The Effect of Lipid/Hydrocolloid Coatings on the Postharvest Storage Quality of 'Golden Delicious' Apples

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Abstract

The performance of three different lipid/hydrocolloid coatings was tested on Golden Delicious apples. The coatings consisted of a mixture of lipid, wax, and various gum blends. The three treatments were compared to an uncoated group (control). Both objective and sensory tests were performed to determine the shelf-life stability of the apples. Objective results indicated that all three treatments significantly decreased ($P<0.0083$) the respiration rates of the apples when compared to the control. The treatment groups also significantly ($P<0.0083$) maintained the texture of the apples along with a lower ($P<0.0083$) starch degradation rate. The treatment groups also significantly ($P<0.0083$) maintained the malic acid level in the apple. There were no significant differences ($P>0.0083$) among the groups with regard to soluble solids and fresh weight loss. Externally, the treated apples had a significantly greener hue (Hunter color "a") than the control apples, however, there were no significant differences ($P>0.0083$) in yellow color (Hunter color "b") between the groups. Sensory results indicated that the treated apples were firmer, crisper and juicier ($P<0.0083$) than the control apples. However there were no significant differences ($P>0.0083$) in the sweetness, tartness, and appearance of all of the groups. Overall, the derived coatings could serve as a resource for extending and maintaining the shelf life of perishable fruit.

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Chapter 1: Introduction

In recent years, the exploration of extending and improving shelf life and overall quality of fruit has been an important part of research. Investigators have found and have been finding many different ways to achieve overall quality of fresh fruit. The focus of these findings has been centered on creating different coatings for fresh fruit. The formulations for these coatings are still being studied and perfected to establish the right balance between freshness and off flavors.

The usage of coatings to extend the shelf life of fresh produce is a cheaper method when compared to other preservation methods. These coatings can retard and even control the rate of respiration of the fruit and eventually control the rate of decay. Before coatings became widely used, temperature and humidity control were the only means that would help to regulate the rate of respiration and ripening (Daniels, 1973).

Edible coatings are used primarily for improving overall food quality, extending shelf life, and improving economic efficiency of packaging materials (Kester and Fennema, 1986). Coatings can help with the foods' respiration rate, ripening, and overall flavor (McHugh and Senesi, 2000). These physical properties will affect the shelf life of the fruit, and slowing down these processes will make available a more shelf-life stable product for the consumer.

The consumer also looks for certain characteristics when buying fresh produce. Some of these characteristics are price, size and shape, color, flesh texture, dessert quality, and cooking quality (Smock and Neubert, 1950a). Edible coatings can help preserve and maintain the aforementioned characteristics. Edible coatings are also inexpensive because they will help in diminishing any costs of losing fruit because of poor storage conditions. They also may help in maintaining the color of the fruit by controlling senescence and ripening and by reducing respiration (Sumnu and Bayindirh, 1995). Some edible coatings can help with a slower ripening process, resulting in improved fruit texture (Drake et al. 1987).

Chapter 2: Review of Literature

2.1 Types of Apples

There are over 1800 varieties of apples, but each apple serves a specific purpose because of their distinct characteristics. However, only about twenty cultivars are not grown commercially in the United States (Root, 1996). Apples differ in both tree and fruit characteristics. Yield, age of bearing, shape and size of tree, vigor of tree, annual bearing, fruit drop, evenness of fruit ripening, insect and disease resistance, pollination requirements, and winter injury are just some of the characteristics that many fruit growers look for in a tree. These characteristics are important when determining desirability and acceptance for the fruit grower. When discussing fruit characteristics, it is important to include size and shape of fruit, color, flesh texture, dessert quality, cooking quality, storage life, and storage disorders. Storage life and quality of apples is very important to the consumer when buying apples.

There are fourteen varieties of apples that account for 90% of the production of apples in the United States and out of that fourteen only five account for most of the world apple production. Delicious, Golden Delicious, McIntosh, Rome Beauty, and Granny Smith are those five cultivars, but a majority of other apples come from these parent apples. For example, Gala apples are a cross between Golden Delicious and Kidds Orange, while Jonagold is a cross between Golden Delicious and Jonathon apples. Fuji apples are a production of the crossing of Delicious and Ralls Janet.

Golden Delicious apples originated in 1900 in West Virginia, but are not related to the Red Delicious apple. Golden Delicious apples usually range in size from medium to large fruit with a yellow color of the skin. This variety of apple usually is conic shape and has a firm, crisp, tender flesh texture with medium acidity. This apple has a cold storage season of 90-120 days with a maximum of 150 days. They have a sweet, delicate flavor and tend to store well (Root, 1996). This apple is a parent of many apples such as Jonagold, Spingold, Gala, and Mutsu. Gala apples have a thinner and less dense cuticle as compared to other apples, mainly Golden Delicious apples. Therefore, some coatings may not be as effective on Gala apples than on Golden Delicious apples

Red Delicious apples were discovered in 1881 near Peru, Iowa. There are 100 known strains of Red Delicious that have been propagated and grown in the United States. Red Delicious apples are sweet and mild, and are usually used for eating and not cooking. The Red Delicious tree is a productive and adaptable to different growing conditions (Root, 1996).

Red Delicious apples are medium red in color with a 100% blush and are oblong conic in shape with a crisp, juicy, mealy flesh texture with a low degree of acidity. The apple is medium to large in size and has a cold storage season that is very similar to the Golden Delicious apple of 90-120 days with a maximum of 180 days (Smock and Neubert, 1950a).

McIntosh apples are found mainly in New England and eastern-Canada. This apple is a tender-fleshed, aromatic apple (Root, 1996). It is a medium sized apple with medium red color. It is described as a roundish oblate in shape and tender and juicy in taste, mainly due from its medium acidity. McIntosh apples ripen early and have 120-150 days of cold storage. McIntosh is a parent of such apples as Spartan, Empire, and other hardy modern cultivars (Root, 1996).

2.2 Chemical Properties of Apple Fruit

2.2.1 Water

Water is important for the eating quality and the actual size of the fruit. The water content helps determine the eating quality of the apple. An increase in water within the fruit will determine the size of the apple. An increase in size of the fruit usually indicates an increase in water content because when the fruit is on the tree, there is a slight increase of water as the fruit develops. However there is a slight decrease in water content after ripening peaks, but as that occurs, there is an increase in the percentage of total solids (Smock and Neubert, 1950b). The amount of water within the fruit will vary for each variety.

Transpiration is the loss of water from living tissues in vapor form. Water losses occur from the leaves of the fruit, but also from the actual fruit itself. If a fruit is small in size there is usually an increase in transpiration because of the great surface area per unit of weight than larger fruits.

At harvest time apples have on average about 84% water. By the time most apples are severely shriveled and can no longer be marketed, there has been a loss of only 5-7% water in the fruit. Water loss causes a lower quality apple because with the water loss, the apple could be shriveled which is not appealing or desirable to the consumer. There is also a reduced eating quality of the apples if there is a significant water loss making the apples less crisp and turgid.

2.2.2 Sugars

Sugars are a major constituent within the apple and are very important to the solid material in the flesh of the apple. Fructose, glucose, and sucrose are the sugars that are found in the flesh of the apple. The variety of the apple determines the exact proportions of each of these sugars in the flesh. Fructose and glucose increase in absolute amount and in percentage of fresh weight as the fruit develops on the tree (Smock and Neubert, 1950b). Sugars are manufactured by photosynthesis in the leaves of the apple. The exact amount of sugar manufactured is not known. There is some chlorophyll present in the skin of the young fruit, so some manufacturing could occur.

The amount of sugar present in the apple is due to many different factors. The location of the apples is important in the amount of sugar that is present. Even from orchard to orchard there could be differences in sugar content. This could be due to the soil or the climatic variations. The amount of sugar can also vary between season to season within the same variety in the same location. The temperature and light characteristics greatly affected the sugar content within the apple (Smock and Neubert, 1950b).

2.2.3 Starch

Starch consists of two components, amylopectin and amylose. Amylopectin is a branched structure while amylose is a linear structure. It is not known which of these two compounds predominates in apples.

Starch is deposited early in the apple fruit's development on the tree. Starch is known as a storage material since it must be broken down before it can be used in the fruit's metabolism. Starch deposition begins in the cell layers near the skin and proceeds near the core. Starch is usually found near the core of the apple and as the fruits mature, the starch begins to hydrolyze into sugars. Starch begins to disappear from the core areas and last from the areas just under the skin. This conversion of starch to sugars takes place rapidly during ripening (Smock and Neubert, 1950b).

The starch content of apples can vary from variety to variety and from season to season in a given variety. Temperature and light could also be a factor in the amount of starch. If there are low temperatures and low light, then photosynthesis cannot take place as efficiently, thereby causing a decrease in sugar production (Smock and Neubert, 1950b).

2.2.4 Acids

Malic acid is the main acid that is found in the fruit of the apples. Ascorbic, oxalic, and lactic acids are present in such small amounts such that their association is insignificant to the total acidity of the fruit. The acidity of the apple is important because it affects the eating and cooking quality of the apple.

Acidity is usually expressed as total titratable acidity. The amount of acid present in the apple increases steadily as the fruit matures on the tree just before harvest when there is a slight decline. The titratable acidity steadily decreases as the fruit matures on the tree. The pH rises steadily but the increase is not very significant.

Acidity varies from variety to variety. There could be a difference in the percent of acidity is great as .38-1.11% between each variety (Smock and Neubert, 1950b). There also is a difference of acidity between season to season. A season with high light intensity and duration has resulted in fruits with high acidity as well as high sugar content (Smock and Neubert, 1950b). An apple with high sugar and high acidity was usually accompanied by a low astringency and therefore, a sweet, or mild tasting apple.

2.2.5 Color

Young apples are green in color. As the fruit matures a yellow or red color develops. As the apples are maturing on the tree, a yellow color will be produced. Apples are picked when at least some of yellow is showing through. This yellow color is described as the ground or underlying color. If an apple has a red color, such as Red Delicious, then that color is described as the surface color. However, if an apple is yellow in color, such as Golden Delicious, there is an absence of surface color.

The amount of leaves and the ratio of leaves to fruit can affect the ground color of the fruit. Apples such as Jonathon require at least 30 leaves per fruit and any fewer leaves result in a greenish ground color at harvest. However, more than 40 leaves per fruit do not result in any additional development of ground color (Smock and Neubert, 1950b).

Temperature can affect the color development of apples. Temperature is a major factor in the efficacy of photosynthesis within the plant. Sugar formation is an important factor in the development of the color of the fruit and photosynthesis is key to the formation of sugar. Low temperatures are necessary for the conversion of sugar into anthocyanins. Reducing the respiration rate, which is a result of the low temperatures, may be responsible for the sugars accumulating.

2.2.6 Ripening

Many physiological changes occur during the ripening process in fruits. As soon as the fruit is detached from its environment, the fruit begins senescing, or aging. Proper handling of storage, environment, and temperature are important to control the rate at which senescing occurs.

Apple is a climacteric fruit. During the transition from mature to ripening, there is a rapid increase in respiration and ethylene biosynthesis. Apples that are physiologically mature have the ability to ripen following harvest. Ripe fruit have physical characteristics associated with good eating quality (texture, aroma, and flavor). Ideally apples are harvested just before the climacteric and they ripen either during or after storage (Klein, 1992).

The increase of ethylene production and sugars also trigger the ripening process. Ethylene can cause accelerated ripening and early senescence of fresh fruits during storage. Formation of ethylene may be the result of oxidative decarboxylation of the α-keto acid analogs of methionine. However, if there is an increase production of ethylene, off flavors and aromas can occur in the fruits (Klein, 1992).

The softening of the tissue of the fruits is another result from the ripening process. Softening is triggered by ethylene production, and increase in firmness retention was found in stored apples when the environment contained an absence of ethylene (Klein, 1992). This increase in ethylene production can decrease firmness and, therefore, a decrease in acceptability of the fruit.

There are many factors that can affect the texture of a fruit: the type of commodity, variety, maturity, ripeness, size, storage conditions, temperature, humidity, and atmosphere. Firmness and crispness are desirable character traits for apples, therefore controlling the atmosphere and the temperature is important to maintain the firm and crisp characteristics that are desirable.

2.3 Influence of Fertilization and Mineral Nutrition on the Quality of Fruits

There have been known effects of nitrogen, potassium, magnesium, phosphorous, and boron on the quality of fruits. These elements have a great effect on quality because of their interaction with calcium in the fruit cells. Calcium occupies a central position in fruit nutrition and the quality of fruit (Bramlage et al., 1979; Sharples, 1979).

Bitter pit is a disorder that was found to be associated with low calcium levels in apples (Bramlage et al., 1979), thereby affecting the quality levels of the fruit. Cork spot is another disorder that is associated with low calcium levels in the fruit. In the warmer growing seasons, cork spot is the primary concern, while bitter pit is the primary concern in the cooler seasons.

There have been many approaches to improving fruit calcium status to help reduce the incidence of physiological disorders. Since calcium is limited in soils with a low pH, there have been regular liming programs in areas that have a low pH soil. Calcitic lime is preferred over dolomitic lime because dolomitic lime does not provide a good source of calcium to the soil. Calcium nitrate is another possibility as a source of fertilizer.

Foliar sprays with calcium salts seem to be the most direct way to provide the fruit with the most adequate calcium levels. It was shown that a single application of 2.5

or 5 percent calcium chloride made two weeks before harvest controlled Spartan apple breakdown (Bramlage et al., 1979).

Other disorders can be linked to soil nutrition. Low temperature breakdown is a disorder that affects many apples stored below 4°C. Apples such as Bramley's Seedling apples are very susceptible to low temperature breakdown and the mineral composition of the fruit can also be related to the susceptibility of these disorders. Apples that have low phosphorous status can be more susceptible to these disorders (Yogaratnam and Sharples, 1982). Since calcium sprays are routinely incorporated into the summer spray programs for the apple orchards, phosphorous sprays may be the solution to the low phosphorous levels within the fruit.

Yogaratnam and Sharples (1982) found that spraying with a suitable form of phosphate early in the season is an efficient and practical method of raising the phosphorous status of the apple trees. Therefore, phosphorous sprays could be used to improve the storage capability of Bramley's Seedling apples. The use of phosphorous sprays with the calcium sprays raised the phosphorous levels while increasing the calcium levels.

2.3.1 Organic Farming

Organic apple production does not involve the use of synthetic mineral fertilizers for soil preparation, pesticides, herbicides, fungicides, and growth regulators (DeEll and Prange , 1992). Organic production relies mostly on crop rotation, crop residues, mechanical cultivation, thermal disinfection, manure, compost, guano, and biological pest control (Basker, 1992). All of these methods help maintain soil productivity and fertility, and at the same time control insects and pests.

Organic processes can alter the postharvest behavior of apples as compared to conventionally grown apples. DeEll and Prange (1992) reported that organic fertilizers had different effects on sugar and acid content in different apples. These organic fertilizers were found to decrease the sugar content in Cox's Orange Pippin and had no effect on Golden Delicious. When using poultry and chicken manure as fertilizer for the apple production, the acid content of Cox's Orange Pippin increased. However, when using cattle manure the acid content of Golden Delicious apples decreased, while when using poultry manure, the acid content increased.

DeEll and Prange (1992) performed a study to investigate the postharvest quality and sensory attributes of organically and conventionally grown McIntosh and Cortland apples stored in refrigerated rooms or in controlled atmospheres. They ultimately found that there was no consistent quality or sensory differences between organically and conventionally grown apples. The differences that they found tended to be influenced more by cultivar and storage conditions than by the production method.

2.4 Post Harvest Effects on Apples

2.4.1 Scald

Storage scald is a postharvest disorder of apples that is characterized by brown patches that appear on the skin during storage. Scald is produced from the progressive internal browning of hypodermal cells. The browning extends through the first five or six layers of the hypodermis. Epidermal cells are not usually affected, unless the disorder is severe and the cells become sunken and collapse. It has been found that a naturally occurring terpine, α-farnescene, which is found in the cuticle of apples, is linked to the occurrence of scald in storage of apples (Huelin and Coggiola, 1968). The compounds that are directly responsible for scalding, conjugated triene hydroperoxides (CTH), are a result from the oxidation of α-farnescene. Lipoxygenase combined with α-farnescene has also been linked to increase of scald incidence (Feys et al., 1980).

There is a relationship between the amount of scald produced and the amount of oxidation of α-farnescene in the apple cuticle. If there is an antioxidant present to prevent the oxidation of α-farnescene, then the incidence of scald on the apples decreases (Anet and Coggiola, 1974). There are wide ranges of antioxidants that can inhibit the oxidation of α-farnescene in vitro. However, when they were added to apples either as a dip or an injection, only amine-type of antioxidants seems to inhibit the oxidation of α-farnescene and the phenolic-type of antioxidants being effective with some, mainly α-tocopherol, acting as pro-oxidants (Anet and Coggiola, 1974). α-Tocopherol is found as a minor constituent in oils and is used in most oil-based coatings. Ju et al. (2000a) investigated the use of oils without α-tocopherol contained within them. Apples coated with stripped oil coatings (α-tocopherol <5μl 1-1) proved to reduce scalding and maintain skin color, flesh firmness and titratable acidity (Ju et al., 2000a).

There are also non-chemical controls to help in the prevention of scald incidence in apples. Hot water dips are a way to inactivate some of the compounds that might be producing the scald in the apples. Dipping the apples for 30 or 60 seconds at 54°C was shown to inhibit scald in Stayman and Delicious apples. Rome Beauty apples however were not affected by hot water dipping. These particular apples had an increased incidence of injury when dipped for that length of time and at that particular temperature (Hardenburg and Anderson, 1965). Also, dipping the apples for 60 seconds in 49°C water baths did not control scald.

Radiation is another non-chemical control method for preventing scald. Radiation has shown to alter the respiratory system. Ionizing radiation was shown to cause changes in membrane permeability, however, these changes did not affect scald development. Therefore ionizing radiation did not cause a significant amount of changes to help prevent scald development in apples.

The use of amine-type antioxidants inhibited the oxidation of α-farnescene in apples. Ascorbyl palmitate has been shown to have promise as an anti-scald treatment due to its ability to decrease CTH in apples when it is used in conjunction with coatings (Bauchot and John, 1996). Some investigators have shown that butylated hydroxytoluene (BHT) has shown some anti-scald activity (Wills and Scott, 1977), while other investigators have demonstrated that BHT caused some browning in apples (Little et al., 1980). BHT was effective in reducing the scald in 'Granny Smith' apples. The amount of ascorbic acid found in the peel of the apples is inversely proportional to the scalding process.

2.4.2 Effect of Different Atmosphere Types on Fruit Storage

Oxygen and carbon dioxide concentrations within the storage facility are very important when trying to prevent scald. Ultralow oxygen concentrations and only slightly elevated concentrations are recommended for apples for storage (Streif and Bangerth, 1988). With these conditions it is possible to achieve minimal loss in firmness, fresh weight, acidity and even vitamin C. However, there are some disadvantages to these conditions. There can be increases in specific storage disorders, such as low-temperature breakdown or impaired taste of the fruit, despite the improvement in texture and juiciness. With these conditions and also with coatings there is a reduced production of aroma volatiles and the absence of these volatiles could be a reason for the diminished flavor. Lau (1998) found that apples stored in 1.2-1.5% oxygen with 1.0-1.2% carbon dioxide concentrations improved retention of flesh firmness and titratable acidity. These conditions also reduced the incidence of scald and core browning as compared to air storage. Growing seasons also affect the way that the apples respond to different treatments. If the fruit was picked in a cool growing season, then the apples may have an increase risk of injury and other storage disorders. Lau (1998) found that when the apples were picked after a warm season, there was a decreased risk of browning disorders and internal cavity disorders. Controlled atmosphere (CA) storage is one way to help maintain these concentrations.

In controlled atmosphere storage, oxygen, carbon dioxide, and nitrogen levels are controlled. Controlled atmosphere storage is used to help lower respiration rates and to delay ripening. The criteria for this particular type of storage requires that oxygen levels are decreased that are required for oxidative metabolism and carbon dioxide levels are increased. Anaerobic respiration is also a consideration when oxygen levels are decreased. Oxygen levels below 2% cause anaerobic conditions in the storage facility, which can cause off flavors and aromas in the fruit by the production of ethanol.

Cool temperatures, usually between 4°C-15°C, are imperative to retard senescence because these fruits are more likely to decay. When storing fruits at low temperatures, there is a chance for chilling injury that may occur. Apples stored at 0 to 4°C for several months developed many physiological disorders including internal browning, soft scald, and brown core (Bramlage et al., 1979).

2.5 Coatings as an Alternative for Preserving Fruit Quality

2.5.1 History of Coating Usage on Fruits and Vegetables

Coating fruit has many benefits to the consumer. Consumers desire fresh produce with a healthy and bright shine, which wax or other coatings can achieve. The use of coatings primarily helps in improving over all food quality and extending the shelf life of the food.

One of the most important uses of the edible coatings is the resistance to the migration of moisture. There is a critical water activity for every food. Each food must maintain a particular water activity to exhibit optimum quality and acceptable safety, and coatings have been found to help maintain those standards (Kester and Fennema, 1986). Deteriorative chemical and enzymatic reactions are also influenced by the amount of moisture in a food product. Labuza (1982) found that the rates of many deteriorative reactions increased 2 to 3 fold for each 0.1 unit elevation in water activity over the range. Losing moisture in a food product can also hurt the fresh weight of a product. Many products are sold by weight basis, and if moisture is lost, then the weight is decreasing, therefore, monetary value for that product decreases. The rate of moisture transfer between a food product and the atmosphere can be greatly reduced by using an edible film or coating (Kester and Fennema, 1986).

In addition to the reduction of moisture loss of a food product, edible films and coatings can help in the reduction of gas exchange in a food product. Deterioration of food from oxygen is mainly due to the oxidation of lipids, vitamins, flavor compounds, or pigments. The use of edible coatings to reduce aerobic respiration in fruit and vegetables could be very desirable because of its significant economic advantage. It would save money in the long run because there would be no need for the equipment and technology for controlled atmospheric storage, and also coatings allow for respiratory control to be maintained during distribution of the product throughout retail channels (Kester and Fennema, 1986).

Use of coatings can also reduce shrinkage due to water loss, to provide a barrier to free gas exchange, to improve the appearance and marketability by application of a shiny, sweat resistant film, and to provide a carrier for decay control fungicides, growth regulators, and coloring agents (Shellhamer and Krochta, 1997). Wax coatings are important to keeping fruit fresh because in the majority of cases, waxed commodities lose weight more slowly than unwaxed controls (Hagenmaier and Shaw, 1992). When there is a coating on the fruit, the water loss is decreased and the coating provides a lower respiration rate than uncoated fruit. The coating provides a barrier to prevent oxygen and carbon dioxide diffusion, which lowers the respiration rate of the fruit. Coatings help prevent spoilage and loss of water, which helps with the firmness of the fruit. All of these factors are important to the consumer either indirectly or directly, and because of these factors researchers are focusing on this problem.

There are two different ways of treating fruit for storage purposes. There is a way of using edible coatings and a way of using edible films. An edible coating is usually a thin layer of edible material that is usually applied as a liquid by spraying, dipping, or panning. An edible film is a thin layer of material that is formed to the fruit. These coatings are usually solid sheets, which are applied on or between food components.

2.5.2 Wax

Using a wax based coating is a popular method for extending the shelf life of fruit. It has been found that commodities that have a waxy skin lose moisture and water slowly (Wills et al., 1989). There are many different formulations that researchers have tested to determine if the coatings will reduce moisture loss, but also extend storage life by reducing the fruit's respiration rate. Many of these formulations have been based on a combination of paraffin wax, which gives good control of water loss but a poor luster to the produce, and carnauba wax, which imparts an attractive luster but provides a poorer control of water loss (Wills et al., 1989).

Candelilla wax is a very effective coating that has extended the shelf life of many fruits such as bananas, tomatoes, muskmelons, limes, and other citrus fruits. Candelilla has a similar low-oxygen permeability but a 50% lower water vapor permeability, than does carnauba wax (Alleyne and Hagenmaier, 2000). Shellac is commonly used with other waxes because it contributes to a higher gloss product. It is a versatile compound that dissolves in alcohols and alkaline solutions.

Saftner (1999) experimented by using Golden Delicious and Gala apples with a shellac or wax based coating. The wax based coating contained candelilla wax, isopropyl alcohol, morpholine, oleic acid, and water. The shellac coating contained water, shellac, fatty acid soaps, and fast drying solvents. The researcher found that these two coatings delayed ripening and maintained fresh weight and flesh firmness as compared to the shrink-wrapped films that were used. The study also found that the two coatings reduced total volatile levels within the apples. There was also a decrease in internal oxygen and increase in carbon dioxide levels brought on by the coatings reducing respiration, thereby, increasing the shelf life of the apples.

2.5.3 Lipid

Oiled paper wraps have become the primary control for reducing the occurrence of scald in apples and pears. This method was found to be best by using oil strips of paper that were spread uniformly throughout the carton or bin where the apples were packed. Diphenylamine (DPA) and 6-ethoxy-1,2-dihydro-2,2,4-trimethyl quinoline (ethoxyquin) replaced the use of oil strips of paper (Ingle and D'Souza, 1989). DPA and 6-ethoxy-1,2-dihydro-2,2,4-trimethyl quinoline were a more effective treatment for fruits. However, consumers became more aware of the dangers of chemicals in fresh fruits and vegetables and were hesitant to accept or even buy fresh fruits and vegetables that were treated with DPA and ethoxyquin. Availability of these chemicals is also uncertain, therefore it is important that a new non-chemical method be found that would produce the same results as DPA and ethoxyquin. Due to this problem, oil treatment now has been accepted as an adequate replacement for DPA and chemical treatments. However, the effectiveness of oil treatments alone was not as effective as DPA, therefore researchers needed to investigate how this method could be improved. Scott et al. (1995) found that using commercial plant oils such as, canola, castor, palm, peanut, and sunflower were effective in reducing scald in 'Granny Smith' apples. Ju et al. (2000b) found that the use of emulsions (corn, soybean, peanut, cottonseed, and linseed oils) was also an adequate alternative to DPA because these coatings reduced scald in 'Delicious' apples after six months of regular storage. However, these methods were not as successful as using DPA.

Lipid surfactants have been shown to decrease superficial water activity. Superficial water activity is the activity of water directly at the surface of a foodstuff. Superficial water activity also correlates with the rate of water loss from a food product. Using a surfactant could help decrease the rate of water loss in a food product.

2.5.4 Carbohydrate

Carbohydrate based coatings, such as chitosan, has been shown to inhibit the growth of several fungi, which can degrade a fruit. Chitosan is a carbohydrate based coating that is derived from the alkaline deacetylation of chitin. Chitosan has been known to inhibit the growth of several fungi. This coating is able to form a semi-permeable film, which is able to modify the internal atmosphere and to decrease transpiration losses (Zhang and Quantick, 1998). These same researchers studied chitosan coatings with strawberries and raspberries, as compared to different fungicides. They found that chitosan coatings are able to prolong the storage life and control the decay of strawberries and raspberries. Chitosan films are more permeable to oxygen than to carbon dioxide, which does not promote an anaerobic environment and off flavors and odors.

Sucrose polyester (SPE) coatings also are used for fruits and vegetables. Semperfresh is an improved formulation of the sucrose polyester coating. The major difference is the improved dispersion due to a higher proportion of short chain unsaturated fatty acid esters (Drake et al., 1987). Drake et al. (1987) found that applying SPE (Semperfresh) to Golden Delicious apples significantly maintained the keeping quality of the apples. They also found that apples treated with SPE alone maintained color longer than both apples treated with SPE + wax and the control (untreated) apples. Maintenance of color suggested increase shelf life while rapid change in color indicated a decrease in shelf life. Apples that were treated with SPE coatings and stored at refrigerated temperatures displayed slower skin color development, and slower firmness and acid loss in comparison with the control apples. However, apples stored in a controlled atmosphere environment showed similar changes, however no change in firmness was noted. Wax coated apples alone showed no differences between themselves and the control apples. The SPE + wax treatments showed similar attributes as the SPE coating alone. There could be some beneficial uses of the SPE + wax coating because of enhancement of quality attributes with a desirable fresh fruit finish.

2.5.4.1. Gums

2.5.4.2. Carboxy-methyl Cellulose

Gums are ingredients that are soluble in water and capable of thickening and stabilizing a mixture. Carboxy-methyl cellulose (CMC) is a type of gum that is derived from cellulose. It is highly water-soluble in hot or cold water, but is insoluble in organic solvents. The degree of substitution (DS) is important to its solubility. For water solubility, CMC must have a DS of 0.4 or greater. The uniformity of the side chains determines the behavior of CMC. Nonuniform distribution causes naked sections of molecules that will be available for junction zone formation, producing thixotropic gels. There are many ingredients that may be used with CMC including proteins, sugar, starches, and other hydrocolloids. CMC when hydrated swells and will clog the pores, thus preventing the loss of juice and flavor. Oxidation would also be inhibited whereby firmness and texture would be maintained (Daniels, 1973). CMC has the ability to form strong, oil-resistant films, which makes it useful in many applications. It is a clear, stable solution that has many major food applications such as a thickener, suspending aid, lubricant, humectant, film former, and moisture binder.

2.5.4.3 Locust Bean Gum

Locust bean gum is from the locust bean seed. Locust bean gum is soluble only in hot water and it requires at least 90°C for complete stabilization. Locust bean gum is rarely used alone and it is usually used synergistically with CMC, xanthan gum, guar gum or carageenan to help form rigid gels. Locust bean gum has long chains with "naked sections" that can interact with cellulose derivatives to aid synergistically by increasing the viscosity of a solution. For maximum interaction between locust bean gum and other properties of other gums, it is imperative that the mixture to be heated above 60°C (Whistler and BeMiller, 1997a).

Locust bean gum has many functions in food products. It can serve as a binder and stabilizing agent in processed meats to help improve homogeneity and texture. Locust bean gum also produces elastic gels and prevents syneresis of rigid gels. It also has increased water binding results and water retention in many food products. Locust bean gum is added to sauces and dressings because of its ability to give the desired mouthfeel. Locust bean gum can also give viscosity to a product when used with other gums.

2.5.4.4 Xanthan Gum

Xanthan gum is derived from *Xanthomonas* campestris bacteria, which can be found on the leaves of cabbage. Xanthan gum is an unique gum because of its structure. Xanthan gum is made up of β-D glucopyranosyl units with β-D mannopyranosyl-(1->4)- β-D glucopyranosyl-(1->2)-6-O-acetyl-β-D mannopyranosyl trisaccharide units. It is so unique because it remains unchanged to varying temperatures and pH changes. Because of its unique characteristics, it can be used in various food systems. Because of its stability properties over a wide range of temperatures, it is irreplaceable as a thickener and stabilizing agent in such products as salad dressings and chocolate syrup. Xanthan gum has a high water soluble characteristic. Xanthan gum helps form an excellent emulsion and is an excellent suspension stabilizer. There is a synergistic increase in viscosity when xanthan gum is used with guar gum. Xanthan gum is used primarily in the stabilization of suspensions and emulsions. Xanthan gum is ideal for stabilizing aqueous solutions, dispersions, emulsions, and suspensions. These products need not to be too thick nor too thin when cooled or heated and xanthan gum gives a uniform thick quality to these products. The unique properties result from the rigid, linear, cellulose backbone, which is stiffened bye the trisaccharide side chains (Whistler and BeMiller, 1997b).

2.5.4.5 Gum Arabic

Gum Arabic is derived from the Acacia tree and is highly soluble in water. Gum Arabic is also known as an exudate gum. Gum Arabic also has a high viscosity at very low concentrations. Gum Arabic also helps emulsify and distribute fatty components within a system. Gum Arabic's emulsifying capabilities can help it form a thick layer around oil droplets in a system. Gum Arabic also has a high compatibility with high concentrations of sugar, whereby, crystallization of sugar is prevented. Gum Arabic has a wide variety of uses in the food industry. Some of its use is involved in the preparation of flavor in oil-in-water emulsions, mainly citrus oils (Whistler and BeMiller, 1997c). Gum Arabic can also be used in spray dried products as an emulsifying agent to help prevent the oxidation and rancidity of these citrus oils and flavors.

2.5.4.6 Maltodextrin

Maltodextrin is a nutritive polysaccharide that is derived from corn starch. Maltodextrin interacts well in a system with gums and fibers because of its ability to bind and hold water. Maltodextrin has many functional benefits in a variety of applications. The benefits include water binding capabilities, humectancy, viscosity, and bulking capabilities. Maltodextrin has a wide range of dextrose equivalencies (DE) that can range from 5-20. However, maltodextrins with a higher DE have the ability to absorb moisture, while maltodextrins with a lower DE are nonhygroscopic. Maltodextrins are bland, with virtually no sweetness, and are excellent for contributing bulk for food systems (Whistler and BeMiller, 1997d). Maltodextrin is also used in low fat cheeses and in films because of its ability to be dispersed easily.

Maltodextrin is sometimes used a fat replacer in many baked products. Making a gel from maltodextrin aids in the replacement of fat. Using this gel, maltodextrin then acts as the texture of hydrogenated shortening (Nonaka, 1997). Its high solubility in dry mixes aids in the fat replacement because it enhances the dispersion of other ingredients. As a high molecular weight carbohydrate, maltodextrin holds water tightly and builds body in baked goods. In baked goods it is critical to retain moisture for texture and extended shelf life and maltodextrin can help retain that moisture.

2.6 Protein

The use of proteins as edible films and coatings has not been studied as extensively as carbohydrate coatings. Gelatin is a popular protein based coating used in a variety of applications. Gelatin is derived from collagen and is composed of 18 different amino acids, which helps it form a long, branched molecule. The interaction between the ionic crosslinks between the amino and carboxyl groups of the amino acid side chains help form the thermally reversible gels when warm. Gelatin is often used with acacia (gum arabic) to help form films (Kester and Fennema, 1986).

2.7 Calcium

Calcium is a post harvest treatment to increase the shelf life of many fruits. Calcium is mainly used in pressure infiltrated processes, which can decrease the incidence of bitter pit, scald, water core, and internal breakdown. Calcium infiltration with a combination of hydrophobic wax or shellac based emulsions and then packaged with a shrink wrap film can be an alternative to help increase the shelf life of apples.

Calcium infiltration is used because it is necessary that the calcium contacts the fruit and be absorbed directly by it because calcium that falls on the leaves or branches is not transferred to the fruit (Wills et al., 1989). Calcium chloride (CaCl2) is usually used because it is inexpensive and has been approved by the FDA for postharvest use. However, there are potential problems that are associated with calcium infiltration. With an increase in Ca concentrations, there is an increase in lenticel pitting and surface discoloration. This injury is very hard to predict and it is probably due to a phototoxic response to excessive Ca in the fruits. Another explanation can be related to salt stress due to the relationship between the concentration of salt and the incidence of injury. The injury can also be reduced by rinsing the apples of extra Ca that is left after infiltration. Storing the apples after infiltration in a high humidity environment can also decrease the incidence of Ca induced injury. Using a coating along with the Ca treatments, seemed to decrease the likelihood of Ca induced injury. Saftner and Conway (1998) found that postharvest treatments of Ca (0.14 mol L –1), water (used as a rinse), and a subsequent coating can help slow ripening, reduce respiration, and also reduce ethylene production rates. Combining these treatments can help improve the internal atmosphere while also reducing peel injury that can be caused by Ca treatments alone. Shrink wrapping of the fruit seemed to be less effective than the other coatings to delay ripening and also in maintaining quality of the fruit.

The best results that were found by using calcium infiltration is by using apples that have a closed calyx so that calcium is forced via the lenticels, and is then spread around the perimeter tissue where the disorders occur. With an open calyx fruit, the uptake of the calcium is difficult to control as it readily enters the fruit via the calyx and the excess solution accumulates in the core often leading to injury or rotting (Wills et al., 1989).

2.8 Composite Films

Using a combination of carbohydrates, proteins, and lipids can utilize the varied functionalities of each class of film formers. Composite coatings can usually increase the performance of a coating by enhancing moisture barrier properties. Using plasticizers and lipids within starch-based coatings improved the performance by increasing barrier properties to water vapor maintaining the selective gaseous permeability (Kester and Fennema, 1986). The lipid component in the coating formulation can serve as a good barrier to water vapor while the hydrocolloid component can provide a selective barrier to oxygen and carbon dioxide (Kester and Fennema, 1986). Water vapor permeability depends on the hydrophilic-hydrophobic ratio of the film components. Water vapor permeability increases with polarity, unsaturation, and branching degree of the lipid (Garcia et al., 2000). These researchers found that the addition of lipids to polysaccharide based films produced good barriers to water vapor due to its hydrophobicity. They also found this to be important to fruits and vegetables because composite coatings retard moisture loss and subsequent shriveling of fresh produce.

Using composite coatings can also enhance gas barrier properties. Coating fresh fruits and vegetables with CMC and sucrose fatty acid esters help reduce anaerobic respiration by the reduction of the transport of oxygen than carbon dioxide. This reduction then caused a decrease in oxygen concentration of the fruits' internal tissue without an equal increase in carbon dioxide (Kester and Fennema, 1986). Films with a carbohydrate base that includes a plasticizer generally had lower carbon dioxide and oxygen permeabilities (Garcia et al., 2000). Garcia et al. (2000) also found that starch based coatings alone left pores and cracks in the coatings and with the incorporation of plasticizers in the formulation prevented cracks which lead to better barrier qualities.

2.9 Methods for Coating Application

There are many different methods of applying the coatings on the selected fruit. Dipping, spraying and hand coating are the methods that are most common. The amount of coating that is used on the fruit could be detrimental to the fruit's sensory attributes. If the coating is too thick, the gas permeability of the fruit is severely limited. This environment produces an anaerobic environment, whereby ethylene and other degradation products are produced. Off flavors are usually associated with this reaction.

There are two applications for using wax coatings. Either a solvent wax system or a water wax emulsion is used. A water wax emulsion is now more common. A solvent wax system is composed of mostly aliphatic hydrocarbons with a smaller percent of aromatic hydrocarbons with a solvent; usually the solvent is either acetone or ethyl acetate. A more common application, water wax emulsion, is an oil-in-water emulsion of the hydrophobic coating material. When using the water wax emulsion, the fruit does not have to be dry when applying the coating, but when using the solvent wax system, the fruit must be dry before applying the coating (Daniels, 1973).

Chapter 3: Justification and Purpose of the Study

The most important and probably the most widely grown fruit tree in the world is the apple. About one third of the total apples that are grown in the world are produced in the United States (http://pestdata.ncsu.edu/cropprofiles/docs/vaapples.html, 2001). Apples are an important part of the American diet and economy, therefore, it is important to maintain the quality and storage capabilities of the apple.

Virginia ranks sixth in the nation for apple production. Virginia growers on average produce 8-10 million bushels of apples annually. The Virginia apple industry contributes an estimated $235 million dollars for the state's economy. In addition, the apples that are grown in Virginia are also sold to over 15 states and more than 20 countries (http://pestdata.ncsu.edu/cropprofiles/docs/vaapples.html, 2001).

Although there are many different varieties available world wide, only about 25 are commonly grown in Virginia. The most popular varieties that are grown in Virginia orchards are Red Delicious, Golden Delicious, Rome, Stayman, Gala, Winesap, York, Granny Smith, Jonathan, Fuji, and Ginger Gold (http://www.virginiapples.org, 2001). Apple trees generally grow well in a wide range of soil types, although the highest quality fruit is produced where deep, well-drained, moderately fertile soils are available. Cool nighttime temperatures (40°-60° F) during harvest also allow for apples with a firmer flesh, redder color, better storage characteristics and better flavor. Such temperatures are typically found at elevations greater than 800 feet above sea level, or in the western portion of the state. Typically most of the apple production of the state is in the western portion including, the mountainous region of the northern Shenandoah Valley, through the Roanoke valley, the rich countryside of Albermarle and Rappahannock counties, and the southwest counties of Patrick and Carroll. The majority of the apples grown are in the Shenandoah Valley.

Fruit disorders can occur at harvest, during storage and transit, and at the retail level. Scald, shriveling, and loss of firmness are all disorders that can affect the quality of the apple to the consumer. Once properly identified, there are steps that can be taken to correct and prevent any further occurrence of these disorders. Edible coatings and films can be a method to help correct and prevent these problems and disorders.

There are various types of coatings. Shellac can be used as a type of coating or as an ingredient within a coating formulation that is in virtually all high-gloss coatings, but these types of coatings have some disadvantages. Shellac coatings tend to whiten when exposed to moisture, and shellac has a low gas permeance, which makes coated fruits susceptible to pitting and development of off flavors (Hagenmaier and Shaw, 1992).

Edible films and coatings can help facilitate other methods of storage and keeping quality. Many of its functions can help extend the storage and quality characteristics of the fresh produce by providing a barrier for moisture, oxygen, and solute transmission. The use of bi-layer or composite coatings is beneficial to the apple because each ingredient functions synergistically to provide a stronger barrier for protection. Wax, for example, when used alone on apples was not effective in preventing moisture loss, however, when wax was used in conjunction with a lipid surfactant there was a decrease in superficial water activity (Wills et al., 1989). Garcia et al. (2000) also found that using lipids with polysaccharides in coatings produced excellent barrier properties to water vapor. Therefore, lipids and carbohydrates offer a synergistic union to maintain and extend the post-harvest quality in apples.

The objectives of this study were:

- To formulate a lipid/hydrocolloid coating for Golden Delicious apples to help prevent storage disorders and to improve the overall keeping quality of the post harvested apple.
- To evaluate the effect of the coating on the physical properties of the apple, such as moisture loss, respiration rate, firmness, starch content, titratable acidity and soluble solids.
- To evaluate the effect of the formulated coatings on the sensory properties of the apple.

Chapter 4: Materials and Methods

4.1 Experimental Design

Golden Delicious apples were grown and donated through the auspices of the Department of Horticulture at Virginia Tech. Apples were then coated with three different formulations (see Section 4.2 and 4.3). A control group (uncoated) was utilized in the study. The study was designed as a factorial experiment with repeated measures. Upon delivery of the harvested fruit, apples were controlled for size and color from the lot. The apples were then divided into four groups (three groups were used for the experimental coatings and an uncoated group served as the control). Apples were coated and stored under refrigerated conditions. The study lasted for eight weeks. Each week during the study, apples were randomly selected from each group and subjected to objective and sensory analyses.

4.2 Coating Materials

The coating formulations are found in Appendix A.

4.3 Coating Application

Vegetable oil, parafilm, and water were placed in a double boiler and heated until the parafilm was melted (170°F). The mixture was then transferred to a blender container. The blender was turned on to “blend” cycle and the dry ingredients were added until they were dissolved.

Coatings were applied manually by spreading a thin layer of coating evenly onto the fruit’s surface. Coatings were then allowed to dry at room temperature. Fruit was then placed into refrigerated storage at 40°-45°F with an 80-85% humidity level during the duration of the study.

4.4 Texture

The texture of the fruit was measured by the Stevens LFRA Texture Analyzer (Scarsdale, NY). The probe, TA-9, was programmed to travel a distance of 10mm with a speed of 2mm/sec and with a normal cycle.   The readings were made by cutting transverse slices of the fruit (½ inch thick) and then placing the sample on the stage. Five apples from each group were used each week during the study. One slice per apple was used and measurements were made at three different sampling sites on each fruit (Appendix B).

4.5 Fresh Weight Loss

Fresh weight loss measures the amount of moisture that is lost during storage. Five apples were chosen randomly from each of the groups to measure their weight on a top loading balance (Denver Instruments XP-1500, Avarada, CO) during the eight-week period. The apples were weighed once a week for the eight-week period.

4.6 Respiration Rates

Respiration rate measures the amount of carbon dioxide production of the fruit. Respiration rate increases or decreases with a change in temperature, therefore, the apples were removed from refrigerated storage one day prior to testing and were allowed to equilibrate to room temperature. The same group of apples that was chosen for the fresh weight loss (Section 4.5) was also used for the respiration rate analysis. Apples were weighed and placed into a chamber with two tubes attached. One tube delivered outside air to the chamber at a rate of five liters per minute, while the second tube transferred air and gases produced by the apples to an infrared gas analyzer (The Analytical Development Company, Model LCA 2, Hoddeson, England). The equation for determining respiration rate is found in Appendix C.

4.7 Color

Fruit skin color was measured by the Hunter D25 L Optical Sensor Colorimeter (Reston, VA). Hunter L, a, and b values were measured. The group of apples that was used for fresh weight loss and respiration rates (Sections 4.5 and 4.6, respectively) was also used for the color analysis. Color samples were taken from opposites sides of the whole fruit, approximately 3cm X 5cm in size. Measurements were then averaged.

4.8 Titratable Acidity

Titratable acidity (AOAC official method 942.15 Acidity (Titratable) of Fruit Products) was measured by using the glass electrode method. Three apples from each group were randomly selected and then placed in a blender container and pulverized. One hundred grams of the apple mixture were titrated with 0.1M of NaOH until the pH reached 8.10. The total volume titrated was used to calculate the percent of malic acid present in the apple (Appendix D). This test was performed once a week in triplicate with each treatment and control group.

4.9 Starch

The iodine-starch test was administered once a week with five replications for each treatment and control group. A 5-mm transverse section of the apple was removed from the point of the greatest diameters. The apples were then dipped into a 0.75% iodine solution (7.5 g iodine, 25 g potassium iodide per liter) (Li et al. 1999). In order to evaluate the starch index number, samples were qualitatively rated for the amount of blue color development after removal from the starch solution. A chart was used to determine the index number (1 (large amount of starch)-9 (small amount of starch)) (Appendix D)(Priest and Lougheed, 1988). Chart used for rating starch content is intended for McIntosh apples. Since Golden Delicious apples have the same starch pattern within their flesh as McIntosh apples, the chart was used for comparing starch patterns.

4.10 Soluble Solids

Soluble solids were measured by using the AOAC official method 932.14. A refractometer (Leica Mark II Plus Refractometer, Model 10480/10481, Buffalo, NY) was used to measure soluble solids. This analysis was performed once a week with five replications for each treatment and control group. The juice of the apples from each group was placed on the stage of the refractometer and the solids were measured.

4.11 Sensory

Quantitative Descriptive Analysis (QDA) was used to evaluate the characteristics of the coated fruit. Seven panelists were selected to evaluate the fruit samples. The panelists, graduate students from the Human Nutrition, Foods, and Exercise Department, volunteered to participate in the study. There were three-1 hour sessions to train the panelists on selecting attributes that were to be used for evaluating the fruit samples. At these sessions panelists were informed about the study and their responsibilities.

The first session consisted of instructing the participants about sensory evaluation procedures and the significance of sensory analysis to the study. The panelists also signed consent forms (Appendix F). The second session consisted of the panelists tasting apples and deriving the descriptors to be evaluated. The derived descriptors were: the outside texture (crisp or mushy), the inside texture (mealy or firm), the sweetness of the apple (mild or strong), the tartness of the apple (mild or strong), the juiciness of the apple (juicy or dry), and the overall appearance of the outside of the apple (shiny or dull). The third session was a training session for the panelists to become familiarized with the derived scorecard (Appendix G) and the descriptors.

The panelists evaluated the fruit samples once a week for eight weeks. The panelists were seated in a sensory booth in Wallace 335. The room was maintained at 73°F with 50% humidity. The samples were prepared prior to the panelists' arrival to prevent enzymatic browning of the fruit and at the same time to minimize any biases. The samples were prepared in a separate room in order to secure anonymity of the samples. A random three-digit number was assigned to each group every week. The panelists were given two slices of apple per group, with a total of eight slices. The panelists were instructed not to converse while testing the samples in order to prevent bias. Panelists evaluated each descriptor, and data was quantified from each descriptor (Powers, 1988). Quantification of data involves measuring from left to right on the line where the evaluator marks when making his/her decision. This measurement quantifies the descriptor that the panelist is analyzing (QDA).

4.12 Statistical Analysis

Statistical analysis was conducted on the Statistical Analysis System (SAS Institute, Inc., SAS Circle Box 8000, Cary, NC). The tests for the fresh weight loss, respiration rates, and color were analyzed by a randomized complete block design using analysis of variance. A general linear model was also used and a Bonferroni adjustment was made to the data. The pairwise error rate was calculated as 0.0083. The balance of the tests (titratable acidity, texture, soluble solids, starch and sensory evaluation) were analyzed by repeated measures using analysis of variance (ANOVA). The data was also analyzed by looking at the main effect of the treatments. Bonferroni adjustments were made and the pairwise comparison error rate was calculated as 0.0083.

Chapter 5: Results and Discussion

5.1 Respiration Rates

Apples are considered a climacteric fruit. The climacteric phase occurs when the respiration rate varies with the maturity stage and ripening. The change from unripen to ripen stage occurs at the peak of climacteric rise in the oxidative metabolism of the apple. Respiration can also be used as a marker for the ripening process. The climacteric peak can correspond to the optimum eating ripeness, or may precede or postdate this mark. Because of these markers, it is necessary to control the rate at which fruit respire. When there is a rise in the respiration of the fruit, ethylene production increases 1,000 fold (Knee, 1993). Respiration could in fact be increased by the enhanced presence of ethylene. Ethylene synthesis rises after harvesting of the fruit. The later the fruit is harvested, the more the fruit is affected by ethylene treatments with regard to respiration (Knee, 1993).

Measuring the respiration rate determines the amount of carbon dioxide that is produced by the apple. Refrigeration (below 10°C) is a method that can help stabilize the climacteric rise. It can be difficult to measure the effects of ethylene on refrigerated storage; leading to the assumption that ethylene has no role in ripening under those conditions (Knee, 1993). An increase in carbon dioxide production is an indication that the apple is undergoing the ripening process. Other factors affect the increased respiration of the fruit: softening of the flesh, color change from green to yellow, and synthesis of aroma compounds. Malic acid is the main acid found in apples. Malate is the major organic acid that is used for respiration. The utilization of malate as a respiratory substrate is mediated by malic enzyme. This enzyme catalyzes the reductive decarboxylation of malate to pyruvate, eventually producing carbon dioxide. Also with the increased levels of ATP that is produced in respiration events, ATP can be used to drive the starch breakdown or pigment synthesis.

Results indicated that the control apples had produced a significantly ($P<0.0083$) higher amount of carbon dioxide over the entire eight-week period (Table 1). All experimental treatments (Treatment 1, Treatment 2, and Treatment 3) had similar respiration rates (23.71, 24.13, and 21.99mg/CO2/hr, respectively)(Table 1). The coatings created a barrier that appeared to control the respiratory gas exchange, therefore the shelf life of the apples was prolonged. Alleyene and Hagenmaier (2000) and Smith et al. (1987) found that the presence of an artificial barrier around the fruit indicated a trend towards higher concentrations of carbon dioxide and lower oxygen levels internally. There were no differences between treatments suggesting that all of the coatings had similar oxygen and carbon dioxide permeability. The control of ethylene production could also be a factor in the control of respiration. Ethylene is produced by the apple during ripening, however, the coatings that were used could control for the production of this gas.

Carboxy-methyl cellulose use in treatment 3 coating could possibly help in the gas exchange in the apple. This treatment produced a low respiration rate (21.99 mg/CO2/hr). Carboxy-methyl cellulose can swell when it is hydrated, therefore, clogging the pores of the fruit to prevent respiration.

Treatment two contained algin and had a respiration rate of 24.13 mg/CO2/hr. This rate was considerably lower than the control suggesting that the algin could have

Table 1. The effect of coatings on respiration rates of Golden Delicious apples over an eight week period.

TREATMENTS	RESPIRATION RATES ($MG/CO_2/HR$)
Treatment 1	23.71 ± 1.16 a
Treatment 2	24.13± 1.16 a
Treatment 3	21.99 ± 1.16 a
Control	40.68 ± 1.16 b

Values with the same letter are not significantly different at p>0.0083.

Treatment One		Treatment Two		Treatment Three	
Oil [a]	4.8g	Oil	4.8g	Oil	5.0g
Parafilm	0.5g	Parafilm	0.5g	Parafilm	0.5g
Surfactant	0.1g	Surfactant	0.1g	Surfactant	0.1g
Maltodextrin	8.0g	Maltodextrin	8.0g	Maltodextrin	8.0g
Gum Arabic	0.3g	Locust Bean	0.1g	CMC [b]	0.3g
Locust Bean	0.3g	Algin	0.1g	Locust Bean	0.2g
Water	86.4g	Gum Arabic	0.1g	Water	85.9g
		Water	86.1g		

a-Vegetable Oil
b-Carboxy-Methyl Cellulose

helped in decreasing the respiration rate by forming a viscous solution around the fruit in preventing gas exchange. Algin is able to form gels in food systems. However, algin requires calcium ions to form a strong gel. Without calcium ions, algin is possible to form viscous and soft gels. These gels could also help in the prevention of gas exchange in the fruit.

Treatment one contained a greater portion of gum arabic than in the other coatings. Gum arabic is known for its emulsifying and binding capabilities. This increased amount could aid in binding the coating to the fruit and also with the emulsification of the ingredients that contributed to the overall protection of the fruit.

5.2 Texture

The softening of a fruit's texture is a major quality attribute that often dictates shelf life. There are three different mechanisms that can cause the softening of the texture: loss of turgor, degradation of starch, or breakdown of the fruit cell walls. Degradation of starch could have a considerable role in the deterioration of the texture; however, it is thought that softening of the fruit can be particularly due to cell wall degradation (Knee, 1993). The cell walls of apples consist mainly of cellulose and pectin, with a small portion of hemicellulose. Cell separation is one of the causes of softening in fruit. Removing the calcium ions from the junction zones between pectin molecules could be another mechanism which causes softening. Adding calcium ions reverses cell separation and therefore reverses softening (Stow, 1989).

Texture was measured as the amount of force that was needed to penetrate through the surface of the sliced fruit. The treated apples had significantly ($P<0.0083$)

firmer flesh than control apples (Table 2). There were no differences between treatments, which indicated that the coatings prevented firmness loss in the apple (Fig. 1). The firmness of the apples could be attributed to many factors. Oil based coatings can help in the reduction of ethylene production. Ethylene can contribute to a fruit's loss in firmness (Ju et al., 2000a). The overall coating can also help in delay ripening of the fruit. The coating provides a barrier for transpiration, which can help in the loss of turgor, and thereby be a factor for the loss of firmness. Carboxy-methyl cellulose when hydrated can help clog the pores of the apple, and prevent the loss of water. Algin and gum arabic can also help create a barrier to prevent the further loss of water and turgor. Treatment two preserved the firmest texture in the treated apples throughout the study, suggesting that algin could serve as a powerful barrier for transpiration loss.

5.3 Titratable Acidity

The major acid present in apples is malic acid, however, there are some small amounts of citric and quinic acids. Malic acid is metabolized at a greater rate and extent than the other acids and may fall 50% during the entire life of the fruit (Knee 1993). Malic acid is a major substrate of respiration and therefore is utilized during the respiratory life of the fruit. The major pathway of metabolism of the acid is via the Krebs (TCA) cycle. The metabolism of malate by tissues of the apple increases as the apple passes through the climacteric, therefore, there is a correlation between the stimulation of carbon dioxide production by malate and whole fruit respiration (Hulme and Rhodes, 1971).

Table 2. The effect of coatings on flesh texture of Golden Delicious apples over an eight week period

Treatments	Firmness (load/g)
Treatment 1	325.47 ± 24.87 a
Treatment 2	335.12 ± 24.87 a
Treatment 3	311.03 ± 24.87 a
Control	277.67 ± 24.87 b

Values with the same letter are not significantly different at $p>0.0083$.

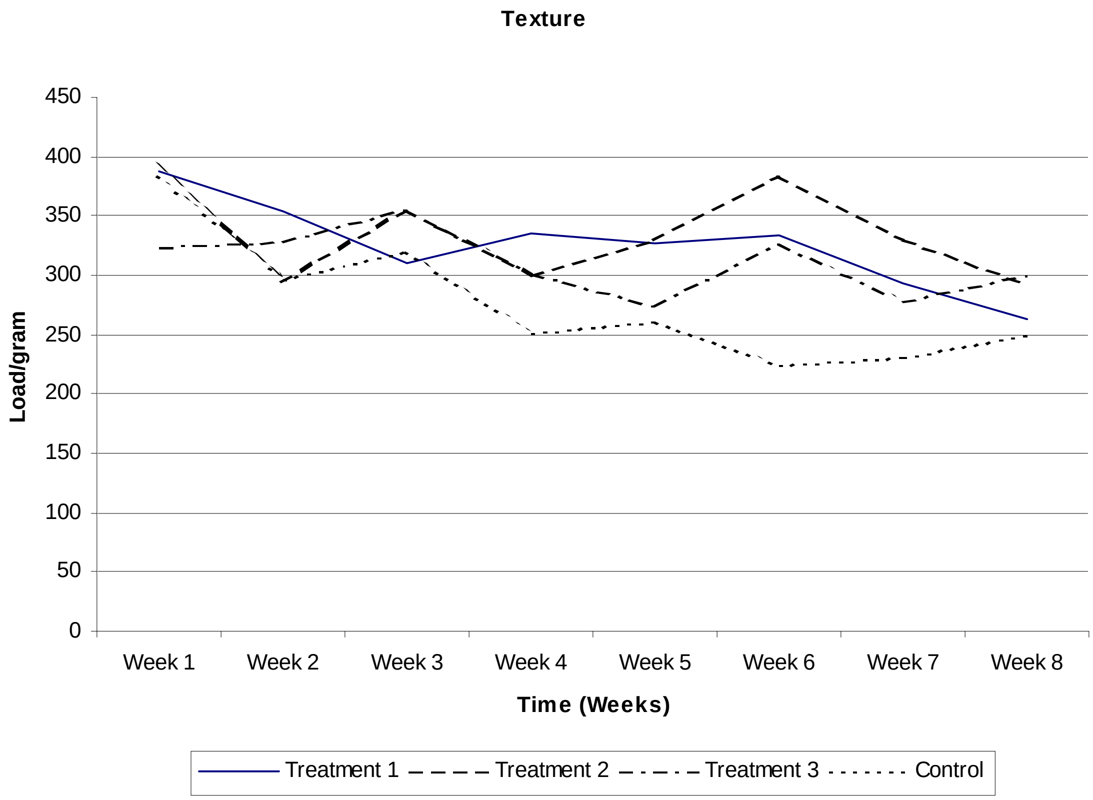


Figure 1. The effect of coatings of texture changes in Golden Delicious apples during eight weeks of storage

Control apples had a significantly ($P<0.0083$) lower percentage (0.15% malic acid) of titratable acidity when compared to the treatment apples (Table 3). There were no significant differences ($P>0.0083$) between the treatments (Fig 2). At the beginning of the study, the average malic acid was 0.20% between all groups. As the study continued there was a marked decrease in malic acid content. However, the control apples experienced more of a decrease in malic acid when compared to the treated apples. The control apples also had a significantly ($P<0.0083$) higher rate of respiration when compared to the treatment apples (Table 1). As the respiration rate increases, the metabolism of malate is increased, therefore, there would be less malic acid available. The treated apples significantly slowed the respiration of the apples as compared to the control; therefore the metabolism of malate was not as high due to a low respiration rate. The oil that is used in the coatings can also help in the reduced diffusion of ethylene, which triggers ripening (Ju et al., 2000a). The gums that were used in the treated apples also helped in the decrease in the respiration, therefore, decreasing the metabolism of malate.

5.4 Starch

As an apple ripens, there is a breakdown of starch to glucose. Starch hydrolysis usually begins at the later stage of growth, but before the onset of the climacteric, which would contribute to a further increase in free sugars. The increase in sucrose within the apple is largely due to the hydrolysis of starch during the stages of ripening (Whiting, 1970). Sucrose is then hydrolyzed to form more glucose and fructose.

Table 3. The effect of coatings on titratable acidity of Golden Delicious apples over an eight week period.

Treatments	Titratable Acidity (% Malic Acid) per 100g of sample
Treatment 1	0.17 ± 0.01 a
Treatment 2	0.18 ± 0.01 a
Treatment 3	0.17 ± 0.01 a
Control	0.15 ± 0.01 b

Values with the same letter are not significantly different at p>0.0083.

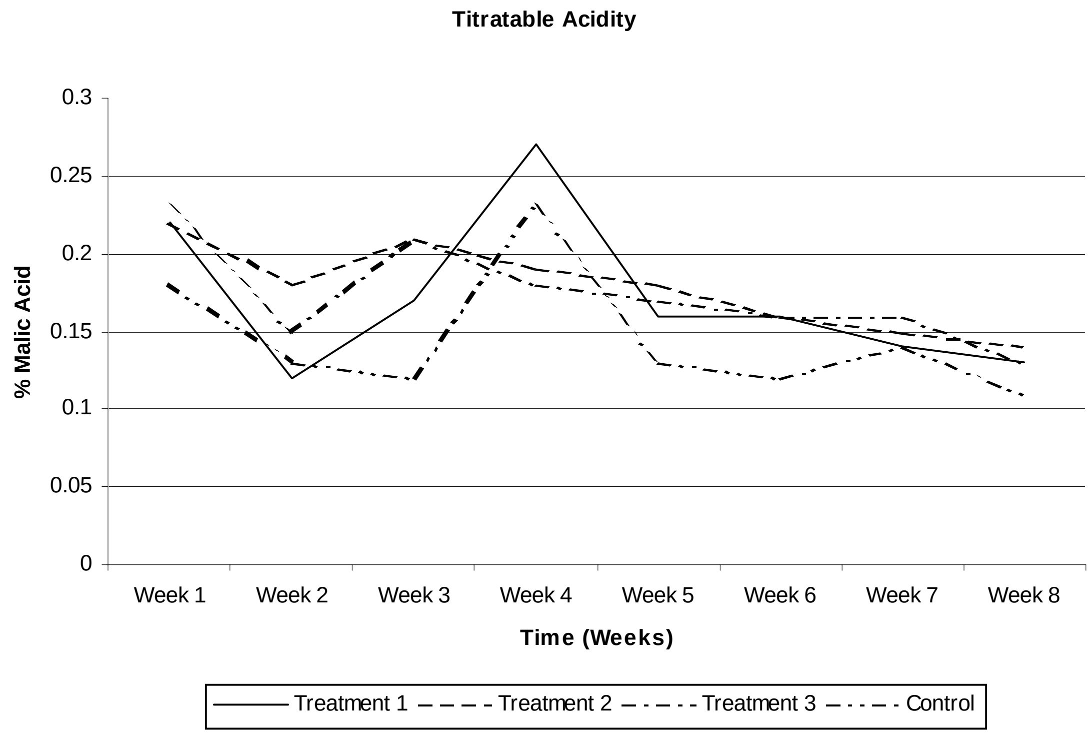


Figure 2. The effect of coatings on titratable acidity of Golden Delicious apples over an eight week period.

The breakdown of carbohydrates weakens cell walls and the cohesive forces that bind the cells together. This chain of events then causes a breakdown in the texture of the fruit. Protopectin is the insoluble form of pectin. This polymer is cross-linked to other chains with calcium bridges and is bound to other sugars. During ripening, protopectin is gradually broken down to lower molecular weight substances, which are more soluble in water. The rate of degradation of pectic substances is directly correlated with the rate of softening of the fruit (Wills et al., 1981).

There are a number of enzymes that are involved in the hydrolysis of starch. Starch phosphorylase seems to be one of the most important enzymes found in apples. However, β-amylase is present when the fruit is developing, while α-amylase increases as the fruit ripens after the majority of the starch disappears (Clements, 1970).

As apples mature the starch content gradually decreases because of the hydrolysis of starch into sugars. Starch deposition begins in the cell layers near the skin and proceeds near the core. Starch begins to disappear from the core areas and last from the areas just under the skin. However there are different starch patterns observed in different cultivars of apples. Golden Delicious apples have a similar pattern to McIntosh apples, while Red Delicious apples have a completely different starch pattern.

There was significant difference ($P<0.0083$) between the three treatments as compared to the control (Table 4 and Appendix E). The disappearance of starch proceeded first from the core areas and then continued to the outside of the apple. The starch index number ranges from 1-9, the larger the starch index number indicates the decreased presence of starch within the apple. There was also a decline in starch content within all of the groups; however, the control group had a more significant decrease in

Table 4. The effect of coatings on starch content of Golden Delicious apples over an eight week period.

Treatments	Starch Index
Treatment 1	5.1 $\pm$ 0.60 a
Treatment 2	5.68 $\pm$ 0.60 a
Treatment 3	6.15 $\pm$ 0.60 a
Control	6.85 $\pm$ 0.60 b

Values with the same letter are not significantly different at p>0.0083.

1-3=Immature

4-6=Mature

7-9=Over-Mature

starch (Figure 3). The coatings that were utilized on the treated apples slowed down the respiration rates and at the same time the apple structure was maintained.

The color of the reaction with the iodine in the apples was a blue color. This blue color results from the iodine reacting with the amylose is in the apple. The iodine is able to penetrate into the helical structure of the amylose to develop the deep blue color. When iodine is reacted with the highly branched amylopectin, the iodine is only able to penetrate into the small branches, therefore, resulting in a reddish-blue color. However, in apples the iodine is mainly reacting with the amylose. Therefore there maybe more amylose present in the apple rather than amylopectin.

5.5 Soluble Solids

Carbohydrates are generally the most abundant group of constituents in fruits (Wills et al. 1981). Carbohydrates can account for 2-40 percent of the fruit's tissue. Sugars are mainly present in ripe fruit, while starch is present in unripe fruit. During ripening, there is a conversion from starch to sugars. The main sugars that are present in apples are glucose, fructose and sucrose. Glucose is present approximately 2g/100g fresh fruit, while fructose is present 6g/100g fresh fruit, and sucrose is present 4g/100g fresh fruit (Wills et al., 1981).

Soluble solids were measured to determine the maturity of the apple. The main constituents of soluble solids are sugars and sugar content of the juice increases steadily as the fruit matures on the tree. There were no significant differences ($P>0.0083$) between the experimental treatments and the control (Table 5). There were also no

Figure 3. The effect of coatings on starch content of Golden Delicious apples over an eight week period.

Table 5. The effect of coatings on soluble solids of Golden Delicious apples over an eight week period.

Treatments	Soluble Solids
Treatment 1	12.18 ± 0.56 a
Treatment 2	13.55 ± 0.56 a
Treatment 3	13.48 ± 0.56 a
Control	12.87 ± 0.56 a

Values with the same letter are not significantly different at $p>0.0083$.

differences (P>0.0083) within the treatments. Baldwin et al. (1999) confirmed these findings with mangos whereby no significant differences (P>0.0083) were found in soluble solids, but did find differences in titratable acidity and firmness. Soluble solids did increase over time in all treatments, indicating the breakdown of starch into glucose. Starch breakdown is indicative of fruit ripening. Since no differences were detected, soluble solids may not be a good indicator for shelf life stability.

5.6 Fresh Weight Loss

Cell separation occurs during the growth of the apple. In apples the air spaces tend to form canals through the cortex and the air spaces continue to increase in volume during fruit storage and ripening. This increase in volume of the air cells may be involved in ripening related changes in texture and could account for water loss and subsequent weight loss.

Fresh weight loss measures the amount of moisture that is lost through the peel during storage. There were no significant differences (P>0.0083) among the treatments and the control group (Table 6). There was, however, a steady decrease in weight loss time between all groups (Figure 4). The control group experienced a greater decrease than the treated groups. Smith et al. (1987) also found that there were only slight reductions in fresh weight loss in bananas and apples. The coatings can bind to the lenticels and help provide a barrier for oxygen and carbon dioxide exchange whereby preventing water loss. However, the coatings seemed to serve as a better barrier for gas exchange, but not for transpiration loss.

Table 6. The effect of coatings on fresh weight of Golden Delicious apples over an eight week period..

Treatments	Fresh Weight (g)
Treatment 1	224.18 ± 6.89 a
Treatment 2	206.85 ± 6.89 a
Treatment 3	218.71 ± 6.89 a
Control	218.38 ± 6.89 a

Values with the same letter are not significantly different at p>0.0083.

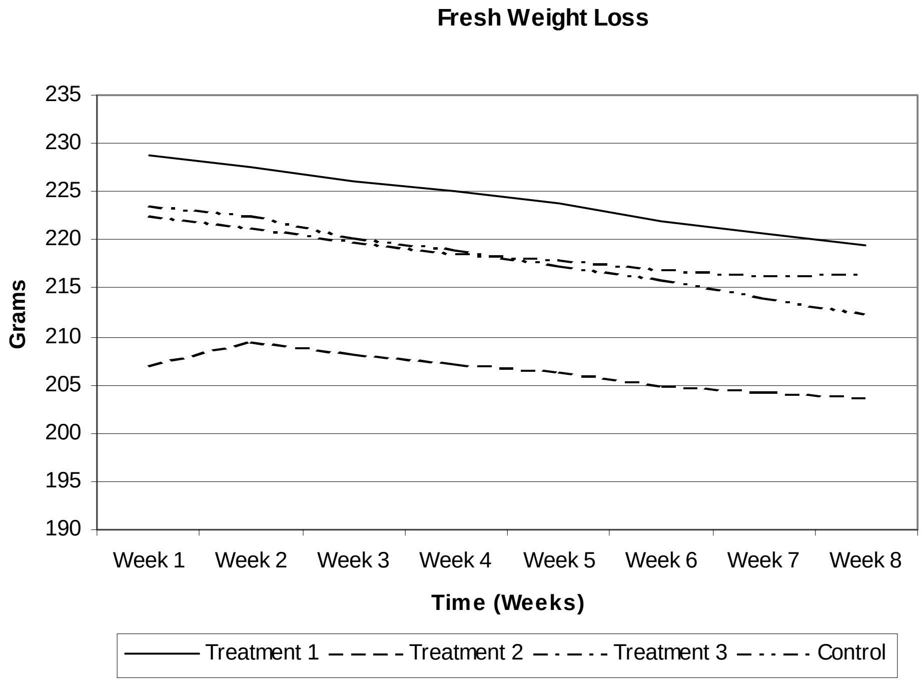


Figure 4. The effect of coatings on fresh weight of Golden Delicious apples during eight weeks of storage.

5.7 Color

Color is the most obvious change that occurs when fruit changes from the unripen to ripen state. The most common change is from green (chlorophyll) to yellow (carotenoids). Color changes during ripening depend mainly on the disappearance of chlorophyll *a* and *b* (Knee, 1993). The loss of the green color is also due to the degradation of the chlorophyll molecule. The degradation could occur from the pH change, which can be due to the leakage of organic acids from the vacuole, oxidative systems or the presence of chlorophyllase. There is an increase in the activity of chlorophyllase in the fruit during the climacteric period. The removal of the phytol side group converting chlorophyll to chlorophyllide proceeds further with a breakdown to pheophytin. Chlorophyllase has been known to remove this phytol group, however, it has been suggested that chlorophyllase might also be involved in the synthetic addition of the phytol group (Hulme and Rhodes, 1971).

Carotenoids, which are unsaturated hydrocarbons, are also present within the apple. Carotenoids are stable compounds and can remain intact in the tissue even when extensive senescence occurs. Carotenoids are usually present at the initial stages of development, however, they are masked by the presence of chlorophyll. Only when chlorophyll is broken down, does the carotenoid become visible. β-carotenes, lutein, violaxanthin, neoxanthin, and cryptoxanthin are the main carotenoids that are found in apples. During ripening, carotenes decrease while xanthophylls, particularly lutein and violaxanthin increase substantially (Knee, 1993). These color changes could be a result from ethylene synthesis.

There were significant differences ($P<0.0083$) between the treatment groups and the control group regarding the Hunter "a" color (Table 7). The means for the control apples (-6.04 ± 1.00) were much higher than the treatment apples (-10.7, -8.15, and –11.01 ± 1.00, respectively), indicating that the treatment apples were greener than the control apples.

There were no significant differences ($P>0.0083$) between the treatment groups and the control group regarding the Hunter "b" color (Table 7). The means for the control apples were higher than the treatment apples indicating that the control apples were more yellow than the treatment apples.

When apples go through the ripening process, there is a decrease in chlorophyll production in the skin. When there is a disappearance of chlorophyll, the carotenoids are then expressed, since the chlorophyll is masking the carotenoids, thus turning the apples yellow. Hulme and Rhodes (1970) found that during ripening of Golden Delicious apples at 20°C the chlorophyll content fell by 75%, while at the same time the xanthophylls increased five-fold. During this period, however, the carotene concentration decreased while there was no change in the concentrations of quercitin glycosides, which have been thought to contribute to the yellow color of the fruit. The coatings impeded ripening by decreasing respiration in the apple and also decreasing the ethylene synthesis that could cause a color change in the apple.

Table 7. The effect of coatings on color of Golden Delicious apples over an eight week period.

Treatments	Hunter L*	Hunter a*	Hunter b*
Treatment 1	73.66 $\pm$ 0.77 a	-10.7 $\pm$ 1.00 a	52.29 $\pm$ 0.80 a
Treatment 2	74.95 $\pm$ 0.77 a	-8.15 $\pm$ 1.00 a	50.93 $\pm$ 0.80 a
Treatment 3	75.01 $\pm$ 0.77 a	-11.01 $\pm$ 1.00 a	51.91 $\pm$ 0.80 a
Control	75.29 $\pm$ 0.77 a	-6.04 $\pm$ 1.00 b	53.43 $\pm$ 0.80 a

Values with the same letter in the same column are not significantly different at $p>0.0083$.

***L= 0=Black; 100=White**

***+a= Red**

***-a= Green**

***+b= Yellow**

***-b= Blue**

5.8 Sensory Evaluation

Quantitative descriptive analysis (QDA) was utilized in the study. Panelists determined the descriptors to evaluate the apple samples. The panelists were then trained on the specific descriptors to ensure consistent results. Data derived is used to corroborate objective data derived in the study.

The panelists measured the outside texture of the apple. This texture was measured by the amount of force that was needed to initially bite into the apple. A score of zero on the graphic rating scale indicated that the apple was crisp and on the higher side of the scale, a score of fifteen indicated that the apple was mushy. There were significant differences ($P<0.0083$) between treated apples and the control (Table 8). The coatings helped decrease the respiration rates in the apple (Table 1), whereby, preventing the degradation of the apple tissue and also by slowing the metabolism of the apple.

The inside texture of the apple was evaluated. The inside texture was defined as the degree to which the apple falls apart or stays together. The descriptors were decided as 0=mealy and 15=firm. There were significant differences ($P<0.0083$) between the treatment groups and the control (Table 8). The results indicated that the control apples were mealier, while the treated groups were firmer. There was a significant decrease ($P<0.0083$) in the texture of the control apples when compared to the treated apples (Table 2). During ripening, there is a decrease of the texture in the fruit. There is also evidence that oil based coatings can decrease ethylene production. Increased ethylene production has been shown to decrease firmness of the fruit (Ju et al., 2000a). The

Table 8. The effect of coatings on soluble solids of Golden Delicious apples over an eight week period.

Treatments	Texture (Outside)	Texture (Inside)	Sweet	Tart	Juiciness	Appearance
Treatment 1	5.55 ± 1.11 a	8.73 ± 1.20 a	7.74 ± 1.21 a	7.74 ± 1.21 a	6.20 ± 0.87 a	7.38 ± 1.22 a
Treatment 2	6.84 ± 1.11 a	8.29 ± 1.20 a	7.69 ± 1.21 a	7.69 ± 1.21 a	6.04 ± 0.87 a	6.96 ± 1.22 a
Treatment 3	4.79 ± 1.11 a	8.59 ± 1.20 a	7.95± 1.21 a	7.72 ± 1.21 a	6.30 ± 0.87 a	7.39 ± 1.22 a
Control	7.77 ± 1.11 b	6.43 ± 1.20 b	6.41 ± 1.21 a	6.41 ± 1.21 a	7.44 ± 0.87 b	8.33 ± 1.22 a

Values with the same letter in the same column are not significantly different at $p>0.0083$.

Texture (Outside)	**0=Crisp; 15=Mushy**	**Flavor (Tart)**	**0=Mild; 15=Strong**
Texture (Inside)	**0=Mealy; 15=Firm**	**Juiciness**	**0=Juicy; 15=Dry**
Flavor (Sweet)	**0=Mild; 15=Strong**	**Appearance**	**0=Shiny; 15=Dull**

coatings also offered a barrier for gas exchange that reduced the respiration, which in turn can slow down the ripening process. Therefore, the results from the panelists showed that there were noticeable sensory differences in the apples.

The flavor of the apples was also tested. The panelists treated sweetness and tartness individually. A score of zero indicated mild sweetness or tartness and a score of 15 indicated a strong sweet or tart flavor for each respective descriptor. There were no significant differences ($P>0.0083$) for either descriptor (Table 8). There were also no significant differences ($P>0.0083$) with regard to the soluble solids (Table 5), indicating that there was not a significant ($P>0.0083$) decrease in sugar within the apple. The panelists also confirmed that there were no differences ($P>0.0083$) in the sweetness of the apples. However, there were significant differences ($P<0.0083$) between the treatment groups and the control with regard to titratable acidity (Table 3). Since there were no differences detected for these descriptors, this suggests that the perception of acid may be difficult to determine. Also, the percentage of acidity in the apples was similar (Table 3) and this in turn made determination difficult for the panelists.

The panelists also tested the juiciness of the apple. Juiciness was defined as the amount of wetness or juiciness of the sample. The anchors for the scale were zero=juicy and fifteen=dry. There were significant differences ($P<0.0083$) between the treatment groups and the control group (Table 8). The panelists indicated that the control samples were significantly drier than the treatment samples. As the apple ripens, there is a loss of water in the apple. The coatings acted as a barrier for transpiration losses, therefore, there was an increased perception of juiciness. However, there were no significant differences ($P>0.0083$) in the fresh weight loss in the apples (Table 6). There was a marked decrease in weight loss in the control apples; however, this decrease was not significant ($P>0.0083$). This marked decrease may have affected the panelists' perception of the apples.

Finally, the panelists also tested the appearance of the apple. A score of zero indicated a shiny appearance and a score of fifteen indicated a dull appearance. There were no significant differences ($P>0.0083$) between the treatment groups and the control (Table 8). The coatings did not significantly increase the shiny appearance of the apple in the panelists' perception. The coatings were applied to produce a shiny more acceptable coating that would be positive for consumers. However, the apples were not buffed or shined after the application of the coating. On the industrial side, coatings are applied and often buffed to produce a glossy finish.

Figure 5 shows the summary of the sensory results. The control apples had more of a mushy, dry texture with a dull appearance. The treated apples were firmer and juicy, however, sweetness and tartness were non significant ($P>0.0083$) between all of the experimental groups.

5.9 Postharvest Disorders

Apples are very susceptible to postharvest disorders. Many postharvest disorders are often difficult to identify through symptoms alone. In the first week of the study, there was an incidence of a condition that was affecting treatment two apples. The condition consisted of the apple having a large brown soft spot on the calyx side of the apple. The spot was spongy in touch and brown in color. After cutting the apple, the

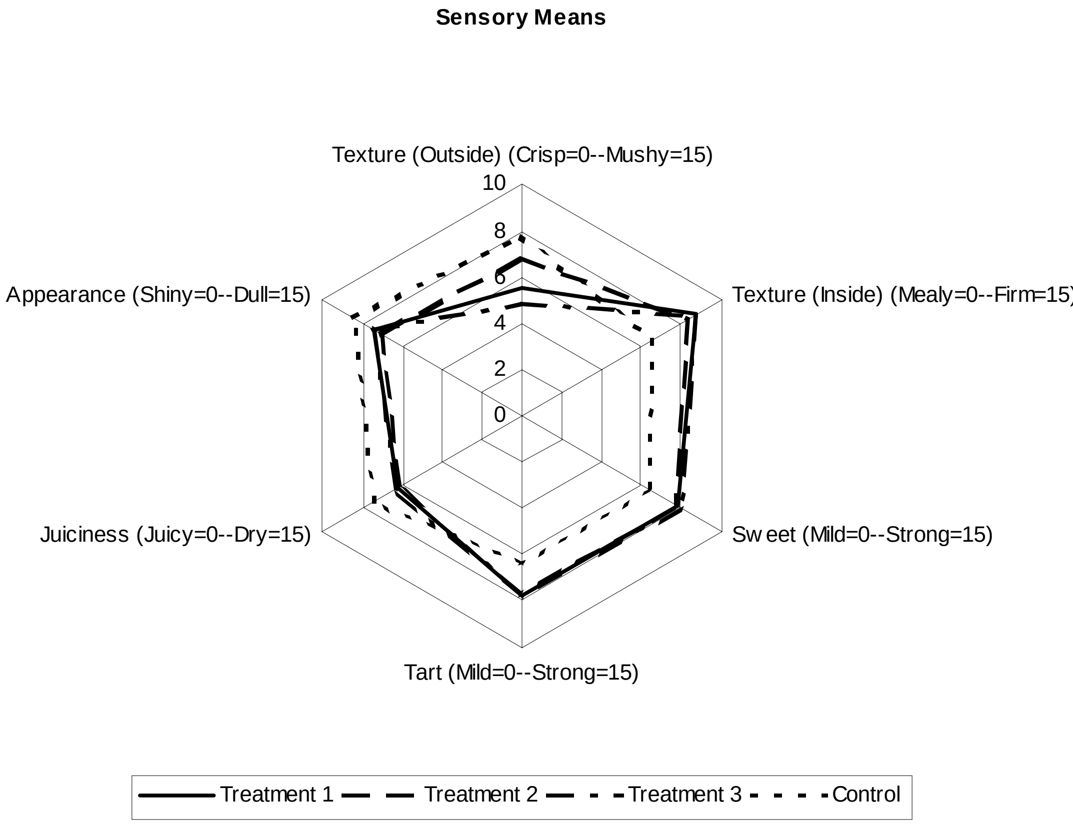


Figure 5. Spider web illustrating the effect of coatings on sensory characteristics of Golden Delicious apples during eight weeks of storage

inside of the apple was both watery and juicy. The apple smelled very sweet and there was an absence of an alcoholic aroma that may be associated with anaerobic fermentation. At week five, the same group of apples (approximately 20 apples) was still affected by this condition. Upon cutting the apple open at week five, there was a larger breakdown of the tissue. The fruit was extremely watery and the tissue was degrading rapidly. No further testing was performed on the infected apples. A literature search was conducted to find a possible cause. Mucor rot was defined as a possible cause for the apple breakdown. However, this was not proven in the laboratory.

Mucor rot is a fungal postharvest disorder that develops at the stem or calyx end of the fruit, or at a puncture wound of the skin. The tissue is soft, watery, and light brown in color. After about two months in cold storage, infected fruit completely decay, releasing large amounts of juice containing sporgangiospores (Spotts, 1990).

Sporangiospores of *Mucor piriformis* are soil borne. Around 75% of the spores are found in the top two centimeters of the soil and are associated with fallen fruit. Fallen fruit are infected by the soil, spores that are spread by rodents, birds, and insects from decaying fruit. The fungus survives best in cool, dry soil, not at temperatures above 20°C.

Fruit becomes more susceptible to infection during the last month before harvest. Late-harvested, over mature fruit are more susceptible to decay than mature fruit. The infection occurs during harvesting and the rot occurs during storage (Spotts, 1990).

There is no fungicide in the United States that is available to protect against *M. piriformis*. Minimizing the contact of the fruit to the soil would be a way to decrease the incidence. Harvesting in the dryer weather, rather than wet weather is another method in reducing the incidence of this fungus. This disease also occurs less in low-oxygen atmosphere storage, rather than in air cold storage. Lowering the relative humidity and also drying the fruit before placing the fruit in storage is another way to reduce Mucor rot. Therefore, the coatings that were applied could have facilitated this condition, and during the weeks that the fruit was stored the decay became manifested.

Chapter 6: Summary, Conclusions, and Recommendations for Future Research

6.1 Summary

Wax coatings are the predominant form of coatings that are used in industry to help keep apples and other fruit shelf stable. However, these types of coatings are not very good barriers for gas exchange or transpiration. There is high demand for a better, high quality coating for fruits.

Research is now focusing on composite coatings to increase the shelf life of fruits and vegetables. Using a combination of wax, lipids, and gums can be an option to expand the possibilities of different coatings on fruits and vegetables.

The respiration rates can be a good marker to a fruit's maturity and ripeness. Composite coatings using a combination of lipids, wax, and gums have shown to significantly ($P<0.0083$) decrease the respiration of apples as compared to the control. The combination of the gums helped to provide emulsification abilities and at the same time decreased gas exchange. Specifically, gum arabic can provide emulsification abilities and binding properties to provide barriers around the apple. Carboxy-methyl cellulose can swell when hydrated, therefore clogging the pores of the fruit in preventing respiration. Algin also can provide a barrier of protection around the apple by producing viscous solutions.

Texture can also be a marker for the apple's maturity. The degradation of starch, loss of water, and breakdown of the cell walls can be factors affecting the loss of texture. The coated apples significantly ($P<0.0083$) maintained the texture of the apples as compared to the control apples. The oil that was contained in the coatings has been shown to reduce the ethylene production in the apple (Ju et al., 2000a). The production of ethylene can contribute to the increased ripening in the fruit, eventually reducing the texture of the fruit. Algin was also shown to serve as an effective barrier for water loss. Water retention can in turn help maintain the texture of the fruit.

As the fruit ripens, there is a decrease in acids. Malic acid is the main acid that is present within the apple. Malic acid is the major substrate of respiration, therefore, the more the fruit respires, the more malic acid is used. The coatings significantly decreased ($P<0.0083$) the respiration rates and, therefore, the coated groups had higher acid levels when compared to the control.

The degradation of starch can affect the texture of the apple, and at the same time cause an increase in sugars within the apple. The starch content of the apple was significantly ($P<0.0083$) maintained by the composite coatings. The coatings can cause a decrease in respiration which can slow down the over all metabolism of the apple. Subsequently, a decrease in the degradation of starch into sugars would be the result.

The degradation of starch can increase the sugar content in the apple because of the hydrolysis of starch into sugars. There were no significant ($P>0.0083$) differences in the sugar content of the treated apples and the control group. Starch breakdown in the apple is indicative of fruit ripening. However, since no differences were detected, soluble solids may not be an adequate indicator of stability.

Fresh weight loss is a gauge to determine the quantity of water that is lost through the cuticle of the apple by way of transpiration. There were no significant differences ($P>0.0083$) between the treated apples and the control apples. There was a decrease in weight over the eight-week period. There was an average of approximately 1.0g loss per week. The coatings did help provide benefits for the decrease of respiration; however, the coatings did not offer water retention within the apple.

The color change in the apple is an outward change that is visible when an apple ripens. Production of ethylene could cause an increase in the color change in the apple. Decreasing the respiration rate and ethylene synthesis could affect color change. The coatings did decrease the respiration of the apples, thus reducing the ethylene synthesis and preventing color change in the apple. There were significant differences ($P<0.0083$) in the Hunter "a" color between the treated groups and the control groups, indicating that the treated apples were greener than the control apples. A greener apple indicates a less mature apple. However, there were no significant differences ($P>0.0083$) between the treated groups and the control groups regarding the Hunter "b" color. Even though the results were not significant ($P>0.0083$), the means for the control apples were higher than the treated apples, signifying that the control apples were more yellow than the treated apples, and perhaps an indication for increased ripening.

The texture of the apple was maintained by the coatings and the sensory results reflected these findings. The panelists found that there were significant differences ($P<0.0083$) in texture, both outside and inside, when comparing the treated apples and the control apples. The coatings helped decrease the starch degradation, which can be a factor in the loss of texture in the apple.

The sweetness and tartness of the apples can also provide another insight into the panelists' perception of these characteristics. The panelists did not find significant differences ($P>0.0083$) in both of these characteristics between the treated groups and the control groups. There were also no significant differences ($P>0.0083$) in the soluble solids (Table 5) of the apples, however, there were significant differences ($P<0.0083$) in the acidity of the apples (Table 3). This may suggest that the panelists may have difficulty or more training in the determination of acidity in the apple.

Juiciness in the apple can be an indicator of the water that is contained within the apple. There were no significant differences ($P>0.0083$) in weight loss of the apples; however, the panelists did find significant differences ($P<0.0083$) in juiciness between the treated apples and the control apples. There was more of a decrease over time in weight of the control apples as compared to the treated apples, however this was not significant ($P>0.0083$) (Table 6). This decrease could have been enough for the panelists to detect differences.

The appearance of the apples is the first perception of quality that the consumer sees. The panelists did not find significant differences ($P>0.0083$) in the appearance of the apples. The coatings can provide a shiny, glossier finish to the apple, however, for this study the apples were not buffed to produce a shiny appearance. In industry, the apples can be buffed to help improve the shine, and at the same time consumer acceptability.

Postharvest disorders are very common in apples. Mucor rot was a possible fungal disorder that affected a group of apples in treatment two. The apples were extremely watery and the fruit was decaying very rapidly over the eight-week period. Mucor rot is seen more in late-harvested, over mature fruit. The fungus is spread by the soil and best survives in cool, dry areas. The rot develops at the stem or calyx end of the fruit; the tissue is soft, watery and light brown in color. All of these attributes were observed in the infected apples and this disorder may be associated with these apples.

6.2 Conclusions and Recommendations for Future Research

Composite coatings seem to be the best way to protect and preserve the quality of the apple. The type of coating and the ingredients within will dictate its uses and success. Using a combination of lipids, wax, and gums appeared to work synergistically at an acceptable level. The oil helps to prevent scald, while the wax and the gums slowed down the respiration rate and other changes that might occur in the fruit. However, there could be an improved formula that might also provide an enhanced barrier for protection.

Xanthan gum could be selected as an alternative hydrocolloid to provide stability within the coating. However, xanthan gum and locust bean gum together may not be the best choice due to the 'naked sections' within the structure of the locust bean gum that could react with xanthan to form a rigid gel. This would not be conducive to coatings. However, xanthan gum and guar gum used simultaneously are able to produce an increase in viscosity. This increase in viscosity would provide stability to the coating and aid in moisture retention within the fruit. More research needs to be done on the interaction of these gums and their performance as coatings for fruit.

Using an antioxidant within the coating may also help in the reduction of postharvest disorders. The coatings by themselves work to prevent the degradation of the fruit, and using an antioxidant can help prevent postharvest disorders, such as scald. Using an antioxidant has been shown to prevent the oxidation of α-farnescene. The oxidation of α-farnescene increases the incidence of scald development in apples (Anet and Coggiola, 1974). Oil is a main ingredient in these types of coatings and using antioxidants can also prevent rancidity. Oil can oxidize and become rancid when exposed to light or oxygen and the antioxidants can help prevent the oxidation of the oil and maintain the coating's integrity. An antioxidant, such as butylated hydroxytoluene (BHT) might be the most effect when added to the coating.

Ethylene production and its in relationship to the objective data would have added depth to the study. Ethylene can trigger ripening, and subsequent softening of the fruit. Studying the point at which ethylene production is produced and then relating that production to the texture analysis or the respiration rates would have given more insight into the biochemistry of fruit ripening.

Controlled atmospheric storage has been known to preserve the quality of fresh fruits and vegetables. In controlled atmospheric storage, oxygen, carbon dioxide, and nitrogen levels are controlled. This type of storage is used to help lower respiration rates and to delay ripening. Using composite coatings and also the controlled atmospheric storage can possibly work synergistically to provide an optimum environment to help delay ripening and to increase the shelf life of fruits and vegetables.

Sensory evaluation is an integral part of food research. QDA analysis indicated that the majority of the attributes were comparable to the objective tests; however, more research would be needed to determine consumer acceptability. The coatings may provide delayed ripening, but they also may produce off flavors. Affective testing can help provide answers to that question.

Through all of the objective and sensory tests, there were no significant differences ($P>0.0083$) within the treatments. This leads to the assumption that the three coatings performed equally to delay ripening. Treatment one and treatment three coatings produced an aesthetically pleasing coating to the eye and seemed to maintain the quality of the apple. Treatment two experienced rotting, in the form of Mucor rot, therefore, degraded the apple. Consequently, it can be assumed that the combination of gum arabic and locust bean gum or CMC and locust bean gum can have a positive effect on the keeping quality of the apple during storage. Although the results were not significant ($P>0.0083$), the respiration rates in treatment two were higher in the other treatments, suggesting that there could possibly be more ripening occurring. Additional research is needed to investigate this treatment. Also, because there was some degradation of the apple in treatment two, further research needs to be done on the effect of Mucor rot and also on how to prevent and treat this fungus.

Literature Cited

Alleyne, V. and Hagenmaier, R.D. (2000) Candelilla-shellac: An alternative formulation for coating apples. *HortScience.* 35(4):691-693.

AOAC (2000) Official Methods of Analysis of AOAC International. 17^{th} ed. (W. Horowitz, ed.) Gathersburg, MD, 37:932.14.

AOAC (2000) Official Methods of Analysis of AOAC International. 17^{th} ed. (W. Horowitz, ed.) Gathersburg, MD, 37:942.15.

Anet. E.F.L.J. and Coggiola, I.M. (1974) Superficial scald, a functional disorder of stored apples: X. Control of α-farnescene autoxidation. *Journal of the Science of Food and Agriculture.* 25:293-298.

Baldwin, E.A., J.K. Burns, W. Kazokas, J.K. Brecht, R.D. Hagenmaier, R.J. Bender, and E. Pesis. (1999) Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. *Postharvest Biology and Technology*. 17:215-226.

Basker, D. (1992) Comparison of taste quality between organically and conventionally grown fruits and vegetables. *American Journal of Alternative Agriculture.* 7(3):129-136.

Bauchot, A.D. and John, P. (1996) Scald development and the levels of α-farnescene and conjugated triene hydroperoxides in apple peel after treatment with sucrose ester-based coatings in combination with food-approved antioxidants. *Postharvest Biology and Technology*. 7:41-49.

Bramlage, W.J., Drake, M., and Lord, W.J. (1979) The influence of mineral nutrition on the quality and storage performance of pome fruits grown in North America. *Acta Horticulture.* 92:29-40.

Clements, R.L. (1970) Protein patterns in fruits. In: *The Biochemistry of Fruits and their Products, Vol. 1.* (Hulme, A.C., ed) pp.159-178. Academic Press, Norwich, England.

Daniels, R. (1973) Fruit and vegetable coatings. In: *Edible Coatings and Soluble Packaging.* pp. 66-95. Noyes Data Corporation, Park Ridge, NJ.

DeEll, J.R. and Prange, R.K. (1992) Postharvest quality and sensory attributes of organically and conventionally grown apples. *HortScience.* 27(10): 1096-1099.

Drake, S.R., Fellman, J.K., and Nelson, J.W. (1987) Postharvest use of sucrose polyesters for extending the shelf-life of stored ‘Golden Delicious’ apples. *Journal of Food Science.* 52(5): 1283-1285.

Feys, M., Naesens, W., Tobback, P., and Maes, E. (1980) Lipoxygenase activity in apples in relation to storage and physiological disorders. *Phytochemistry*. 19:1009-1011.

Garcia, M.A., Martino, M.N., and Zaritzky, N.E. (2000) Lipid addition to improve barrier properties of edible starch-based films and coatings. *Journal of Food Science.* 65(6):941-947.

Hagenmaier, R.D., and Shaw, P.E. (1992) Gas permeability of fruit coating waxes. *Journal of the American Society of Horticultural Science.* 117(1):105-109.

Hardenburg, R.E. and Anderson, R.E. (1965) Postharvest chemical, hot water, and packaging treatments to control apple scald. *Processing of the American Society of Horticultural Science.* 87:93-99.

Huelin, F.E. and Coggiola, I.M. (1968) Superficial scald, a functional disorder of stored apples: IV. Effect of variety, maturity, oiled wraps and diphenylamine on the concentration of α-farnescene in the fruit. *Journal of the Science of Food and Agriculture.* 21:44-48.

Hulme, A.C. and M.J.C. Rhodes. (1971) Pome fruits. In: *The Biochemistry of Fruits and their Products, Vol. 2.* (Hulme, A.C., ed) pp.333-369. Academic Press, Norwich, England.

Ingle, M. and D'Souza, M.C. (1989) Physiology and control of superficial scald of apples: A review. *HortScience.* 24(1):28-31.

Ju, Z. Y, Duan, Z, Ju, and E.A. Curry. (2000a) Stripped plant oils maintain fruit quality of 'Golden Delicious' apples and 'Bartlett' pears After Prolonged Cold Storage. *Journal of Horticultural Science and Biotechnology.* 75(4): 423-427.

Ju, Z., Duan, Y., and Ju, Z. (2000b) Mono-, di-, and tri-acylglycerols and phospholipids from plant oils inhibit scald development in 'Delicious' apples. *Postharvest Biology and Technology*. (19):1-7.

Kenkle, J. (1988) Acid-Base Titrations and Calculations. In: *Analytical Chemistry for Technicians.* (J. Kenkle ed.) pp.87-121. Lewis Publishers, Inc., Chelsea, Michigan.

Kester, JJ. and Fennema, OR. (1986) Edible films and coatings: A review. *Food Technology*. 40(12):47-59.

Klein, B.P. (1992) Fruits and vegetables. In: *Food Theory and Applications.* (Bowers, J., ed) pp. 687-766. Macmillan Publishing Company, New York, NY.

Knee, M. (1993) Pome Fruits. In: *Biochemistry of Fruit Ripening.* (Seymour, G.B, J.E. Taylor and G.A. Tucker, ed) pp. 325-346. Chapman and Hall, London, UK.

Labuza, T.P. (1982) Moisture gain and loss in packaged foods. *Food Technology.* 36(4):92.

Lau, O.L. (1998) Effect of growing season, harvest maturity, waxing, low oxygen, and elevated carbon dioxide on flesh browning disorders in 'Braeburn' apples. *Postharvest Biology and Technology.* 14: 131-141.

Li, S.J., Facteau, T.J., Chen, P.M., and Mielke, E.A. (1999) Comparison of amylase activity and starch content in normal cork spotted 'D'anjou' pears. *Journal of Food Biochemistry.* 23(5):509-518.

Little, C.R., Taylor, H.J., and Peggie, I.D. (1980) Multiformulation dips for controlling storage disorders of apples and pears: II. Assessing scald inhibitors. *Scientia Horticulture.* 13:315-321.

McHugh, T.H. and Senesi, E. (2000) Apple wraps: A novel method to improve the quality and extend shelf life of fresh-cut apples. *Journal of Food Science.* 65(3): 480-485.

Nonaka, H.H. (1997) Plant carbohydrate-derived products as fat replacers and calorie reducers. *Cereal Foods World.* 42(5):377-378.

Powers, J.J. (1988) Current practices and applications of descriptive methods. In: *Sensory Analysis of Foods, Second Ed.* (Piggott, J.R. ed.) pp.187-266. Elsevier Science Publishers LTD, New York, NY.

Priest, K.L. and Lougheed, E.C. (1988) Evaluating maturity of McIntosh and Red Delicious apples. *Ministry of Agriculture and Food.*

Root, W.H. (1996) Apples and apple processing. In: *Processing Fruits: Science and Technology: Major Processed Products Vol. 2.* (Somogyi, L.P., Barnett, D.M., and Hui, Y.H., eds.) pp. 1-35, Technomic Publishing, Lancaster, PA.

Saftner, R.A. (1999) The potential of fruit coating and film treatments for improving the storage and shelf-life qualities of 'Gala' and 'Golden Delicious' apples. *Journal of the American Society for Horticultural Science.* 124(6):682-689.

Saftner, R.A. and Conway, W.S. (1998) Effects of postharvest calcium and fruit coating treatments on postharvest life, quality maintenance, and fruit-surface injury in 'Golden Delicious' apples. *Journal of the American Society for Horticultural Science.* 123(2):294-298.

Salunke, D.K. and Desai, B.B. (1984) Deciduous fruits-apple and pear. *Postharvest Biotechnology of Fruits, Vol. I.* pp. 123-137. CRC Press, Inc., Boca Raton, FL.

Scott, K.J., Yuen, C.M.C., and Kim, G.H. (1995) Reduction of superficial scald of apples with vegetable oils. *Postharvest Biology and Technology*. 6:219-223.

Sharples, R.O. (1979) The influence of orchard nutrition on the storage quality of apples and pears grown in the United Kingdom. *Acta Horticulture.* 92:17-28.

Shellhammer, T.H. and Krochta, J.M. (1997) Edible coatings and film barriers. *Lipid Technologies and Applications.* (Gunstone, F.D. and Padley, F.B eds.) pp. 453-479. Marcel Dekker, Inc, New York, NY.

Smith, S., J. Geeson, and J. Stow. (1987) Production of Modified Atmospheres in Deciduous Fruits by the Use of Films and Coatings. *HortScience.* 22(5):772-776.

Smock, R.M and Neubert, A.M. (1950a) Varieties of apples. In: *Apples and Apple Products.* (Z.I. Kertesz ed). pp. 1-177. Interscience Publishers, Inc., New York, NY.

Smock, R.M and Neubert, A.M. (1950b) Chemistry and physiology of developing fruit *Apples and Apple Products.* (Z.I. Kertesz ed). pp. 1-177. Interscience Publishers, Inc., New York, NY.

Spotts, R.A. (1990) Mucor Rot. In: *Compendium of Apple and Pear Diseases.* (A.L. Jones and H.S. Aldwinckle, eds.). pp. 57-58. APS Press, St. Paul, MN.

Stow, J. (1989) The involvement of calcium ions in maintenance of apple fruit tissue structure. *Journal of Experimental Botany.* 40:1053-1057.

Streif, J. and Bangerth, F. (1988) Production of volatile aroma substances by ‘Golden Delicious’ apple fruits after storage for various times in different carbon dioxide and oxygen concentrations. *Journal of Horticultural Science.* 63(2): 193-199.

Sumnu, G. and Bayindirh, L. (1995) Effects of coatings on fruit quality of Amasya apples. *Lebensmittel-Wissenschaft and Technologie.* 28:501-505.

Whistler, R.L. and BeMiller, J.N. (1997a) Guar and locust bean gums. In: *Carbohydrate Chemistry for Food Scientist.* pp. 171-178. Egan Press, St. Paul, MN.

Whistler, R.L. and BeMiller, J.N. (1997b) Xanthan. In: *Carbohydrate Chemistry for Food Scientist.* pp. 179-185. Egan Press, St. Paul, MN.

Whistler, R.L. and BeMiller, J.N. (1997c) Exudate Gums. In: *Carbohydrate Chemistry for Food Scientist.* pp. 211-216. Egan Press, St. Paul, MN.

Whistler, R.L. and BeMiller, J.N. (1997d) Starch. In: *Carbohydrate Chemistry for Food Scientist.* pp. 117-152. Egan Press, St. Paul, MN.

Whiting, G.C. (1970) Sugars. In: *The Biochemistry of Fruits and their Products, Vol. 1*. (Hulme, A.C., ed) pp.333-369. Academic Press, Norwich, England.

Wills, R.B.H., T.H. Lee, D. Graham, W.B. McGlasson, and E.G. Hall. (1981) Physiology and Biochemistry. In: Postharvest: An Introduction to the Physiology and Handling of Fruits and Vegetables. (Wills, R.B.H., T.H. Lee, D. Graham, W.B. McGlasson, and E.G. Hall, ed). pp.17-37. The AVI Publishing Company inc, Westport, Conn.

Wills, R.B.H., McGlasson, W.B., and Graham, D. (1989) Commodity Treatments. In: *Postharvest: An Introduction to Physiology and Handling of Fruit and Vegetables.* (Lee T.H. and Hall, E.G., eds.) pp. 114-121, VanNostrand Reinhold, NY, NY.

Wills, R.B.H. and Scott, K.J. (1977) Evaluation of the use of butyalted hydroxytoluene to reduce superficial scald of apples. *Scientia Horticulture.* 6:125-127.

Yogaratnam, N. and Sharples, R.O. (1982) Supplementing the nutrition of Bramley's Seedling apple with phosphorous sprays II. Effects on fruit composition and storage quality. *Journal of Horticultural Science.* 57(1):53-59.

Zhang, D. and Quantick, P.C. (1998) Antifungal effects of chitosan coating on fresh strawberries and raspberries during storage. *Journal of Horticultural Science and Biology*. 73:763-767.

http://pestdata.ncsu.edu/cropprofiles/docs/vaapples.html. (2001).

http://www.virginiapples.org. (2001).

Appendix A

Coating Formulations

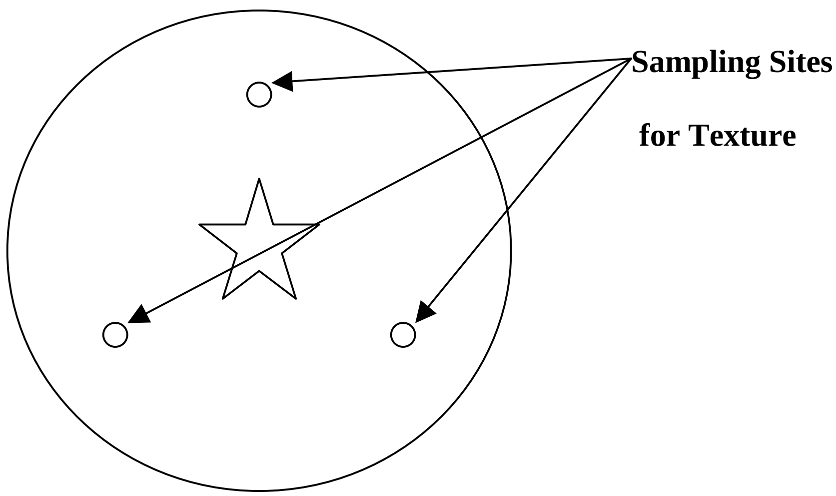
Coating Formulations

Treatment One		Treatment Two		Treatment Three	
Oil [a]	4.8g	Oil	4.8g	Oil	5.0g
Parafilm	0.5g	Parafilm	0.5g	Parafilm	0.5g
Surfactant	0.1g	Surfactant	0.1g	Surfactant	0.1g
Maltodextrin	8.0g	Maltodextrin	8.0g	Maltodextrin	8.0g
Gum Arabic	0.3g	Locust Bean	0.1g	CMC [b]	0.3g
Locust bean	0.3g	Algin	0.1g	Locust Bean	0.2g
Water	86.4g	Gum Arabic	0.1g	Water	85.9g
		Water	86.1g		

a-Vegetable Oil
b-Carboxy-methyl cellulose

Appendix B

Sampling Sites for Texture Evaluation



Cross section slicing of the apple illustrating the sampling sites for the texture analysis.

Appendix C

Respiration Rate Formula

Formula for calculating respiration

Respiration= (CO_2 [(F)(K)]/fruit weight
[Units are in mg CO_2/hr/kg]

(CO_2=difference in CO_2 concentration between the air entering the chamber and air leaving the chamber; units are in ppm by volume x 10-6

F=air flow through the chamber (liters/hour; 5 L/hr)

K=(44,000 mg CO_2/22.4) x (273/294), approximate conversion of liters of CO_2 to mg of CO_2 if you assume a temperature of 21°C and no adjustment for atmospheric pressure to sea level.

Fruit weight is converted from g to mg.

Appendix D

Malic Acid Formula

Formula for calculating percent malic acid

$$\% \text{ Malic Acid} = \frac{\text{Total volume titrated in ml x M of NaOH x eq. wt. Malic Acid x 100}}{\text{ml of sample}}$$

M of NaOH=0.1M

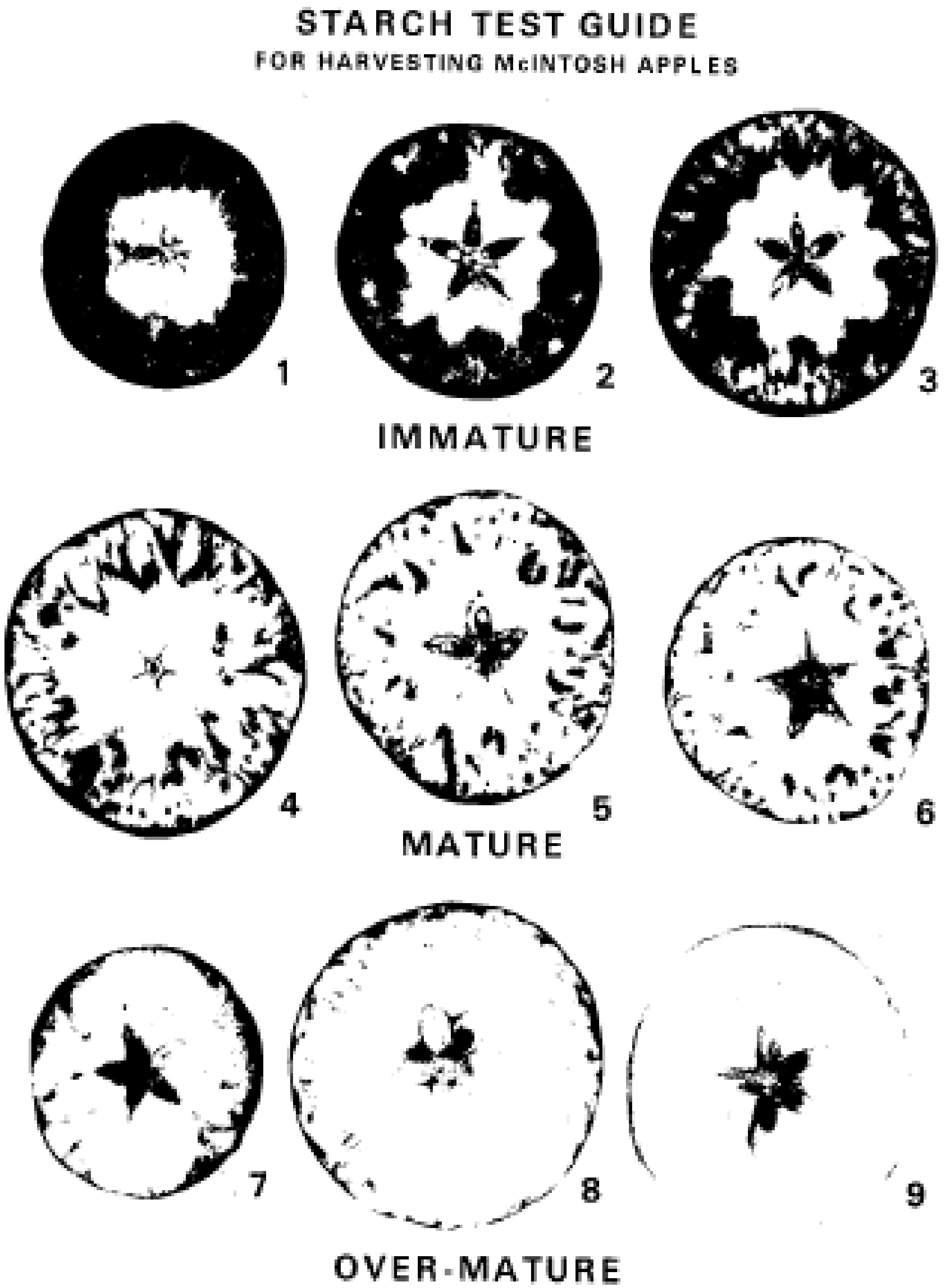
Equivalent weight of Malic acid=72.0

ml of sample used=100ml

(Kenkel, 1988)

Appendix E

Starch Evaluation Chart



(Priest and Lougheed, E.C., 1988)

Appendix F

Informed Consent Forms

VIRGINIA POLYTECHNIC INSTITUE AND STATE UNIVERSITY

Informed Consent for Participants
Of Investigative Projects

Title of Project: <u>The Effect of Lipid Hydrocolloid Coatings on the Postharvest Storage Quality of 'Golden Delicious' Apples</u>

Investigator: <u>Jocelyn Totty</u>

I. Purpose of the Research Project:

The purpose of this research project is to formulate lipid hydrocolloid coatings for Golden Delicious apples to help prevent storage disorders and to improve the overall keeping quality of the post harvested apple. The sensory evaluation will include seven individuals that will be recruited through flyers. Participants will not be excluded because of age or gender.

II. Procedures:

Quantitative Descriptive Analysis (QDA) will be used to evaluate the characteristics of the coated fruit. 7-10 panelists will be selected to evaluate the fruit samples. There will be three-one hour training sessions to train the panelists on selecting the attributes that they will evaluate. Once the attributes are unanimously decided upon, the panelists will participate in further training sessions to learn testing procedures with the derived scorecard. The panelists will then come in to Room 335 Wallace Hall once a week for eight weeks to sample the fruit and evaluate the fruit on the selected attributes. Panelists will evaluate each descriptor, and data will be quantified from each descriptor.

III. Risks

There are no posed risks to the subjects who participate in this sensory evaluation. All ingredients that are used are FDA approved.

IV. Benefits of this Project

There are no direct benefits to the participant, however there are benefits to the society at large if the project is successful. If the project is successful, then there is a potential for a new method of preservation for apple grower and distributors that is inexpensive and will help keep the fruit fresher longer.

V. Extent of Anonymity and Confidentiality

Assigning each subject a number will preserve the confidentiality of each subject. They will then fill out the sensory scorecards with only their assigned number. It is not imperative that the investigators know the participants' identity because it is just opinions, not personal information.

VI. Compensation

There is no compensation that will be given for the completion of this study

VII. Freedom to Withdraw

Subjects are free to withdraw at any time during the study without penalty. Subjects are free not to answer any questions or respond to experimental situations that they choose without penalty. There may be circumstances under which the investigator may determine that a subject should not continue as a subject.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, by the Department of Human Nutrition, Foods, and Exercise.

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

- To report to 335 Wallace Hall on Wednesday for eight weeks at the assigned time
- To sample and evaluate the experimental apples once a week for eight weeks

Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

______________________________ ______________________________

Signature Date

Should I have any questions about this research or its conduct, I may contact:

Jocelyn Totty______________________	231-7708__________
Investigator	Phone
Dr. Frank Conforti__________________	231-8765__________
Faculty Advisor	Phone
E.R. Stout_________________________	___________________
Chair, IRB, Research Division	Phone

Appendix G

Sensory Scorecard

Panelist #______________

Please examine the following apple samples and rate them according to the characteristics discussed. Place a vertical line that best describes the property of the sample given.
(e.g. ___________________)

Please take sufficient time for each sample and evaluate each characteristic given.

Texture (Outside)

Crisp **Mushy**

Texture (Inside)

Mealy **Firm**

Flavor—Sweet

Mild **Strong**

Flavor—Tart

Mild **Strong**

Juiciness

Juicy **Dry**

Appearance

Shiny **Dull**

Vita

Jocelyn A. Totty was born August 22, 1978 in Richmond, Virginia. She attended Meadowbrook High School in Richmond, Virginia and completed her studies there in 1996. She then attended Virginia Polytechnic Institute and State University, where she received in May, 2000, a Bachelor of Science degree in Consumer Foods from the Department of Human Nutrition, Foods, and Exercise. Upon completion of her undergraduate degree, she returned to Virginia Polytechnic Institute and State University to pursue a Masters of Science degree in Foods from the Department of Human Nutrition, Foods, and Exercise, which she completed on May 28, 2002. She plans on pursuing a career in the food industry.