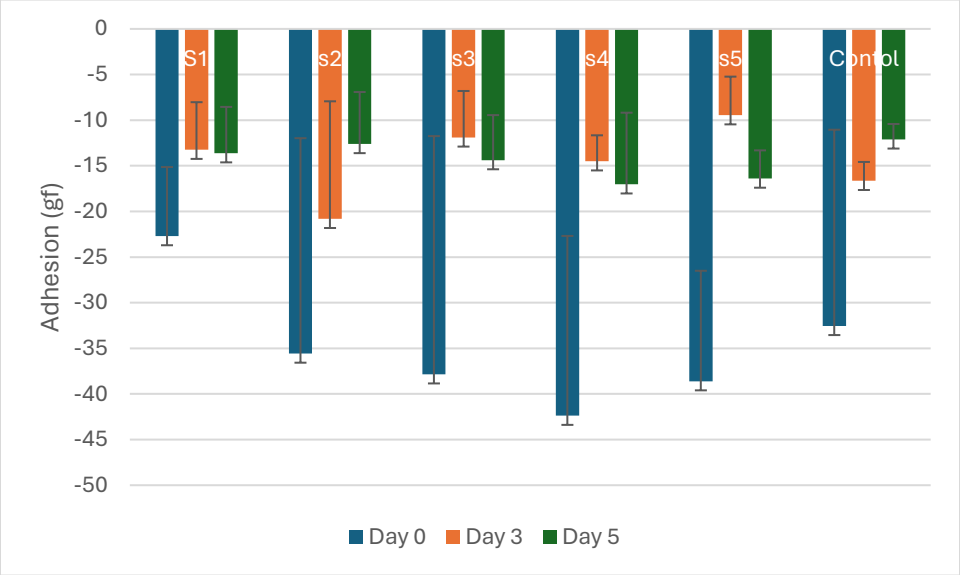


Despite the hardness of solution 5 edible coated apple slices being the lowest, there were no significant differences ($p>0.05$) among the hardness resulting from the use of edible coating solutions on sliced apples. The hardness was reduced in all the edible-coated apple slices. The texture of edible-coated sliced apple samples may be due to loss of moisture and, breakdown of pectin which is located in the fruits's cell wall and is responsible for firmness. Research has shown that pectin contributes to fruit cell wall structure, through cross-linking of calcium ions with de-esterified homogalacturonan (a type of pectin), causing cell wall stability (Willats *et al.*, 2001). During fruit ripening and storage even at refrigeration temperature, pectin is broken down by pectin-degrading enzymes such as endo- polygalacturonase resulting in softening and loss of hardness of cells in fruits (Wang *et al.*, 2018).

There was a significant increase ($p< 0.05$) in the adhesion of the sliced apple slices from day 0 to day 3 in all the coated and control apple slices, however, there was no significant difference

(p>0.05) in the adhesion of all coated sliced apples and the control samples, as illustrated in Figure 13 below. The stringiness of the sliced apple samples also increased with a significant difference observed from day 3 to day 5 (p<0.05) in each edible coated sliced and the control samples.

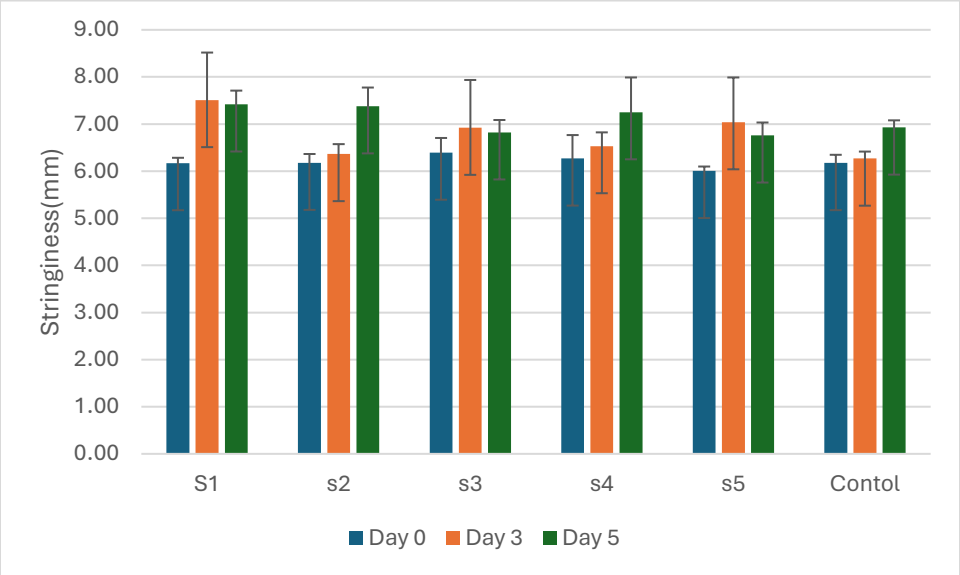
Figure 13. Adhesiveness (gf) in control and coated sliced apples during 5-day Storage at 4^0C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD*(Source: Own Work)*



There was also no significant difference in stringiness among all the edible coated and control sliced apple samples (p>0.05). There was however an increase in stringiness in all sliced apple samples from the initial day to the final day as illustrated in Figure 14 below. The increase in adhesiveness and stringiness may be attributed to pectin breakdown in the fruit's cells as previously discussed.

Figure 14. Springiness (mm) in control and coated sliced apples during 5-day Storage at 4^0C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD

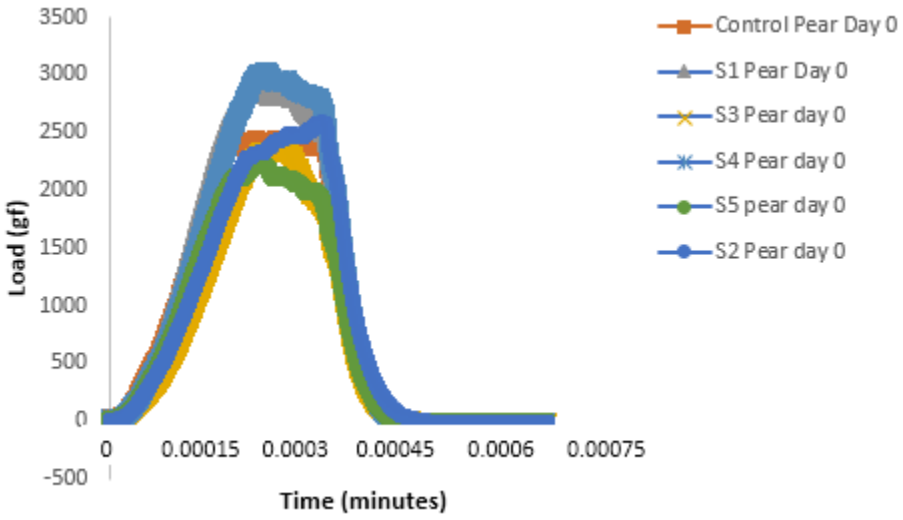
(Source: Own Work)



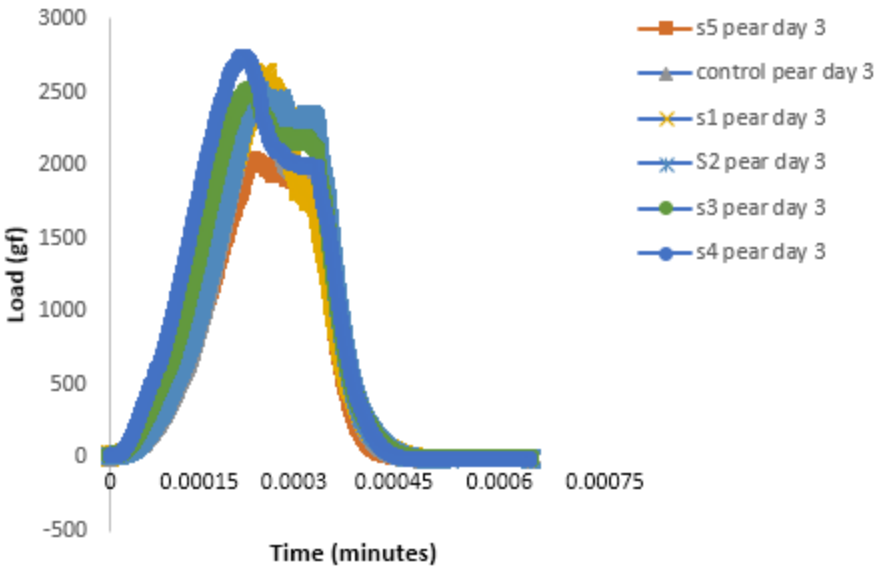
5.4.2 Sliced Pear Texture

Texture profile analysis was carried out on coated and control sliced pear samples. The load vs time graph was obtained and the hardness of the sample is observed as the highest peak in the curve. The change in hardness on days 0, 3, and 5 for each edible coating solution and the control is presented in Figure 15 below.

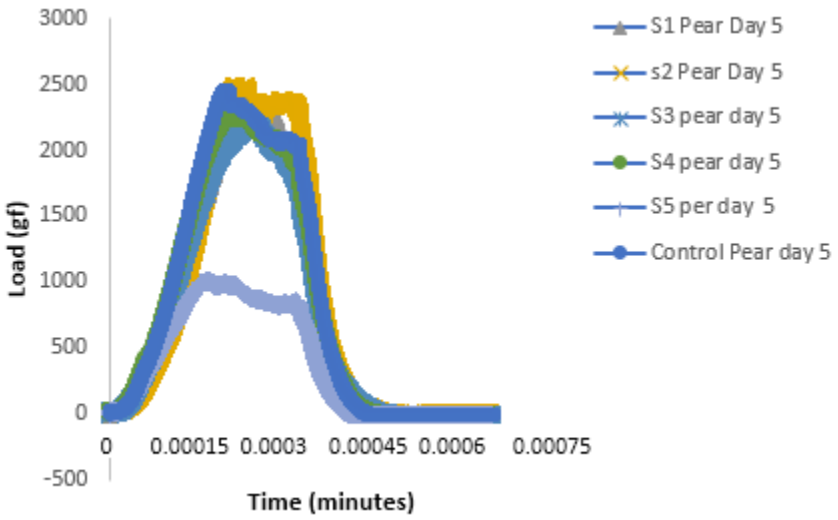
Figure 15. Load vs Time graph for control and coated sliced pear during 5-day Storage at 40C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. *(Source Own Work)*



(a)



(b)

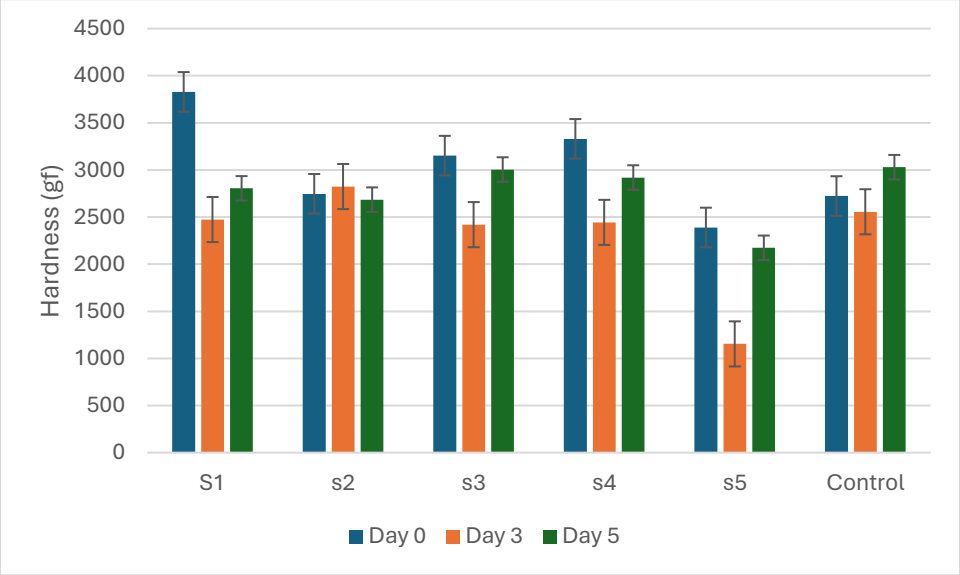


(c)

Hardness in the sliced pear samples decreased during the 5-day storage period as shown in Figure 16 below. The decrease in hardness of pear samples may be attributed to moisture loss from the sliced samples and enzymatic pectin hydrolysis (Wang *et al.*, 2018). Sliced pear samples coated with Solution 5 (1%sodium alginate/ 1.5% glycerol/ 0.5% ascorbic acid/ 5% apple pomace) had

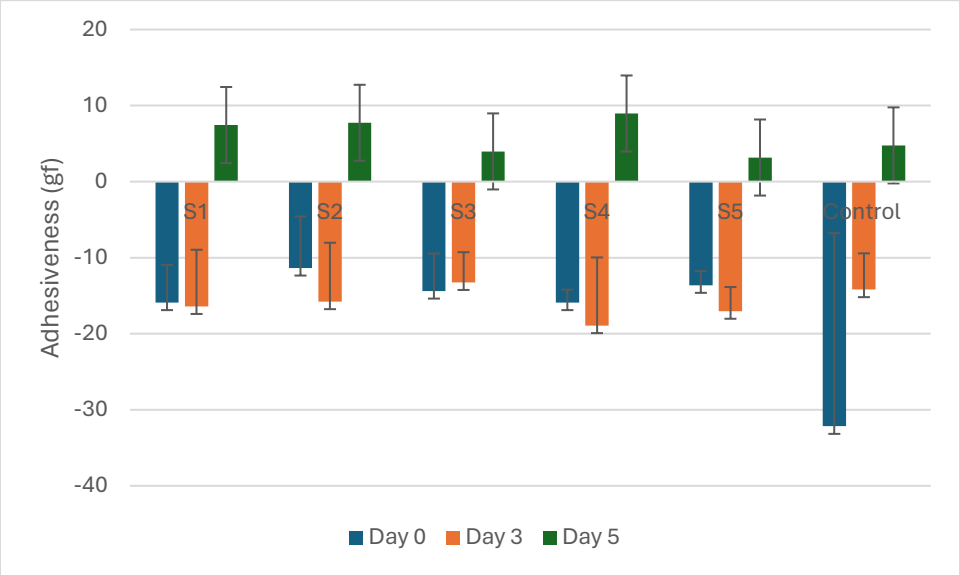
the least hardness 1153.984 (gf). When compared to solution 4 which contained (1%sodium alginate/ 1.5%glycerol/ 0.5% citric acid/ 5% apple pomace), solution 5, solution 4 functioned better to prevent softening of the samples. This may be attributed to the presence of citric acid in solution four which has been recorded to be better in preserving fruit firmness when combined with calcium ions than ascorbic acid in the presence of calcium ions (Wasim Aslam, 2018).

Figure 16. Hardness (gf) in control and coated sliced pears during 5-day Storage at 4^0C±1. S1- 1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD *(Source: Own Work)*

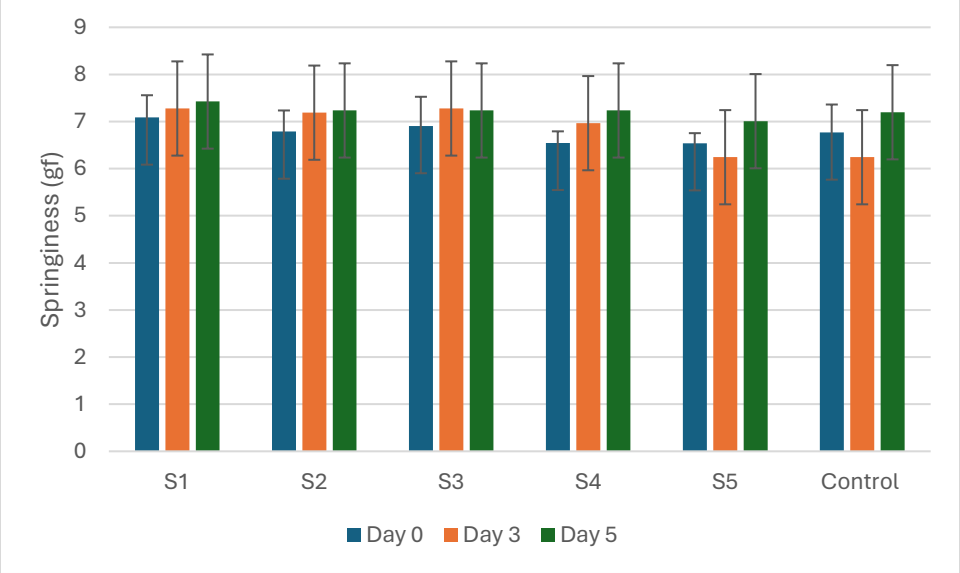


There was an increase in adhesiveness in all edible coated sliced pear samples over the 5-day storage period, however, the difference was not significantly different ($p>0.05$) among the coated sliced pear samples and when compared to the control ($p>0.05$). Springiness also increased during the 5 days and this increase was significant ($p<0.05$) in each of the edible coating solutions and the control, however, there was no significant difference ($p>0.05$) between the springiness of the coated pear slices when compared to the control. The slight increase in both springiness and adhesion may be due to loss of moisture in the samples and the enzymatic breakdown of pectin in the fruit's cell wall (Wang *et al.*, 2018). Adhesiveness (gf) and springiness (gf) are illustrated in Figure 17 a and b respectively below.

Figure 17. Adhesiveness (gf) (a) and stringiness (mm) (b) in control and coated sliced pears during 5-day Storage at 4^0C±1. S1-1%Sodium Alginate+ 1.5% glycerol; S2- 1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid; S-3 1%Sodium Alginate+ 1.5% glycerol+ 0.5 %Ascorbic acid; S4-1%Sodium Alginate+ 1.5% glycerol+ 1%Citric acid+ 5%Apple Pomace Extract; S5- 1%Sodium Alginate+ 1.5% glycerol+ 0.5 % Ascorbic acid+ 5%Apple Pomace Extract. Error bars represent ±SD *(Source: Own Work)*



(a)



(b)

6. SUMMARY

Sliced fruits such as pears and apples offer convenience and freshness to consumers, but their shelf-life is shorter due to processes like cutting and peeling, leading to issues like surface colour loss, browning, texture loss, and off- flavours (Yousuf and Qadri, 2020; Yousuf, Sun and Wu, 2022). Edible packaging, an alternative to traditional methods such as Modified Atmosphere Packaging, has been explored to extend the shelf-life of sliced fruits by regulating transpiration, and physiological disorders Edible biopolymers such as polysaccharides (alginate), proteins, lipids, and food industry by-products example apple pomace are utilised in edible packaging manufacture, with additives example, example plasticizers like glycerol (Salgado *et al.*, 2015; Chiralt *et al.*, 2020; Pedro *et al.*, 2022).

Apple pomace, a by-product of the apple industry, poses a disposal challenge, but research suggests it has antioxidant and antimicrobial properties when used in edible film manufacture due to its high phenolic compounds (Raudone *et al.*, 2017; De La Rosa *et al.*, 2019; Cömert, Mogol and Gökmen, 2020; Lan *et al.*, 2021).

This study aimed to extend the shelf-life of sliced ‘Idared’ apples and ‘Conference’ pears using an edible coating made from apple pomace extract, addressing the disposal challenge of apple pomace. The apple pomace extract was used in two different edible coating solutions: one containing citric acid, sodium alginate, and glycerol, and in the other ascorbic acid replacing citric acid. Additionally, the effect of the apple pomace extract was also compared to that of a control sample containing distilled water and three other edible coating solutions containing different combinations of citric acid, ascorbic acid, glycerol, and sodium alginate.

Quality assessment such as browning, colour parameters, weight loss, and texture was conducted during the storage period of five days at 4^0C±1, to investigate the impact of the different edible coating solutions.

% Weight loss was determined by deducting the final weight loss from the initial weight loss and calculating it as a % of initial weight loss. In the apple slices, the edible coating solutions were not effective in preventing weight loss. The control sample had the lowest % weight loss (14%) attributed to the wound healing process of sliced apple, and among the edible coating solutions, the solutions containing apple pomace extract (4,5) had the lowest % weight loss which can be

attributed to the pectin present in the apple pomace leading to the formation of a flexible network. In the pear slices, the edible coatings were not effective in reducing weight loss, despite the control having the highest % weight loss and the 4th solution containing apple pomace having the lowest % weight loss.

The a*, b*, and L* values were determined using the Chroma Meter CR-400, and the browning index was calculated using these values. During the 5-day storage at 4^{0}C±1, all sliced apple samples showed a decrease in lightness (L*) values, with the control solution exhibiting the highest decrease. However, all five edible coating solutions maintained consistent lightness values. The b* and a* values increased during storage, with the control sample showing the highest increase in yellowness and redness. Solutions with apple pomace extract exhibited the least increase, indicating better colour stability. The browning index increased in all samples, but significantly less in the edible coating solutions compared to the control. Apple pomace extract, citric acid, and ascorbic acid contributed to reduced browning. However, none of the solutions fully prevented browning in the sliced apples.

In the sliced pear samples, the lightness L* value remained consistent during the storage period and no significant difference was observed between the edible coatings and the control. The edible coating solutions reduced yellowness (b*) and redness (a*) compared to the control, with solution 5 showing the least b* value. However, solution 4 had the highest a* value among the edible coating solutions. Browning index increased significantly less in coatings than the control, this may be attributed to the apple pomace extract's antioxidant properties. Citric acid and ascorbic acid also contributed to oxidation prevention. However, none fully prevented browning or colour change in the pears.

This study also investigated the texture of sliced pear during the 5-day storage at 4^{0}C±1. Texture Profile Analysis was carried out and load (gf) vs time graphs were obtained. The hardness, adhesiveness, and springiness were the texture parameters obtained from the analysis. Results of the sliced pear samples revealed a decrease in hardness of sliced pear samples during the 5-day storage, attributed to moisture loss and enzymatic pectin hydrolysis. Solution 5 (1% sodium alginate, 1.5% glycerol, 0.5% ascorbic acid, 5% apple pomace extract) had the least hardness indicating that solution 4 (1% sodium alginate, 1.5% glycerol, 0.5% ascorbic acid, 5% apple pomace extract), has better preservation of firmness. This can be attributed to citric acid’s superior

ability to preserve fruit firmness when combined with calcium ions. Adhesiveness and springiness increased in all coated pear samples over the 5-day storage, but the differences were not significant among the edible coating solutions and when the edible coating solutions were compared to the control. Suggesting moisture loss and pectin breakdown as the cause of the increase in springiness and adhesiveness.

For the sliced apple samples, the control samples showed increasing hardness, possibly due to the wound-healing process of wounded apples and the crosslinking of calcium ions with pectin in the cell wall. Coated samples, on the other hand, showed decreased hardness, and there were no significant differences in the samples in which apple pomace extract was used when compared to the edible coating solutions containing sodium alginate, glycerol, and antioxidants. Increased adhesiveness and stringiness were observed, attributed to pectin breakdown in the cell wall, a process accelerated during storage and fruit ripening.

Overall, the study suggests that apple pomace extract has the potential as an edible coating to extend the shelf-life of sliced fruits, even when used with antioxidants and plasticizers. However, further investigation and research are needed on the full optimization of the apple pomace extract as an edible coating.

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