DISSERTATION

MINIMIZING THE STORAGE LOSSES OF POTATOES UNDER DIFFERENT STORAGE TREATMENTS

Submitted by

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ABSTRACT

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Potato (Solanum tuberosum L.) ranks fourth in the world as an essential food crop thus it's one of the most consumed agricultural products worldwide. Potato is not only an important food source of carbohydrates but also for antioxidant components and ascorbic acid. Most potato production is destined for commercial processing, followed by fresh table consumption and seed stock. The demand for potatoes for fresh markets and processing is year-round. It is critically important to maintain consistently high potato quality throughout the storage and marketing periods to the final consumer. Long-term storage is necessary to ensure year-round supply for the potato fresh market and processing industry.

The major reasons for potato postharvest losses are water loss, mechanical damage, physiological damage (including nutrient loss and color loss), insect damage, and disease damage. The potato is a living entity thus natural processes, such as transpiration, respiration, and reproduction, continue even after the potato tubers are harvested. Transpiration and respiration are responsible for physical water loss from tubers and thus weight loss, which is maximum during the first two months of potato storage. Transpiration is responsible for approximately 90% of the total loss. In comparison, the weight loss due to respiration is less than 10% of the total loss. During respiration, the tubers generate heat, which becomes an important consideration for the storage of potatoes, and it is necessary to get rid of it. Hence, it becomes clear the importance of low temperature, high humidity, and ventilation in potato storage to slow

down the process of transpiration and respiration and thereby maintain tuber quality. The excessive loss of moisture in the potato causes tubers to shrink and may become unmarketable. Also, sprouting significantly increase water loss in stored potatoes and diminishes the nutritive quality of the potato. Another manifestation of loss in potatoes is the color loss in colored potatoes. Sometimes the consumers may reject the colored potato if it has a faded or uncharacteristic color.

The present research project consists of four studies. The aim of the first study was to examine the effect of speed and operation period of ventilation fans on the quality of Rio Grande Russet and power consumption during six months of storage. The second part of the study focused on investigating the effect of methods of reducing the postharvest field heat on the quality of two potato cultivars during storage and French fries made after the reconditioning process. In the third part of the present research, the optimum edible coating formulations for potatoes were studied to extend the shelf life under different storage conditions and to study the effects of edible coatings on sensory, physical, and nutritional properties in three potato cultivars. The fourth study was aimed to determine the effect of different edible coatings on two types of potato red skin cultivars to extend the shelf life and maintain the color and quality of potatoes.

In the first study, the effect of speed and duration of ventilation fans on the quality of Rio Grande Russet stored at 5 °C ± 2 and 95 % RH ± 5 in the 2016 and 2017 seasons were investigated. Three fan speeds were used in this study: 52 cubic feet per minute (CFM), 13 CFM, or 0.6 CFM, the three fans' speeds were operated under continuous and intermittent systems in addition to the control (zero ventilation). The tubers were analyzed periodically for weight loss, texture, ethylene production, respiration rate, sprouting incidence, power consumption, and bioactive compound (total phenolics, total flavonoids, reducing sugars, and ascorbic acid) during

the storage period. The results of this study (Chapter 3) showed that the weight loss was greater under continuous ventilation compared to intermittent ventilation in both the 2016 and 2017 seasons. Similarly, tuber weight loss increases as the fan CFM increases in continuous and intermittent operation. Intermittent ventilation at 0.6 CFM significantly decreased weight loss compared to the control. There was no significant difference in tuber weight loss between continuous and intermittent ventilation at 52 and 13 CFM. Tubers stored under continuous or intermittent ventilation at 52 CFM underwent significant texture loss compared to the control. The textures of the tubers showed that there was no significant difference between continuous and intermittent ventilation at 0.6 CFM and continuous ventilation at 13 CFM. The intermittent 0.6, 13, and 52 CFM ventilation increased ethylene production significantly over the control after six months of storage. The greatest level of ethylene production was observed in the 0.6 CFM intermittent ventilation treatment. There was a considerable difference in respiration rate detected after six months between intermittent ventilation at 13 and 0.6 CFM fans and continuous ventilation fans at 52 CFM. The result was shown there was a significant difference between continuous and intermittent ventilation on sprouting. In the 2017 season, continuous ventilation at 52 and 13 CFM significantly reduced the sprouting rate. Tubers exposed to intermittent ventilation at 13 and 0.6 CFM expressed a significantly greater sprouting rate compared to the control. There was a significant difference in power consumption between continuous and intermittent ventilation. Continuous ventilation at 52 CFM significantly increased total flavonoid content and decreased reducing sugars compared to intermittent ventilation at 0.6 CFM. This study indicates the importance of using slow and medium CFM fans in long-term potato storages to reduce tuber weight loss and power consumption.

In the second study, the effect of three methods to reduce tubers' field heat; temperature lowering stepwise (TLS), temperature lowering gradually (TLG), and the temperature lowering immediately (TLI) on the quality of Russet Norkotah 3 and red skin numbered line CO 07102-1R was studied. The tubers were analyzed at harvest time and when the tubers reached 3 °C and after six months of storage at 3 °C for weight loss, texture, wound healing, total phenolics, reducing sugars, and the color of French fries. The results of the second study (Chapter 4) indicate that the lowest significant weight loss was in the TLG method, and the highest significant weight loss was in the TLI reduction method. After six months of cold storage, the lowest significant weight loss was in the TLS method. There was no significant difference in weight loss between TLG and TLI reduction methods in the case of Russet Norkotah 3. Texture loss during the wound healing period (when tubers reached 3 °C) was significant in the case of the TLS method in both cultivars and the loss was lowest in the TLG and TLI method, and there was no significant difference between the TLG and TLI methods. On the other hand, after six months of storage, the highest texture loss was noted in the TLI method followed by the TLG method. Texture loss in Russet Norkotah 3 was significantly less than the loss in the TLI method after six months. The wound healing was more effective in the TLS reduction method, especially with Russet Norkotah 3. This study indicates the TLG method is a better treatment in short-term storage when the tuber has more skin damage, while the TLS method is better for russet cultivar in the long-term storage in terms of weight loss as the tuber has more time to heal. The French fries color was lighter at harvest time (USDA grade 0), while there were no differences in French fry color prepared from tubers stored by TLS and TLG methods (both had USDA grade 2). French fries were darker in the case of the TLI method (grade 4). There was a significant difference in the effect of field heat reduction methods on the total phenolics content during the

wound healing period. Total phenolic compounds were significantly high in TLG and TLI methods compared with the TLS method. There was no significant difference between the TLG and TLI field heat reduction method. The content of reducing sugars was significantly high in all field heat reduction methods at the end of the wound healing process compared with the content at zero time. However, there was no significant difference between the TLS and TLG methods in CO 07102-1R variety while there was a significant difference with Russet Norkotah 3. The highest significant amount of reducing sugars was in the TLI method.

The purpose of the third study was to determine the effect of applying edible coatings on freshly harvested potatoes under different storage conditions. Seven edible coating combinations were used in this study included zein formulation (F1), sodium alginate formulation (F2), potato starch emulsion with cinnamon oil formulation (F3), sodium alginate emulsion with cinnamon oil formulation (F4), potato starch and alginate emulsion with cinnamon oil formulation (F5), zein and chitosan emulsion with cinnamon oil formulation (F6), and potato starch, chitosan, and sodium alginate with cinnamon oil formulation (F7). The formulations were applied on three potato tuber cultivars, Rio Grande Russet (RG), Yukon Gold (YG), and Purple Majesty (PM), and were studied over two seasons (2017 and 2018). The treated tubers were stored in three conditions: high relative humidity storage conditions (HRHSC) at 90% ±5% RH and 5 °C ±1 °C; low relative humidity storage conditions (LRHSC) at 55% ± 5% RH and 5 °C ±1 °C; and room temperature. The tubers were analyzed periodically for weight loss, texture, ethylene production, respiration rate, sprouting incidence, sensory evaluation, and bioactive compound (total phenolics, total flavonoids, reducing sugars, and ascorbic acid) during the storage period. The results of this study (Chapter 5) showed that the weight loss was greater under HRHSC compared to LRHSC and the room temperature in both the 2017 and 2018 seasons. Most of the

formulae had a limited effect with HRHSC and were more effective when stored at room temperature and LRHSC. The effect of the formulae was not significant for the weight loss under HRHSC except for the RG tubers coated with F3 and F7 and PM tubers coated with F4. In the LRHSC and room temperature groups, the effects of all coatings were significant. The weight loss data showed that the F1 coating had the lowest weight loss among the formulae in the three cultivars at room temperature. Moreover, YG potato tubers had the lowest weight loss after applying coatings compared with RG and PM. The firmness of the coated tubers showed a negative relationship with weight loss. The effects of the treatments were not significant in the HRHSC but were significant in the LRHSC. The firmness loss in the 2017 season was more significant in RG and PM in the LRHSC treatment. The firmness loss was significantly less in the RG and PM treated with F3 under HRHSC. In the HRHSC of the 2018 season, the formula F7 was effective for PM and YG. In the LRHSC, all formulae were effective, especially F7. Tuber's respiration rate was high at harvest time. Then because of the low storage temperature, it decreased. At the end of storage, the respiration rate increased again, especially in the LRHSC. There were no significant differences among the 2017 season formulae, storage time, and cultivars in the HRHSC. The respiration rate showed significant differences based on the formulae of the 2018 season, especially F4 and F7 in the HRHSC after 3 months. In the LRHSC, all formulae at all storage times were significant ($p < 0.05$). Ethylene production was relatively high at harvest time and then reduced due to low temperature. In the LRHSC, C2H4 was high at zero time and then reduced after three months, and it increased again at the end of storage especially in PM and RG. The effects of the coating were noticeable in the LRHSC compared with the HRHSC. In the formulae of the 2017 season, there were no significant effects on C2H4 levels in the HRHSC or after 3 months in the LRHSC. At the same time, there was a significant

effect on RG and PM after six months at LRHSC with all formulae compared with the control. In the formulae of the 2018 season, there was no significant effect on C2H4 levels after 3 months in the HRHSC. However, all formulae had a significant effect after 6 months on the C2H4 levels compared with the control in the case of PM, RG, and YG, especially when coated with F4 and F7. In the LRHSC, all formulae months were significant after 3 and 6 months. In the 2017 season, all formulae had a significant effect on delayed sprouting, especially the F1 formulation, which stopped the sprouting completely at the time of measurement. The F2 and F3 formulations significantly delayed potato tuber sprouting compared with control samples in all cultivars. In the 2018 season, the effectiveness of F4 and F7 with PM was more noticeable than that of the other formulae. The F4 and F5 were more effective in improving the sensory qualities of tubers, such as the color, gloss, and general acceptability, compared with the control samples of all cultivars. However, tubers coated with F6 were not acceptable by the judges due to whiteness and bad odor. There was no significant change in the levels of total phenolics and reducing sugars due to the application of coatings.

In the fourth study (chapter 6), we aimed to investigate the effect of edible coatings and cold storage conditions on the skin color of red potatoes (Ciklamen and Modoc) stored for six months at 4 ± 2°C and 90 ± 5% relative humidity (RH). The four different formulations used were sodium alginate (F1), sodium alginate and potato starch (F2), zein and chitosan (F3), and chitosan, sodium alginate, and potato starch (F4), in addition to the control treatment with distilled water. The treated samples were assessed periodically during six months of storage for the changes in color, levels of reducing sugars, total phenolics, and sensory qualities. The effect of the edible coatings on the tubers was noticeable immediately after the treatment. The results of chroma value measurements revealed a significant effect of the treatment of tubers with the

edible coatings on the color at all storage periods. F1 and F2 formulations were the most effective, whereas F3 formulation was less effective, as during the storage period, there was no significant change in the skin color of the tubers after each treatment. The coatings had a limited effect on the level of reducing sugars. However, there were significant differences in the case of Modoc. F4 formulation decreased the concentration of reducing sugars to the highest degree, while F2 and F3 exerted a negligible effect. Meanwhile, the concentration of reducing sugars increased in all treatment groups relative to the storage time possibly due to the impact of low temperature. Moreover, F1 and F4 formulations exerted a significant effect on anthocyanin content examined after three months of storage. Alginate-based edible coatings significantly improved the sensory evaluation, especially in terms of the color, gloss, and general acceptability of red skin potatoes.

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DEDICATION

I dedicate this work to my mother Emsaura and father Fathi who first taught me the value of education. Thank you for your endless love, prayers, and sacrifices. To my wife and children without whom, this work would have not been completed.

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1.1 History of potato

The name potato was originated from the Spanish word patata, a compound known as Taino batata (sweet potato) and Quechua (potato). Usually, "Irish potatoes" and "white potatoes" are used in the United States to differentiate other potatoes from sweet potatoes. The tuber of potato became first domesticated in the region of southern Peru between 3000 BC and 2000 BC. Historical records of local farmers along with DNA analyses show evidence that the *Solanum tuberosum ssp*. was the most cultivated potato variety worldwide. In addition, tubers provided the source of energy to the Inca Empire nearly 10,000 years ago (National Research Council, 1989). The Western man has first known the potato tuber in the late 1530s while traveling through Peru. The tubers moved in the 1570s to Europe, where the amateur botanists studied and cultivated them. After analyzing the potato tubers, the botanists have identified it as toxic plant and placed it in limited use. For the next three decades, the tuber spread through Europe (Krieger, 2010). In 1780, Ireland adopted the potato tuber as a crop plentiful grown. Tubers were a common farming product due to their high yield. One acre of potato can provide food for at least ten individuals for the whole year. Tuber cultivation created an upsurge in the population of Europe in the 1800s, mostly regarded as the main part of the population diet (Wheatcroft, 2000). The Potato-farming industry quickly became vulnerable to disease because of a lack of genetic diversity. One devastating potato disease that spread in Ireland was the Phytophthora infestans which caused the potatoes to become green, taste bitter, and causes illnesses if consumed by humans. The disease quickly spread to poor communities in Western Ireland and caused what so-called the Great Irish Famine. The extreme shortage of potato, which was the main food then, reduced the population of Ireland significantly through starving to death and immigration

(Paping et al., 2007). By the mid 1800s, as the potato gained acceptance across Europe, it gradually made its way back to North America through the Atlantic Ocean. The potato became one of the world's main crops, reaching one million tons by 1900.

1.2 Potato production

The world's leading producers of potato production and consumption are Europe, Asia, and North America. Currently, China and India are the world's leaders in potato production, producing almost a third of the world's potato supply. The United States was once the leading producer of crops. Europe and Asia have increased their demand, which together accounts for 80% of the world's production usage (Hijmans, 2001). There are more than 100 varieties of potatoes sold throughout the United States. Each of these varieties fit into one of seven potato type categories which are: Russet potatoes, Red potatoes, White potatoes, Yellow potatoes, Blue/purple potatoes, Fingerling potatoes and Petite potatoes. *Solanum tuberosum* is the fourth largest in the western diet as a familiar crop. While most of the potatoes consumed in the form of fried or processed products, third-world countries use the crop as nutritional value as well (Fernie & Willmitzer, 2001).

Depending on their cultivar, potato plants are herbaceous perennials growing to approximately 60 cm high and produce flowers with colors ranging from pink, blue, red, white, and purple. Five stages of tuber growth that are: sprout development, plant establishment, tuber initiation, tuber bulking, and tuber maturation (Thornton, 2020). These stages are highly affected by different factors. Growth times differ according to conditions such as the climate, height, temperature, type of soil, variety of cultivar, geographical location, and availability of moisture. Growth stage one, i.e., the sprout development, usually allows for new plant growth from March to as late as June, while harvesting can take place in August or as late as October for growth

phase five (Krieger, 2010). Favorable conditions lead to tuber growth during stage two, i.e., plant establishment, which is alternatively referred to as vegetative growth. In general, warmer storage temperatures of 3 to 4 °C with constant cooler temperatures maintained during the dormant period create favorable conditions for development. The stage of plant establishment leads to the growth of the potato's roots and shoots. This eventually leads to the new tubers are initiated. The plant vegetative development is important to build a good root system, which is important to future growth and can re-grow after the dormant season. The tips of the stolen hook start to swell in stage three, known as tuber initiation, leading to the initiation of a new tuber. This process for the tuber types occurs during the early flowering. For this stage, proper amounts of nitrogen and cool nights are needed for optimal tuber growth. If an inadequate water supply is present, this will lead to earlier tuber initiation (Thornton, 2020). In stage four, i.e., tuber bulking, the growth rate remains relatively constant and linear. For instance, Russet Burbanks grow 6-10 cwt/ac per acre a day. This growth rate is ideal except if a fluctuation happened in conditions that may lead to decreasing the rate of tuber growth that can cause yield and quality losses. There are three main factors that influence tuber yield. These factors are 1) photosynthetic activity, 2) duration of the leaf canopy, and 3) the length of the linear growth phase of the tubers. The environment is another major influence on the production in stage four. The environmental factors include fertilization, spacing, planting date, seed physiological age, irrigation, pest management, and temperature. The ideal temperature that supports the vine growth is about 16 °C for the soil and 25 °C for the air. These two temperatures can be obtained because of the canopy of the leaves. This temperature condition also helps to complete the potato vines and tubers for nutrient resources. Fertilization is the other main factor that makes the appropriate supply of nutrients to tuber plants possible. Nutrient deficiencies restrict canopy growth and reduce the length of the

canopy which leads to a reduced production of carbohydrates and tuber growth. Fertilization in excess may cause imbalances in nutrients and slows tuber growth rate (Krieger, 2010).

Stage five is the final stage of the tuber development where the tuber maturation occurs. When the vines die, the skin, i.e., the periderm, hardens and thickens, which is very important, to protect the tuber more during harvest, handling, and storage. In this stage, the free sugars in the tubers are converted into starch. During this time, tubers often achieve lower respiratory levels. Low respiration rates lead to less dry matter, which means that the tubers may stay dormant for long periods, which is crucial to enhance the quality of fresh market consumption. There is a greater capacity for properly mature potatoes to resist pathogens in storage. In mature potatoes, the starch can be converted back to free sugars that are reducing specific gravity. Growers can handle their crops to produce the best quality tubers with experience and understanding of harvesting conditions (Krieger, 2010).

1.3 Potato harvesting

The focus of harvest management should be optimizing the potato crop quality characteristics and minimizing the presence of foreign material to maximize value. Virtually every potato market, therefore, has quality incentives that affect the returns of the grower. These considerations can involve direct price changes in the potato qualities including tuber size, bruise, and gravity. The opportunity to decline a crop can take place if it does not satisfy minimum requirements.

During the physiological or chemical maturity, tubers reach their peaks of specific gravity and yield, while sucrose and reducing sugars reach their lowest concentrations. If the crop gets overmature, sugars and cell composition change will be reduced and the sensitivity to blackspot bruise will increase. Varieties, fertilizer rates, and the environment affect the vine

senescence levels or date on which over maturity begins to cause tuber quality changes. After the tubers reach physiological or chemical maturity, the process of vine kill takes place. Most potato growers use chemical, mechanical, or a combination of those two practices for vine kill. Mechanical methods most common involve rolling with heavy tires to smash the stems and to flail or cut the stems or leaves. There are many advantages to the mechanical method, including low cost, slow acting to allow tuber size and tuber specific gravity to continue increasing, and the ability to break up vines into small pieces that are possible to remove during the harvest process. The disadvantages of the mechanical method include the relatively long time to treat the field, a slow death rate in plants, and the trend of some plants to develop new growth after treatment. Due to the disadvantages of the mechanical method, the chemical mechanical compound method of vine killing considered the most effective method. For instance, of the chemicals used in the chemical method are glufosinate-ammonium, pyraflufen-ethyl, carfentrazone-ethyl sulfuric acid.

Bruising is an important defect that tubers may be exposed to any time they are handled from harvest through storage and during movement to the end market. There are four classifications of bruises (shatter bruise, blackspot, and pressure bruise) which are all may result from mechanical injury. Bruising may minimize potato quality and its economic value. The sensitivity of the tubers to bruising (often referred to as bruising sensitivity) is affected by cultivar, soil, and tuber conditions. It needs knowledge of each of these variables to reduce tuber bruising. These conditions can be maintained via a season-long management plan that starts before potatoes are planted and continue through harvest (Thornton, 2020). To ensure minimal bruising, potato cultivars need to be treated differently due to the difference in the sensitivity of each cultivar from the other. Some cultivars appear to be very sensitive to shattering bruises, but no blackspot bruises are present. On the other side, some cultivars appear to produce almost all

black spots, and there are no shattering bruises. In terms of bruising, soil moisture during harvest is a significant factor. Before harvesting the soil should be irrigated lightly to allow the clods to break apart. The soil moisture should be between 60–75% at the harvest time to allow carrying the soil to the secondary conveyor on the harvester where it should separate completely from the tubers. Soil that is too moist does not detach from the tubers, but too dry soil may sift out too early, reducing the total load of soil and tubers which increases bruising.

Fertilizer appropriate management leading to a correct level of plant nutrition in the growing season will reduce tuber susceptibility to bruising damage. The plant nutrition can directly influence the tubers sensitivity to bruise. Also, fertilizer may have an indirect impact on the size of the tuber, the content of dry matter, and the tuber's maturity. The most nutrients that impact tuber quality are nitrogen, phosphorus, potassium, and calcium. The tuber moisture level is a factor that affects the type of bruise that occurs when harvested. Blackspot bruise is more common when tubers are dehydrated, while hydrated tubers are more likely to have shatter bruise. The lowest number of bruising is achieved when tubers have an intermediate hydration amount. Optimally, when tubers pulp temperatures are between 7 and 18 °C, potatoes should be harvested. The temperatures of cold tuber pulp raise black spots and shatter bruise, but the kind of bruise damage depends on the degree of tuber hydration. Cold, hydrated tubers appear to shatter bruise more easily, whereas blackspot bruise is more easily formed by warm dehydrated tubers. Furthermore, the number of tubers that pass through the harvest equipment should match the harvesting equipment capacity. This is because tubers that fall on each other are less likely to be affected than tubers that fall on a conveyor. For that purpose, to hold conveyors full of potatoes, the speed of all conveyors on the harvester must be adjusted in relation to the ground speed of the harvester. The harvester must be tested for impact areas where tubers strike bare

steel. These possible damaging areas should be protected by padding. For most possible harm points, a thin layer of rubber material is inadequate padding. A proper use of padding materials can sufficiently protect tubers against bruises. Bruising does not accrue only during the harvesting operation, but it might occur when potatoes are loaded and offloaded during transportation and storing. Foreign materials are of a great concern to the potato industry, whether they are intended for the fresh or processing market. Any substance other than a potato tuber is a foreign material. Glass, stones, metal, plastic, rubber, bones, aluminum cans, paper, and crop residuals are common potato load contaminants. These materials can be of a serious safety concern if they move through the food chain without detection.

1.4 Potato consumption

The importance of the species of potato tubers is demonstrated by their position as the third most widely consumed crop. In the United States, the most grown starchy vegetable is potatoes. The United States per capita intake of potatoes in 2005 was 132.2 lbs (Krieger, 2010). The demand for potatoes for fresh market and processing is year-round with a decreasing demand in the fall. Potato consumed in the United States is in the following forms: frozen fries, fresh, chips, shoestring, dehydrated, canned, potato starch, and flour (Fuglie, 2002).

1.5 Potato Composition

The potato, as a root or modified stem, belongs to the *Solanum tuberosum* family and contains mainly starch, fiber, and other minerals and vitamins (Perez Sira, 2000). The potato processing industry must consider factors such as dry matter content, sugars, proteins, and nitrogen compounds because those factors affect the potato storage parameters, processing flexibility, and end-use. About 60-80 % of the dry matter in potato is starch. The dry matter and

the potato starch content correlate greatly. The dry matter of potato tubers is made up of starch, sugars, compounds of nitrogen, lipids, organic acids, phenolic substances, minerals, and non-starch polysaccharides. The potato dry matter is affected by many factors such as maturity, growth patterns as influenced by nitrogen and potassium fertilizer application, climate, and soil (Krieger, 2010). Non-starch polysaccharides mostly composed of cellulose 2.7 - 3.8%, hemicelluloses 1.8%, pectin substances 0.7 - 1.5%, and lignin 1.1 - 1.6%. In total, collectively they constitute about 6% of the dry matter of potato (Kita, 2002).

The storage life of the potato is influenced by starch composition. Starch is the main polysaccharide in most plants and comprises a mixture of 75% -79% amylopectin and 21-25% amylose. Amylose is a chain of straight glucose units, while amylopectin is a straight chain that content several branched chains that exist after about every 20 glucose units. Amylose and amylopectin are stored in granular form as a mixture in amyloplasts of storage cells, which store and synthesize starch (Lewis et al., 1994). Glucose, fructose, and sucrose are the primary sugars in potato tubers. Glucose and fructose are classified as reducing sugars. Sucrose is a disaccharide that consists of bonded glucose and fructose in the form that does not allow to exist a free group, thus, sucrose is nonreducing sugar. In the biosynthesis, storage, and starch breakdown of potatoes, both starch and sugar play an important role (Krieger, 2010).

Nearly 4000 different species of potato tubers have distinctive culinary characteristics. Unique culinary characteristics of potato tubers include consistency and waxiness. Baking or floury tubers have more starch (20-22 %) than waxy or boiling potatoes (16-18 %). Due to starch compounds, amylose and amylopectin, tubers differ in comparison. When potato is cooked in water, amylose, the long-chain molecule, diffuses from the starch granule which can be observed

in mashed potato. In comparison, the higher potato amylopectin content which is a highly branched molecule help to preserve the shape of the tuber during cooking (Krieger, 2010).

1.6 Statement of the problem

Storage is a crucial stage in the shelf life of potato tubers and the preservation of slow natural decomposition after tubers are harvested and placed through the wound healing process. It is very important that the storage area be adequately ventilated, as dark as possible and temperatures are kept close to 4 ° C through storage time. To prevent tubers shrinkage and pressure bruising during storage, tubers need to be stored at a relative humidity of 95%. Temperatures can rise to 7-10° C for short-term storage. If the temperature is below 4 °C the starch converts to free sugars, which can cause rising the acrylamide amount, changing the taste and characteristics of the cooked potatoes (Krieger, 2010). Consequently, tuber quality can deteriorate because of storage-temperature fluctuations, moisture loss, and enzymes activity. Depending on the potato cultivars, typical losses during the harvest range from 5-40% (Perez Sira, 2000).

Most of the tuber's weight loss occurs during the initial period of storage. This period is typically the first two months of cold storage, which can referred to as the wound healing period. If the wound healing did not occur properly (faster or slower than necessary), the weight loss will be more than should it be. Also, improper ventilation conditions cause an increased undue in power consumption and tubers weight loss during the long term of cold storage. Although using proper storage conditions will reduce the tuber's quality loss significantly. The weight loss will continuously occur during storage and marketing. Application of edible coatings may reduce the quality loss without affecting the potato quality properties.

1.7 Purpose of the study

This research had several purposes. The first purpose was to investigate whether the ventilation time and condition have an impact on the quality of the Rio Grande russet potato. The second objective was to study the effect of the field heat reduction methods on the quality of russet and red skin potato and the French fries made from them. The third purpose was to investigate the application of the edible coatings on the quality of Rio Grande russet, Youkan gold, and purple majesty tubers. The last objective was to study the application of edible coatings on the quality and the color of Ciklemen and Modoc (red skin potatoes).

1.8 Assumptions of the study

The research presumed the accuracy of testing equipment and the seasonal availability of potato cultivars that were used in all study projects. Also, in this research, the absence of human error in the testing methods and scientific methodology perfection was assumed. The representation of typical moisture and nutrients contents in the tested tubers were assumed.

1.9 Limitations of the study

This study controlled the humidity and temperature during the period of the research. The fluctuations in humidity and temperature of the controlled environment were minimal. Other resources of temperatures and environmental conditions that could also influence the shelf life of the tubers were not examined. This research study was conducted in more than one growing season. In the ventilation project, the storage was limited in space because there were 14 drums of 55 gallons each. For this reason, we conducted this research in two seasons with two replications for each treatment. In the project of application of edible coatings, there were seven

formulae and three different storage conditions wherefore the study was conducted in two different seasons because of the limitation of storage space.

1.10 Methodology of the study

The independent variables in the study included the type of potato, Rio Grande Russet, Youkan Gold, Purple Majesty, Ciklemen, Modoc Russet Norkotah 3, and CO 07102-1R. And three methods of field heat reduction ((temperature dropping stepwise (TDS), temperature dropping gradually (TDG), and temperature dropping immediately (TDI)). Three fan speeds (0.6, 13, 52 CFM) in continuance and intermittent operation system. Seven formulae of edible coatings (zein (F1), alginate (F2), potato starch (F3), alginate with essential oil emulsion (F4), potato starch and alginate mixture (F5), zein and chitosan mixture (F6), and potato starch, chitosan, and alginate mixture (F7)) under three storage conditions (high relative humidity storage conditions (HRHSC) at 90% ±5% RH and 5 °C ±2 °C; low relative humidity storage conditions (LRHSC) at 55% ± 5% RH., and 5 °C ± 2 °C; and room temperature). The dependent variables were weight loss, texture change, ethylene production, respiration rate, sprouting rat, total phenolics, total flavonoids, total reducing sugars, vitamin C, total anthocyanins, skin color, and French fries color over the storage time.

Data results from each experiment in this study should indicate which storage process application would have less effect on the potato quality properties and whether it could extend the shelf life of the tuber products. Through measuring the quality parameters (potato tubers weight loss, texture change, ethylene production, respiration rate, sprouting rate, color change, sensory evaluation, and nutritional value) would be possible to determine which storage practice works better.

1.11 References

Fernie, A. R., & Willmitzer, L. (2001). Molecular and Biochemical Triggers of Potato Tuber Development. *Plant Physiology*, *127*(4), 1459–1465. https://doi.org/10.1104/pp.010764.

Fuglie, K. O. (2002). Economics of potato storage: Case studies. Potato: Global Research and Development, 2, 6–11.

Hijmans, R. J. (2001). Global distribution of the potato crop. American Journal of Potato Research, 78(6), 403–412.

Kita, A. (2002). The influence of potato chemical composition on crisp texture. Food Chemistry, 76(2), 173–179. https://doi.org/10.1016/S0308-8146(01)00260-6.

Krieger, H. (2010). Shelf Life Determillatioll of Idaho ami Red Potatoes Stored ill Tltree Types of Bags Graduate Degree/Major: Food and Nutritional Sciences Research Adviser: Carol Seaborn, Ph. D., RD, CD, CFCS (Doctoral dissertation, University of Wisconsin-Stout).

Lewis, C. E., Lancaster, J. E., Meredith, P., & Walker, J. R. (1994). Starch metabolism during growth and storage of tubers of two New Zealand potato cultivars. New Zealand Journal of Crop and Horticultural Science, 22(3), 295–304.

National Research Council-Office of International Affairs. (1989). Lost crops of the Incas: Little known plants of the Andes with promise of worldwide cultivation. Retrieved from http://www.nap.eduiopenbook.php?isbn=030904264X.

Paping, R., Vanhaute, E., & Gráda, C. Ó. (2007). When the potato failed: Causes and effects of the last European subsistence crisis, 1845-1850 (Vol. 9). Brepols.

Perez Sira, E. E. (2000). Determination of the correlation between amylose and phosphorus content and gelatinization profile of starches and flours obtained from edible tropical tubers using differential scanning calorimetry and atomic absorption spectroscopy.

Thornton, M. (2020). Potato Growth and Development. In J. C. Stark, M. Thornton, & P. Nolte (Eds.), Potato Production Systems (pp 19–33). Springer International Publishing. https://doi.org/10.1007/978-3-030-39157-7_2.

Wheatcroft, S. G. (2000). Black'47 and Beyond: The Great Irish Famine in History, Economy, and Memory. JSTOR.

2 Chapter 2: Literature review

2.1 Potato storage

The potato (*solanum tuberosum* L) is one of the most consumed agricultural products around the world, it comes after rice, wheat, and maize (Zheng et al., 2020). About 310 million tons of potatoes are produced in the world every year. The largest potato producer of the world is China, followed by Russia, India, and the USA (Hijmans, 2001). Further, in the cold regions of the world, potatoes are essential food (Eltawil et al., 2006). Colorado State comes in fourth place in the USA by 2.3 billion pounds each year. In Colorado, potato is planted in mid of the spring and harvested in mid of the fall. The demand for potato for processing and fresh market is year-round with a decreasing demand in the fall. The majority potato consumption in the USA goes into commercial processing, fresh table consumption and seed stock. Potato is one of the semi-perishable crops. Hence, potato cannot be stored from one crop year to next like other grains due to physiological decay. However, potato, unlike many vegetables and fruits, can be stored for sundry months without loss of quality (Fuglie, 2002). In general, horticultural produces are stored at a lower temperature because of their highly perishable nature and to extend their shelf life. Hence, preserving these types of foods in their fresh form requires to minimize the chemical, biochemical, and physiological changes via low temperature and high relative humidity (Lal Basediya et al., 2013). When cooling horticultural produces, various methods are compared to determine how long it will take for produce to reach its desired storage temperature. Generally, room cooling of packaged produce, is the slowest and most cost-effective method, while forced-air cooling is much faster since produce comes into direct contact with cold air as it is pushed through packages (Kader, 2002). When using room cooling, a produce is simply loaded into a cold room, and cold air is forced to circulate between the boxes, sacks, or bulk loads such as

bins. This cooling method is best suited to less perishable commodities such as potatoes. The goal of storage is to maintain quality and quantity of marketable tubers throughout the storage period to maximize the economic returns. Potatoes storage facilities need to be carefully designed and should be dark and well ventilated to keep the potatoes alive and slow down the natural process of decomposition. In general, fruits and vegetables continue to respire after harvest. Therefore, the most important issue during potato storage beside spoilage is the weight loss. Annual losses in potato storages due to water loss are about $12 million in Colorado (NASS, 2015). Weight loss (shrinkage) occurs due to physical water loss throughout transpiration and respiration. Weight loss determines the shelf life of tubers' storability and, hence, their keeping quality. Oxygen consumed through respiration is used to oxidize glucose to give the energy necessary for metabolic activity with the liberation of carbon dioxide, water, and heat. The respiratory activity represents a host of complex reactions responsible for postharvest ripening and senescence (Maftoonazad et al., 2008). Continued exposure to unsaturated air in the storage chamber increases desiccation or water loss (transpiration) in the product which leads to a quality loss (loss of turgidity, wilting, and weight loss). The magnitude of post-harvest losses in fresh fruits and vegetables is estimated to average around 25–40% in some regions of the world (Kasso & Bekele, 2018). These losses represent a large proportion of total costs of horticultural business and greatly reduces the profitability of the marketing chain. Another aspect to consider is minimizing the color change in the varieties of colored potatoes and preserving the nutritional value of the stored potato tubers. For instance, the price can be low if the color fades or changes to pink in the red potato varieties during the storage. The purple and red-colored potatoes varieties contain the highest concentrations of phenolic compounds and anthocyanins with high

antioxidant activity compared with other potato varieties. In addition to the high nutritional value, colored potatoes are exceptionally attractive to consumers (Hamouz et al., 2011).

2.2 Potato wound healing

A potato tuber most external layer is the periderm that protects potatoes from water loss and pathogen attack. Thus, this layer of the tuber is susceptible to mechanical damage which is common during potato harvest and handling process. Potato skin wounds may be in the form of cuttings, punctures, abrasions, broken areas, or any area with damage in the periderm (Wang et al., 2020). The wound surfaces that result from mechanical damage on tubers provide a pathway for infectious pathogens, which results in extreme tuber spoilage and rot during storage (Lulai, 2007). Moreover, wound healing can affect the long-term storability of potatoes and can be harmful to the quality of the final product (Knowles et al., 1982). Surprisingly, potato tubers are fitted with the ability to cure by forming the periderms on the wounds against tuber flesh evaporation and pathogen attack (Bernards, 2002). The ability of potato tubers to heal wounds varies with cultivars (Peck, 2015). A crucial step in the effective management of potato storage is an adequate wound healing in the first two to three weeks after harvest. During this step the potatoes are held at a high-temperature environment and then the temperature is reduced until a final holding temperature is reached. The aim of wound healing is to cure the periderm damage on the tuber's skin quickly under a warm and humid environment. The rapid development of the wound periderms is important to reduce the weight loss and spread of diseases (Artschwager, 1927). The rate of wound healing depends on various factors including wound type, cultivar, and storage conditions. The deep wounds are more difficult to heal as they are hideaway from the air of ventilation, which can reduce the capacity of the wounds to dry (Peck, 2015). Depending on the susceptibility of the cultivars to rotting diseases such as bacterial soft rot, pink rot, and

pythium leakage, varieties may react differently to wound healing, some may be quicker or slower than others (Wang et al., 2020). The formation of wound periderms begins when cell division increases and suberin deposition occurs in response to injuries (Dastmalchi et al., 2014). Additionally, the wound healing ability of potato cultivars is influenced by the phenylpropanoid, fatty acid, and reactive oxygen metabolism activities in tubers. Phenylpropanoid metabolism plays a significant role in the healing of potato tubers, which is considered the cornerstone for suberin and lignin. Peroxidase in potato tissues is associated with the response to suberization. The polymerization of phenolic acids into a suberin aromatic network occurs through a free radical conjugation cycle mediated by peroxidase-H_2O_2 (Dastmalchi et al, 2014; Morris et al., 1989). The evolution of the primary suberization and wound periderm is preferable at a high relative humidity of 95%–98%, the presence of oxygen, and a temperature around 10.0 °C to 15.6 °C. Warmer temperature enhances the suberization while the cold temperatures restrain it (Morris et al., 1989). The wounds of the potato and its mechanical damage and under-optimizing healing conditions lead to drying out and bacterial or fungal infection. Such problems make as many as 40 - 50 % of harvested potatoes unsuitable for human consumption and produce significant waste (Dastmalchi et al., 2016). Current industry practice for potato wound curing in the USA is to store at a high humidity (95% -98%) with a and sufficient airflow for freshly harvested potatoes for two to three weeks at 10.0 to 12.8 °C (Peck, 2015). Before the wound healing process ends, high humidity is necessary to minimize the water loss from the tuber. Keeping a high relative humidity can restrain tuber dehydration in the healing period and help control the total shrinkage of tubers throughout the storage period (Daniels-Lake et al., 2014). Proper airflow in the storage pile can prevent moisture condensation on potato tubers surface which reduces the tuber surface spread of diseases, as well as gets rid of water and carbon

dioxide resulting from tubers respiration. Temperatures below 10 °C decrease the rate of wound healing, and therefore tubers need a longer curing time that gives diseases a chance to spread; temperatures above 15.6 °C can be helpful in the formation of the wound periderm but can has a negative consequence such as raising weight loss rate and diseases development (Wang et al., 2020). Consequently, the wound healing period at relatively high temperatures should be only long enough to allow a quick cure, but not too long to influence quality characteristics through the spread of diseases, weight loss, and reduced shelf life of the fresh market cultivars, and poor frying quality (Ellis et al., 2019).

A 50 % of the potato produced in the USA in 1981 was utilized as a processed products and about 45% were frozen French-fried products (Toma et al., 1986). The quality of French fries determined by the color and the structure of fries. The structure and composition of cells of the principal tissue in potato tubers, the parenchyma, strongly influence the French fries quality traits. In turn, the structure and composition of the cells are influenced by several factors including the period of storage, cultivar, and site (Agblor & Scanlon, 2002). Wound healing is a common practice following the harvesting of potatoes to encourage dormancy and increase of the post-harvest life. The treatment at 15 °C over 14 days in dry conditions minimizes the occurrence of skin spots from 70% to 4%, while curing reduces the skin spots only to 53% under humid conditions. Kim and Lee (1992) and Wang et al (2015) mentioned that improving potato chips colors via reducing the non-enzyme browning during frying at high temperatures might be achieved by potato tubers reconditioning. Storing potato tubers under 4 °C led to accumulating the reducing sugars in what is known as a phenomenon, cold sweetening which responsible for the browning process of chips and fries during the frying process. During cold sweetening, stored potatoes starch degradation occurs primarily through phosphorylase reactions of starch, and

eventually, through various enzymatic reactions, led to accumulating of reducing sugars (Abong et al., 2012). To minimize browning color, tubers usually need to be warmed for around two weeks to decrease the reducing sugars content before frying (Li et al., 2007). Tubers are usually held at around 21°C for 3 weeks before they are fried or blanched to leach soluble substances to reduce the reducing sugars content before the frying (Toma et al., 1986). The potato processing industry requires tubers with characteristics of acceptable consumer preference qualities. Significant factors and considerations of tubers include sugar levels, dry matter, cultivars, maturity stage, storage condition, and exposure to the reconditioning process. Fructose and glucose are the most important reducing sugars that cause browning color in potato fried products. The high content of reducing sugars in the tuber induces the Maillard reaction (between reducing sugars and amino acids) that is responsible for an undesirable darkening in potato fried products. On the other hand, the low level of reducing sugars is preferred as that this low concentration result in light colors products which are one of the desirable qualities in potato fried products. The reducing sugars level in potato is influenced by many factors, e.g., genotype, environmental and storage conditions. Immature tubers have a higher reducing sugar content than mature tubers. However, the genetic differences have the greatest effect on the reducing sugars content in tubers.

2.3 Potato weight loss

To reach the optimum extension of the postharvest life of food products, there are three critical factors should be taken into consideration. First, the reduction in the physiological process of maturation and senescence. Second, the reduction in desiccation. Third, the reduction in the rate of microbial growth (Erbil & Muftugil, 1986). Temperature and relative humidity are critical environmental factors that decisively affect proper potato storage. Suitable air movement

is required to maintain a steady temperature and humidity through the storage space. Air movement is also desired to prevent extravagant shrinkage due to moisture loss (Voss et al., 2001). The requirements of potato storage are 90 to 95 % relative humidity and optimum temperature of 4 to 6 ℃ for seeds, 6 to 10 ℃ for fresh market use and 10 to 16 ℃ for processing tubers (Külen et al., 2013). Transpiration and respiration are the first causes of physical water loss from tubers and thus weight loss. Transpiration is responsible for approximately 90% of the total weight loss, while the respiration causes a relatively small amounting of weight loss, i.e., less than 10% of the total weight loss. Most of the weight loss in tubers takes place within the first 2 months of storage. Managing storage temperature is one of three major factors can control weight loss besides relative humidity and ventilation. In terms of temperature, the storage period can be divided into three periods. First is the wound healing or curing period. Some research data show that 10 to 13 °C is a good arrangement temperature for both maturation and wound healing. At the same time, this level of temperature is low enough to control progress for any rot organisms. Maintain temperature at 10 to 13 °C for at least one month to ensure complete wound healing and maturation then lower temperature to holding level. At a holding temperature period, the temperature should be around 7 °C until the end of the storage period. In the third temperature period, which comes before the marketing, tubers temperature is increased to around 10 °Cand where a rapid temperature change is avoided. Warming the tubers before marketing, will decrease bruise susceptibility during removal from storage and decrease the reducing sugars amount in tubers which in turn will reduce the brown color in potato fried products (Olsen & Kleinkopf, 2020). When fruits and vegetables lose moisture, there is a later loss of sugar in the cells.

One of the requirements of an ideal storage environment is the maintenance of conditions that minimize tuber weight loss. Potato tubers' age, storage temperature and relative humidity (RH) are important factors correlated to weight loss. Air velocity has the lowest correlation coefficient with potato tubers weight loss. The ventilation rate affects the weight loss of potato tubers up to a certain loss critical point (Butchbaker et al., 1973). With unsaturated (lower RH) air circulating in the storage, moisture will be lost from the tuber surface due to transpirational water loss. The permeability of the tuber's skin also plays a critical role in the rate of weight loss. Temperature is an important consideration in the potato storage process. Although higher temperatures are considered desirable during the first few weeks of storage to heal tuber wounds. Relatively high temperature causes an increase in the respiration rate, tuber vapor pressure, and enhance sprouting conditions later during the storage life of the potatoes (Butchbaker et al., 1973). The reducing sugars are accumulated higher at a low storage temperature of 40 ºF to 45 ºF than at the temperature of 50 ºF to 55 ºF (Ezekiel et al., 2007). However, higher storage temperature leads to higher moisture loss. Therefore, the storage manager must balance between potato mass loss and quality. To minimize the moisture loss, the relative humidity in the potato storage should be between 90 to 95% unless if the potatoes were wet (Pinhero et al., 2009). In this case, the RH can be reduced to let tubers dry to prevent fungal growth and spoilage. In other situations, reducing the RH is necessary such as the presence of frozen potatoes or appearance of some diseases such as leak (Pythium spp.) or late blight (Phytophthora infestans). In cold regions, the ambient temperature usually drops to sub-zero temperatures during winter. To mitigate this problem, the storage managers can rotate respiratory heat generated by potatoes throughout the storage. Rotating respiratory heat can be done by minimizing the intake of fresh air and recirculating air in potato piles by operating fans intermittently for less time. Running the

fans in this way will save a considerable amount of energy as well. The demand for potatoes usually rises during December, January, and February. As is known, potatoes need to be warmed before shipping to the processors in what is known as the potato re-acclimation process (the re-acclimation process requires more energy). Hence, the process of potato storage consumes a lot of energy, where sometimes the energy demand exceeds 75% more than usual from December to January. Therefore, any energy-savings by running the fans intermittently and/or for less time will be reflected in the final cost of potatoes (Jayas et al., 2001). Reducing the cost of electric power consumption is one of the important goals of industrial refrigeration and potato storage management. This goal can be achieved through developments of new storage designs, improvement in the existing designs, and improvements in ventilation operations (Chourasia & Goswami, 2009). Significant energy can be saved by using ventilation only when necessary and thus can reduce the period of ventilation (Jayas et al., 2001). Using Variable Frequency Drives (VFDs) controls the ventilation rate by manipulating fan speeds thus reducing energy consumption. For instance, using 50% of fan speed produces a 50% flow but consumes only 15% energy.

Potato respiration continues during all storage stages but does not stay constant. Different rates of potato respiration have been recorded in different potato cultivars such as 1.0 mg CO_2 kg^{-1} h^{-1} for mature dormant tubers at 7.5°C to 83 mg CO_2 kg^{-1} h^{-1} after harvest of immature potatoes (Jayas et al., 2001). Under normal storage condition, the concentration of CO_2 from 0.2 to 0.3 % is common in ventilated potato piles. The level of CO_2 in potato storage is accumulated to about 3.2% in less than 48 hours after the application of the sprout inhibitor (isopropyl-N-3-chloro-phenyl carbamate known as CIPC). High level of CO_2 is correlated to the increase of the

reducing sugars concentrations in potatoes which are responsible for the brown color in fried potato products making them undesirable by consumers (Daniels-Lake et al., 2005).

Ethylene is a secondary metabolic production of potatoes. Stress (low temperature) can increase the levels of ethylene in potatoes. Under improper ventilation conditions, ethylene level may accumulate up to a significant concentration around tubers (Daniels-Lake et al., 2005). The mature potatoes produce a low amount of ethylene about 0.1 $\mu L\ kg^{-1}\ h^{-1}$ at 20 °C. Wounds and bruises on tubers cause a significant increase in ethylene production. Potato sensitivity to ethylene varies from one cultivar to another (Daniels-Lake et al., 2005). Potatoes as a non-climacteric crop are not sensitive to external ethylene. In the case of the immature potatoes, a low level of ethylene raises the respiration rate which consequently causes more weight loss (Reid & Pratt, 1972).

The quality of the nutritional value of stored crops is influenced by several factors such as transpiration, respiration, ethylene production, length of storage, initial chemical composition, delay harvesting, and the storage conditions. Storage conditions include temperature, relative humidity, and ventilation (Genanew, 2013). Ventilation has a direct and indirect impact on the quality of the stored crops. The effect of ventilation on weight loss of tubers is an example of a direct impact. Whereas the effect of ventilation on the composition of the air inside the storage and the level of ethylene (which in turn affects the chemical composition of the tuber) is an example of an indirect impact on the quality of the tubers. In the same context, changing the storage air composition affects microbial growth on fresh fruits and vegetables. For instance, the air that contains a high level of both CO_2 and O_2 significantly restrains microbial growth (Y. Zheng et al., 2008). Also, changing the storage air composition of controlled atmospheres (CA) or modified atmosphere packaging (MAP) along with low-temperature storage reduces the

ethylene production rates and respiration rate. In addition, it slows down the change in the chemical composition of the stored crops (Pariasca et al., 2001). In general, ethylene affects the chemical composition of the stored crops. For instance, the content of vitamin C in some stored crops can be affected by the amount of ethylene in the storage (Watada, 1986).

2.4 Edible coating application

Various preservation technologies, including low-temperature storage, modified atmosphere packaging, UV irradiation, and ozonation, have been used to reduce deterioration, extend shelf life, and retain the nutritional value of fresh fruits and vegetables (Duan et al., 2011). In addition to reducing temperature immediately, coating individual fruits and vegetables is a useful method to provide a protective film for extended freshness, control of the internal gas atmosphere, minimizing respiration rates. Coating fruits and vegetables may also serve as a barrier to water vapor and reducing moisture loss, which subsequently, minimizes or eliminate the postharvest deterioration problems. In fact, many of the functions of edible coatings are like synthetic packaging films in term of providing barriers to moisture and oxygen (Yaman & Bayoındırlı, 2002).

The first edible coating recorded use was in China in the twelfth century on oranges and lemons. The first use in the United States was in the sixteenth century, where the food products were coated with lipid coatings paraffin wax, carnauba wax and emulsion oil-in-water coatings to control moisture loss for fresh fruits and vegetables. The edible coating can be defined as primary packaging made from edible components.

The edible coating may contain proteins, polysaccharides, lipids, or a mixture of these compounds. Recently, most research of the edible materials field have focused on composite or multicomponent films to take the advantages of each component individually as well as to

minimize their disadvantages. The thin layer of edible coating can be directly applied to food or formed into a film and be used as a food envelope without changing the original ingredients or the processing method. Edible coatings have been used to improve the moisture and gas barriers, sensory perceptions, mechanical properties, microbial protection, and extend the shelf life of some food products. Edible films and coatings can be considered as food preservatives because of their ability to improve overall food quality (Galus & Kadzińska, 2015). During the respiration in living tissues, oxygen is consumed to oxidize glucose to give the necessary energy for metabolic activity and carbon dioxide, water, and heat as by-products. The respiratory activity is accountable for complex reactions responsible for postharvest ripening and senility. Continuous transpiration, especially in unsaturated air, enhances desiccation or water loss in the product which translates to deterioration of quality properties such as loss of turgidity, wilting, and weight loss. In some regions of the world, the proportion of post-harvest losses in fresh fruits and vegetables is estimated to 25–40%. (Kasso & Bekele, 2018). These losses represent a large percentage of the total costs of the products, which absolutely reduces the profitability of the marketing chain.

The selectivity of the permeability of edible coating films to O_2, CO_2 and water vapor delays the natural physiological ripening process, as a result, the losses are reduced. The reduction in water loss and modification of the internal atmosphere is greatly affected by the character of the product skin and the permeance of the coating film (Maftoonazad et al., 2008). In addition to the mentioned advantages of applying fruit and vegetable costings, edible coatings are used to improve appearance and texture and to reduce water loss. Formulations can be designed to carry desired additives that help to extend product stability and, therefore, shelf life, encapsulate flavor

during storage and improve mechanical handling properties by helping fruit slip over packing lines with less injury (Martínez-Romero et al., 2006).

The transpiration and respiration processes continue after fruits and vegetable harvest. Wherefore, the permeabilities of the coating film to water vapor, oxygen, and carbon dioxide are the key to the selection of coating formulation to be applied to food products. The water vapor permeability (WVP) of edible films is the most extensively studied property of edible films. Mainly due to the importance of the role of water in the deteriorative reactions and probably partly due to the ease of the measurement.

Lipid, either as the main component or as an additive in the film formulation, usually helps to reduce water vapor transfer due to its hydrophobic character. Coatings contribute to the reduction of oxygen permeability, which plays a role in many degradation reactions in foods, such as fat and oil rancidity, microorganism growth, enzymatic browning, and vitamins loss. On the other hand, the permeability to oxygen and carbon dioxide is essential for living tissues, such as fresh fruits and vegetables, for respiration. So, moderate barrier coatings are more appropriate. If a coating with the appropriate permeability is chosen, a controlled respiratory exchange can be established and thus the preservation of fresh fruits and vegetables can be prolonged. It is expected that the oxygen permeability of edible films can be controlled by using some antioxidants as additives in the film composition. Ascorbic acid or citric acid can be used for this purpose. Although data on permeability properties of edible films are being accumulated in the literature, the number of studies on the application of such films on foods is limited (Ayranci & Tunc, 2004). Application of physical barriers as coatings on the fruit surface regulates the selective permeability to O_2, CO_2, and water vapor, thereby retarding the natural physiological ripening process. Coatings have been used to delay ripening (by modify the internal air

composition), reduce water loss, and improve the appearance in some fruits and vegetables. The degree of water reduction and composition of the internal air is greatly affected by the permeance of the coating film and the character of the product skin.

The edible coating as mentioned before may be composed of polysaccharides, proteins, lipids, or a blend of these compounds. Alginate is one of the carbohydrate materials used in coating. Alginate exists in brown algae as the most abundant polysaccharides, accounting for up to 40% of the dry matter. It is in the intercellular matrix as a gel containing sodium, calcium, magnesium, strontium, and barium ions. Pavlath (1999) made films using alginic acid which were transparent and flexible, but they dissolved in water. When alginic acid films were immersed in a solution of salts with multivalent ions, their solubility was restricted. Treatment with calcium and zinc resulted in water-insoluble films. These films had their tensile strength increased by an order of magnitude (Maftoonazad, Ramaswamy, & Marcotte, 2008).

Zein is the most essential storage protein of maize. It consists of 45% to 50% of maize protein. In 1897, it was first described based on its water solubility (Shukla & Cheryan, 2001). Zein coatings have been used to coat nuts and candy for increased glitter and prohibition of oxidation and development of off odors. Zein was used as an alternative to shellac and carnauba wax to food products coating.

Chitosan is a polysaccharide consisting of (1,4)-linked 2-amino-deoxy-β-d-glucan, which is the second most abundant polysaccharide found in nature. Following cellulose, chitosan is a derivative of chitin. In addition to antimicrobial characteristics, chitosan has been established as a non-toxic, biodegradable, bio-functional, and biocompatible. Chitosan has the advantage of being content with substances like minerals and antibacterial activity in contrast with other organically based food-packaging products (Dutta et al., 2009).

After the discovery of starch in 1811, the organized production of potato starch had already begun early in the 19th century. Starch materials, not only for food purposes but for textiles and adhesives. A dilute aqueous potato starch suspension on heating above the so-called gelatinization temperature of about 65 °C, the granules begin to swell, and a highly viscous transparent solution is obtained it can be used as an edible coating with food. The applications of potato starch in food coating is limited (Kraak, 1992).

2.5 Red skin potato

Red potatoes account for about 10% of the total harvested potato in the United States. Growers' financial returns can lower if the color of the harvested red potato is pink or if the color fades during storage. The presence of anthocyanins in the peridermis is responsible for the skin color of red potatoes (Burton, 1989). Hung et al (1997) noticed that the color intensity and anthocyanin concentration in Norland tubers have been shown to decrease during tuber development. In a study conducted by Lewis et al (1999) on Desiree and Arran Victory tubers, they found anthocyanin concentrations in the periderm increased if stored at 4 °C but decreased in storage at 10 °C or higher temperatures. Cold storage of potato increases the content of sugars which lead to an increase in anthocyanin synthesis (Andersen et al., 2002).

In both fresh and processed fruit and vegetables, anthocyanins serve two functions. It contributes to the consumer health and enhances their overall appearance (Stintzing & Carle, 2004). A significant feature of anthocyanins that they are strong antioxidants in the diet. Anthocyanins regularly consumed by people and have an average daily intake of around 180 mg from various food sources. They are primarily present in the flesh and/or skin of red and purple potato cultivars. Their function is to prevent LDL-cholesterol oxidation and avoid damage to human cells caused by free radicals. The differences in the color between red and purple potatoes

is due to the genetic natural variation in the distribution of anthocyanins pigment. In general, due to the low-cost of the potato crop, colored potatoes may serve as a potential source for natural anthocyanin pigments. Purple and red potatoes may therefore be considered as a new source of natural and value-added antioxidants in the human health and food industries. (Lachman et al., 2012).

All potato tubers contain phenolic compounds whereas in commercially important colored cultivars anthocyanin is a distinctive mark. The development of tubers color can be caused by the accumulation of anthocyanin pigments during growth. Change in the physiochemical environment during potato storage may be resulting in a color change even though no quantitative change in anthocyanin occurs. The physiochemical environment changes may be included phenolics change, that can act as co-pigments, pH change, or the presence metal ions which can affect anthocyanin color. The environmental and growth conditions include nutrient levels, temperature, water potential, and presence of disease, which may affect in anthocyanin concentration in tubers. Similarly, after storage, the colored potato that is ready to be marketed can rely on factors like harvest handling, storage length and conditions. Tuber damage during harvest, light exposure and the presence of pathogens are important factors because these factors are known to increase phenylalanine ammonia-lyase and enzyme activity, which effect the concentrations of phenolic acids, flavonoids, and anthocyanins, which may alter tuber color (Lewis et al., 1999).

2.6 The French fries quality

Fried potato products are widely known and popular amongst many cultures. French fries (also known as fries) either fresh or frozen, are widely manufactured and consumed industrially following a final deep-fat frying process (Vinci et al., 2010). French fries are one of the most

communal potato products around the world, attracting the consumer by their characteristic flavor and texture. Every year billions of potato tubers are processed into French fries in the potato industry. Retail sales of the fries in the USA are about 6 billion a year representing 33% of the total sales on the potato market (Garayo & Moreira, 2002). The sensory properties of French fries depend on both the raw tubers and technological standers used for French fries production (Kita & Lisińska, 2005).

The starch content of the raw tubers an important play role in the French fries' crispness (Kita 2002). The high moisture amount in potato (78%) and pretreatment of the raw tubers can greatly affect fat uptake during frying. The French fries loss of moisture during frying which effects fries texture profile positively (Connor et al., 2001). On the other hand, the fries color depends on the content of reducing sugars that accumulates during the growth and storage periods. The environmental and genetic factors determine the potato tuber's carbohydrate composition (Li et al., 2008). For instance, in newly harvested tubers, the content of glucose and fructose is usually below 0.1 mg/g fresh weight but in cold-stored tubers, it can rise to 8 mg/g fresh weight or higher.

The quality food parameters that are considered by consumers are the appearance and color of a food surface. These parameters are key in accepting the product even before it reaches the consumer's mouth. Potato fried products' color, together with their crispness, oil, and acrylamide content, are significant parameters that should be controlled during the processing (Pedreschi et al., 2005). The color of the French fries should be golden, light without penetration in brown color or black spots. The chemical composition of potato tubers (starch and reducing sugars quantity), the storage conditions, and the subsequent technical processes determine the color of the French fries (Tajner-Czopek et al., 2008). The color of French fries might be dark

during heat processing due to accumulated reducing sugars react with amino acids and form what is called the Maillard reaction which reduces the visual appeal of the French fries (Rommens et al., 2010). Besides the content of reducing sugars and amino acids, the Maillard reaction depends on the temperature and time of frying, as well as the proteins at the product's surface (Marquez & Anon, 1986). In immersion frying, the food product is immersed in an edible fat heated above the boiling point of water and may thus be considered as a process of dehydration (Hubbard & Farkas, 1999).

Blanching is a common procedure step in the production of the French fries. The blanching process is preformed to leach out soluble solids (including reducing sugars that have a major role in the nonenzymatic browning reaction during frying) and reduce enzymic activity that may cause undesirable color, texture, or odor in the final product (Connor et al., 2001). The blanching procedure include a heat treatment on peeled and cut potatoes in hot water or steam at temperatures of 60–85 °C. The time of blanching depends on the potato cultivars used, raw material quality and potato strips. Blanching is often carried out at various water temperatures in two or three stages in the French fries processing plants (Tajner-Czopek et al., 2008).

2.7 References

Abong', G. O., Okoth, M. W., Karuri, E. G., Kabira, J. N., & Mathooko, F. M. (2012). Levels of reducing sugars in eight Kenyan potato cultivars as influenced by stage of maturity and storage conditions. *Vol.*, *2*(2), 9.

Agblor, A., & Scanlon, M. G. (2002). Effect of storage period, cultivar and two growing locations on the processing quality of french fried potatoes. American Journal of Potato Research, 79(3), 167–172. https://doi.org/10.1007/BF02871932.

Andersen, A. W., Tong, C. B. S., & Krueger, D. E. (2002). Comparison of periderm color and anthocyanins of four red potato varieties. American Journal of Potato Research, 79(4), 249–253. https://doi.org/10.1007/BF02986357.

Artschwager, E. (1927). Wound periderm formation in the potato as affected by temperature and humidity. Journal of Agricultural Research, 35(11), 995-1000.

Ayranci, E., & Tunc, S. (2004). The effect of edible coatings on water and vitamin C loss of apricots (Armeniaca vulgaris Lam.) and green peppers (Capsicum annuum L.). Food chemistry, 87(3), 339-342.

Bernards, M. A. (2002). Demystifying suberin. Canadian Journal of Botany, 80(3), 227–240. https://doi.org/10.1139/b02-017.

Burton, W.G. (1989). The Potato. Wiley, New York. pp. 328-329.

Butchbaker, A. F., Promersberger, W. J., & Nelson, D. C. (1973). Weight loss of potatoes as affected by age, temperature, relative humidity and air velocity. American Potato Journal, 50(4), 124–132.

Chourasia, M. K., & Goswami, T. K. (2009). Efficient design, operation, maintenance and management of cold storage. Biological Sci, 1(1).

Daniels-Lake, B., Prange, R., & Walsh, J. (2005). Carbon dioxide and ethylene: A combined influence on potato fry color. HortScience, 40(6), 1824–1828.

Daniels-Lake, B., Prange, R., Walsh, J., Hiltz, K., Bishop, S., & Munro-Pennell, K. (2014). Effects of simulated harvest injury and relative humidity during the first week post-harvest on potato (Solanum tuberosum L.) tuber weight loss during subsequent storage. The Journal of Horticultural Science and Biotechnology, 89(2), 167–172. https://doi.org/10.1080/14620316.2014.11513064

Dastmalchi, K., Cai, Q., Zhou, K., Huang, W., Serra, O., & Stark, R. E. (2014). Solving the Jigsaw Puzzle of Wound-Healing Potato Cultivars: Metabolite Profiling and Antioxidant Activity of Polar Extracts. Journal of Agricultural and Food Chemistry, 62(31), 7963–7975. https://doi.org/10.1021/jf501330h.

Dastmalchi, K., Wang, I., & Stark, R. E. (2016). Potato Wound-Healing Tissues: A Rich Source of Natural Antioxidant Molecules with Potential for Food Preservation. Food Chemistry, 210, 473–480. https://doi.org/10.1016/j.foodchem.2016.04.123.

Duan, J., Wu, R., Strik, B. C., & Zhao, Y. (2011). Effect of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions. Postharvest Biology and Technology, 59(1), 71–79.

Dutta, P. K., Tripathi, S., Mehrotra, G. K., & Dutta, J. (2009). Perspectives for chitosan based antimicrobial films in food applications. Food Chemistry, 114(4), 1173–1182. https://doi.org/10.1016/j.foodchem.2008.11.047.

Ellis, G. D., Knowles, L. O., & Knowles, N. R. (2019). Respiratory and low-temperature sweetening responses of fresh-cut potato (Solanum tuberosum L.) tubers to low oxygen. Postharvest Biology and Technology, 156, 110937. https://doi.org/10.1016/j.postharvbio.2019.110937.

Eltawil, M. A., Samuel, D. K., & Singhal, O. P. (2006). Potato storage technology and store design aspects. Agricultural Engineering International: CIGR Journal.

Erbil, H. Y., & Muftugil, N. (1986). Lengthening the postharvest life of peaches by coating with hydrophobic emulsions. Journal of Food Processing and Preservation, 10(4), 269–279.

Ezekiel, R., Singh, B., Kumar, D., & Mehta, A. (2007). Processing quality of potato varieties grown at two locations and stored at 4, 10 and 12 C. Potato Journal, 34(3–4).

Fuglie, K. O. (2002). Economics of potato storage: Case studies. Potato: Global Research and Development, 2, 6–11.

Galus, S., & Kadzińska, J. (2015). Food applications of emulsion-based edible films and coatings. Trends in Food Science & Technology, 45(2), 273–283.

Garayo, J., & Moreira, R. (2002). Vacuum frying of potato chips. Journal of food engineering, 55(2), 181-191.

Genanew, T. (2013). Effect of Post-Harvest Treatments on Storage Behavior and Quality of Tomato Fruits.

Hamouz, K., Lachman, J., Pazderů, K., Tomášek, J., Hejtmánková, K., & Pivec, V. (2011). Differences in anthocyanin content and antioxidant activity of potato tubers with different flesh colour. Plant, Soil and Environment, 57(10), 478-485.

Hijmans, R. J. (2001). Global distribution of the potato crop. American Journal of Potato Research, 78(6), 403–412.

Hubbard, L. J., & Farkas, B. E. (1999). A method for determining the convective heat transfer coefficient during immersion frying. Journal of Food Process Engineering, 22(3), 201-214.

Hung, C. Y., Murray, J. R., Ohmann, S. M., & Tong, C. B. (1997). Anthocyanin accumulation during potato tuber development. Journal of the American Society for Horticultural Science, 122(1), 20-23.

Ial Basediya, A., Samuel, D. V. K., & Beera, V. (2013). Evaporative cooling system for storage of fruits and vegetables-a review. Journal of food science and technology, 50(3), 429-442.

Jayas, D. S., Irvine, D. A., Mazza, G., & Jeyamkondan, S. (2001). Evaluation of a computer-controlled ventilation system for a potato storage facility. Canadian Biosystems Engineering, 43, 5–5.

Kader, A. A. (2002). Postharvest technology of horticultural crops (Vol. 3311). University of California Agriculture and Natural Resources.

Kasso, M., & Bekele, A. (2018). Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia. Journal of the Saudi Society of Agricultural Sciences, 17(1), 88–96.

Kim, H. O., & Lee, S. K. (1992). Effects of curing and storage conditions on processing quality in potatoes. Physiological Basis of Postharvest Technologies 343, 73–76.

Kita, A. (2002). The influence of potato chemical composition on crisp texture. Food Chemistry, 76(2), 173–179. https://doi.org/10.1016/S0308-8146(01)00260-6.

Kita, A., & Lisińska, G. (2005). The influence of oil type and frying temperatures on the texture and oil content of French fries. Journal of the Science of Food and Agriculture, 85(15), 2600-2604.

Knowles, N. R., Iritani, W. M., Weiler, L. D., & Gross, D. C. (1982). Susceptibility of potatoes to bacterial rot and weight loss as a function of wound-healing interval and temperature. American Potato Journal, 59(11), 515–522. https://doi.org/10.1007/BF02852600.

Kraak, A. (1992). Industrial applications of potato starch products. Industrial Crops and Products, 1(2–4), 107–112.

Külen, O., Stushnoff, C., & Holm, D. G. (2013). Effect of cold storage on total phenolics content, antioxidant activity and vitamin C level of selected potato clones. Journal of the Science of Food and Agriculture, 93(10), 2437–2444.

Lachman, J., Hamouz, K., Orsák, M., Pivec, V., Hejtmánková, K., Pazder\uu, K., Dvořák, P., & Čepl, J. (2012). Impact of selected factors–Cultivar, storage, cooking and baking on the content of anthocyanins in coloured-flesh potatoes. Food Chemistry, 133(4), 1107–1116.

Lewis, C. E., Walker, J. R. L., & Lancaster, J. E. (1999). Changes in anthocyanin, flavonoid and phenolic acid concentrations during development and storage of coloured potato (Solanum tuberosum L) tubers. Journal of the Science of Food and Agriculture, 79(2), 311–316. https://doi.org/10.1002/(SICI)1097-0010(199902)79:2<311::AID-JSFA199>3.0.CO;2-Q.

Li, L., Paulo, M. J., Strahwald, J., Lübeck, J., Hofferbert, H. R., Tacke, E., & Gebhardt, C. (2008). Natural DNA variation at candidate loci is associated with potato chip color, tuber starch content, yield and starch yield. Theoretical and applied genetics, 116(8), 1167-1181.

Li, X.-Q., Griffiths, R., Lagüe, M., DeKoeyer, D., Rothwell, C., Haroon, M., Stevens, B., Xu, C., Gustafson, V., Bonierbale, M., Regan, S., & Flinn, B. (2007). Est sequencing and analysis from cold-stored and reconditioned potato tubers. Acta Horticulturae, 745, 491–495. https://doi.org/10.17660/ActaHortic.2007.745.35

Lulai, E. C. (2007). Chapter 22—Skin-Set, Wound Healing, and Related Defects. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. Mackerron, M. A. Taylor, & H. A. Ross (Eds.), Potato Biology and Biotechnology (pp. 471–500). Elsevier Science B.V. https://doi.org/10.1016/B978-044451018-1/50064-6.

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. International Journal of Food Science & Technology, 43(6), 951–957.

Marquez, G., & Anon, M. C. (1986). Influence of reducing sugars and amino acids in the color development of fried potatoes. Journal of Food Science, 51(1), 157-160.

Martínez-Romero, D., Alburquerque, N., Valverde, J. M., Guillén, F., Castillo, S., Valero, D., & Serrano, M. (2006). Postharvest sweet cherry quality and safety maintenance by Aloe vera treatment: A new edible coating. Postharvest Biology and Technology, 39(1), 93–100. https://doi.org/10.1016/j.postharvbio.2005.09.006.

Morris, S. C., Forbes-Smith, M. R., & Scriven, F. M. (1989). Determination of optimum conditions for suberization, wound periderm formation, cellular desiccation and pathogen resistance in wounded Solanum tuberosum tubers. Physiological and Molecular Plant Pathology, 35(2), 177–190.

NASS, U. (2015). Nass-national agricultural statistics service. URL Http://Www Nass Usda Gov/(Accessed 27 August 2015) Varunsatian, S, Watanabe, K, Hayakawa, S, Nakamura.

O'Connor, C. J., Fisk, K. J., Smith, B. G., & Melton, L. D. (2001). Fat Uptake in French Fries as Affected by Different Potato Varieties and Processing. Journal of Food Science, 66(6), 903–908. https://doi.org/10.1111/j.1365-2621.2001.tb15194.x.

Olsen, N., & Kleinkopf, G. (2020). Storage Management. In Potato Production Systems (pp. 523–545). Springer.

Pariasca, J. A. T., Miyazaki, T., Hisaka, H., Nakagawa, H., & Sato, T. (2001). Effect of modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage on the quality of snow pea pods (Pisum sati6um L. var. Saccharatum). 11.

Pavlath, A. E., Gossett, C., Camirand, W., & Robertson, G. H. (1999). Ionomeric films of alginic acid. Journal of Food Science, 64(1), 61-63.

Peck, S. M. (2015). Integrating Cultivar, Temperature and Quality into Early Storage Management Decisions for Wound Healing in Potatoes (Solanum tuberosum L.) [M.S., University of Idaho]. https://search.proquest.com/docview/1728921036/abstract/82D5C639DC3B4620PQ/1.

Pedreschi, F., Moyano, P., Kaack, K., & Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. Food Research International, 38(1), 1–9. https://doi.org/10.1016/j.foodres.2004.07.002.

Pinhero, R. G., Coffin, R., & Yada, R. Y. (2009). Post-harvest storage of potatoes. In Advances in potato chemistry and technology (pp. 339-370). Academic press.

Reid, M. S., & Pratt, H. K. (1972). Effects of Ethylene on Potato Tuber Respiration. Plant Physiology, 49(2), 252–255. https://doi.org/10.1104/pp.49.2.252.

Rommens, C. M., Shakya, R., Heap, M., & Fessenden, K. (2010). Tastier and Healthier Alternatives to French Fries. Journal of Food Science, 75(4), H109–H115. https://doi.org/10.1111/j.1750-3841.2010.01588.x.

Shukla, R., & Cheryan, M. (2001). Zein: The industrial protein from corn. Industrial Crops and Products, 13(3), 171–192. https://doi.org/10.1016/S0926-6690(00)00064-9.

Stintzing, F. C., & Carle, R. (2004). Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. Trends in food science & technology, 15(1), 19-38.

Tajner-Czopek, A., Figiel, A., & Carbonell-Barrachina, Á. A. (2008). Effects of potato strip size and pre-drying method on french fries quality. European Food Research and Technology, 227(3), 757–766. https://doi.org/10.1007/s00217-007-0784-8

Toma, R. B., Leung, H. K., Augustin, J., & Iritani, W. M. (1986). Quality of French Fried Potatoes as Affected by Surface Freezing and Specific Gravity of Raw Potatoes. Journal of Food Science, 51(5), 1213–1214. https://doi.org/10.1111/j.1365-2621.1986.tb13087.x.

Vinci, R., Mestdagh, F., De Muer, N., Van Peteghem, C., & De Meulenaer, B. (2010). Effective quality control of incoming potatoes as an acrylamide mitigation strategy for the French fries industry. Food Additives and Contaminants, 27(04), 417–425. https://doi.org/10.1080/19440040903453276.

Voss, R. E., Baghott, K. G., & Timm, H. (2001). Proper environment for potato storage. Vegetable Research and Information Center. The University of California.

Wang, Q., Cao, Y., Zhou, L., Jiang, C.-Z., Feng, Y., & Wei, S. (2015). Effects of postharvest curing treatment on flesh colour and phenolic metabolism in fresh-cut potato products. Food Chemistry, 169, 246–254. https://doi.org/10.1016/j.foodchem.2014.08.011.

Wang, Y., Naber, M. R., & Crosby, T. W. (2020). Effects of Wound-Healing Management on Potato Post-Harvest Storability. Agronomy, 10(4), 512.

Watada, A. E. (1986). Effects of ethylene on the quality of fruits and vegetables. Food Technol, 40(5), 82-85.

Yaman, Ö., & Bayoındırlı, L. (2002). Effects of an edible coating and cold storage on shelf-life and quality of cherries. LWT-Food science and Technology, 35(2), 146-150.

Zheng, X., Jiang, H., Bi, Y., Wang, B., Wang, T., Li, Y., Gong, D., Wei, Y., Li, Z., & Prusky, D. (2020). Comparison of wound healing abilities of four major cultivars of potato tubers in China. Postharvest Biology and Technology, 164, 111167. https://doi.org/10.1016/j.postharvbio.2020.111167.

Zheng, Y., Yang, Z., & Chen, X. (2008). Effect of high oxygen atmospheres on fruit decay and quality in Chinese bayberries, strawberries and blueberries. Food Control, 19(5), 470–474. https://doi.org/10.1016/j.foodcont.2007.05.011.

3 Chapter 3: The impact of ventilation conditions on the quality of Rio Grande Russet tubers during long-term cold storage

3.1 Introduction

Potato (*Solanum tuberosum* L.*)* ranks fourth in the world as an essential food crop (Chemeda et al., 2014; Gupta et al., 2015). Long-term storage of up to 10 months is necessary to provide a year-round supply of potatoes to both fresh market and processing industries. Potatoes are stored as pile in bins or in wooden/metal/plastic stacked cribs in storage rooms under high relative humidity (>95%) and at low temperatures (3 °C to 7 °C). One of the requirements of the ideal storage environment is the consistency of the conditions that minimize tuber's weight loss. Potato tubers' age, storage temperature, and relative humidity are crucial factors that correlate with weight loss.

Tuber weight loss is most significant during the first few days after harvesting due to high rates of respiration and field heat (Voss et al., 2001). In the first month, postharvest, tuber weight loss in storage is estimated at 3%; total weight loss during the entire storage period (8-10 months) can reach 5-8% (Olsen and Kleinkopf 2020). Cooling gradually removes field heat from the storage pile; during this process, the temperature differential between the bottom and top of the pile must be kept to a minimum (1-2 °C). The higher the vapor pressure deficit, the greater the moisture loss from the tuber during harvest and storage. Transpiration accounts for 90% of tuber weight loss, and it is mostly due to the diffusion of water vapor through the skin and into the surrounding air (Lutman, 1934). The ventilation rate affects the weight loss of potato tubers along with the age of tubers and pulp temperatures (Butchbaker et al., 1973).

Temperature is vital to the potato storage process. High temperature increases the respiration rate, tuber vapor pressure, and enhances sprouting during the later storage of potatoes. Moderate

temperatures (~13 °C) are considered desirable during the first few days of storage to promote the healing of tuber wounds (Butchbaker et al., 1973).

Consistent ventilation is critical for the maintenance of tuber quality in potato storages. Most of the potato storage air systems have been designed to supply air in the range of 10-20 CFM per ton (Sanford 2006). Research recommends the requirement of 20 + CFM/ton air supply to handle harvested tubers that have been stressed in the field due to disease or harvested in wet conditions. During holding periods, most storage managers reduce ventilation rates. This can be done by lowering fan run hours. Another way to control the ventilation rate is by adjusting the fan speeds with Variable Frequency Drives (VFDs). VFDs control the ventilation rate by manipulating fan speeds, thus reducing energy consumption. For instance, reducing fan speed to 50% produces a 50% airflow but reduces energy consumption by 85% (Koski and Oberg 2003).

In North American potato production regions, the ambient temperature often drops to sub-freezing temperatures during winter. Storage temperatures are maintained by minimizing the intake of fresh air and recirculating air. Another temperature management strategy in storage rooms is intermittent fan operations. Intermittent ventilation retains respiratory heat generated by potatoes and saves considerable energy. In summer months, refrigeration maintains storage temperatures to reduce sprouting, weight loss, and disease incidence. The final cost of potato storage will reflect any energy-savings from intermittent or shortened duration ventilation (Jayas et al., 2001). Reducing the cost of power consumption is an important goal of industrial refrigeration and potato storage management. This goal can be enhanced through storage design, improved storage operation, and optimized ventilation operations (Chourasia & Goswami, 2009). Significant energy saving can be achieved by ventilating only when necessary, thus reducing the duration of ventilation (Jayas et al., 2001).

Several factors influence the nutritional value of stored crops, such as transpiration, respiration, ethylene production, initial chemical composition, delayed harvest. Also influential are storage conditions, including the length of storage, and storage temperature, relative humidity, and ventilation (Genanew, 2013). Ventilation has direct and indirect impacts on the quality of the stored potatoes. The effect of ventilation on weight loss of tubers is an example of a direct impact. The effect of ventilation on the composition of the air inside the storage room and the level of ethylene affect the chemical composition of the tuber; this is an example of an indirect impact. In the same context, changing the storage air composition affects microbial growth on fresh fruits and vegetables. For instance, air that contains a high level of both CO_2 and O_2 significantly restrains microbial growth (Zheng et al., 2008). Altered storage air composition, controlled atmospheres (CA), modified atmosphere packaging (MAP), and low-temperature storage reduce ethylene production and respiration rate. It slows the change in chemical composition of stored crops (Pariasca et al., 2001). Ethylene affects some chemical components of stored crops. For instance, ascorbic acid content of some stored tomatoes can be altered by the ethylene concentration in the storage air. However, ethylene does not significantly affect soluble solids or acid content in others (Watada, 1986).

Studies on the effect of ventilation conditions on potatoes are limited. The challenge is to maintain long-term storage temperature with minimum ventilation to maintain tuber quality in long-term storage. There is little information available in the literature on the duration of operation of fan and speed to reduce storage losses. Therefore, this study was conducted to examine the effect of speed and operation period of ventilation fans on the Rio Grande Russet on tuber weight loss, texture, ethylene production, respiration rate, sprouting rate, nutritional value, and power consumption during six months of storage.

Rio Grande Russet is a high yielding fresh market russet released by Colorado State University breeding and selection program and is a commonly grown variety in Colorado and other potato growing areas of the USA. This variety is popular because of its attractive shape and is resistant to hollow heart, black spot bruise and shatter bruise. The results from this study will eventually help fresh pack growers to alter storage conditions to reduce tuber weight loss and power consumption.

3.2 Materials and Methods

3.2.1 Small scale storage drum design

Fifty-five-gallon plastic drums were outfitted with fans installed in the lower quarter of the drum, as shown in figure (1). A steel mesh screen (½ inch) was installed above the fan to support the potatoes in the drum and to facilitate air circulation throughout the mass of tubers (about 150 lbs. in each drum). To facilitate air circulation, holes were made in the lids of the drums. Fans were placed at the hole drilled in the bottom quarter of the drum. The gapes in the fan's frame were sealed with a duct tape. Drums were held in a cold room at 5 ±2 °C with 95% RH ± 5 for the duration of the experiment. Two replications per treatment per season were established.

Figure 3.1. A 55-gallon drum equipped with a fan and mesh screening across the lower quarter to elevate tubers and facilitate air circulation. The fan controls were passed through a hole drilled in the drum and sealed with duct tape.

3.2.2 Tuber sampling

The study was performed in the 2016 and 2017 storage seasons. The Rio Grande Russet tubers used in the study were obtained from the San Luis Valley Research Center, Center, CO. The tubers were harvested in late September of the 2016 season and mid-October in the 2017 season. Tubers were collected randomly from a storage pile after the wound healing stage. One hundred and fifty pounds of tubers with greater than 113g, randomly selected were loaded in each drum and moved to cold rooms with 95% RH. This experiment was carried for six months in cold storage to measure weight loss, texture, ethylene production, respiration rate, nutritional value, and power consumption. The sprouting rate was measured at the end of seven months of storage. Tubers were not treated with any sprout inhibitor.

3.2.3 Fans

The stored potatoes in modified drums were exposed to one of three direct current (DC) fan speeds: 52 CFM (high), 13 CFM (medium), and 0.6 CFM (slow) representing high, medium, and low ventilation conditions. We selected these three different CFM fans based on recommended range, volume of the space and exchange the air in the drum. The three levels of CFM fans were run under two operating systems: continuous and intermittent for a total of six treatments. A power timer (Titan Controls Cycle Timer, Denver, CO, USA) controlled the intermittent operating system. The time required by the intermittent operating system for complete recycling of air inside the drums for two times was calculated. At 52 CFM, a complete air exchange required 25 sec; 13 CFM requires 2 minutes and 0.6 CFM, requires 32 min. The fans were controlled with a timer to run for every three hours for two complete cycles. The control treatment was zero ventilation means no fans were mounted on the drum. However, the drums were of the same design with holes on top and bottom to allow unforced airflow.

3.2.4 Equipment and Devices

A large weighing scale (Giantex 660 lbs. floor platform, San Diego, CA, USA) was used to measure the differences in drum weights with accuracy up to 0.1 pounds during the experiment. A portable gas analyzer was used to measure ethylene production and respiration rates by the tuber samples (F-900 Felix Instruments Place, Camas, USA). A texture analyzer (Brookfield CT3, Middleboro, MA, USA) was used to measure the change in tuber texture before and after six months of cold storage. Total phenolics, flavonoids, and reducing sugars were estimated by spectrophotometric methods, using a Costar 3370 spectrophotometer (Corning, NY, USA). Ascorbic acid content was estimated using a Waters 2695 HPLC system (Waters Corporation, Milford, MA, USA).

3.2.5 Weight loss percentage

The weights of outfitted drums and potatoes were recorded at time zero and after three and six months of storage. Total weight loss was defined as the difference between the initial and final drum weight; percent loss was calculated as

$$[(\text{initial weight} - \text{final weight})/\text{initial weight}] * 100$$

3.2.6 Texture change

Texture was determined using a modification of Crossen's method (2017) using a-Brookfield CT3 texture analyzer, outfitted with a spherical probe. One unit of change in texture was defined as the weight (g) required to pierce 3 mm into the tuber skin. Two readings were taken from each of 15 tubers (stem and bud end) selected at random from each treatment. Means were calculated from these measurements.

3.2.7 Ethylene production and respiration rate

Ethylene production and respiration rates were measured using a modification of the method described by De Jesús Avena et al. (1994). The flow system was used to measure CO_2 and ethylene during storage at zero, three, and six months. Three tubers after weighing were placed in a one-gallon jar connected to an ethylene gas analyzer (F-900, Felix Instruments, Camas, WA USA). Respiration rate was calculated as the ratio of carbon dioxide to oxygen. Each measurement was performed three times for each treatment.

3.2.8 Spouting rate

The experiment ran continuously until the initiation of sprouting (after seven months of cold storage). Ten tubers were randomly selected from each treatment to calculate the sprouting rate.

The sprouting rate was calculated as the percentage of the weight of the sprouts to the weight of whole tubers with sprouts (Mehta and Singh 2016).

The sprouting rate = (sprouts weight/tuber weight with their sprouts) * 100

3.2.9 Power consumption

Because the motors that drive the fans are direct current (DC) motors, the energy consumed by each fan was calculated over six months based on the voltage (V) and current (I) ratings of each fan. The time (t) is expressed as the number of hours operated in the six months period. The power (P) and energy (E) are calculated and expressed in Watts and Watt-hours, respectively using the following equations:$P = V\ I$

$$E\ =\ P\ t$$

where the unit of voltage is volt (V), the unit of current is Ampere (A), the unit of power is Watts (W), and the unit of energy is Watt hour (Wh)

3.2.10 Bioactive compounds; total phenolics, total flavonoids, reducing sugars and ascorbic acid

3.2.10.1 Extraction procedure

Phenolic compounds, flavonoids, and reducing sugars were extracted using a modified method described by Perla et al. (2012). At zero, three, and six months of storage, five tubers from each treatment were cut into small pieces, frozen, freeze-dried and ground and then held at -80°C until further analysis. One gram of freeze-dried material was weighed in a 10 ml falcon tube and 5 ml of 90% methanol was added to the powder. The mixture was vortexed for 1 min, after which the tubes were incubated overnight in an orbital shaker at 150 rpm at 25°C. Homogenates were then centrifuged at 5000 rpm for 25 min, followed by filtration through grade 40 Whatman filter paper. The remaining precipitate in the tubes was re-extracted using 5 ml of

90% methanol under the same conditions. The final volume was made to 10 ml with 90% methanol and kept at -80 °C for further analysis.

3.2.10.2 Determination of total phenolics

Total phenolic content of the tubers was determined using the method described by Perla et al. (2012). To 50 µL of distilled water in 96-well flat-bottomed assay plate (Costar 3370, Corning, NY), 20 µL aliquots of extracts were added. Next, 75 µL of commercial FCR solution (MPP Biomedical Solon, OH) was added and mixed for 1 minute in the plate reader (Power Wave XS2, BioTek Instruments, Winooski, VT). Eighty µL of 75 gL^{-1} sodium carbonate solution was added and mixed with a pipette tip. The microplate was shaken in the plate reader for 5 min. The absorbance of the contents was measured at 760 nm against a gallic acid in 90% methanol standard. Total phenolics values were quantified as µg of gallic acid equivalent per gram of dry weight of potato samples using a 7-point calibration curve with an R^2 value of 0.979.

3.2.10.3 Determination of total flavonoids

Total flavonoids were determined using a method described by Perla et al. (2012) with slight modifications. Briefly, 80 µL of the extract was added to 80 µL of Aluminum chloride (20 gL^{-1}) ethanolic solution in a 96 well flat-bottomed microplate on ice. The plate was shaken for 20 minutes in the plate reader. Plates were then sealed with parafilm and held under darkness at 25°C for one hour. After the plates were shaken for 30 s, the absorbance of the mixture was measured at 415 nm against a quercetin hydrate in methanol standard. Total flavonoids were expressed as µg of quercetin equivalents per g of dry weight using a 6-point calibration curve with an R^2 value of 0.997.

3.2.10.4 Determination of reducing sugars

Reducing sugars were determined by a modified 96-well microplate assay method previously described by (King et al., 2009). One hundred and twenty µL aliquot of a dinitrosalicylic acid reagent (10 g L^{-1} dinitrosalicylic acid, 2 g L^{-1} crystalline phenol, 10 g L^{-1} sodium hydroxide and 0.5 g L^{-1} fresh sodium sulfite) was added to each PCR tube (BioExpress, Kaysville, UT) and 20 µL of the extract was added and mixed well. The mixture was heated in a water bath at 99 °C for 15 min and then cooled at 4 °C for 1 min and kept at 20 °C to stop the reaction. After thorough mixing, 100 µL of the mixture of each tube was added to 40 µL of 400 g L^{-1} potassium sodium tartrate tetrahydrate solution in a 96-well flat-bottom microplate. The plates were well mixed for 2 min in the plate reader, and the absorbance was measured with the plate reader at 570 nm against a glucose standard (800 ml L^{-1} methanol); reducing sugars were expressed as mg glucose per g of dry matter.

3.2.10.5 Determination of ascorbic acid

Ascorbic acid in potato samples was estimated according to the method described by (Hamed et al., 2019) with some modifications. Ascorbic acid was extracted from the freeze-dried potato samples using 2.5% meta-phosphoric acid. Five hundred mg of the sample's powder was vortexed with 10 mL of 2.5% meta-phosphoric acid in a 15 mL tube for one min. Resulting supernatant were centrifuged at 5000 rpm for 20 min, then filtered through Whatman grade 40 filter papers. The quantification of ascorbic acid was conducted using a Waters 2695 HPLC system equipped with a Photodiode Array Detector (PDA) and a C18 column (Waters Corporation, Milford, MA, USA) at a flow rate of 0.4 mL/ min with gradients of mobile phase composed of 2.5% meta-phosphoric acid (solvent A) and 98% methanol (solvent B). The PDA was set to an excitation wavelength of 254 nm. A range of ascorbic acid standards from 0.1 to 10

μg/mL in 2.5% meta-phosphoric acid were prepared. The quantity of ascorbic acid in potato samples in mg/100g was calculated from the standard curve with an R^2 value of 0.92.

3.2.11 Statistical analysis

Data was collected from tubers harvested at the end of the 2016 and 2017 growing seasons. Total phenolics, total flavonoids, reducing sugars, ascorbic acid, respiration rate, and ethylene productions were measured in triplicate. Two replicates of weight loss were measured; limited access to drums and storage space reduced the numbers of units. Fifteen tubers were measured for texture change per treatment. Sprouting rate is the result of ten measurements. All results are presented as mean ± standard deviation (SDD) values. The data were subjected to analysis of variance (ANOVA), and Tukey's test was performed to determine whether differences between treatments were significant at $P < 0.05$. All statistical analyses were performed with R software version 3.4.3 for Windows.

3.3 Results

3.3.1 Weight loss

The percent weight loss of Rio Grande Russet potatoes in storage is shown in Figure 2 and Table 1. The percent weight loss increased with storage time at 5 °C ± 2 and 95 % RH ± 5 (data not shown). The weight loss was greater under continuous ventilation compared to intermittent ventilation in both 2016 and 2017 seasons. Similarly, in the 2016 and 2017 seasons, tuber weight loss increases as the fan CFM increases in continuous and intermittent operation. Intermittent ventilation at 0.6 CFM significantly decreased weight loss ($P< 0.05$) compared to the control. There was no significant difference in tuber weight loss between continuous and intermittent

ventilation at 52 and 13 CFM (P>0.05). Additionally, there was no significant difference in weight loss of tubers between continuous and intermittent ventilation at 0.6 CFM (P > 0.05).

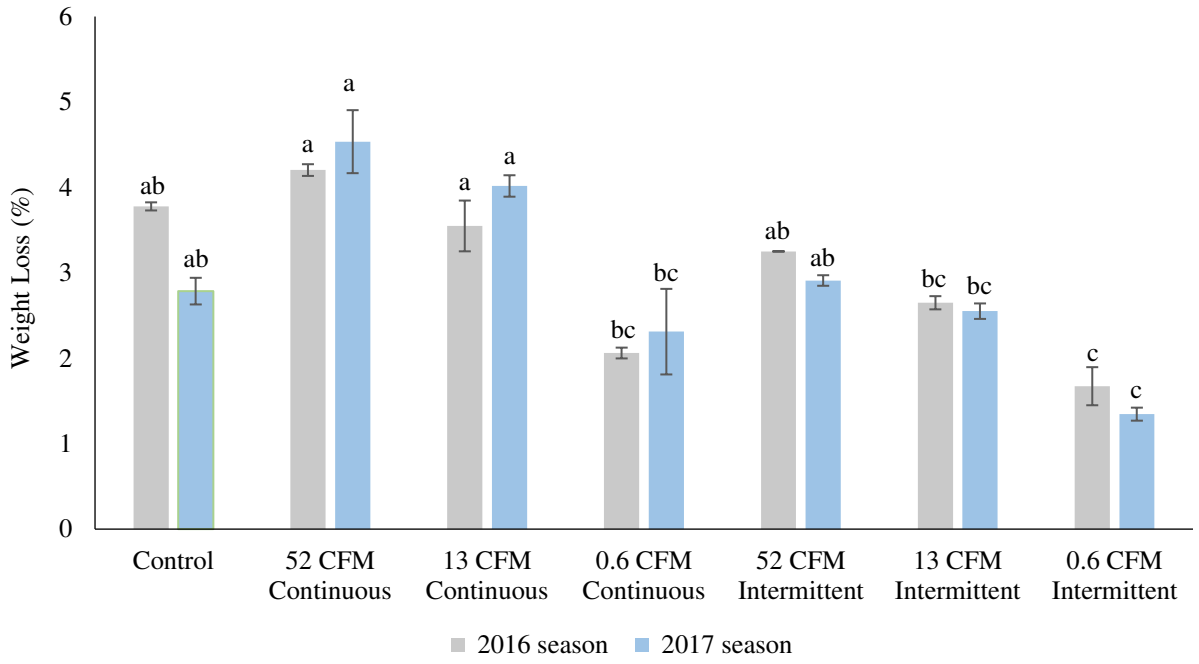


Figure 3.2. Effect of ventilation conditions on tuber weight loss (%) of the Rio Grande Russet potatoes after six months of cold storage at 5 °C ± 2 and 95 % RH ± 5 in 2016 and 2017 season. Data expressed as mean ± S.D., n = 2. The different letters are significantly different (P < 0.05).

3.3.2 Texture change

The texture measurement indicates the tuber turgidity and is an indicator of the firmness of the tuber. Figure 3 shows the firmness measurements of tubers from all treatments stored for six months at 5 °C ± 2 and 95 % RH ± 5 in the 2016 and 2017 seasons. In the 2017 season, intermittent ventilation at 0.6 CFM resulted in significant texture loss (Table 1). By contrast, tubers stored under continuous or intermittent ventilation at 52 CFM underwent significant texture loss compared to the control. The statistical analysis of averages of textures of the tubers showed that there was no significant difference between continuous and intermittent ventilation at 0.6 CFM and continuous ventilation at 13 CFM (Table 1). Nor were there significant

differences between continuous ventilation at 13 and 52 CFM and intermittent ventilation at 52 CFM.

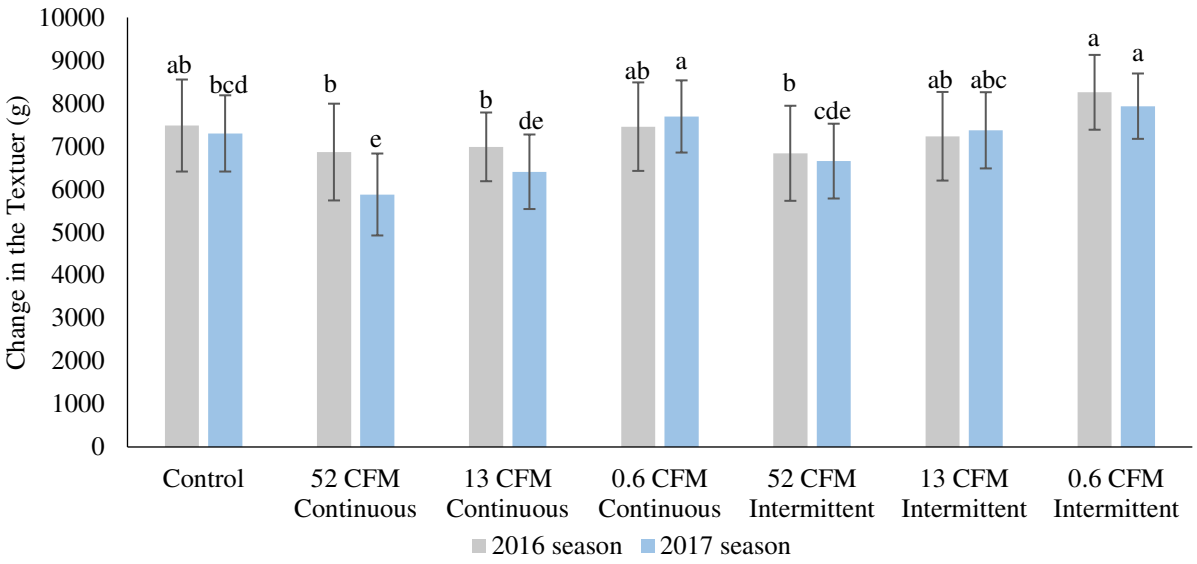


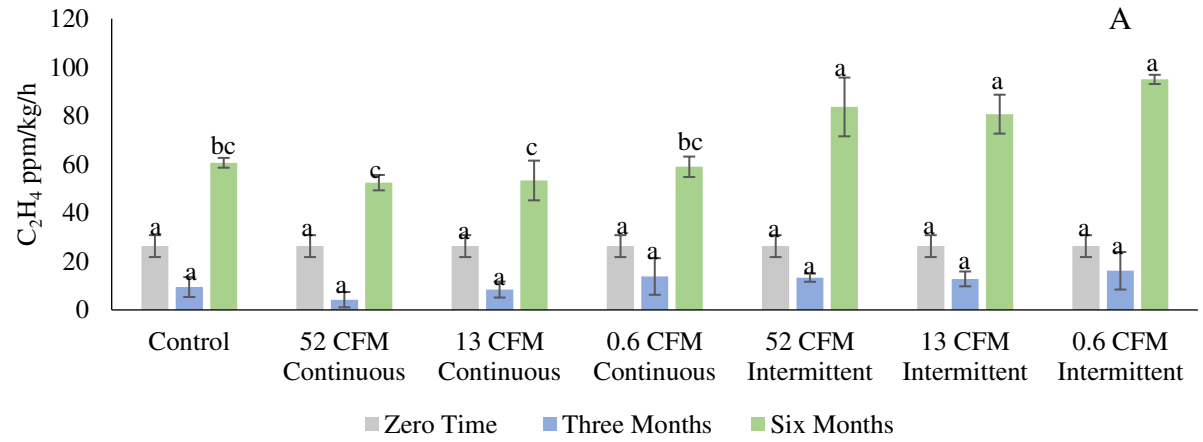
Figure 3.3. Effect of ventilation condition on texture (g) of the Rio Grande Russet after six months of cold storage at 5 °C ± 2 and RH 95 % ± 5 in 2016 and 2017 season. Data expressed as mean ± S.D., n = 30. The different letters are significantly different ($P < 0.05$).

3.3.3 Ethylene production and respiration rate

Ethylene production measurements of all treatments stored for six months at 5 °C ± 2 and 95 % RH ± 5 in the 2016 and 2017 seasons are shown in figure 4 a and b. There were no significant differences ($p > 0.05$) between the treatments after three months of storage in either season. However, at the end of the storage time, six months, there was significance ($p < 0.05$). For instance, in the 2016 season, after six months of storage, there was a significant difference in ethylene production between the continuous and intermittent ventilation treatments at any fan speed. However, there was no significant differences between the fan speeds within the continuous or intermittent treatments. Intermittent high, medium, and slow CFM ventilation increased ethylene production significantly over the control after six months of storage. The

greatest level of ethylene production was observed in the low-speed intermittent ventilation treatment.

The respiration rate (CO_2/O_2) measurements in the 2016 and 2017 season of all treatments stored six months at 5 °C ± 2 and 95 % RH ± 5 are shown in figure 5 a and b. There was no significant difference ($p > 0.05$) between treatments after three months of storage in either year. However, after six months in storage time, there were significant differences in respiration rate ($p < 0.05$). For example, there was a considerable difference in respiration rate detected after six months between intermittent ventilation in both years at 13 and 0.6 CFM fans and continuous ventilation fans at 52 CFM (Figures 5a and b).



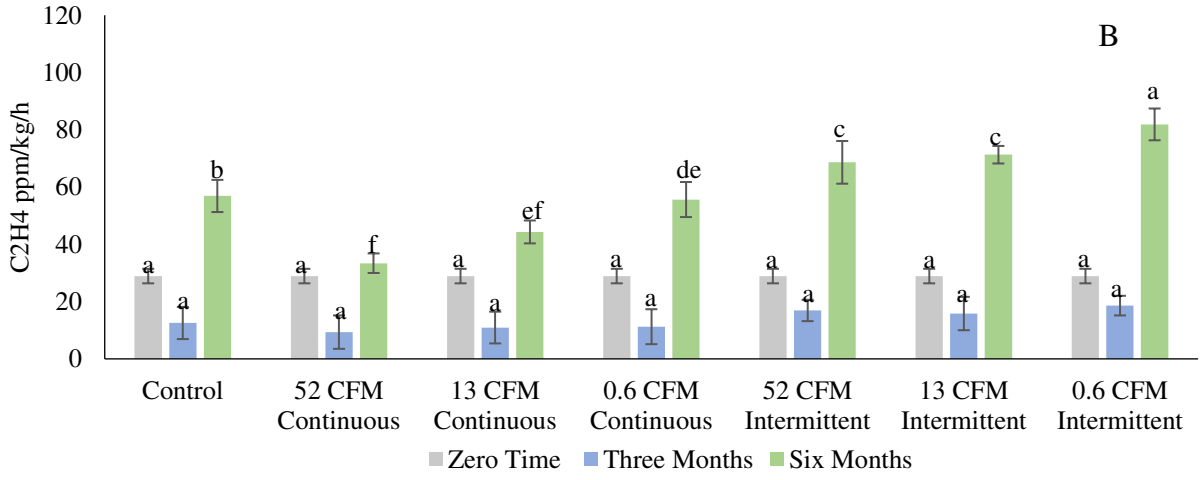


Figure 3.4. Effect of ventilation condition on ethylene production (ppm/kg/h) by Rio Grande Russet after six months of cold storage at 5 °C ± 2 and RH 95 % ± 5 in 2016 (A) and 2017 (B) season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

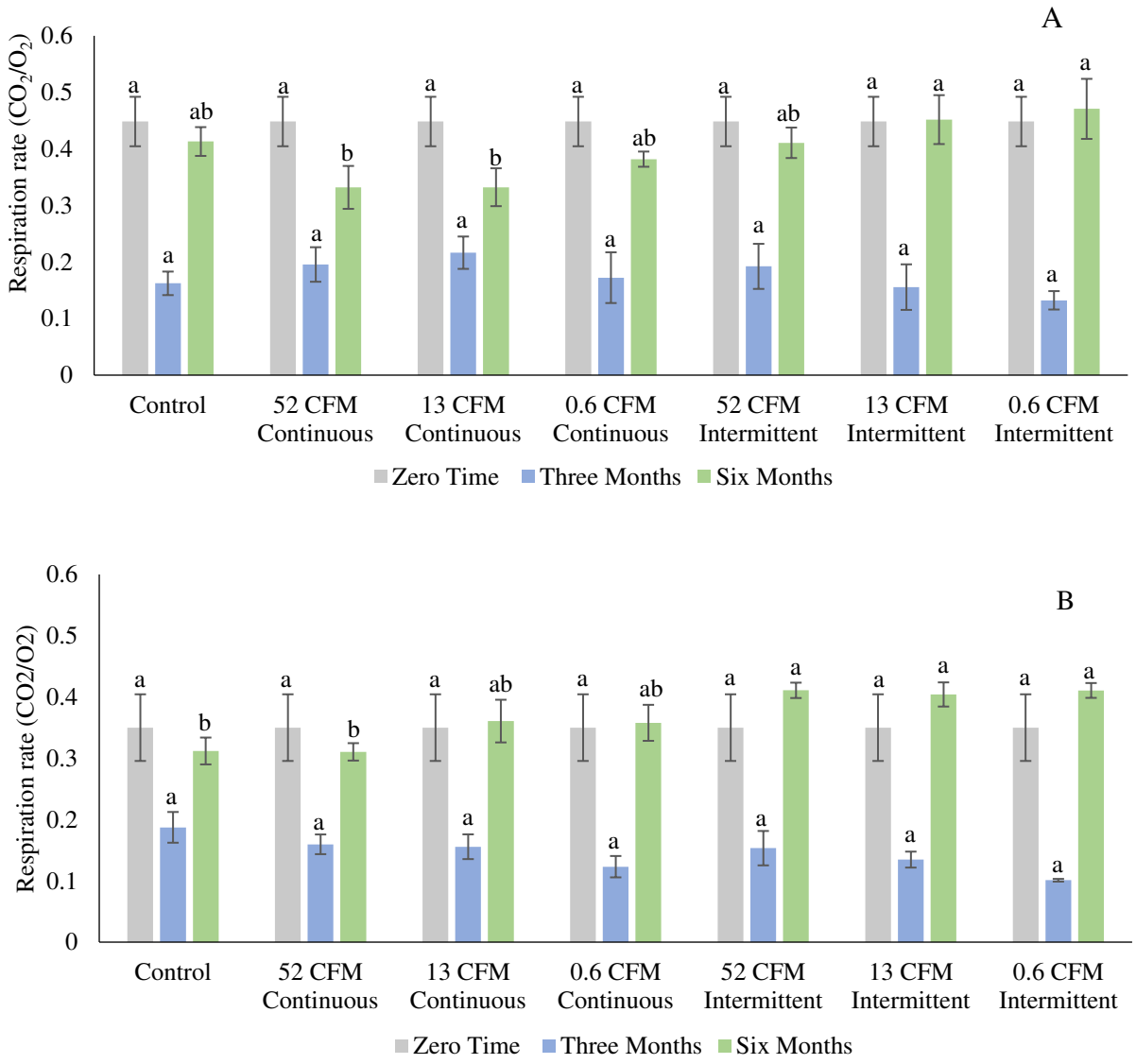


Figure 3.5 Effect of ventilation condition on the respiration rate of Rio Grande Russet after six months of cold storage at 5 °C ± 2 and 95 % RH ± 5 in the 2016 (A) and 2017 (B) season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

3.3.4 Sprouting

The effect of ventilation condition on sprouting in the 2016 and 2017 season (% of the sprout weights to the tuber weight) of all treatments in the Rio Grande Russet potatoes stored for more than six months at 5 °C ± 2 and RH 95 % ± 5 is shown in Figure 6 and 7. ANOVA analysis of the sprouting rates of tubers harvested at the end of the 2016 season shows that there was no significant difference between the control and continuous ventilation at any speed (Table 1) However, there was a significant difference between continuous and intermittent ventilation on sprouting. In the six months following the 2017 harvest, continuous ventilation at high and medium speeds significantly reduced the sprouting rate. Tubers exposed to intermittent ventilation at medium and low speeds expressed significantly greater sprouting rate compared than the control.

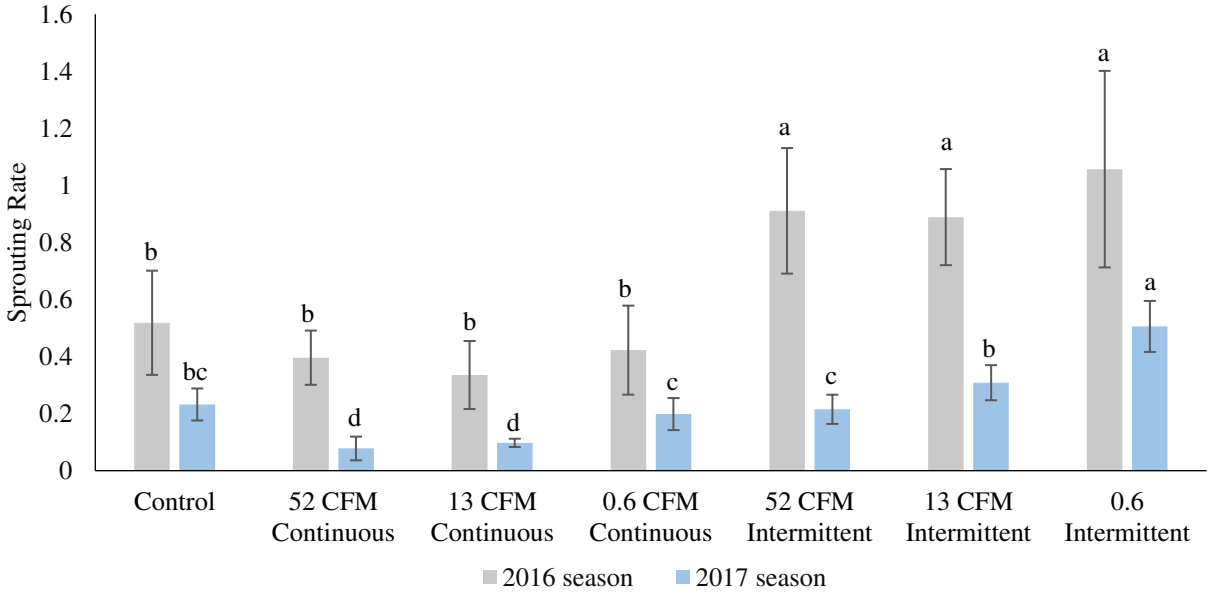


Figure 3.6. Effect of ventilation condition on the sprouting rate of the Rio Grande Russet after about seven months of cold storage at 5 °C ± 2 and 95 % RH ± 5 in the 2016 and 2017 season. Data expressed as mean ± S.D., n = 10. The different letters are significantly different ($P < 0.05$).

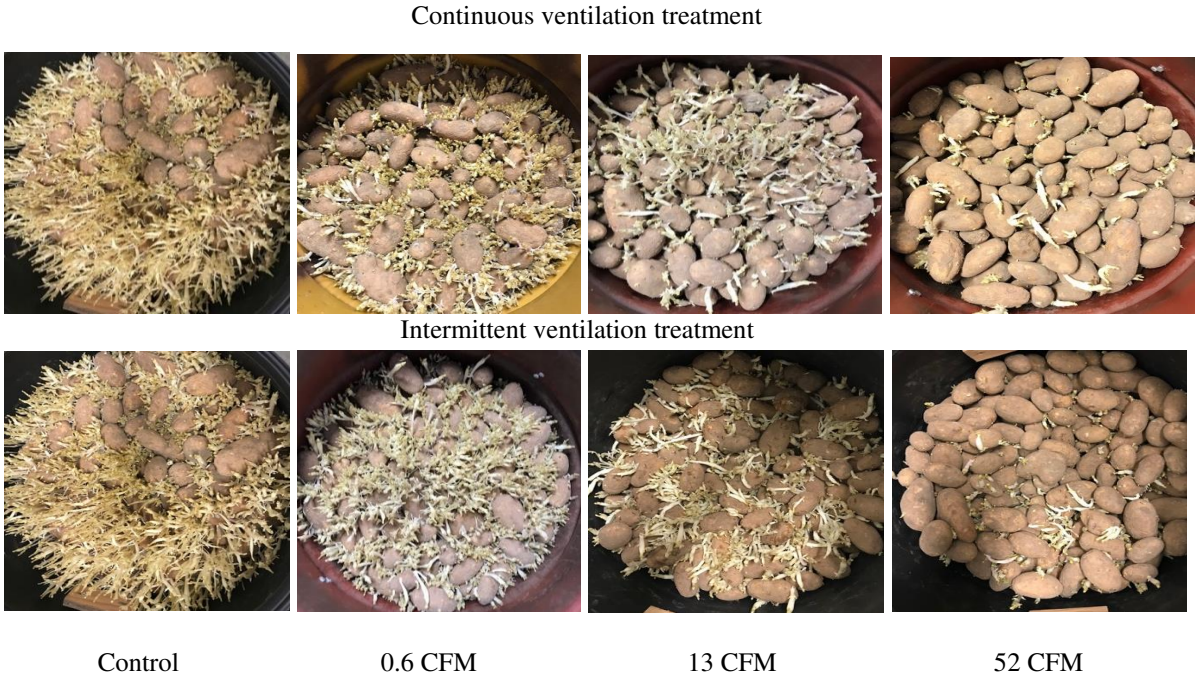


Figure 3.7. Effect of different ventilation treatments on the sprouting of Rio Grande Russet potatoes. The top row represents continuous ventilation, while the bottom row represents intermittent ventilation.

3.3.5 Power consumption

Figure 8 shows the amount of power consumed (Watt/six months) by fans under conditions of continuous or intermittent ventilation. Fans running continuously at high and medium speed consume more power than other fans. Fans running continuously at low speed consumed power more moderately. On the other hand, the consumption of power by intermittent fans was negligible.

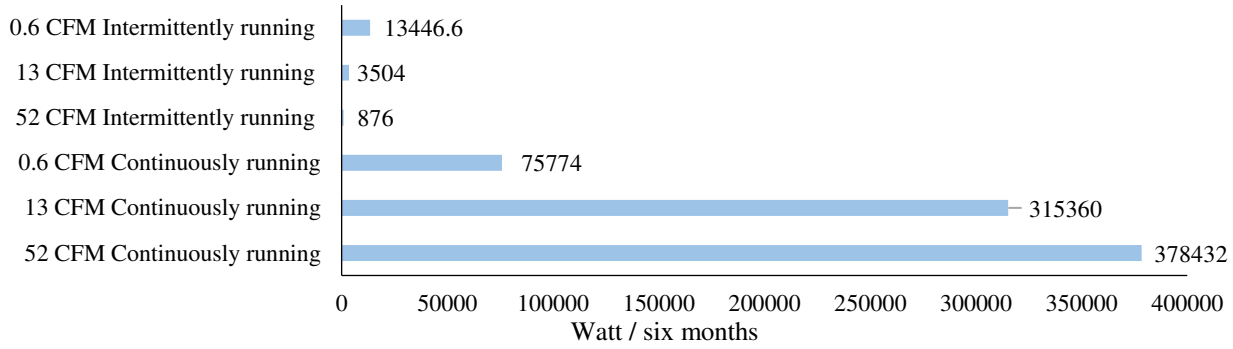


Figure 3.8. Effect of fan speeds and the timing of the operating system on the power consumption during six months of cold storage in the 2016 and 2017 season

3.3.6 Nutritional value

Table 2 shows the nutritional value of Rio Grande Russet tubers stored at 5 °C ± 2 and 95 % RH ± 5 for six months under different ventilation conditions in the 2016 and 2017 seasons. There were trends in the nutritional value in tubers between the 2016 and 2017 seasons, where the total phenolics and reducing sugars content were higher in 2017 while the total flavonoids and vitamin C content were higher than the 2016 season. No significant effect ($p > 0.05$) of ventilation conditions and fan speeds was observed on total phenolics and ascorbic acid after six months of storage in the 2016 and 2017 seasons. The trend in both seasons is that the total phenolics increased after six months of storage, while ascorbic acid content decreased. There was a significant effect of fan speed on total flavonoids and reducing sugars. For instance, total flavonoids and reducing sugar content under continuous ventilation at 52 CFM were significantly different ($p > 0.05$) from their concentrations under intermittent ventilation at 0.6 CFM in the 2016 season. Total flavonoids decreased as the storage progressed while reducing sugars increased.

Table 3.1. Effect of ventilation conditions on tuber weight loss (%), texture change (g), and sprouting rate (%) of the Rio Grande Russet after six months of cold storage at 5 °C ± 2 and 95% RH ± 5 in 2016 and 2017 season. Season means are averages of seven treatments and two replications (weight loss), thirty replications (texture change), and ten replications (sprouting

rate). Treatments means are averages of two season and two replications (weight loss), thirty replications (texture change), and ten replications (sprouting rate). Means within a column followed by different letters are significantly different (P<0.05)

Main Effect	Weight loss (%)		Texture change (g)		Sprouting rate (%)	
	2016 season	2017 season	2016 season	2017 season	2016 season	2017 season
Treatment						
Control	3.78^{ab}	2.79^{ab}	7484.1^{ab}	7300.25^{bcd}	0.52^{a}	0.23^{bc}
Continuous 52cfm	4.20^{a}	4.54^{a}	6866.1^{a}	5878.35^{a}	0.39^{a}	0.08^{a}
Continuous 13cfm	3.55^{a}	4.02^{a}	6987.15^{a}	6407.4^{ab}	0.34^{a}	0.10^{a}
Continuous 0.6cfm	2.06^{bc}	2.31^{bc}	7457.65^{ab}	7695^{a}	0.42^{a}	0.19^{b}
Intermittent 52cfm	3.25^{ab}	2.91^{ab}	6837.35^{a}	6655.7^{abc}	0.911^{b}	0.22^{b}
Intermittent 13cfm	2.65^{bc}	2.55^{bc}	7234.15^{ab}	7372.65^{cde}	0.89^{b}	0.31^{c}
Intermittent 0.6cfm	1.67^{c}	1.35^{c}	8257.15^{b}	7934.65^{e}	1.05^{b}	0.51^{d}
Average	2.97		7169.12		0.44	
ANOVA	P-value		P-value		P-value	
Treatment (T)	<0.0001		0.22		0.0008	
Season (S)	0.25		0.024		< 0.0001	
T * S	0.003		0.82		< 0.0001	

Table 3.2. Effect of ventilation conditions on the nutritional value of Rio Grande Russet stored six months at 5 °C ± 2 and 95 % RH ± 5 in the 2016 and 2017 season. Values are expressed as mean ± S.D., n = 3. Values in the same column with different superscripts are significantly different (P < 0.05).

Season	Treatments	Total Phenolics		Flavonoids		Reducing sugars		Ascorbic acid	
		Initial	6 M	Initial	6 M	Initial	6 M	Initial	6 M
2016	Control	731.36±21.06	763.19±19.27^{a}	80.83±5.77	21.99±2.52^{ab}	2.74±0.37	15.6±3.52^{ab}	77.44±6.92	40.62±4.13^{a}
	Continuous 52cfm	731.36±21.06	783.99±15.57^{a}	80.83±5.77	31.99±5.13^{b}	2.74±0.37	11.29±2.59^{a}	77.44±6.92	44.07±4.09^{a}
	Continuous 13cfm	731.36±21.06	795.32±21.00^{a}	80.83±5.77	25.99±3.51^{ab}	2.74±0.37	14.65±4.93^{ab}	77.44±6.92	45.44±2.44^{a}
	Continuous 0.6cfm	731.36±21.06	763.09±13.35^{a}	80.83±5.77	20.66±5.13^{ab}	2.74±0.37	13.97±3.51^{ab}	77.44±6.92	44.44±3.85^{a}
	Intermittent 52cfm	731.36±21.06	769.59±11.07^{a}	80.83±5.77	23.66±4.16^{ab}	2.74±0.37	12.88±4.72^{ab}	77.44±6.92	44.61±2.29^{a}
	Intermittent 13cfm	731.36±21.06	763.96±5.64^{a}	80.83±5.77	22.32±3.61^{ab}	2.74±0.37	14.99±4.04^{ab}	77.44±6.92	40.33±3.61^{a}
	Intermittent 0.6cfm	731.36±21.06	760.47±11.50^{a}	80.83±5.77	18.32±3.6^{a}	2.74±0.37	19.65±3.05^{b}	77.44±6.92	38.63±2.52^{a}
2017	Control	795.09±53.74	856.66±41.73^{a}	61.99±4.66	11.16±1.33^{a}	4.81±0.21	18.27±0.98^{ab}	69.57±3.48	38.35±2.57^{a}
	Continuous 52cfm	795.09±53.74	983.65±40.46^{a}	61.99±4.66	26.74±2.05^{a}	4.81±0.21	15.45±2.09^{a}	69.57±3.48	34.39±4.52^{a}
	Continuous 13cfm	795.09±53.74	987.49±24.67^{a}	61.99±4.66	21.71±2.66^{a}	4.81±0.21	17.16±1.6^{a}	69.57±3.48	32.87±3.38^{a}
	Continuous 0.6cfm	795.09±53.74	885.04±82.27^{a}	61.99±4.66	16.17±3.46^{a}	4.81±0.21	19.07±1.06^{ab}	69.57±3.48	37.71±3.01^{a}
	Intermittent 52cfm	795.09±53.74	1004.33±45.9^{a}	61.99±4.66	21.48±3.67^{a}	4.81±0.21	17.31±0.6^{a}	69.57±3.48	34.28±3.91^{a}
	Intermittent 13cfm	795.09±53.74	874.94±214.3^{a}	61.99±4.66	23.38±2.58^{a}	4.81±0.21	18.04±1.43^{ab}	69.57±3.48	33.3±2.66^{a}
	Intermittent 0.6cfm	795.09±53.74	837.42±65.34^{a}	61.99±4.66	11.29±1.56^{a}	4.81±0.21	22.63±0.84^{b}	69.57±3.48	31.74±4.5^{a}

3.4 Discussion

Ventilation in potato storages is necessary to remove respiratory heat, excess CO_2, ethylene, and to maintain optimum temperature and RH (Koski & Oberg, 2003, and Voss et al., 2001). The shrinkage during storage time is one of the properties that determine potato tuber quality. Weight loss in potatoes is largely due to the difference in vapor pressure between the tuber and the surrounding atmosphere (Ali et al., 2010). Other critical factors that contribute to weight loss are storage conditions, cultivar, potato skin morphology, harvest quality, disease infection, and sprouting. Appropriate storage temperature, humidity, and ventilation will extend storage life and maintain the quality of potato tubers (Kasso & Bekele, 2018).

The results of our study suggest that continuous ventilation will cause more weight loss in the Rio Grande Russet potatoes than intermittent ventilation. High-speed fans, when operated continuously or intermittently, caused significantly greater weight loss ($P < 0.05$) than low-speed fans. For instance, tubers stored under continuous ventilation at 52 CFM lost about 5% of their weight, compared to about 1% under intermittent ventilation at 0.6 CFM. The greater airspeed around tubers might cause more weight loss because the fast-moving air disturbs the saturated humidity steady phase surrounding the tubers. These results are consistent with that of (Koski & Oberg 2003) and (Heltoft et al., 2016). Rapidly moving air quickly replaces the saturated moist air with lower RH. The replacement of saturated air under slower airspeed will be slow and gradual, resulting in less weight loss, as shown in figure 2. Our results indicate that the weight loss in tubers during long-term storage increased with the fan speed.

Horticultural products lose texture due to deterioration of cellular and intracellular structure and cell wall composition. This phenomenon, softening, is a biochemical process, and includes hydrolysis of starch and polysaccharide layers by enzymes (Ali et al., 2010). Texture loss is also

associated with water loss. Free and bound water molecules work together to maintain the firmness of the tubers (Taşdelen & Bayindirli, 1998). The textural changes noted in this study are consistent with the hypothesis that texture loss is correlated with weight loss in the potato tubers. For instance, the greatest loss of texture occurred under continuous ventilation at 52 and 13 CFM (Fig.3). The change of texture correlates with the loss of tuber weight (Fig. 2).

At zero time in this study, the respiration rate of the tubers was high. This is mainly due to the field heat of potatoes at harvest, which was around 15 °C in the 2016 season and 13 °C in the 2017 season. This is consistent with Hardenburg et al. 's (1986) observation that storage conditions, such as high-temperature increase respiration rate. In addition, the presence of wounds and mechanical damage on tubers might contribute to the high rate of respiration (Maftoonazad et al., 2008). Weather conditions in the 2016 & 2017 seasons can account for the differences in sprouting rate, weight loss, and other nutrient values, as indicated in Table 1 and 2. There was more precipitation in the 2017 season than in 2016 during the growing season of May 22nd to October 23rd (https://coagmet.colostate.edu). Levy (1986) observed differences in sprouting, tuber yield, and quality in different seasons grown under different water and temperature conditions.

The respiration rate significantly decreased after three months of storage at 5 °C. Although the respiration rate after three months of storage (Fig. 5 a and b) was higher for tubers exposed to continuous ventilation at 52 CFM than tubers exposed to intermittent ventilation at 0.6 CFM, the differences were not significant ($p > 0.05$). After six months of storage, the respiration rate of tubers held under intermittent ventilation at 0.6 and 13 CFM increased significantly ($p < 0.05$) compared with tubers held under continuous ventilation at 52 and 13 CFM. Since no sprouting inhibitor was used in this study, these results suggest that tuber sprouting is more due to the

combined effect of the respiration rate, ethylene production and airflow speed. Respiration contributes to weight loss in potatoes due to the breakdown of the carbohydrates. If the heat generated by respiration is not eliminated by ventilation, it can cause significant transpirational water loss in potatoes (Maftoonazad et al., 2008).

Ethylene concentrations (Fig.4 a and b) were significantly greater in tubers held under intermittent ventilation rather than continuous ventilation storage at 4 °C for six months. Consequently, the tuber sprouting rates were considerably higher after seven months of storage at 4 °Camong tubers stored under intermittent as opposed to continuous ventilation. These results reinforce what Hardenburg et al. (1986) suggested: that exposure to high levels of ethylene may induce the sprouting of potato tubers after six months of storage at 4 °C.

In this study, fans running continuously consumed significantly more power fans running intermittently. The power consumed by all fans running intermittently at any speed (0.6, 13, and 52 CFM) for six months equaled about 25% of the power consumed by fans running continuously at 0.6 CFM for the same period. The VFD fans significantly reduced energy use without adversely affecting the quality of the stored potato tubers (Koski & Oberg, 2003).

We assessed the effect of fan speed, and resultant volume of airflow, on the nutritional value of the potato tubers stored for six months at 4 °C and 95% relative humidity. The results of this study showed that airflow has no significant effect ($p > 0.05$) on total phenolics and ascorbic acid after six months of storage. There was a significant difference ($p < 0.05$) in total flavonoids and reducing sugars among tubers stored under continuous ventilation at 52 CFM compared intermittent ventilation at 0.6 CFM after six months of storage at 4 °C. These differences may be due to the effects of ventilation on ethylene content and respiration rate as Genanew (2013), and Watada (1986) reported, with the note that some tubers had begun to sprout after six months of

storage. In this study, reducing sugars were greater for tubers stored under continuous ventilation at 0.6 CFM than for tubers stored under continuous ventilation at 52 CFM. This result contradicts the findings of Heltoft et al. (2016).

Our study on the effect of ventilation on potato storability is a small scale compared to commercial potato storage facilities. Our experimental design and storage conditions followed commercial potato storage. Our recommendation can be easily tested and applied in commercial storage settings without the risk of loss.

3.5 Conclusions

This study showed that continuous ventilation increased Rio Grande Russet tuber weight loss compared with intermittent ventilation. Generally, weight loss increased with fan speed. Tubers stored under intermittent ventilation at 0.6 CFM experienced significantly lesser weight loss ($P < 0.05$) than the control. Further, under intermittent ventilation at 0.6 CFM, tubers underwent a less significant firmness loss. Continuous ventilation at 13 or 52 CFM significantly reduced ethylene production. Sprouting rate, without the use of sprouting inhibitors, was significantly different between continuous and intermittent ventilation conditions, as was power consumption. With some exceptions, fan speeds had a limited effect on the nutritional value of Rio Grande Russet in terms of total phenolics, flavonoids, reducing sugars, and ascorbic acid. Low intermittent and low continuous fans are effective in reducing weight losses in the 2016 and 2017 season. However, potato storages in North America need constant humidity to prevent weight loss. Based on our current study, we recommend using continuous low to Medium CFM fans with a sprout inhibitor application to reduce weight loss in the long-term storage of Rio Grande Russet tubers. Our results have the potential to reduce the cost of storage in Rio Grande Russet and other fresh pack potatoes.

3.6 Reference

Ali, A., Maqbool, M., Ramachandran, S., & Alderson, P. G. (2010). Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (Solanum lycopersicum L.) fruit. *Postharvest Biology and Technology*, *58*(1), 42–47. https://doi.org/10.1016/j.postharvbio.2010.05.005

Butchbaker, A. F., Promersberger, W. J., & Nelson, D. C. (1973). Weight loss of potatoes as affected by age, temperature, relative humidity and air velocity. *American Potato Journal*, *50*(4), 124–132.

Chemeda, A. S., Bultosa, G., & Dechassa, N. (2014). Effect of variety and storage on the tuber quality of potatoes cultivated in the Eastern Highlands of Ethiopia. *Science, Technology and Arts Research Journal*, *3*(1), 84–89.

Chourasia, M. K., & Goswami, T. K. (2009). Efficient design, operation, maintenance, and management of cold storage. *Biological Sci*, *1*(1).

Crossen E. (2017). Textural, Color and Sensory Attributes of Fruits and Vegetables Dried Using Electric Forced-Air and Solar Dehydrators. *Theses and Dissertations*.

De Jesús Avena-Bustillos, R., Krochta, J. M., Saltveit, M. E., de Jesús Rojas-Villegas, R., & Sauceda-Pérez, J. (1994). Optimization of edible coating formulations on zucchini to reduce water loss. *Journal of Food Engineering*, *21*(2), 197–214.

Genanew, T. (2013). *Effect of Post-Harvest Treatments on Storage Behavior and Quality of Tomato Fruits*.

Gupta, V. K., Luthra, S. K., & Singh, B. P. (2015). Storage behaviour and cooking quality of Indian potato varieties. *Journal of Food Science and Technology*, *52*(8), 4863–4873.

Hamed, M., Kalita, D., Bartolo, M. E., & Jayanty, S. S. (2019). Capsaicinoids, Polyphenols and Antioxidant Activities of Capsicum annuum: Comparative Study of the Effect of Ripening Stage and Cooking Methods. *Antioxidants*, *8*(9), 364. https://doi.org/10.3390/antiox8090364.

Hardenburg RE, Watada AE, Wang CY. (1986). The commercial storage of fruits, vegetables, and florist and nursery stocks (No. 66). USS Department of Agriculture, Agricultural Research Service.

Heltoft, P., Wold, A.-B., & Molteberg, E. L. (2016). Effect of ventilation strategy on storage quality indicators of processing potatoes with different maturity levels at harvest. *Postharvest Biology and Technology*, *117*, 21–29. https://doi.org/10.1016/j.postharvbio.2016.02.002

Jayas, D. S., Irvine, D. A., Mazza, G., & Jeyamkondan, S. (2001). Evaluation of a computer-controlled ventilation system for a potato storage facility. *Canadian Biosystems Engineering*, *43*, 5–5.

Kasso, M., & Bekele, A. (2018). Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia. *Journal of the Saudi Society of Agricultural Sciences*, *17*(1), 88–96.

King, B. C., Donnelly, M. K., Bergstrom, G. C., Walker, L. P., & Gibson, D. M. (2009). An optimized microplate assay system for quantitative evaluation of plant cell wall–degrading enzyme activity of fungal culture extracts. *Biotechnology and Bioengineering*, *102*(4), 1033–1044.

Koski, S. (n.d.). Potato Fan VFDs Phase 2 Report, Oct. 2003, prepared for Northwest Energy Efficiency Alliance. *Portland, OR*.

Levy, D. (1986). Tuber yield and tuber quality of several potato cultivars as affected by seasonal high temperature and by water deficit in a semi-arid environment. P*otato Research* 29: 95–107.

Lutman, B. F. (1934). Carbon dioxide formation by clean and scabby potatoes. *Journal of Agricultural Research*, *48*(12), 1135–1144.

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. *International Journal of Food Science & Technology*, *43*(6), 951–957.

Mehta A and Singh B. (2016). On-farm storage of table and processing potatoes in heaps. *Indian Journal of Horticulture*, 73(1), 82-86.

Olsen N, Kleinkopf G. (2020). *Storage Management. In Potato Production Systems (pp. 523-545). Springer, Cham.*

Pariasca, J. A. T., Miyazaki, T., Hisaka, H., Nakagawa, H., & Sato, T. (2001). *Effect of modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage on the quality of snow pea pods (Pisum sati6um L. var. Saccharatum)*. 11.

Perla, V., Holm, D. G., & Jayanty, S. S. (2012). Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. *LWT-Food Science and Technology*, *45*(2), 161–171.

Sanford S.A. (2006). Benefits of adjustable speed fans for bulk potato storage ventilation Systems Wisconsin's Annual Potato Meeting, Stevens Point, WI - February 14-16,

Taşdelen, Ö., & Bayindirli, L. (1998). Controlled Atmosphere Storage and Edible Coating Effects on Storage Life and Quality of Tomatoes. *Journal of Food Processing and Preservation*, *22*(4), 303–320. https://doi.org/10.1111/j.1745-4549.1998.tb00352.x

Voss, R. E., Baghott, K. G., & Timm, H. (2001). Proper environment for potato storage. *Vegetable Research and Information Center. The University of California*.

Watada, A. (1986). Effects of ethylene on the quality of fruits and vegetables. *Food Technology*, 4.

Zheng, Y., Yang, Z., & Chen, X. (2008). Effect of high oxygen atmospheres on fruit decay and quality in Chinese bayberries, strawberries and blueberries. *Food Control*, *19*(5), 470–474. https://doi.org/10.1016/j.foodcont.2007.05.011

4 Chapter 4. The Effect of Field Heat Reduction Methods on Fresh and Processing Qualities in a Red and Russet Potato cultivar

4.1 Introduction

Potato (*Solanum tuberosum L.)* is the world's fourth-largest food crop and has considerable impacts on food security and economic growth (Zheng et al., 2020). Long-term storage is necessary to ensure year-round supply for the fresh market and processing industry (Wang et al., 2020). The outermost layer of potato tuber is the periderm is susceptible to mechanical damage during the harvest and handling provides a pathway for pathogens, which causes tubers infected with many diseases such as pink rot, Pythium leak, late blight, soft rot, silver scurf, black dot, and early blight (Lulai, 2007, Barel & Ginzberg, 2008, and Wang et al., 2020). Potato tubers have the ability to heal wounds by forming the wound periderm to prevent water loss and pathogen attack (Bernards, 2002). A crucial step in potato storage management is wound healing, which happens in the first two to three weeks after harvest. The formation of wound periderm is enhanced under a warm and humid environment which depends on various factors, cultivar, crop management, and tuber maturity (Artschwager, 1927)..

Phenylpropanoid metabolism plays a significant role in the healing process of tubers, which provide suberin and lignin compounds involved in wound periderm formation (Dastmalchi et al., 2014; Morris et al., 1989). The formation of wound periderm begins with cell division and suberin deposition in response to injuries (Dastmalchi et al., 2014). The primary suberization and wound periderm formation is preferable at high relative humidity (RH) 95%–98%, in the presence of oxygen, and at temperature 10.0 °C to 15.6 °C. Warmer temperature enhances the suberization while the cold temperatures slow it down (Morris et al., 1989). Consequently, the wound healing period at relatively high temperatures should be only long enough to allow faster healing, but not too long to affect quality characteristics such as disease growth, weight loss, and

shelf-life for fresh market cultivars and frying quality (Daniels-Lake et al., 2014, Ellis et al., 2019).

The potato processing industry requires tubers with characteristics of acceptable consumer preference qualities. A 50 % of the potatoes produced in the United States in 1981 was utilized as a processed product, and about 45% was frozen French-fried products (reference). Significant tuber quality considerations are sugar levels, dry matter amount, cultivar, maturity stage, storage condition, and exposure to the reconditioning process. The high content of reducing sugars in the tuber induces the Maillard reaction (between reducing sugars and amino acids) responsible for undesirable darkening in potato fry products.

On the other hand, the low level of reducing sugars is preferred as they result in the desired lighter color of potato fry product. Potato tuber reducing sugar levels are influenced by several factors, e.g., genotype, growing conditions, agronomic practices and storage conditions (Agblor & Scanlon, 2002). The tuber's physiological maturity is significant, and immature tubers have higher sugar content than mature tubers. During cold sweetening of potatoes stored at low storage temperatures, starch degradation occurs primarily through starch phosphorylase reaction, and eventually through various enzymatic reactions resulting in the accumulation of reducing sugars (Abong et al., 2009). Tubers usually warmed for around two weeks, minimizing the reducing sugars before frying to reduce darkening (Li et al., 2007). Kim and Lee (1992) mentioned that potato reconditioning improved chip color via reducing the non-enzyme browning during frying at high temperatures. Tubers are usually held at around 21°C for three weeks before they are fried or blanched to leach soluble substances to lower the reducing sugars before the frying (Toma et al., 1986).

This present study aims to investigate the effect of methods of reducing the postharvest field heat on the quality of Russet Norkotah 3 and CO 07102-1R potato tubers during storage and French fries made after the reconditioning process.

4.2 Materials and methods

4.2.1 Sampling

This study was conducted in the 2018-2019 growing season. The cultivars that have been used were Russet Norkotah 3 and Red CO 07102-1R. All the samples were obtained at the harvest time, mid of October, from the San Luis Valley Research Center in Colorado. Tubers were harvested mechanically, and disease-free tubers were selected for this study. The tubers were divided into several groups to keep with the number of treatments where there were 200 tubers in each treatment.

4.2.2 Chemicals

Folin Ciocaltteu Reagent (FCR), sodium carbonate, gallic acid, dinitro salicylic acid, crystalline phenol, sodium hydroxide, sodium sulfite, potassium sodium tartrate tetrahydrate, glucose, and metaphosphoric acid were purchased from Sigma Aldrich Corporation (St. Louis, USA). All other obtained chemicals were of analytical grade.

4.2.3 Experimental design

The tubers were kept in mesh bags, divided into three sets, and placed in three separate storage units. Each storage unit temperature was managed differently but maintained 95% RH in each unit. In the first and second storage units, the temperature was set at two degrees below the harvest's pulp temperature. In the first storage unit with the TLG method, the temperature was

brought down one degree every two days until 3 °C was reached and maintained at 3 °C for one month. In the second storage unit with the TLS method, the temperature was initially reduced by one degree every two days until 12 °C was reached and maintained at 12 °C for two weeks. After that, the temperature was reduced by one degree every two days until 3 °C was reached and maintained for one month. The third set of tubers followed the TLI method, where tubers after harvest were kept at 3 °C in the storage unit 3 for one month. Before the French fries were made, the tubers were maintained at 20 °C for two weeks for all treatments.

4.2.4 Determining the weight loss

Weight loss in tubers in each treatment during storage was measured by monitoring the tubers' weight change at the end of each stage. Weight loss was expressed as the percentage of weight loss to the initial weight.

4.2.5 Firmness determination

The texture was determined by using the method developed by Crossen (2017) with some modifications. The texture was measured using the Brookfield CT3 texture analyzer. The analyzer was fitted with a spherical probe, and the force required (g) to pierce 3 mm on the surface of the tubers. About 30 measurements were taken from 15 tubers (two readings from each tuber stem and bud end) for each treatment to calculate the mean.

4.2.6 Wound healing

The wound healing process was evaluated visually. Tubers with mechanical damage on the skin due to the harvest process were selected. When assessing wound healing, we rated tubers based on the color of the healed skin; minimal healing (MH), average healing (AH), and perfect healing (PH).

4.2.7 French Fries

The French fries were made according to the method described by Garmakhany et al. (2014). The Fresh fries were made at zero time and when the tubers reached 3 °C without the reconditioning process. Also, after storing the tubers at 3 °C for one month, the tubers were subjected to the reconditioning process where potatoes were removed from cold storage and kept at 20 °C for two weeks in order to decrease the amount of reducing sugars that have been increased during cold storage. Before frying, tubers were peeled with an abrasive peeler. They were converted to pieces of $6\times1\times1 cm^3$ by means of a domestic striper. Then, blanching was performed in hot water (93 °C) for 4 min then the products were washed immediately with cold water. After that, the samples were fried in a controlled temperature deep fryer Teafall (TEFlon and Aluminium, French) filled with 2.5 L of corn oil which purchased from a local market. Frying conditions were 2.5 min at 350 °C. The color standards for French-fried potatoes (USDA, 1988) were used to determine the color grade of French fries.

4.2.8 The extraction procedure for estimating the total of phenolics and reducing sugars

Phenolic compounds and reducing sugars were extracted using the method described by (Perla et al., 2012) with some modifications. Potato tubers were collected from each treatment at zero and after each stage. Then, all materials were cut into small pieces and frozen, then freeze-dried, and kept at -80 °C for further analysis. A g freeze-dried material was weighted in a 10ml falcon tube, and aqueous 5 ml 95% methanol was added. The mixtures were vortexed for 1 min, then the tubes were incubated overnight in an orbital shaker at 150 rpm at 25 °C. Then, the homogenates were centrifuged at 5000 rpm for 25 min, followed by filtration using Whatman (40 nm). The remaining in the tubes were re-extracted under the same condition. The final volume was made to 10 ml with methanol and kept at -80 °C for further analysis.

4.2.8.1 Determining the total of the total phenolics

Total phenolics content in potatoes was estimated based on the method developed by Perla et al. (2012). After placing 50 µL of distilled water in a 96-well flat-bottom assay plate (Costar 3370, Corning, NY), 20 µL of extracts were added. After that, 75 µL of commercial FCR solution (Folin & Ciocalteu's phenol reagent) (MP Biomedical Solon, OH) was added and mixed for 1 min in a plate reader (Power Wave XS2, BioTek Instruments, Winooski, VT). Eighty µL of 75 g L^{-1} sodium carbonate solution was added and directly mixed with a pipette. The microplate was shaken in a plate reader for 5 min. The absorbance of the contents was measured at 760 nm. For the standard, gallic acid in methanol was used, and the total phenolic values were quantified as µg of gallic acid equivalent per gram of dry weight of potato samples using a 7-point calibration curve with an R^2 value of 0.979.

4.2.8.2 Determination of reducing sugars

Reducing sugars were determined by a previously described 96-well microplate assay described by King et al. (2009) with some modifications. The dinitrosalicylic acid reagent was prepared first (10 g L^{-1} dinitrosalicylic acid, 2 g L^{-1} crystalline phenol, 10 g L^{-1} sodium hydroxide, and 0.5 g L^{-1} fresh sodium sulfite). A 120 µL of the dinitrosalicylic acid reagent was added to each PCR tube (BioExpress, Kaysville, UT), and 20 µL of the extraction was added and mixed well. The mixture was heated in a water bath at 99 °C for 15 min and then cooling at 4 °C for 1 min and holding at 20 °C to prevent a further reaction. After mixing the contents of each tube, 100 µL of the mixture was transferred to a 96-well flat-bottom microplate containing 40 µL of 400 g L^{-1} potassium sodium tartrate tetrahydrate solution. The plates were well mixed for 2 min in the plate reader, and the absorbance was measured with the plate reader at 570 nm.

Glucose standard was prepared in 800 ml L^{-1} methanol, and reducing sugars were expressed as mg glucose per g of dry matter.

4.2.9 Statistical analysis

The total phenolics, total flavonoids, reducing sugars, and vitamin C were measured in triplicate. The weight loss was measured in seven replications. Texture change was conducted in thirty replications. All results were inserted as mean ± standard deviation (SD) values. The data were subjected to analysis of variance (ANOVA), and Tukey's test was performed to examine if differences between treatments were significant at $P < 0.05$. All statistical analyses were performed with the R software version 3.4.3 for windows.

4.3 Results

4.3.1 Weight loss

The weight loss of CO 07102-1R and Russet Norkotah 3 during the wound healing period and after six months of storage at 3 °C and 90 % RH is shown in Figures 1 and 2. In the period of wound healing, there was no significant difference in the weight loss in the case of the Russet Norkotah 3 in all methods of field heat reduction. The lowest significant weight loss was in the TLG reduction method, and the highest significant weight loss was in the TLI reduction method. After six months of cold storage, the lowest significant weight loss was in the TLS reduction method. There was no significant difference in weight loss between TLG and TLI reduction methods in the case of Russet Norkotah 3. In the case of CO 07102-1R potatoes, there were significant differences between all methods where the lowest significant weight loss was in the TLS method, and the highest loss was in the TLI method.

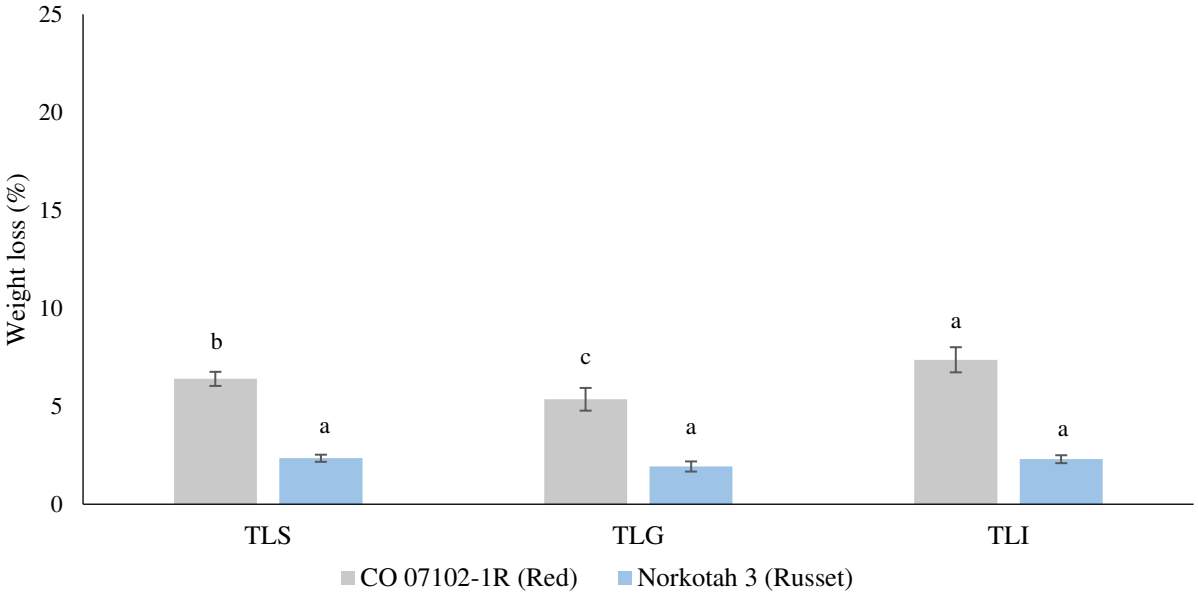


Figure 4.1. The effect of field heat reduction on the weight loss (%) of potato tubers after reaching 3°C. Data expressed as mean ± S.D., n = 7. The different letters are significantly different ($P < 0.05$).

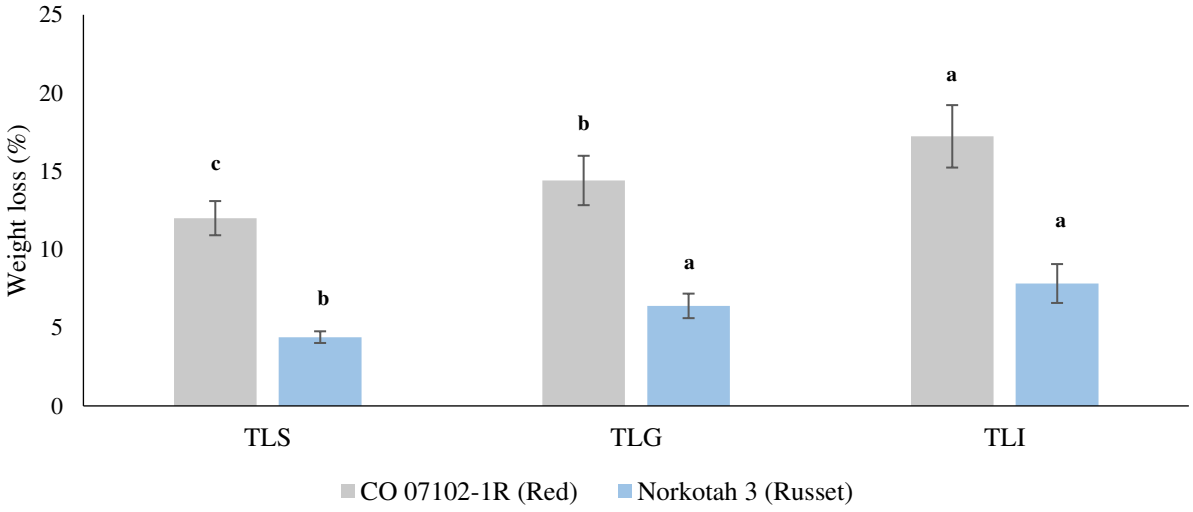


Figure 4.2. Effect of field heat reduction method on weight loss (%) of potato tubers after six months of storage at 3 °C. Data expressed as mean ± S.D., n = 7. The different letters are significantly different ($P < 0.05$).

4.3.2 Texture change

The change in the texture of CO 07102-1R and Russet Norkotah 3 at zero time and during the wound healing period and after six months of storage at 3 °C and 90 % R.H are shown in figure 3 and 4. Texture loss during the wound healing period was significant less in the case of the TLS method in both CO 07102-1R and Russet Norkotah 3 and the loss was lowest in the TLG and TLI reduction method, and there was no significant difference between the TLG and TLI methods. On the other hand, after six months of storage, the highest texture loss was noted in the TLI method followed by the TLG method. Texture loss in Russet Norkotah 3 was significantly less the TLS method after six months. The texture loss was low in the TLS method with CO 07102-1R and Russet Norkotah 3.

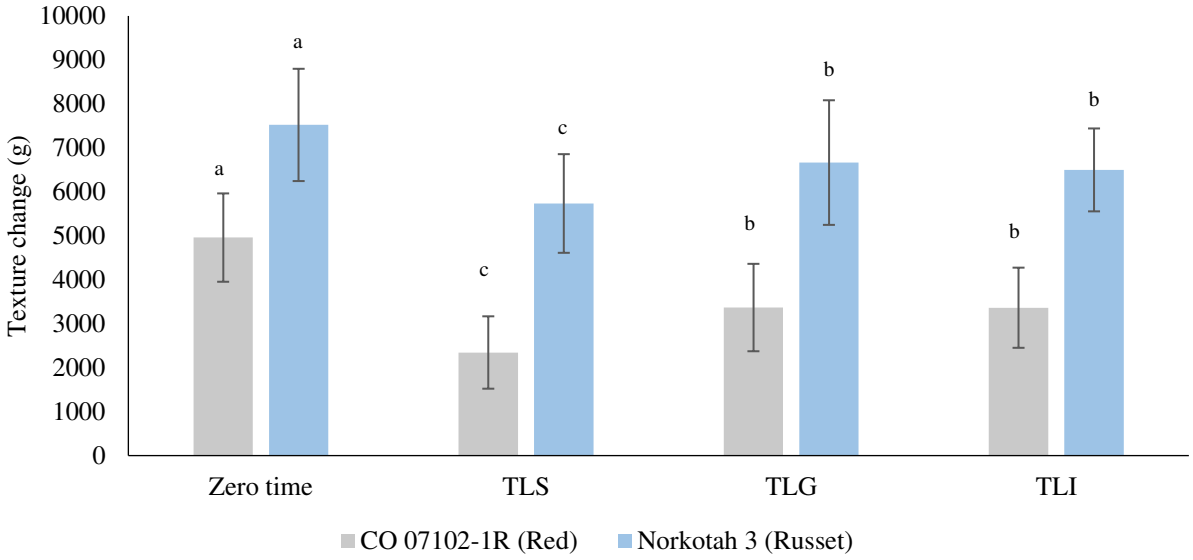


Figure 4.3. The effect of field heat reduction method on texture change (g) of potato tubers after 3 °C was reached Data expressed as mean ± S.D., n = 40. The different letters are significantly different ($P < 0.05$).

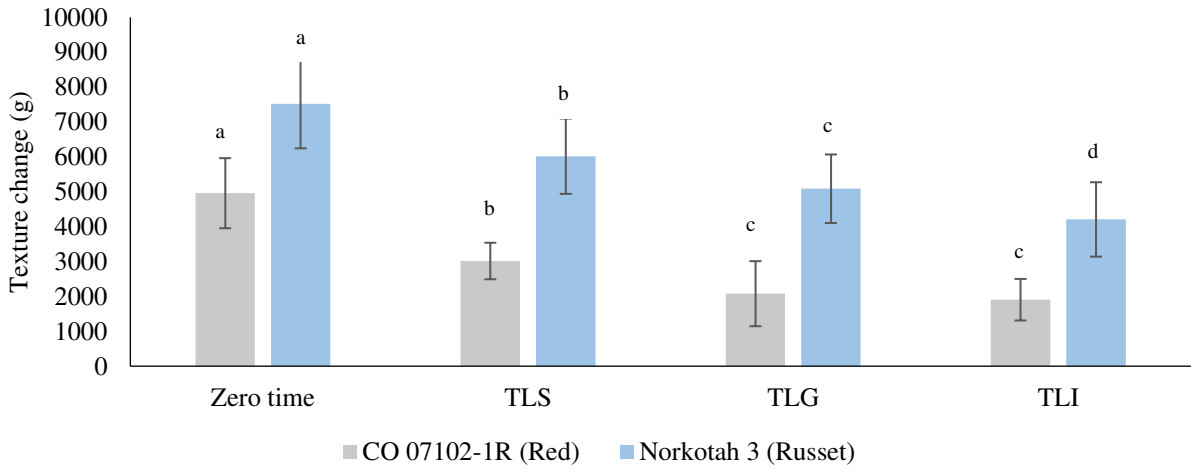


Figure 4.4. Effect of field heat reduction method on texture change (g) of potato tubers after six months of storage at 3 °C. Data expressed as mean ± S.D., n = 40. The different letters are significantly different ($P < 0.05$).

4.3.3 Wound healing

Table .1 shows the visual evaluation of the process of wound healing in CO 07102-1R and Russet Norkotah 3 during the wound healing period. The TLS reduction method was shown to perform relatively better in wound skin healing than the TLG reduction method where the TLI reduction method, there was no healing. The best among the wound healing methods was the TLS method with Russet Norkotah 3, and the worst among wound healing methods in both CO 07102-1R and Russet Norkotah 3 was the TLI reduction field heat method.

Table 4.1. The effect of the field heat reduction method on wound healing of potato tubers after 3 °C was reteached. MH: minimal healing; AV: average healing; and PH: perfect healing.

	CO 07102-1R	Russet Norkotah 3
TLS when 3 °C was reached	AH	PH
TLG when 3 °C was reached	AH	AH
TLI when 3 °C was reached	MH	MH

4.3.4 French fries

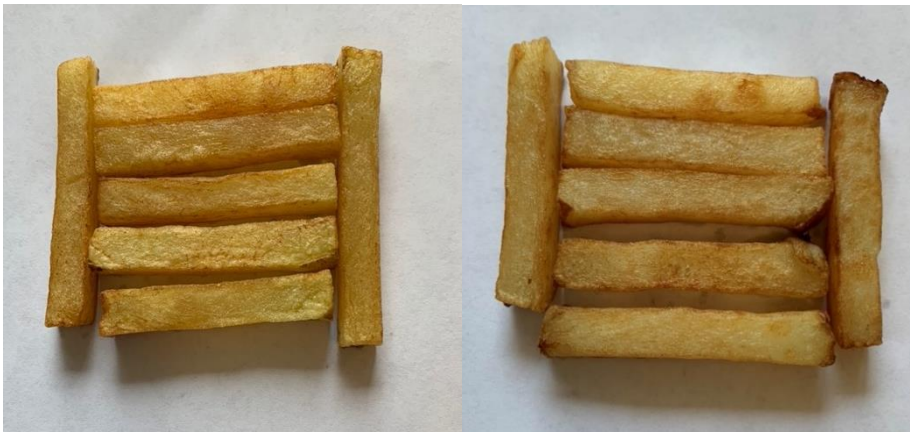
Table 2 and figure 5,6,7 and 8 show the visual evaluation of the color of French fries made from the CO 07102-1R and Russet Norkotah 3 at zero time and after the wound healing period and two weeks of reconditioning at 20 °C. The color of French fries at zero time was at grade 1 in both CO 07102-1R and Russet Norkotah 3. The lowest grade (4) was in the case of the TLI method. The TLS and TLG methods were given the French fries color grade 2 with both CO 07102-1R and Russet Norkotah 3. All the samples were subjected to the reconditioning process for two weeks at 20 °C before the French fries were made.

Table 4.2. The effect of field heat reduction method on the color of French fries made from potato tubers after one month of storage at 3 °C and two weeks of reconditioning at 20 °C.

Time	CO 07102-1R	Russet Norkotah 3
Zero Time	Grade 0	Grade 0
TLS at 3 °C and after two weeks of reconditioning at 20 °C	Grade 2	Grade 2
TLG at 3 °C and after two weeks of reconditioning at 20 °C	Grade 2	Grade 2
TLI at 3 °C and after two weeks reconditioning at 20 °C	Grade 4	Grade 4

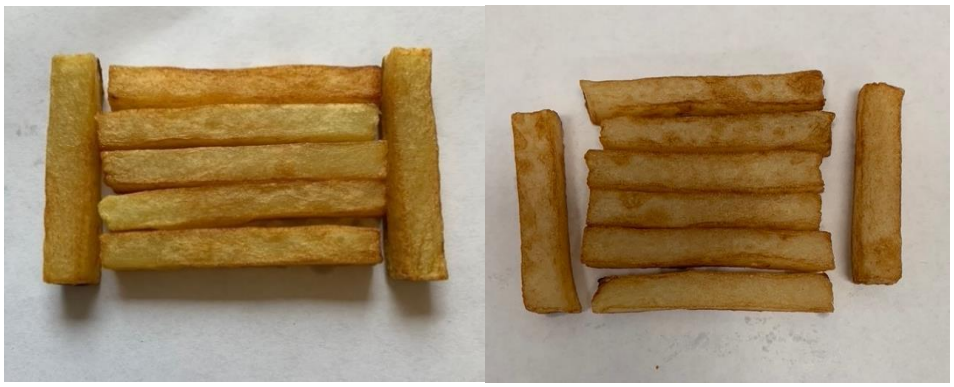
Russet Norkotah 3 CO 07102-1R

Figure 4.5. The color of French Fries made from Russet Norkotah 3 and CO 07102-1R potato tubers at zero time.



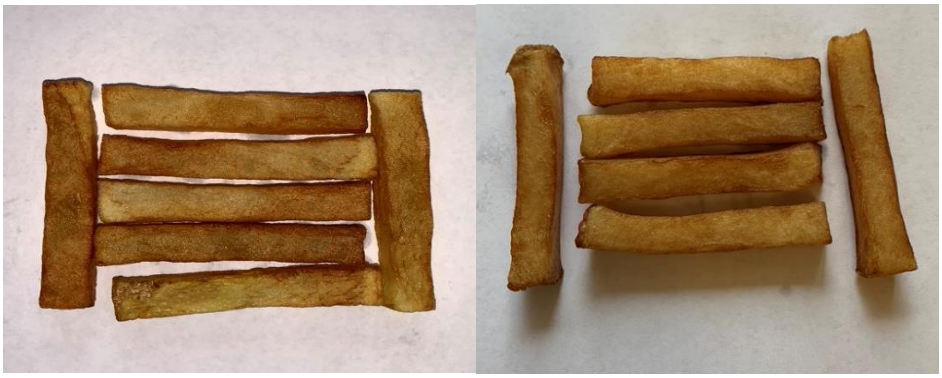
Russet Norkotah 3 CO 07102-1R

Figure 4.6. The effect of field heat reduction (TLS method) on the color of French fries made from potato tubers after one month of storage at 3 °C and two weeks of reconditioning at 20 °C.



Russet Norkotah 3 CO 07102-1R

Figure 4.7. The effect of field heat reduction (TLG method) on color of French fries made from potato tubers after one month of storage at 3 °C and two weeks of reconditioning at 20 °C.



Russet Norkotah 3 CO 07102-1R

Figure 4.8. The effect of field heat reduction (TLI method) on color of French fries made from potato tubers after one month of storage at 3 °C and two weeks of reconditioning at 20 °C.

4.3.5 Bioactive compounds

The total phenolics content of CO 07102-1R and Russet Norkotah 3 at zero time and after the wound healing period and after six months of storage at 3 °C and 90 % RH are shown in figure 9 and 10. There was a significant difference in the effect of field heat reduction methods in the total phenolics content during the wound healing period. The total phenolic compounds concentration was increased at the end of the wound healing process. Total phenolic compounds were significantly high in TLG and TLI methods compared with the TLS method. There was no significant difference between the TLG and TLI field heat reduction method.

The reducing sugars content of CO 07102-1R and Russet Norkotah 3 at zero time and after the wound healing period and after six months of storage at 3 °C and 90 % RH is shown in figure 11 and 12 . The content of reducing sugars was significantly high in all field heat reduction methods at the end of the wound healing process compared with the content at zero time. However, there was no significant difference between the TLS and TLG field heat reduction method in CO 07102-1R variety while there was a significant difference with Russet

Norkotah 3. The highest significant amount of reducing sugars was in the TLI method, especially with Russet Norkotah 3.

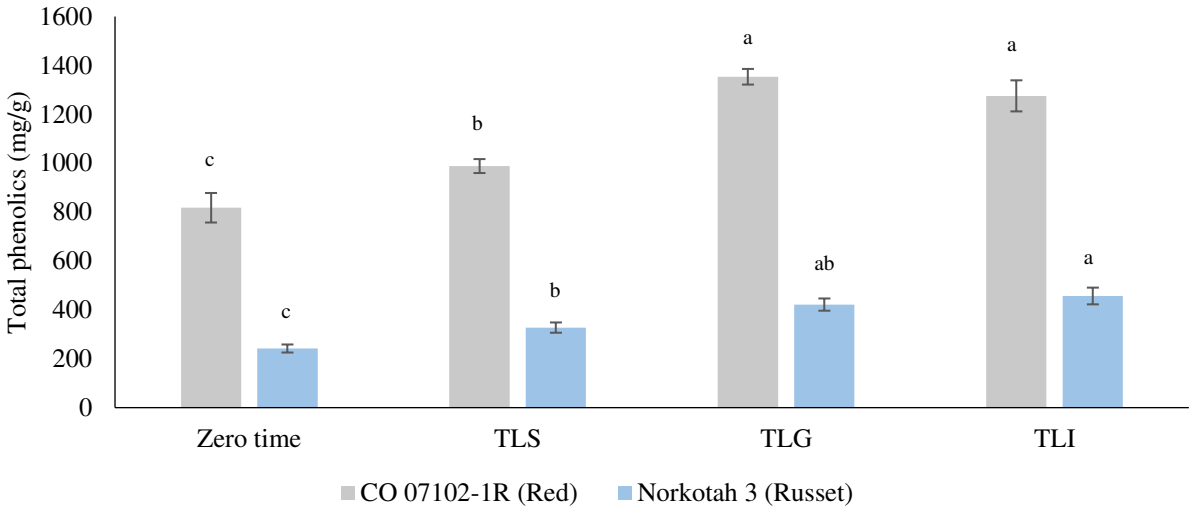


Figure 4.9. The effect of the field heat reduction method on total phenolics (mg/g) in potato tubers after 3 °C was reached. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

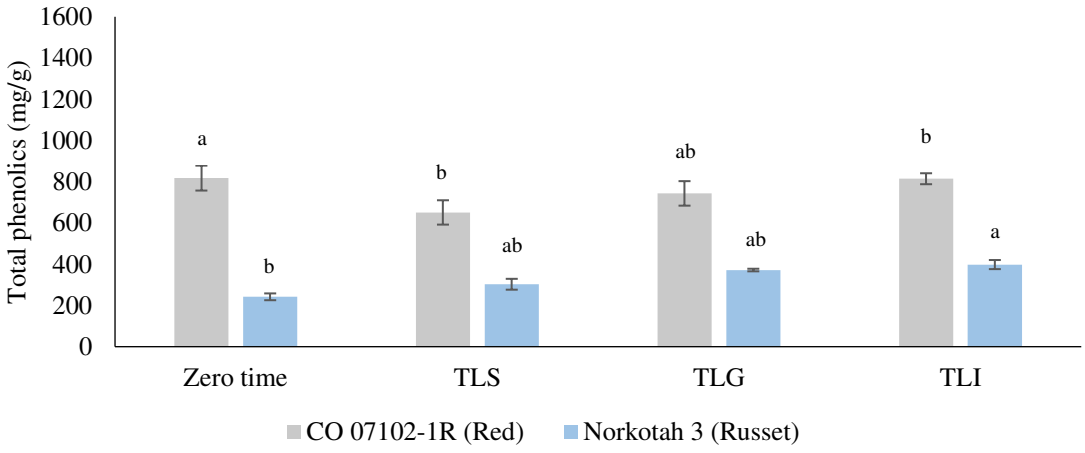


Figure 4.10. The effect of the field heat reduction method on total phenolics (mg/g) of potato tubers after six months of storage at 3 °C. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

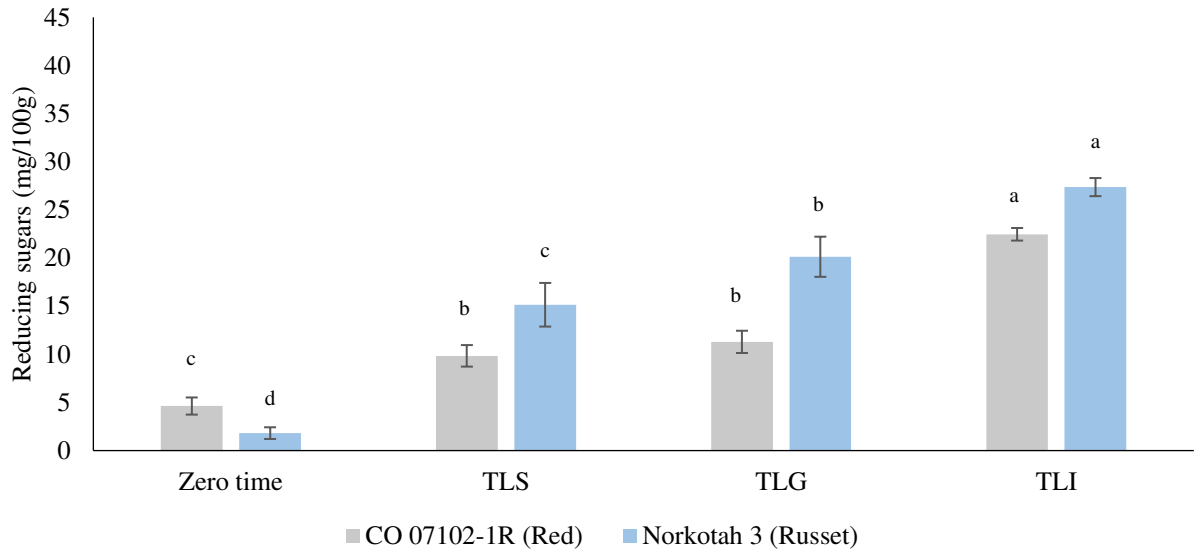


Figure 4.11. The effect of the field heat reduction method on reducing sugars (mg/100 g) of potato tubers after 3 °C was reteaches. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

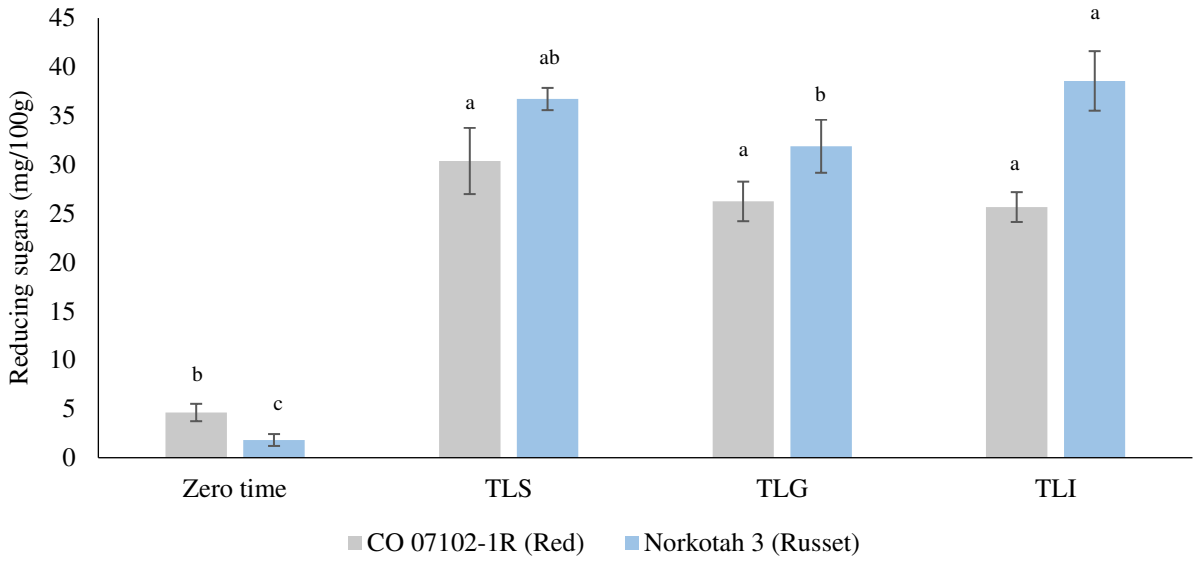


Figure 4.12. The effect of the field heat reduction method on reducing sugars (mg/100 g) of potato tubers after six months of storage at 3 °C. Data expressed as mean ± S.D., n = 3. The different letters are significantly different (P < 0.05).

4.4 Discussion

Tuber harvest damage and storage issues can cause significant losses to potato growers (Dastmalchi et al., 2016). Moreover, incomplete wound healing can affect the long-term

storability of potato tuber, and it is essential to maintain the end product's quality (Knowles et al., 1982). The weight loss is mainly due to the difference in vapor pressure between the tubers and the surrounding atmosphere. However, the most critical factors that determine the quality of potatoes in long-term storage are wound healing, respiration rate, and storage management (Voss et al., 2001).

In response to injuries, the potato tubers produce an impregnated periderm layers with suberin and lignin to the closure of wounded areas resisting dehydration and preventing microbial infection. The differences in weight loss between the TLS and TLG methods can be due to holding tubers at high temperature in the TLS method for a longer time than in the TLG method during the period of wound healing. The difference between cultivars may be due to genetic and agronomic practices. On the contrary, the weight loss at the end of storage time was less in the TLS method. The ability of tubers to wound healing significantly decline with tuber age (Kumar & Knowles 2003; Kumar et al., 2010). The periderm of the tuber is relatively immature at the harvest time, as a result, the water loss from tubers is more rapid than after maturation of periderm when soluble waxes are deposited in the periderm (suberization), reducing considerably the rate of water loss (Schreiber et al., 2005). Wang et al., (2020) mentioned that higher temperatures are effective in the healing process, as the tuber metabolic process are more active. After harvest, some red cultivars kept for healing at 29–32 °C and 90–95 % RH for a longer time. However, such warm temperatures are conducive for pathogen spread and increased water loss. Such conditions in storage also promote other physiological disorders such as pressure bruises and blackspot bruises.

In our study, we found that there are differences in the ability to wound heal between the cultivars. While the Russet Norkotah 3 can heal faster, while the CO 07102-1R tubers were

deficient to heal. The effect of that was evident at the end of storage time when the weight loss of Russet Norkotah 3 was significantly lower than CO 07102-1R potato. Also, the TLS method was more effective than the TLG method in terms of wound healing, where the weight loss was significantly less in the case of the TLS method for both cultivars after six months of storage. This is in agreement with Lulai (2007) and Herman et al., (2017) where they were reported that the ability of various potato cultivars to heal wounds depends upon the levels of tuber metabolism. The carbohydrate metabolism is necessary to provide carbon skeletons for lignin biosynthesis in wounded tubers (Zheng et al., 2020).

Degradation of the intracellular structure and cell wall composition, horticultural products lose texture. This softening phenomenon is a biochemical process involving enzyme hydrolysis of starch and other cell wall polysaccharides (Ali et al., 2010). The loss of texture is often connected to the loss of water, which is related to the substantial movement of water molecules from a tuber cell structure. The free and linked water molecules work together to hold the tubers firm (Taşdelen & Bayindirli, 1998). The textural changes noted in this study are consistent with the hypothesis that textural loss is correlated with weight loss in the potato tubers (Castleberry and Jayanty 2017).

In a study conducted by Wang et al. (2020) on Russet Burbank, wound healing at a higher temperature led to lower stem-end glucose and, therefore, to a lighter fry color than wound-healing treatment a cooler temperature. This is consistent with our study where the color of French fries was at grade 1 at harvest time when the tubers in the mature stage and reducing sugars were at the lowest level. Also, the color of fries made from tubers of the TLS and TLG method were lighter than the fries made from tubers of the TLI method. Processors score fry

color according to USDA requirements. Groups range from USDA 0 (lightest fries) to USDA 4 (darker fries) (USDA,1988).

This study shows that reducing sugars was significantly low at the harvest time compared to the end of storage time, where the level was quite high due to the effect of the LTS (Edwards et al. 2002; Driskill et al. 2007; Pinhero et al., 2011). Also, our study shows that the content of total phenolics was significantly increased at the end of storage time compared to zero time. This is maybe due to the tuber's response to the wound healing, as Wang et al., (2020) was reported in the case of sweet potato. They noticed that the concentration of total phenolics and total flavonoids significantly increased in the wound sites of sweet potato. The total phenolics and total flavonoids considered as anti-pathogen and oxidation-resistant substances, which the plant use them as a defense mechanism to maintain the postharvest quality and shelf life in potato. The total phenolics and reducing sugar content in the TLG and TLI treatments were higher than in the TLS treatment at the end of the wound healing period. This may be because of the field heat reduction was more rapid, consequently, the potato tubers response to the low-temperature stress was faster than in the case of the tubers in TLS treatment. The effect of LTS and reducing sugar accumulation took less time, as a result, the total phenolic content increased because sugars are a phenolic precursor.

Conclusion

This study shows that the TLS temperature reducing method was more effective in terms of reducing weight loss, texture maintenance, wound healing, and fry color compared with TLG and TLI methods. Weight loss was less significant when tubers reached 3 °C with TLG method, however, the weight loss increased significantly after six months of cold storage with the TLG method. In terms of fry color after the tubers exposed to the reconditioning process, there was no

difference between the TLG and TLS method, unlike the TLI method, the fry color was dark (grade 4). The content of total phenolics and reducing sugars significantly increased at 3 °C and after six months of storage respectively, especially in TLI.

The TLS method gives the tubers more time to heal the wounds and generates the components responsible for wound healing, such as suberin. Therefore, we suggest that the TLS is more suitable in thin skin tubers such as red and purple cultivars. TLS more efficient in the case of tubers are exposed to more damage during the harvest process, and the storage time will be short. While that the TLG is more suitable with thick skin potato cultivars such as russet and in the case of long-term storage provided that the tubers have more minor skin damage.

4.5 Reference

Abong', G. O., Okoth, M. W., Karuri, E. G., Kabira, J. N., & Mathooko, F. M. (2009). Levels of reducing sugars in eight Kenyan potato cultivars as influenced by stage of maturity and storage conditions. *Vol.*, *2*(2), 9.

Agblor, A., & Scanlon, M. G. (2002). Effect of storage period, cultivar and two growing locations on the processing quality of french fried potatoes. American Journal of Potato Research, 79(3), 167–172. https://doi.org/10.1007/BF02871932

Ali, A., Maqbool, M., Ramachandran, S., & Alderson, P. G. (2010). Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (Solanum lycopersicum L.) fruit. Postharvest Biology and Technology, 58(1), 42–47. https://doi.org/10.1016/j.postharvbio.2010.05.005

Artschwager, E. (1927). Wound periderm formation in the potato as affected by temperature and humidity. Journal of Agricultural Research, 35(11), 995-1000.

Barel, G., & Ginzberg, I. (2008). Potato skin proteome is enriched with plant defence components. Journal of Experimental Botany, 59(12), 3347–3357. https://doi.org/10.1093/jxb/ern184

Bernards, M. A. (2002). Demystifying suberin. Canadian Journal of Botany, 80(3), 227–240. https://doi.org/10.1139/b02-017

Butchbaker, A. F., Promersberger, W. J., & Nelson, D. C. (1973). Weight loss of potatoes as affected by age, temperature, relative humidity and air velocity. American Potato Journal, 50(4), 124–132.

Castleberry, H. C., & Jayanty, S. S. (2017). Susceptibility to pressure flattening correlates with texture analysis of potato tubers. American Journal of Potato Research, 94(5), 556-566.

Crossen, E. (2017). Textural, Color and Sensory Attributes of Fruits and Vegetables Dried Using Electric Forced-Air and Solar Dehydrators. Theses and Dissertations. https://scholarsarchive.byu.edu/etd/6675

Daniels-Lake, B., Prange, R., Walsh, J., Hiltz, K., Bishop, S., & Munro-Pennell, K. (2014). Effects of simulated harvest injury and relative humidity during the first week postharvest on potato (Solanum tuberosum L.) tuber weight loss during subsequent storage. The Journal of Horticultural Science and Biotechnology, 89(2), 167–172. https://doi.org/10.1080/14620316.2014.11513064

Daraei Garmakhany, A., Mirzaei, H. O., Maghsudlo, Y., Kashaninejad, M., & Jafari, S. M. (2014). Production of low fat french-fries with single and multi-layer hydrocolloid coatings. Journal of Food Science and Technology, 51(7), 1334–1341. https://doi.org/10.1007/s13197-012-0660-9

Dastmalchi, K., Cai, Q., Zhou, K., Huang, W., Serra, O., & Stark, R. E. (2014). Solving the Jigsaw Puzzle of Wound-Healing Potato Cultivars: Metabolite Profiling and Antioxidant Activity of Polar Extracts. Journal of Agricultural and Food Chemistry, 62(31), 7963–7975. https://doi.org/10.1021/jf501330h

Driskill, E. P., Knowles, L. O., & Knowles, N. R. (2007). Temperature-induced changes in potato processing quality during storage are modulated by tuber maturity. American Journal of Potato Research, 84(5), 367–383. https://doi.org/10.1007/BF02987183

Edwards, C. G., Englar, J. W., Brown, C. R., Peterson, J. C., & Sorensen, E. J. (2002). Changes in color and sugar content of yellow-fleshed potatoes stored at three different temperatures. American Journal of Potato Research, 79(1), 49–53. https://doi.org/10.1007/BF02883523

Ellis, G. D., Knowles, L. O., & Knowles, N. R. (2019). Respiratory and low-temperature sweetening responses of fresh-cut potato (Solanum tuberosum L.) tubers to low oxygen. Postharvest Biology and Technology, 156, 110937. https://doi.org/10.1016/j.postharvbio.2019.110937

Herman, D. J., Knowles, L. O., & Knowles, N. R. (2017). Heat stress affects carbohydrate metabolism during cold-induced sweetening of potato (Solanum tuberosum L.). Planta, 245(3), 563–582. https://doi.org/10.1007/s00425-016-2626-z

Kim, H. O., & Lee, S. K. (1992). Effects of curing and storage conditions on processing quality in potatoes. Physiological Basis of Postharvest Technologies 343, 73–76.

King, B. C., Donnelly, M. K., Bergstrom, G. C., Walker, L. P., & Gibson, D. M. (2009). An optimized microplate assay system for quantitative evaluation of plant cell wall–

degrading enzyme activity of fungal culture extracts. Biotechnology and Bioengineering, 102(4), 1033–1044.

Knowles, N. R., Iritani, W. M., Weiler, L. D., & Gross, D. C. (1982). Susceptibility of potatoes to bacterial rot and weight loss as a function of wound-healing interval and temperature. American Potato Journal, 59(11), 515–522. https://doi.org/10.1007/BF02852600

Kumar, G. M., & Knowles, N. R. (2003). Wound-induced superoxide production and PAL activity decline with potato tuber age and wound healing ability. Physiologia Plantarum, 117(1), 108–117.

Kumar, G. N. M., Lulai, E. C., Suttle, J. C., & Knowles, N. R. (2010). Age-induced loss of wound-healing ability in potato tubers is partly regulated by ABA. Planta, 232(6), 1433–1445. https://doi.org/10.1007/s00425-010-1269-8

Li, X.-Q., Griffiths, R., Lagüe, M., DeKoeyer, D., Rothwell, C., Haroon, M., Stevens, B., Xu, C., Gustafson, V., Bonierbale, M., Regan, S., & Flinn, B. (2007). EST sequencing and analysis from cold-stored and reconditioned potato tubers. Acta Horticulturae, 745, 491–495. https://doi.org/10.17660/ActaHortic.2007.745.35

Lulai, E. C. (2007). Chapter 22—Skin-Set, Wound Healing, and Related Defects. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. Mackerron, M. A. Taylor, & H. A. Ross (Eds.), Potato Biology and Biotechnology (pp. 471–500). Elsevier Science B.V. https://doi.org/10.1016/B978-044451018-1/50064-6

Lulai, E. C., & Orr, P. H. (1994). Techniques for detecting and measuring developmental and maturational changes in tuber native periderm. American Potato Journal, 71(8), 489–505.

Lutman, B. F. (1934). Carbon dioxide formation by clean and scabby potatoes. Journal of Agricultural Research, 48(12), 1135–1144.

Morris, S. C., Forbes-Smith, M. R., & Scriven, F. M. (1989). Determination of optimum conditions for suberization, wound periderm formation, cellular desiccation and pathogen resistance in wounded Solanum tuberosum tubers. Physiological and Molecular Plant Pathology, 35(2), 177–190.

Peck, S. M. (2015). Integrating Cultivar, Temperature and Quality into Early Storage Management Decisions for Wound Healing in Potatoes (Solanum tuberosum L.) [M.S., University of Idaho]. https://search.proquest.com/docview/1728921036/abstract/82D5C639DC3B4620PQ/1

Perla, V., Holm, D. G., & Jayanty, S. S. (2012). Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. LWT-Food Science and Technology, 45(2), 161–171.

Pinhero, R., Pazhekattu, R., Marangoni, A. G., Liu, Q., & Yada, R. Y. (2011). Alleviation of low temperature sweetening in potato by expressing Arabidopsis pyruvate decarboxylase gene and stress-inducible rd29A: A preliminary study. Physiology and Molecular Biology of Plants : An International Journal of Functional Plant Biology, 17(2), 105–114. https://doi.org/10.1007/s12298-011-0056-8

Schreiber, L., Franke, R., & Hartmann, K. (2005). Wax and suberin development of native and wound periderm of potato (Solanum tuberosum L.) and its relation to peridermal transpiration. Planta, 220(4), 520–530.

Taşdelen, Ö., & Bayindirli, L. (1998). Controlled Atmosphere Storage and Edible Coating Effects on Storage Life and Quality of Tomatoes. Journal of Food Processing and Preservation, 22(4), 303–320. https://doi.org/10.1111/j.1745-4549.1998.tb00352.x

Toma, R. B., Leung, H. K., Augustin, J., & Iritani, W. M. (1986). Quality of French Fried Potatoes as Affected by Surface Freezing and Specific Gravity of Raw Potatoes. Journal of Food Science, 51(5), 1213–1214. https://doi.org/10.1111/j.1365-2621.1986.tb13087.x

USDA. (1988). USDA Color standards for frozen French-fried potatoes. 4th Ed. Munsell Color. Baltimore, MD.

Voss, R. E., Baghott, K. G., & Timm, H. (2001). Proper environment for potato storage. Vegetable Research and Information Center. The University of California.

Wang, C., Chen, L., Peng, C., Shang, X., Lv, X., Sun, J., Li, C., Wei, L., & Liu, X. (2020). Postharvest benzothiazole treatment enhances healing in mechanically damaged sweet potato by activating the phenylpropanoid metabolism. Journal of the Science of Food and Agriculture, 100(8), 3394–3400. https://doi.org/10.1002/jsfa.10373

Wang, Y., Naber, M. R., & Crosby, T. W. (2020). Effects of Wound-Healing Management on Potato Post-Harvest Storability. Agronomy, 10(4), 512.

Yaman, Ö., & Bayoındırlı, L. (2002). Effects of an edible coating and cold storage on shelf-life and quality of cherries. LWT-Food science and Technology, 35(2), 146-150.

Zheng, X., Jiang, H., Bi, Y., Wang, B., Wang, T., Li, Y., Gong, D., Wei, Y., Li, Z., & Prusky, D. (2020). Comparison of wound healing abilities of four major cultivars of potato tubers in China. Postharvest Biology and Technology, 164, 111167. https://doi.org/10.1016/j.postharvbio.2020.111167

5 Chapter 5. Effect of Edible Coating on Physical and Chemical Properties of Potato Tubers Under Different Storage Conditions

5.1 Introduction

The potato (*Solanum tuberosum* L.) is one of the most consumed agricultural products worldwide after rice, wheat, and maize. Most potato production is destined for commercial processing, followed by fresh table consumption and seed stock. The demand for potatoes for fresh markets and processing is year-round (Emragi et al., 2021a). Rio Grande Russet (RG) is a high-yield fresh market russet released by the Colorado State University breeding and selection program, and it is a commonly grown cultivar in Colorado and other potato growing areas of the USA (http://potatoes.colostate.edu/wp-content/uploads/2014/02/Rio-Grande-Cultivar-sheet.pdf). This russet cultivar is popular because of its attractive shape and yield. Yukon Gold (YG) is a popular yellow flesh cultivar of potato distinguished by its thin, smooth, eye-free skin and yellow-tinged flesh (Johnston and Rowberry. 1981). YG potato is an all-purpose potato suitable for mashing, roasting, boiling, and frying. Purple Majesty (PM) is a high-yielding fresh market specialty with dark purple skin and uniform dark purple flesh (Purple-Majesty-Cultivar-sheet.pdf (colostate.edu). Purple Majesty has a high concentration of phenolics and anthocyanins and has a higher antioxidant activity than other colored cultivars (Emragi and Jayanty 2021b).

Potatoes are one of the most widely consumed vegetables. It is the third-largest source of phenolic compounds in the human diet, after oranges and apples, due to its widespread consumption (Madiwale et al., 2012). Potato polyphenols are considered antioxidants, anticarcinogenic, and antimutagenic agents (Diganta et al., 2018). Potato polyphenols have shown to be effective against cancer cells in the human liver, colon, and prostate in numerous studies (Hellman et al., 2021). Colored flesh potatoes have higher antioxidant capacity compared with their white or yellow counterparts due to high levels of polyphenolic compounds (Diganta

and Jayanty 2014). Other important bioactive compounds of the potato include Vit C and minerals (Madiwale et al., 2012). Potato cultivars with yellow, purple- and red-colored flesh have high levels of flavonoids and carotenoids (Narwojsz et al., 2020). It is well understood that storing and processing foods change their physical and chemical structure, thus affecting their antioxidant activity (Madiwale et al., 2012).

The potato storage requirements are 90 to 95% relative humidity and optimum temperatures, which are 4 to 5 °C for seeds, 6 to 10 °C for fresh market use, and 10 to 15 °C for processing tubers (Emragi et al., 2021c; Külen et al., 2013). Transpiration and respiration are responsible for physical water loss from tubers and thus weight loss, which is maximum during the first two months of potato storage. Transpiration is responsible for approximately 90% of the total loss. In comparison, the weight loss due to respiration is less than 10% of the total loss.

Edible coatings have been used to improve moisture and gas barriers, sensory perceptions, mechanical properties, and microbial protection and extend the shelf life of some produce. The selectivity of edible coating films with permeability to O_2, CO_2, and water vapor delays the natural physiological ripening process. The reduction in water loss and modification of the internal atmosphere is greatly affected by the character of the product skin and the coating film's permeance (Maftoonazad et al., 2008).

The edible coating may contain proteins, polysaccharides, lipids, or a mixture of these compounds. Alginate, one of the most widely used coatings, is present in brown algae as the most abundant polysaccharides, making up 40% of the dry matter. It occurs in the intercellular matrix as a gel with sodium, calcium, magnesium, strontium and barium ions. Pavlath et al. (1999) made films based on alginic acid that were transparent and flexible but dissolved in water. The calcium and zinc treatment produced water-insoluble films (Maftoonazad, Ramaswamy, &

Marcotte, 2008). Zein has been used as an alternative to shellac and carnauba wax in foodstuffs. Zein coatings have been used to coat nuts and candy for increased glitter and to reduce oxidation and development of off odors. coating. Chitosan is the second most abundant polysaccharide found in nature after cellulose. Chitosan, a deacetylated form of chitin, is a natural antimicrobial compound obtained from crustacean shells (crabs, shrimp, and crayfishes) by chemical or microbiological processes (Devlieghere et al., 2004). In addition to the antimicrobial attributes, chitosan has been shown to be non-toxic, biodegradable, bio-functional and biocompatible.

Essential oils are a promising ingredient for edible coating in food packaging because of their natural origins and antioxidant and antimicrobial properties, allowing extended shelf life and adding value to the produce (Atarés & Chiralt, 2016; Vokou 1993). Similarly, in potatoes, essential oils were also used to inhibit sprout growth (Owolabi et al., 2010). Thus incorporating these compounds into the formulation of edible films and coatings may be an interesting way for food packaging to maintain the quality (Sánchez-González, Vargas, et al., 2011;Yuan et al., 2016).

The research about the application of edible coatings on fresh potato tubers are few in the literature. Saha et al., (2014) reported that chitosan-based coatings reduce weight loss and maintained firmness. A similar study by Sun et al., (2008) with chitosan coatings reported resistance to Fusarium dry rot. Saha et al., (2014) reported a reduction in weight loss when coated with chitosan on fresh tubers. Coatings were also applied to reduce greening in potatoes (Banks 1985). Paraffin wax coating played a role in extending tuber dormancy at 15 °C (Karanisa et al., 2019). Our group recently reported on the benefits of coatings to maintain tuber skin color, especially among reds (Emragi and Jayanty 2021b).

Tuber crops are exposed to skin damage during harvest and postharvest handling, thus leaving the crop highly perishable (Atieno et al., 2019; Emragi et al., 2021a). The high moisture content in the tubers leads to their high perishability. Avoiding the postharvest losses associated with tuber crops warrants the need for improved methods for their storage. This study aimed to determine the optimum edible coating formulations for potatoes, to extend the shelf life under different storage conditions, and study edible coatings' effects on sensory, physical, and nutritional properties. This is the first study in our knowledge that tested the effects of different edible coatings on the fresh potato tubers (RG, YG, and PM) under different storage conditions applied after harvest before long-term storage. The results of this work would be used to assess the effectiveness of the selected formulas to extend shelf life and reduce potato storage losses.

5.2 Materials and methods

5.2.1 Materials

5.2.1.1 Tubers

Tuber samples of all three cultivars RG, YG and PM, were studied over two seasons (2017 and 2018). RG, YG, and PM were obtained from the San Luis Valley Research Center, Colorado, at harvest in mid-September to the end of October. One hundred and twenty tubers without blemishes and misshapes were randomly selected for each treatment in both seasons. The potato vines were killed by chemical application once the desired tuber size was achieved. Tubers were harvested three weeks after the vine kill. The death of the vine initiates the maturation of the skin of the tubers to resist skinning and bruising during the mechanical harvest. Tubers' maturity was determined by the skin set. The sizes of the tubers selected were between 340 – 450 g for RG and YG, and PM tubers were between 225 – 340 g. Tubers were stored in

cold rooms with 95% humidity to take out the field heat after harvest. Tuber were treated with coatings after the pulp temperatures reached 5 °C. Before the coating treatment was applied, tubers were washed with tap water and air-dried at ambient temperature.

5.2.1.2 Coating materials

The coating materials used in this study were zein, acid-soluble chitosan, potato starch, sodium alginate, and other materials used in the coating formulations were glycerol, acetic acid ethanol, and Tween 20 purchased from Sigma-Aldrich, Inc. (St. Louis, Mo, USA). Essential oils, cinnamon, and oregano (100% pure) were purchased from Walmart (NOW, Vitacost)

5.2.1.3 Chemicals

Folin Ciocalteu Reagent (FCR), sodium carbonate, gallic acid, aluminum chloride, quercetin hydrate, dinitro salicylic acid, crystalline phenol, sodium hydroxide, sodium sulfite, potassium sodium tartrate tetrahydrate, glucose, and metaphosphoric acid were purchased from Sigma Aldrich Corporation (St. Louis, USA). All other chemicals were of analytical grade

5.2.2 Method

5.2.2.1 Preparation of the coating solutions

The relative amounts of materials in all formulations were decided according to the results of preliminary work conducted in the 2016 season.

5.2.2.2 Zein coatings

Table 1 shows a summary of the composition of the formulae that were used in all seasons. Zein formulation (F1), was prepared according to the method published by Bai et al., (2003) with some modifications. A 7.5% (w/v) zein emulsion was prepared in 80% ethanol. The

solution was stirred at room temperature for 60 min on a magnetic stirrer/hot plate. Glycerol was added at 3% (v/v) (mixed for 5 min) as a plasticizer to improve the coating solution's strength and flexibility. To prepare the zein emulsion with oregano oil (0.75% v/v) and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm using a Sorvall Omni-Mixer Homogenizer (Norwalk, Conn. USA).

Table 5.1. The composition of different coatings used for treating potato tubers

	No Coating	Zein (%)	Potato Starch (%)	Chitosan (%)	Sodium Alginate (%)	Glycerol (%)	Additives (%)
2017	F1	7.5	-	-	-	3	0.75 Oregano
	F2	-	-	-	2	1	-
	F3	-	5	-	-	2.5	0.75 Oregano
2018	F4	-	-	-	1.5	0.75	0.1 Cinnamon
	F5	-	3	-	3	2	0.75 Cinnamon
	F6	4.5	-	1.5	-	5	0.75 Cinnamon
	F7	-	0.5	2	1	2	0.75 Cinnamon

5.2.2.3 Sodium alginate

The method described by Maftoonazad et al., (2008) was used to prepare the sodium alginate coating solution with some modification. A 2% (w/v) (F2) and 1.5% (w/v) (F4) of sodium alginate powder were dissolved in water by heating at 70 °C while stirring until the solution becomes clear. Glycerol was added (50% w/sodium alginate dry weight) as a plasticizer to the coating solution. A 2% (w/v) solution of calcium chloride was prepared to induce the cross-linking by spraying the tubers coated with sodium alginate. To prepare the alginate emulsion with cinnamon oil (0.1% v/v) (F4), and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm using a Sorvall Omni-Mixer Homogenizer (Norwalk, Conn. USA).

5.2.2.4 Potato starch

The method described by García et al., (2000) was utilized to prepare potato starch coating with some modifications. In all potato starch coatings (F3, F5, and F7), 5, 3, 0.5% (w/v) potato starch powder was used respectively. Potato starch aqueous solutions were gelatinized by heating at 90 °C for three hours in distilled water to obtain the clear coating solutions. After leaving the solution to cool down, glycerol was added as a plasticizer at 2.5% (v/v) in F3. To prepare the potato starch emulsion with cinnamon oil (0.75% v/v) (F3), and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm using a Sorvall Omni-Mixer Homogenizer (Norwalk, Conn. USA).

2.2.1.4 Composite coating formulae

The idea of applying the composite coatings on potatoes came through the earlier studies conducted by(Galus & Kadzińska, 2015; Kurek et al., 2014; Galus et al., 2013; Jiang et al., 2012). Three different composite formulae were used in the 2018 season: 1) potato starch and alginate emulsion with cinnamon oil (F5). Potato starch (3% w/v) and sodium alginate (3% w/v) were prepared separately and then mixed at a ratio of 1:1. Glycerol was added (2% v/v formula solution) as a plasticizer. Cinnamon oil (0.75% v/v of formula solution) and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm. 2) zein and chitosan emulsion with cinnamon oil (F6), where the concentration in the formula was 4.5% zein and 1.5% chitosan. The acid-soluble chitosan coating solution was prepared by dissolving 1.5% (W/V) chitosan in 1% aqueous acetic acid. The mixture was homogenized for 2 min and shaken in a 60 °C water bath for 30 min, followed by cooling to room temperature. Zein (4.5% w/v) and chitosan (1.5% w/v) solutions were mixed at a ratio of 3:1. Glycerol was added (5% v/v formula solution) as a plasticizer. Cinnamon oil (0.75% v/v of formula solution), and Tween 20 was

added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm. 3) Potato starch, chitosan, and sodium alginate with cinnamon oil (F7). Potato starch (0.5% w/v), chitosan (2% w/v), and sodium alginate (1% w/v) solutions were prepared separately and mixed at a ratio of 0.5:2:1. Glycerol was added (2% v/v formula solution) as a plasticizer. Cinnamon oil (0.75% v/v of formula solution), and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm.

5.2.2.5 Coating of the tubers

Tubers were divided into sets according to the number of formulae. Tubers were coated by hand a held 0.48-gallon sprayer. The sprinkler head adjustment was standardized with each formula. Formulations were sprayed until the tubers were wet to run off. Tubers gained weight after coating application which is 0.1- 0.25 g depending on coating materials. The control tubers were sprayed with distilled water, and they were air-dried as treated samples.

Air was blown for 15 min to dry the coating films on the surface of the tubers. After applying coatings, tubers were stored in a cold room, and no sprout inhibitor was applied to them.

5.2.2.6 Packaging and storage of treated samples

The treated and control tuber samples were packaged in plastic mesh bags to simulate commercial storage conditions and placed in three different storage conditions: a) a set of treated tubers was stored at 5 °C±1 with 90%±5 relative humidity storage conditions (HRHSC) in the dark for six months in the 2017 and 2018 seasons; and b) a set of treated tubers was stored at 5 °C±1 with 55%±5 RH (LRHSC) in the dark for 6 months in the 2017 and 2018 seasons; c) and a set was stored at room temperature at 18 °C±1 and relative humidity 45-55% for up to 6 weeks to simulate retail display conditions.

5.2.2.7 Physicochemical quality analyses

5.2.2.7.1 Determination of weight loss

For determining the weight loss, five replications (five bags with five tubers in each) for each treatment were weighed at the beginning of the experiment using a digital balance. The same bags were weighed at the end of each storage period. The results were expressed as the percentage loss of initial weight.

5.2.2.7.2 Respiration rate and Ethylene production

The ethylene production and respiration rates were measured at zero, three, and six months of storage using a Felix 900 (Camas, WA, USA) ethylene analyzer. The ethylene measurement (ppm per kg per h) was taken directly from the gas analyzer. The respiration rate was calculated as the ratio of carbon dioxide to oxygen described in Emragi et al., (2021c).

5.2.2.7.3 Firmness determination

The firmness was determined using the method of Crossen (2017), with some modifications. Briefly, the firmness was measured using a Brookfield CT3 texture analyzer (Model CT3-1500, Brookfield Engineering Laboratories, MA). The analyzer was fitted with a spherical probe, and the weight required (g) to form a 3 mm dent on the surface of the tubers. Approximately 30 measurements were taken for each treatment to calculate the mean.

5.2.2.7.4 Spouting rate

Ten tubers were randomly selected from each treatment to calculate the sprouting rate. The sprouting rate was calculated as the percentage of the weight of the sprouts to the weight of whole tubers with sprouts (Emragi et al., 2021c).

The sprouting rate = (sprouts weight/tuber weight with their sprouts) * 100

5.2.2.7.5 Sensory evaluation

The sensory evaluation of the control and treated tubers for color, gloss, texture, odors, and overall acceptability was performed two weeks after the formulae were applied following the method of Bai et al. (2003). A panel of 40 judges was asked to score the difference between the samples in terms of color, gloss, texture, odors, and overall acceptability, with 1 representing dislike extremely; 2 representing moderately dislike; 3 representing neither like nor dislike; 4 representing like moderately; and 5 representing like extremely.

5.2.2.7.6 Bioactive compounds: total phenolics, flavonoids, and reducing sugars

5.2.2.7.6.1 Extraction procedure

Phenolic compounds, flavonoids, and reducing sugars were extracted using the method described by Perla et al., (2012), with some modifications. Briefly, potato tubers were collected at zero, three, and six months from each treatment. One gram of freeze-dried material was weighed in a 10 ml Falcon tube, and 5 ml of aqueous 90% methanol was added. The tubes were shaken overnight in an orbital shaker at 150 rpm at 25 °C. Homogenates were centrifuged, filtered, and kept at -80 °C for further analysis.

5.2.2.7.6.2 Determination of total phenolics

The method of Perla et al., (2012) was used to determine the total phenolic content in potatoes. The total phenolics of the extracts were determined using the FCR reagent (M.P. Biomedical Solon, OH) in a 96-well flat-bottom assay plate (Costar 3370, Corning, NY). The absorbance of the contents was measured at 760 nm. (Power Wave XS2, BioTek Instruments, Winooski, VT). For the standard, gallic acid in methanol was used, and the total phenolic values

were quantified as µg of gallic acid equivalent (GAE) per gram of dry weight of potato samples using a 7-point calibration curve with an R^2 value of 0.97.

5.2.2.7.7 Determination of reducing sugars

A previously described 96-well microplate assay was used to determine the reducing sugar content (King et al., 2009). One twenty microliters of dinitrosalicylic acid reagent were added to 20 µL of the potato extract and mixed well. The mixture was heated, and 100 µL of the mixture was transferred to a 96-well flat-bottom microplate containing 40 µL of 400 g L^{-1} potassium sodium tartrate tetrahydrate solution and the absorbance was measured with a plate reader at 570 nm. The glucose standard was prepared in 95% methanol in the range of 5 to 800 mg/mL. Reducing sugar concentrations were expressed as mg glucose per g of dry matter.

5.2.3 Statistical analysis

The total phenolics, reducing sugars, respiration rate, and ethylene production were analyzed in triplicate. Weight loss was determined in five replications (five bags with five tubers in each). Firmness was determined in twenty replications. All results are reported as the mean±standard deviation (S.D.) values. The data were subjected to an analysis of variance (ANOVA), and Tukey's test was performed to determine whether differences between treatments were significant at $P < 0.05$. All statistical analyses were performed with R software version 3.4.3 for Windows.

5.3 Results

5.3.1 Weight loss

The weight loss of RG, YG, and PM tubers stored at 5 °C±1 under two different relative humidity conditions (90% RH and 55% RH) and at room temperature is shown in Figures 1 and 2 a, b, and c. The weight loss in the control samples was higher compared with treated samples in all cultivars (RG, YG, and PM) under 55% RH and at room temperature in both seasons. The weight loss was less in all cultivars under HRHSC when compared with LRHSC and at room temperature due to high humidity. Additionally, the weight loss increased with storage time (3 months and 6 months) under all conditions in all cultivars (3 months storage time is not shown). Overall, most of the formulae had a limited effect under the HRHSC treatment. The edible coating treatments were more effective when stored at room temperature and LRHSC. The effect of the formulae on the 2017 season was not significant for the weight loss rate of the coated tubers except for in the HRHSC treatment with RG coated with F3 (Fig. 1 a). In the LRHSC and room temperature groups, the effects of the coatings were significant, and all the formulae were effective, especially in tubers coated with F1 at room temperature (Fig 1 b) and F2 in LRHSC (Fig 1 c) and in all three cultivars at room temperature. Although the effect of the coating under HRHSC was not significant on the weight loss, there were some exceptions. The weight loss was significantly less in PM with F4 and RG with F7 under HRHSC (Fig.2a). However, the effects of the coatings were more noticeable at room temperature and LRHSC. Additionally, the formulae were significant ($p < 0.05$) for decreasing weight loss, especially F6 and F7 in the room temperature and LRHSC treatments.

The weight loss results are shown in Figures 1 and 2 a, b, c. The weight loss data showed that the zein coating had the lowest % weight loss among the formulae used in the 2017 season

in the three cultivars at room temperature. Moreover, YG potato tubers had the lowest weight loss after applying these coatings compared with RG and PM. In the 2018 season, chitosan + alginate + potato starch resulted in the lowest weight loss for YG, followed by PM and RG in the HRHSC (Fig 2 a). In the 2017 season, tubers coated with F1 were excluded after three months of storage in the HRHSC and LRHSC treatments due to mold and odor.

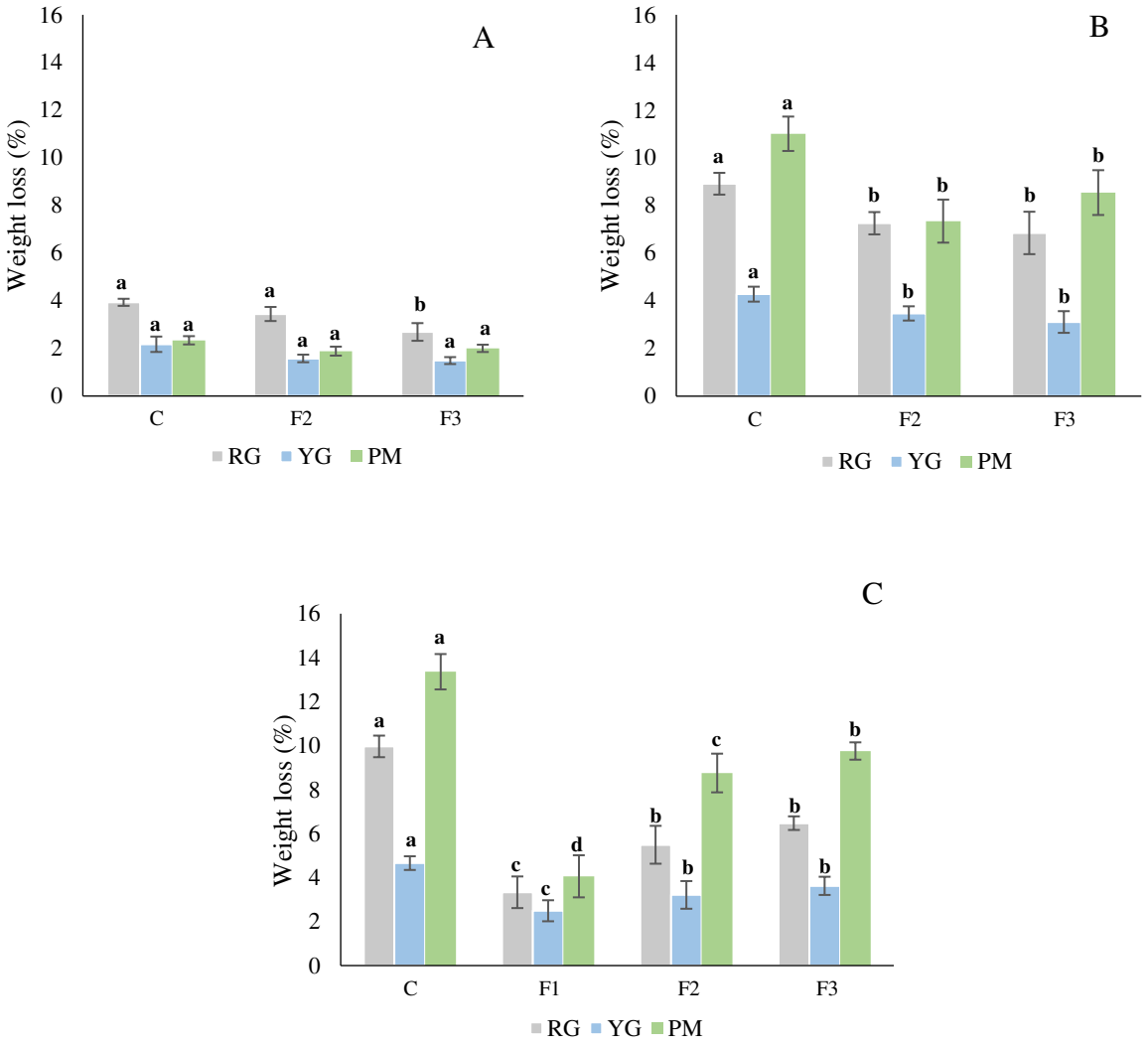


Figure 5.1. a, b and c. Effect of edible coatings on tuber weight loss (%) in the 2017 season in RG, YG, and PM at the end of storage at 5 °C±1 and 90% RH (a) and 55% RH (b) and at room temperature (c). Data are expressed as the mean ± S.D., n = 5. The different letters indicate

significant differences (P < 0.05). C control, F1: zein emulsion with oregano oil, F2: sodium alginate, and F3: potato starch emulsion with oregano essential oil.

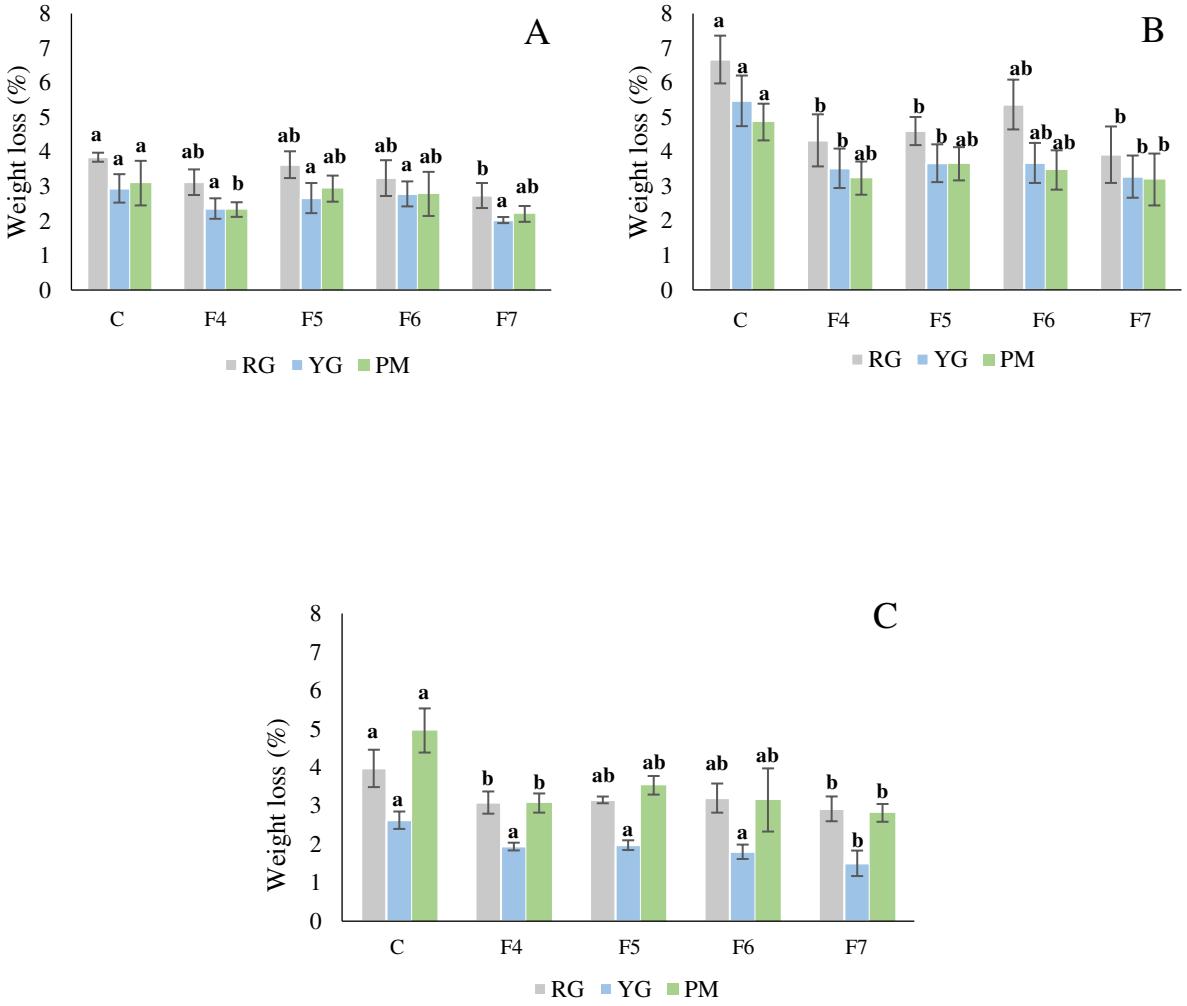


Figure 5.2. a, b and c. Effect of the edible coatings on tuber weight loss (%) in the 2018 season in RG, YG, and PM at the end of storage at 5 °C±1 and 90% RH (a), 55% RH (b) and at room temperature (c). Data are expressed as the mean ± S.D., n = 5. The different letters indicate significant differences (P < 0.05). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

5.3.2 Firmness

The change in the firmness of RG, YG, and PM stored for six months at 5 °C±1 (90% and 55% RH) is shown in Figures 3 and 4 a and b. The firmness of the coated tubers showed a negative relationship with weight loss, i.e., changes in weight loss affected the firmness. The firmness loss in 2017 season was more significant in RG and PM in the LRHSC treatment (Fig 3 b), and the firmness loss was high in the LRHSC compared to HRHSC treatment (Fig 3 a). With some exceptions, the effects of the treatments were not significant ($p > 0.05$) in the HRHSC but were significant in the LRHSC. The firmness loss was significantly less in the RG and PM treated with F3 under HRHSC (Fig 3a). While under LRHSC, the formulae F2 and F3 significantly reduced the firmness loss in RG and PM (Fig 3b). In PM, both alginate and potato starch had significant effects in reducing firmness loss after 6 months of storage. In the HRHSC of the 2018 season, the formula F7 was effective for PM and YG. In the LRHSC, all formulae were effective, especially F7. The F4, F5, and F6 formulae had the same significant effect.

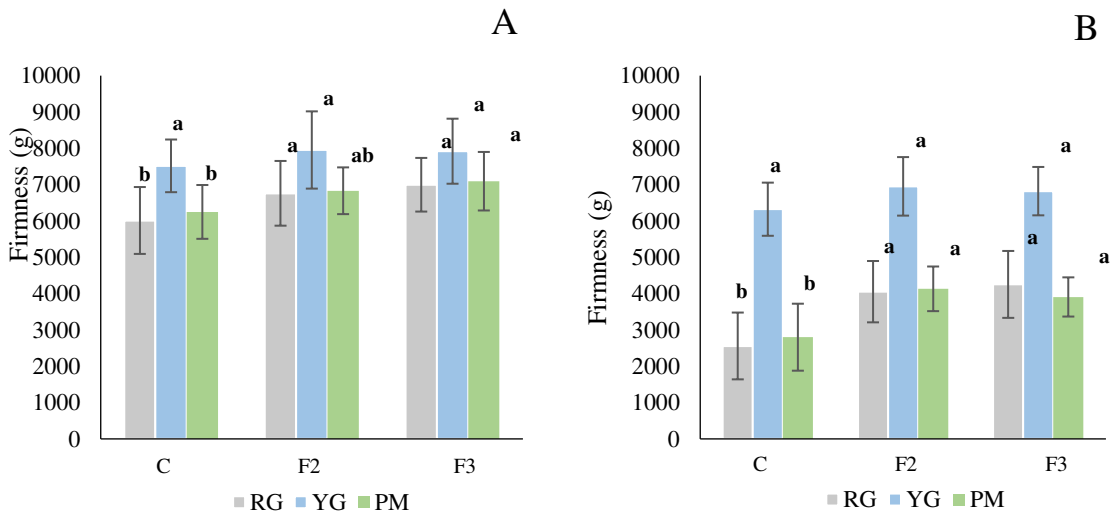


Figure 5.3. a and b. Effect of the edible coatings on tuber firmness (g) of RG, YG, and PM in the 2017 season at the end of storage at 5 °C±1 and 90% RH (a) and 55% RH (b). Data are expressed as the mean ± S.D., n = 20. The different letters indicate significant differences ($P < 0.05$). C control, F2 sodium alginate, and F3 potato starch emulsion with oregano essential oil.

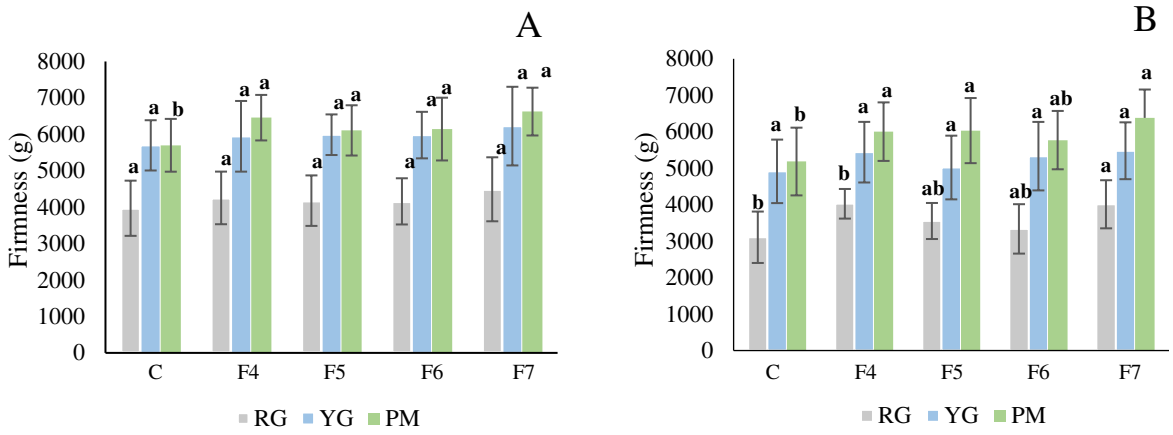


Figure 5.4. a and b. Effect of the edible coatings on tuber firmness (g) of RG, YG, and PM in the 2018 season at the end of storage at 5 °C±1 and 90% RH (a) and 55% RH (b). Data are expressed as the mean ± S.D., n = 20. The different letters indicate significant differences ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

5.3.3 Ethylene production and respiration rate

In general, ethylene production was relatively high at zero time (after harvest) and then reduced due to low temperature, under HRHSC and LRHSC. Ethylene levels reached the lowest level in the 2017 storage season (Fig 7.13, 7.14, 7.15, 7.16). In the LRHSC, C_2H_4 was high at zero time and then reduced after three months, and it increased again at the end of storage due to sprouting in some tubers, especially in PM and RG. In any formula containing zein, the C_2H_4 level decreased significantly. The effects of the coating were noticeable in the LRHSC compared with the HRHSC. In the formulae of the 2017 season, there were no significant effects on C_2H_4 levels in the HRHSC or after 3 months in the LRHSC. At the same time, there was a significant effect on RG and PM after six months at LRHSC with all formulae compared with the control. In the formulae of the 2018 season, there was no significant effect on C_2H_4 levels after 3 months in the HRHSC. However, all formulae had a significant effect after 6 months on the C_2H_4 levels

compared with the control in the case of PM, RG, and YG, especially when coated with F4 and F7. In the LRHSC, all formulae were significant after 3 and 6 months. F4 and F7 were more effective for PM, and all formulae had the same effects on RG and YG.

In general, the respiration rate was high at harvest time (Fig 7.17, 7.18, 7.19, 7.20). Subsequently, because of the low storage temperature, it started to decrease. At the end of storage, when some tubers started sprouting, the respiration rate increased again, especially in the LRHSC. The respiration rate of PM was higher than the respiration rate of RG and YG. No significant difference was observed between PM and RG. There were no significant differences among the 2017 season formulae, storage time, and cultivars in the HRHSC, and the only significant effect in the LRHSC was for the coated (F2 and F3) RG compared with the control sample. The respiration rate showed significant differences based on the formulae of the 2018 season, especially F4 and F7 in the HRHSC after 3 months. In the LRHSC, all formulae at all storage times were significant ($p < 0.05$).

5.3.4 Sprouting rate

The sprouting rate was calculated as a percentage after 8 weeks of storage at room temperature. In the 2017 season, all formulae had a significant effect on delayed sprouting, especially the F1 formulation, which stopped the sprouting completely at the time of measurement (Fig 5 a, b, and c). The F2 and F3 formulations significantly delayed potato tuber sprouting compared with control samples in all cultivars. In the 2018 season, the effectiveness of F4 and F7 with PM (Fig 6 c) and RG (Fig 6 a) was more noticeable than that of the other formulae. Significant differences were not observed for YG (Fig 6 b), which might be due to delayed sprouting in the YG.

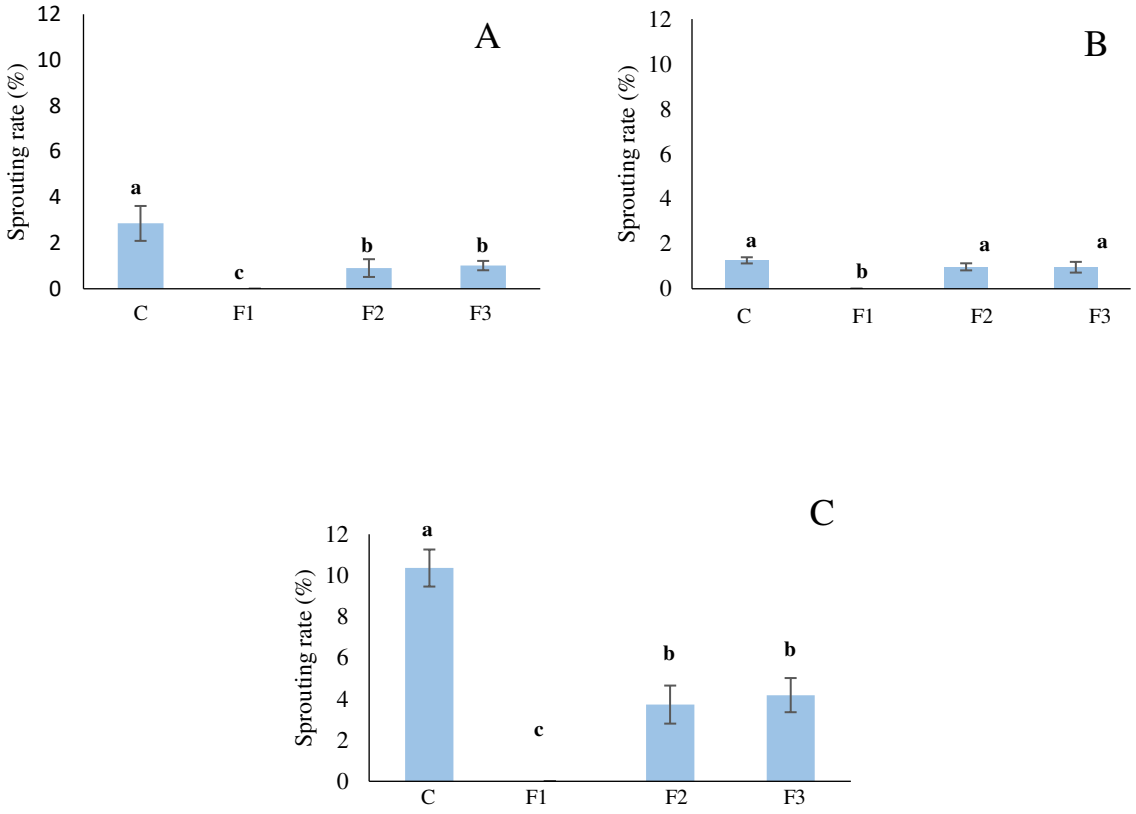
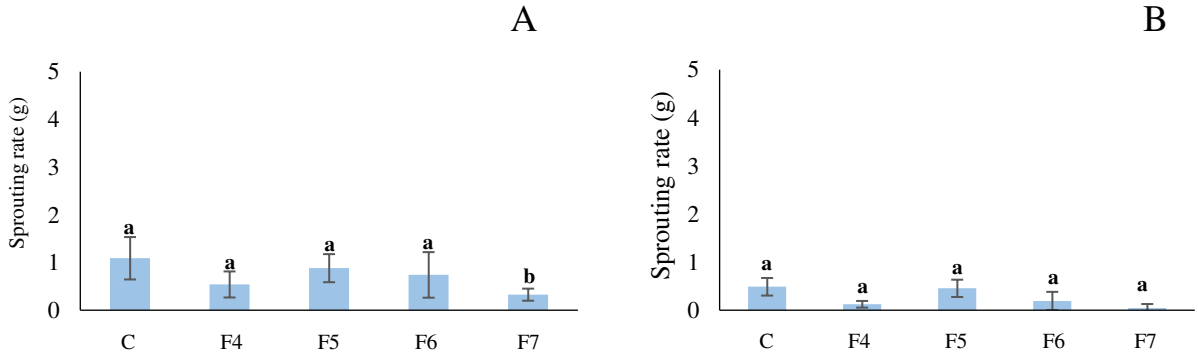


Figure 5.5. a, b, and c. Effect of the edible coatings on the sprouting rate (%) of RG (a), YG (b), and PM (c) after eight weeks of storage at room temperature in the 2017 season. Data are expressed as the mean ± S.D., n = 10. The different letters indicate significant differences ($P < 0.05$). C control, F1: zein emulsion with oregano oil, F2: sodium alginate, and F3: potato starch emulsion with oregano essential oil.



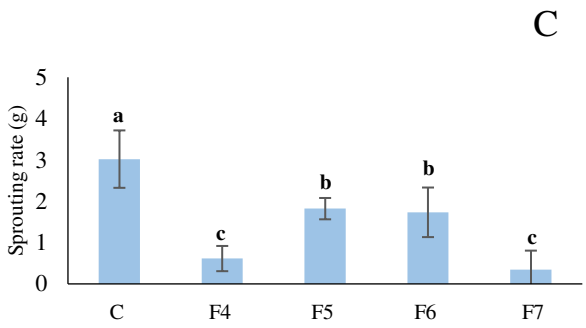
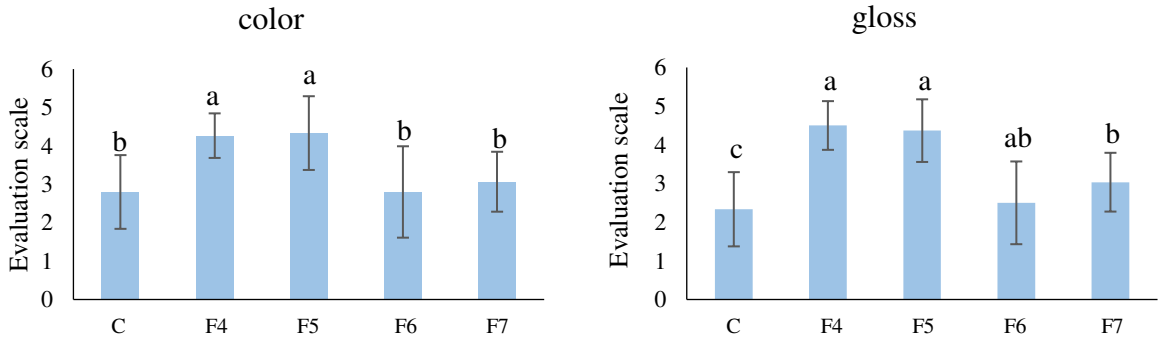


Figure 5.6. a, b, and c. Effect of the edible coatings on the sprouting rate (%) of RG (a), YG (b), and PM (c) after eight weeks of storage at room temperature in the 2018 season. Data are expressed as the mean ± S.D., n = 10. The different letters indicate significant differences ($P < 0.05$).C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

5.3.5 Sensory evaluation

The sensory evaluation was performed only in the 2018 season (Fig 7). F4 and F5 were more effective in improving the sensory qualities of tubers, such as the color, gloss, and general acceptability, compared with the control samples of all cultivars. However, tubers coated with F6 were not acceptable by the judges due to whiteness and bad odor.



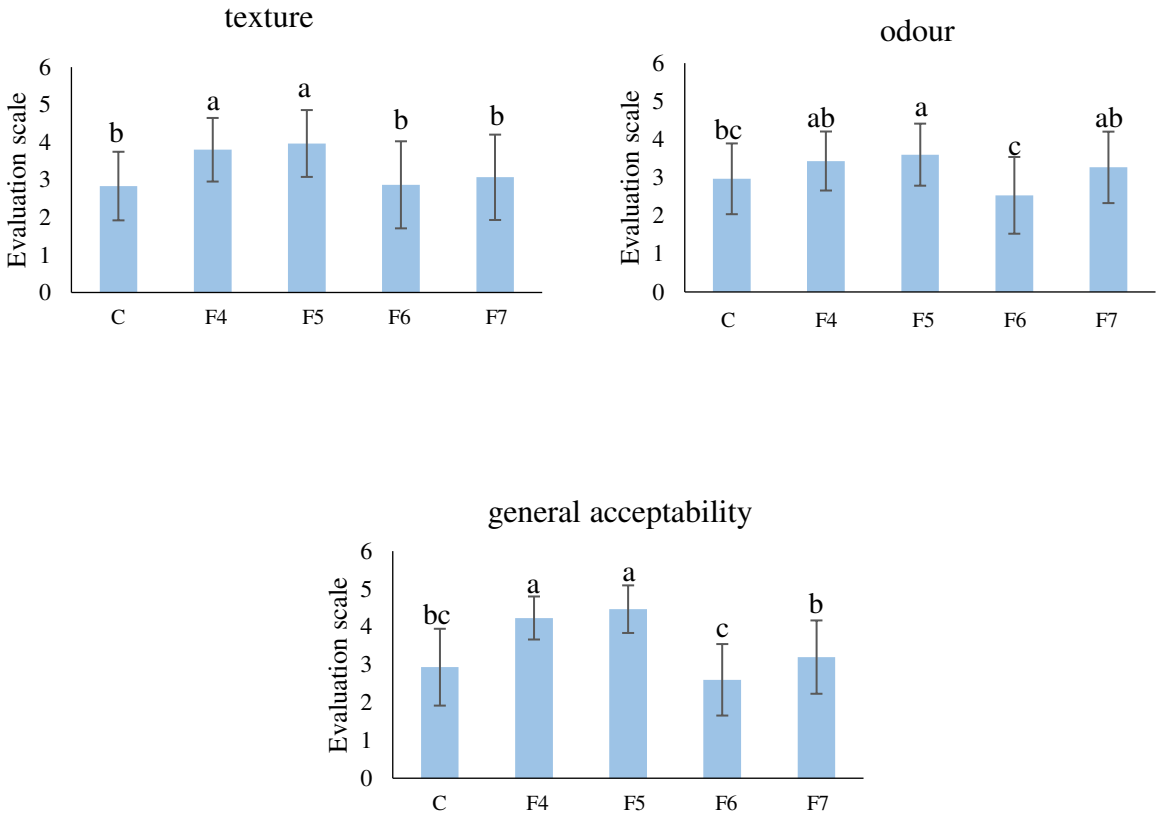


Figure 5.7. Effect of the edible coatings on the sensory evaluation (color, gloss, texture, odor, and general acceptability) of RG, YG, and PM in the 2018 season. Data are expressed as the mean ± S.D., n = 40. The different letters indicate significant differences ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

5.3.6 Bioactive compounds

All three cultivars and all formulae in two storage conditions in both the 2017 and 2018 seasons did not significantly affect the total phenolic content, with some exceptions (Table 2). Generally, the total phenolic content was increased after three months and reduced after six months of storage. The reduction was more noticeable in the LRHSC than the HRHSC.

Generally, there was no significant difference (with some exceptions) in the flavonoid and Vit C contents due to the coating (Table 7.1 and 7.2). All the differences were due to cultivar

and duration of storage or RH. The contents of reducing sugars were at the lowest level at the time of harvest in both seasons (2107 and 2018) and all cultivars (Table 3). Later, because of the low storage temperature during the storage season, the contents gradually increased due to the cold sweetening phenomenon. Therefore, the effect of the coatings was limited in terms of reducing sugar content.

Table 5.2. Effect of the edible coatings on the total phenolics (mg/g D.W.) of the RG, YG, and PM during the period of storage at 5 °C ±1 (90 and 55% RH) in the 2017 and 2018 seasons. Data expressed as the mean±S.D., n = 3. The different letters indicate significant differences ($P < 0.05$).

Season	Treatment	**Rio Grande**					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	795.09±53	1411.26±118^{a}	916.79±30^{a}	795.09±53	1045.21±76^{b}	774.89±53^{a}
	F2	795.09±53	1434.58±107^{a}	938.91±71^{a}	795.09±53	1300.63±91^{a}	914.38±77^{a}
	F3	795.09±53	1357.38±148^{a}	897.07±71^{a}	795.09±53	1218.86±170^{ab}	785.47±95^{a}
2018	C	668.97±53	666.41±49^{a}	266.28±65^{a}	668.97±53	556.79±55^{b}	165.13±64^{a}
	F4	668.97±53	670.9±71^{a}	287.56±35^{a}	668.97±53	740.77±57^{b}	287.44±15^{a}
	F5	668.97±53	652.95±14^{a}	252.82±48^{a}	668.97±53	730.51±79^{b}	310.6±65^{a}
	F6	668.97±53	647.82±216^{a}	264.55±21^{a}	668.97±53	711.92±83^{b}	298.59±75^{a}
	F7	668.97±53	657.44±102^{a}	270.58±41^{a}	668.97±53	809.36±101^{a}	309.36±53^{a}
		Yukon Gold					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	705.15±35	1203.94±209^{b}	680.13±49^{a}	705.15±35	987.01±96^{a}	736.41±3^{a}
	F2	705.15±35	1732.08±135^{a}	710.92±55^{a}	705.15±35	1140.45±58^{a}	705.15±54^{a}
	F3	705.15±35	1628.19±109^{a}	682.54±23^{a}	705.15±35	1034.15±138^{a}	762.39±33^{a}
2018	C	512.56±43	242.05±21^{a}	132.02±15^{a}	512.56±43	202.31±44^{a}	129.76±52^{a}
	F4	512.56±43	261.6±48^{a}	158.24±37^{a}	512.56±43	291.15±59^{a}	182.28±23^{a}
	F5	512.56±43	252.31±87^{a}	142.31±38^{a}	512.56±43	230.13±40^{a}	158.92±55^{a}
	F6	512.56±43	304.87±34^{a}	158.22±15^{a}	512.56±43	226.82±47^{a}	151.28±56^{a}
	F7	512.56±43	274.1±67^{a}	150.77±53^{a}	512.56±43	246.54±26^{a}	175.33±42^{a}
		Purple Majesty					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	2321.79±59	3823.47±117^{a}	2664.74±112^{a}	2321.79±59	2781.63±88^{b}	2445.41±99^{a}
	F2	2321.79±59	3764.31±169^{a}	2721.5±151^{a}	2321.79±59	3464.17±104^{a}	2397.79±62^{a}
	F3	2321.79±59	3891.77±302^{a}	2767.68±47^{a}	2321.79±59	2468.01±281^{c}	2298.7±112^{a}
2018	C	2487.56±432	2213.21±136^{b}	1113.21±127^{a}	2487.56±432	1536.28±321^{b}	1492.49±94^{a}
	F4	2487.56±432	2246.54±165^{ab}	1379.93±233^{a}	2487.56±432	2083.08±92^{a}	1578.95±114^{a}
	F5	2487.56±432	2529.87±87^{a}	1296.54±160^{a}	2487.56±432	2139.49±62^{a}	1618.03±107^{a}
	F6	2487.56±432	2028.59±65^{b}	1161.91±117^{a}	2487.56±432	2035.77±61^{a}	1508.87±96^{a}
	F7	2487.56±432	2258.36±176^{ab}	1391.6±216^{a}	2487.56±432	2014.23±45^{a}	1515.11±95^{a}

Table 5.3. Effect of the edible coatings on the reducing sugars (mg/g D.W.) of the RG, YG, and PM during the period of storage at 5 °C ±1 (90 and 55% RH) in the 2017 and 2018 seasons. Data expressed as the mean±S.D., n = 3. The different letters indicate significant differences ($P < 0.05$).

Season	Treatment	**Rio Grande**					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	4.81±0.2	35.25±0.7^{a}	18.17±2.7^{a}	4.81±0.2	11.81±1.4^{a}	7.41±0.3^{a}
	F2	4.81±0.2	28.97±2.7^{b}	19.35±1.4^{a}	4.81±0.2	7.04±1.3^{b}	9.62±1.1^{a}
	F3	4.81±0.2	37.99±3.5^{a}	19.85±2.4^{a}	4.81±0.2	9.04±1.5^{ab}	6.58±0.6^{a}
2018	C	2.09±0.1	14.35±1.1^{a}	15.9±2.1^{a}	2.09±0.1	4.45±0.1^{a}	5.33±0.4^{a}
	F4	2.09±0.1	13.06±0.7^{ab}	13.94±1.1^{ab}	2.09±0.1	2.82±0.5^{a}	4.47±0.9^{a}
	F5	2.09±0.1	13.87±1^{a}	14.86±1.9^{ab}	2.09±0.1	2.93±0.3^{a}	4.07±0.1^{a}
	F6	2.09±0.1	13.51±2.3^{a}	14.34±1.8^{ab}	2.09±0.1	6.03±0.6^{a}	6.35±0.7^{a}
	F7	2.09±0.1	10.29±1^{b}	12.27±2.1^{b}	2.09±0.1	3.61±0.5^{a}	4.93±0.2^{a}
		Yukon Gold					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	4.68±0.2	39.14±2.2^{c}	32.83±2.5^{a}	4.68±0.2	12.92±1.9^{ab}	11.93±0.4^{a}
	F2	4.68±0.2	46.09±2.8^{b}	35.06±1.6^{a}	4.68±0.2	9.54±1.8^{b}	11.62±1.8^{a}
	F3	4.68±0.2	50.84±4.1^{a}	33.26±2.6^{a}	4.68±0.2	13.89±1.1^{a}	12.87±0.5^{a}
2018	C	1.83±0.3	15.91±1.3^{a}	15.46±0.8^{a}	1.83±0.3	9.62±0.5^{ab}	6.95±0.9^{a}
	F4	1.83±0.3	15.75±1.9^{a}	14.63±1.4^{a}	1.83±0.3	5.33±0.2^{c}	6.23±1.1^{a}
	F5	1.83±0.3	15.79±2.3^{a}	15.67±1.5^{a}	1.83±0.3	6.99±0.6^{ab}	6.45±0.1^{a}
	F6	1.83±0.3	16.13±0.8^{a}	15.67±0.6^{a}	1.83±0.3	10.45±0.8^{a}	8.57±1.2^{a}
	F7	1.83±0.3	15.3±1.4^{a}	15.5±1.9^{a}	1.83±0.3	6.25±1.4^{c}	6.51±0.5^{a}
		Purple Majesty					
		90%			**55%**		
		Zero time	**3 M**	**6 M**	**Zero time**	**3 M**	**6 M**
2017	C	5.76±0.5	32.2±3.4^{a}	33.55±1.4^{a}	5.76±0.5	5.32±0.6^{a}	15.4±0.7^{a}
	F2	5.76±0.5	30.56±1.9^{a}	35.42±1.7^{a}	5.76±0.5	5.94±1.4^{a}	16.26±0.9^{a}
	F3	5.76±0.5	29.9±5.5^{a}	35.4±1.9^{a}	5.76±0.5	5.04±0.3^{a}	14.72±1.1^{a}
2018	C	1.65±0.3	9.21±0.9^{a}	11.44±1.1^{a}	1.65±0.3	5.01±0.5^{a}	6.6±1.3^{a}
	F4	1.65±0.3	9.79±1.1^{a}	12.01±1.1^{a}	1.65±0.3	3.16±0.6^{a}	5.92±0.9^{a}
	F5	1.65±0.3	7.73±1.5^{a}	10.61±0.6^{a}	1.65±0.3	3.61±0.7^{a}	6.61±1.1^{a}
	F6	1.65±0.3	10.17±0.9^{a}	11.68±0.7^{a}	1.65±0.3	2.93±0.1^{a}	5.92±0.9^{a}
	F7	1.65±0.3	8.02±1.1^{a}	10.46±0.6^{a}	1.65±0.3	3.15±0.7^{a}	4.89±1.1^{a}

5.4 Discussion

5.4.1 Weight loss

Water contributes to tuber firmness and freshness appearance. This study showed that the weight loss in all cultivars was less in the HRHSC than the LRHSC and room temperature

storage conditions. These results are consistent with that of Yaman and Bayoindirli (2002), who found that the weight loss of cherries stored under cold conditions was significantly less than that of cherries stored under ambient conditions because of the effects of temperature, differences in vapor pressure, and increased water retention. Although the weight loss under high relative humidity storage conditions was not significant with most of the formulae, less weight loss occurs in the case of coated tubers than the control tubers, which can be explained by the fact that the edible coatings act as barriers to water transfer. Chitosan coating, for example, is efficient at controlling water loss in cucumber and pepper (Jiang et al., 2012). In a study conducted by Meng et al. (2008), the experimental results showed that chitosan spray treatments significantly reduced grapefruit weight loss at 20 °C ($P < 0.05$) but did not show significant differences at 0 °C ($P > 0.05$). Increasing weight loss in a relatively high-temperature environment may be due to increased fruit respiratory activity. Polysaccharide-based emulsions with essential oils (F2, F3, and F4) showed significant effects on reducing weight loss in the LRHSC. Polysaccharide-lipid composite coatings improve the effectiveness of the water barrier via increased lipid content. Hagenmaier & Shaw (1991; 1992) reported that the addition of cinnamon and mustard oils to shellac films improve the water vapor barrier property. Sánchez-González et al., (2011) reported that chitosan films that included essential oils lowered the dehydration rate, which was probably due to the hydrophobic nature of the essential oils.

The leading cause of fruit weight loss during storage is water migration from fruit to the environment. The weight loss percentage differed between the cultivars tested (Fig 1), mainly attributed to their tuber skin type (RG - russet skin; YG – smooth yellow skin, and PM – smooth, delicate purple skin). Ayranci & Tunc (2004) found that apricot's initial water content is higher

than that of pepper; therefore, the weight loss in apricot was greater than that in pepper .That can be attributed to the type and condition of the barrier imposed by the respective skin.

Our study showed that the effectiveness of the edible coating was lower in HRHSC than in the LRHSC. Similar results were found by Gontard et al. (1996), who mentioned that at low relative humidity, wheat gluten film displays very low permeability of gas and water vapor at 25 °C. The gas and water vapor permeabilities increase exponentially when the % RH increases from 60 to 90, possibly due to the effect of plasticizer on water molecules. Pectin, chitosan, pullulan, and myofibrillar protein films are also extremely permeable to gas at high RH. The permeability of protein-based films tested at high RH was high (10 to 28 times higher) in comparison with traditional synthetic films (Gontard et al., 1996). Gontard et al. (1994) reported that although most plastic films are not affected by relative humidity, films made from biological materials might change their mechanical and coating properties under high moisture conditions, which is also observed for fresh fruit and vegetables stored in the HRHSC.

5.4.2 Firmness

Coatings create an atmosphere with high levels of CO_2 and low levels of O_2 that can reduce the activities of cell softening enzymes and allow the retention of firmness during storage (Maftoonazad et al., 2008). Coating delays the degradation of fruit structural components, mainly insoluble pectin and protopectin, and maintains fruit firmness. This study showed that the application of edible coatings significantly improved the retention of firmness in the LRHSC. At the same time, there was no significant difference in the HRHSC, which is consistent with the coated tomatoes showing retention of firmness during storage when compared with the controls (Park et al. 1994).

Tubers coated with the F1 formula started losing firmness significantly after three months of cold storage, which can be explained by the high concentration of zein in the F1 formula, which caused anaerobic respiration. Another reason for a loss of firmness is the effect of the essential oil added to the formulae. Zhuang et al. (1996) reported that coatings caused delayed ripening of tomatoes and kept them firm. Furthermore, the results showed that a formulation with mustard oil and zein resulted in rapid softening, which suggested that mustard oil could cause phytotoxic damage and soften tomatoes during storage after treatment. The loss of firmness in the HRHSC was less than that in the LRHSC due to the difference in relative humidity. The results were consistent with that of Yaman & Bayoindirli (2002), who reported higher firmness values for cherries stored at 1° C than those stored at ambient temperature. Therefore, the relative humidity and cold temperature had a significant effect on the firmness values. The firmness may be affected by the gas composition surrounding the coated fruits within a controlled atmosphere, and tomatoes were significantly firmer compared with coated and uncoated air-storage tomatoes (Taşdelen & Bayindirli, 1998).

5.4.3 Respiration, ethylene and sprouting rate

The application of the edible coatings reduced the respiration rate in all cultivars and under all storage conditions. Excessive gas exchange restrictions are known to lead to anaerobic and off-flavor production through the depletion of endogenous O_2 and increase in CO_2 (Jiang et al., 2012). Such changes probably happened to the tubers coated with the F1 formula, where some tubers developed an unacceptable odor in addition to fungal growth after three months of storage. In some coated fruit and vegetables, the heat produced by respiration can cause more serious harm due to a rise in ambient temperature, which can increase both respiration and transpiration levels (Maftoonazad et al., 2008). Low permeability coatings provide a greater gas

barrier between the internal fruit and the external atmosphere, resulting in an altered internal fruit environment with relatively high CO_2 and low O_2 levels, which can improve fruit shelf life in the same manner as the controlled atmosphere or modified atmosphere packaging method. Suitable low inner O_2 and high CO_2 partial pressures can reduce the respiration rate, maintain firmness, and delay ripening and senescence. Over modification can cause anaerobic metabolism, while less modification of the inner fruit atmosphere imparts fewer advantages in terms of ripening control (Bai et al., 2003). The permeability to carbon dioxide and oxygen without plasticizer was significantly higher than that of plasticized films. Such findings can be due to the presence of pores and cracks on unplasticized film surfaces. Pore size determines the dispersion of permeability values compared to plasticized films. The CO_2 permeability of plasticized starch-based films was not affected by lipid involvement (García et al., 2000).

Ethylene is a gas hormone in fruits and vegetables that influences specific biochemical processes. During harvest time, ethylene production showed in a small increase, which could be due to wounds during the harvest process. Although ethylene concentrations are very low in potato storages, but external sources of ethylene can increase respiration in processing potatoes (Bethke 2014). Higher concentration of exogenous ethylene inhibits the sprouting of potato tubers by affecting carbohydrate metabolism (Dai et al., 2016). The levels of C_2H_4 formation in coated fruits differed according to the type and composition of the coating film (Atieno et al., 2019). The levels of C_2H_4 differed among the cultivars in both seasons and were relatively high in all cultivars in the 2017 season, while in the 2018 season, it was less at the zero time. After three months of cold storage, the C_2H_4 levels were decreased by the effect of the low temperature. There were differences between the control and coated tubers for all cultivars and formulae in both seasons; however, the differences were not significant in the HRHSC. This

finding is consistent with Zahedi et al. (2019), who mentioned that ethylene production significantly decreased in mango fruits coated with chitosan. Chitosan as a barrier film provides a selective membrane for ethylene permeation into or out of the fruit, and it gradually diminishes fruit production of ethylene. Similar results were reported for mango by Jitareerat et al. (2007) and Jongsri et al. (2016) and papaya by Ali et al. (2011). At the end of storage, the levels of C_2H_4 increased, which may be due to some tubers beginning to sprout. The effect of the coating in the LRHSC treatment was noticed, which may be related to a decrease in the gas permeability of the coating materials at low relative humidity conditions, as reported by Gontard et al. (1996). In low humidity conditions, tubers tend to lose more moisture causing stress resulting in ethylene production and sprout initiation (Emragi et al., 2021c). Increased production of C_2H_4 deteriorates the quality properties of the stored fruits, which was what we found at the end of the storage time, especially for PM and RG in the LRHSC, where the C_2H_4 levels increased and sprouting appeared. Similar results were obtained by Atieno et al. (2019) in cassava due to an increase in ethylene production at the early phase of storage. The application of edible coatings delayed the appearance of sprouts significantly after eight weeks of storage at room temperature with all cultivars, especially in the 2017 season.

5.4.4 Sensory evaluation

The application of edible coatings on potatoes improved the sensory evaluations, such as for color, gloss, and general acceptance, especially with the F4 and F5 formulae. Oms-Oliu et al. (2008) found that melon coated with fresh-cut alginate and pectin scored higher for overall preference than the control and gellan-coated cut fruit. The acceptance ratings were > 0.8 for the coated sample color but < 0.6 for the uncoated samples. Similar results were obtained for tomatoes coated with gum arabic by Ali et al. (2010), who performed a sensory evaluation of

color for coated and uncoated tomatoes at the end of storage. Additionally, the results are consistent with those of Martínez-Romero et al. (2006), who found that sweet cherry coated with aloe vera gel had the highest visual aspect scores compared with the control. The type and nature of the surface of the coated products play a major role in consumer acceptance of the coated product. The tubers coated by F1 were excluded from the experiment due to unacceptable odor development, which may be explained by the effect of the concentration of the coating materials, which is one of the important factors that controls the effectiveness of the coating formulation. Ali et al. (2010) found that tomatoes coated with 10% gum arabic had the highest scores in all storage categories while tomatoes coated with 15% and 20% gum arabic had poor pulp color and lower firmness and off-flavor. Untreated controls and tomato treated with 5% gum arabic had lower off-flavor levels and improved overall acceptability. The tubers coated with F1 and F6 developed whitening on the skin after being completely dry, which may explain the lower scores for color and general acceptance that panelists reported to the F6. Bai et al. (2003) reported that apple coated with higher than 11% zein developed unacceptable whitening. Zein has whitening problems when used as a coating, especially in highly humid environments. Preparations with zein and vegetable oil emulsions will significantly reduce whitening problems (Bai et al., 2003).

5.4.5 Bioactive compounds

Generally, most of the edible coatings had no effect on the bioactive compounds of the potatoes, although exceptions were observed in the case of F2, F6, and F7 on total phenolics. In fact, the loss of bioactive components usually associated with water loss. The solubilization of polysaccharides and hemicelluloses in the cell wall of fruits may contribute to senescence and nutrient loss. In this study, the total phenolic content decreased during the storage period under all storage conditions. Although the coatings reduced the loss of phenolics, it was not significant.

These results are inconsistent with chitosan coatings on grapes, in which phenolics increased at the end of the storage period (Meng et al., 2008). Although F3, F6, and F7 reduced the content of reducing sugars in the LRHSC, the effects were not significant. The high content of reducing sugars in the tuber induces the Maillard reaction (between reducing sugars and amino acids) responsible for undesirable darkening in potato fry product (Abong et al., 2009).

Conclusions

Our study showed that the coating treatment of RG and PM maintained better tuber quality in the LRHSC and at room temperature than the control. Coatings are cultivars specific as they did not significantly affect the quality of YG in any treatments. F2, F3, and F7 coating formulations were more effective than the others in terms of weight loss reduction, firmness maintenance, and sensory enhancement for RG and PM cultivars in LRHSC. F1, F2, and F3 coatings significantly delayed tuber sprouting at room temperature for RG and PM cultivars. We did not observe any significant change in the levels of bioactive compounds in potato tubers because of the coatings. The addition of essential oils in coating formulations serves two purposes: to inhibit disease and sprouting. Future research focuses on multi-layered coating and the application of nanotechnologies to coating formulations.

5.5 Reference

Abong, G. O., Okoth, M. W., Karuri, E. G., Kabira, J. N., & Mathooko, F. M. (2009). Levels of reducing sugars in eight Kenyan potato cultivars as influenced by stage of maturity and storage conditions. *Journal of Animal and Plant Sciences*, 2, 76-84.

Ali, A., Maqbool, M., Ramachandran, S., & Alderson, P. G. (2010). Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (Solanum lycopersicum L.) fruit. *Postharvest biology and technology*, *58*(1), 42-47.

https:// DOI .org/10.1016/j.postharvbio.2010.05.005

Ali, A., Muhammad, M. T. M., Sijam, K., & Siddiqui, Y. (2011). Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (Carica papaya L.) fruit during cold storage. *Food Chemistry*, *124*(2), 620–626. Doi.org/10.1016/j.foodchem.2010.06.085

Atarés, L., & Chiralt, A. (2016). Essential oils as additives in biodegradable films and coatings for active food packaging. *Trends in food science & technology*, *48*, 51-62. DOI: 10.1016/j.tifs.2015.12.001

Atieno, L., Owino, W., Ateka, E. M., & Ambuko, J. (2019). Influence of Coating Application Methods on the Postharvest Quality of Cassava. *International Journal of Food Science*, *2019*, 2148914. https://doi.org/10.1155/2019/2148914.

Ayranci, E., & Tunc S. (2004). The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.) Food Chemistry, *87*(3), 339-342. DOI: 10.1016/j.foodchem.2003.12.003

Bai, J., Alleyne, V., Hagenmaier, R. D., Mattheis, J. P., & Baldwin, E. A. (2003). Formulation of zein coatings for apples (*Malus domestica* Borkh). *Postharvest Biology and Technology*, *28*(2), 259–268. DOI: 10.1016/S0925-5214(02)00182-5

Banks, N. H. (1985). Coating and modified atmosphere effects on potato tuber greening. *The Journal of Agricultural Science*, 105(1), 59-62. Doi.org/10.1017/S0021859600055702

Bethke, P. C. (2014). Ethylene in the atmosphere of commercial potato (Solanum tuberosum) storage bins and potential effects on tuber respiration rate and fried chip color. American Journal of Potato Research, 91(6), 688-695.

Crossen, E. (2017). Textural, Color and Sensory Attributes of Fruits and Vegetables Dried Using Electric Forced-Air and Solar Dehydrators. *Theses and Dissertations*. https://scholarsarchive.byu.edu/etd/6675

Dai, H., Fu, M., Yang, X., & Chen, Q. (2016). Ethylene inhibited sprouting of potato tubers by influencing the carbohydrate metabolism pathway. Journal of food science and technology, 53(8), 3166-3174. DOI: 10.1007/s13197-016-2290-0

Devlieghere, F., Vermeulen, A., & Debevere, J. (2004). Chitosan: Antimicrobial activity, interactions with food components and applicability as a coating on fruit and vegetables. *Food Microbiology*, *21*(6), 703–714. https:// DOI .org/10.1016/j.fm.2004.02.008

Diganta Kalita and Sastry S Jayanty* (2014) Comparison of Polyphenol Content and Antioxidant Capacity of Colored Potato Tubers, Pomegranate, and Blueberries. *J Food Process Technol*, 5:8. DOI: 10.4172/2157-7110.1000358

Diganta Kalita, David G. Holm, Daniel V. LaBarbera, J. Mark Petrash, Sastry S. Jayanty* (2018) Inhibition of α-glucosidase, α-amylase, and aldose reductase by potato polyphenolic compounds. Published: January 25, 2018. https://DOI.org/10.1371/journal.pone.0191025

Dutta, P. K., Tripathi, S., Mehrotra, G. K., & Dutta, J. (2009). Perspectives for chitosan based antimicrobial films in food applications. Food Chemistry, 114(4), 1173–1182. https://doi.org/10.1016/j.foodchem.2008.11.047.

Emragi, E., Holm, D. G., & Jayanty, S. S. (2021a). The Effect of Field Heat Reduction Methods on Fresh and Processing Qualities of Red and Russet Potato Cultivars. Journal of Food Science & Technology, 6(2) :345-355. https:// DOI: 10.25177/JFST.6.2.RA.10747.

Emragi, E., & Jayanty, S. S. (2021b). Skin Color Retention in Red Potatoes during Long-Term Storage with Edible Coatings. Foods, 10(7), 1531.https://doi.org/10.3390/foods10071531

Emragi, E., Sathuvalli, V., & Jayanty, S. S. (2021c). The impact of ventilation conditions on the quality of Rio Grande Russet tubers during long-term cold storage. *Journal of Agriculture and Food Research,* 3, 100095. https://DOI.org/10.1016/j.jafr.2020.100095.

Galus, S., Lenart, A., Voilley, A., & Debeaufort, F. (2013). Effect of oxidized potato starch on the physicochemical properties of soy protein isolate-based edible films. *Food Technology and Biotechnology,* 51(3), 403-409.

Galus, S., & Kadzińska, J. (2015). Food applications of emulsion-based edible films and coatings. *Trends in Food Science & Technology*, 45(2), 273-283. https:// DOI.org/10.1016/j.tifs.2015.07.011

García, M. A., Martino, M. N., & Zaritzky, N. E. (2000). Lipid Addition to Improve Barrier Properties of Edible Starch-based Films and Coatings. *Journal of Food Science*, *65*(6), 941–944. https:// DOI.org/10.1111/j.1365-2621.2000.tb09397.x

Gontard, N., Thibault, R., Cuq, B., & Guilbert, S. (1996). Influence of Relative Humidity and Film Composition on Oxygen and Carbon Dioxide Permeabilities of Edible Films. *Journal of Agricultural and Food Chemistry*, *44*(4), 1064–1069. DOI.org/10.1021/jf9504327

Gontard, N., Duchez, C., CUQ, J. L., & Guilbert, S. (1994). Edible composite films of wheat gluten and lipids: water vapour permeability and other physical properties. *International Journal of Food Science & Technology*, *29*(1), 39-50. https:// DOI.org/10.1111/j.1365-2621.1994.tb02045.x

Hagenmaier, R. D., & Shaw, P. E. (1991). Permeability of shellac coatings to gases and water vapor. *Journal of Agricultural and Food Chemistry*, *39*(5), 825–829. DOI.org/10.1021/jf00005a001

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

Hellmann, H., Goyer, A., & Navarre, D. A. (2021). Antioxidants in Potatoes: A Functional View on One of the Major Food Crops Worldwide. *Molecules*, *26*(9), 2446. DOI.org/10.3390/molecules26092446

Jiang, T., Feng, L., & Li, J. (2012). Changes in microbial and postharvest quality of shiitake mushroom (Lentinus edodes) treated with chitosan–glucose complex coating under cold storage. *Food Chemistry*, *131*(3), 780–786. DOI: 10.1016/j.foodchem.2011.08.087

Jitareerat, P., Paumchai, S., Kanlayanarat, S., & Sangchote, S. (2007). Effect of chitosan on ripening, enzymatic activity, and disease development in mango (*Mangifera indica*) fruit. *New Zealand Journal of Crop and Horticultural Science*, *35*(2), 211–218. DOI.org/10.1080/01140670709510187

Johnston, GR and RG Rowberry. 1981. Yukon Gold: A new yellow-fleshed, medium-early, high quality table and french-fry cultivar. *American Journal of Potato Research* 58:241-244. https://. DOI.org/10.1007/BF02853905

Jongsri, P., Wangsomboondee, T., Rojsitthisak, P., & Seraypheap, K. (2016). Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit. *Lwt, Food Science and Technology 73*, 28–36. DOI: 10.1016/j.lwt.2016.05.038

Karanisa, T., Alexopoulos, A.A., Akoumianakis, K.A., Karapanos, I.C. and Passam, H.C. (2019). Effect of surface coating with waxes on the dormancy of potato tubers grown from true potato seed (TPS). *Acta Hortic 1242*, 711-718. DOI:10.17660/ActaHortic.2019.1242.105

King, B. C., Donnelly, M. K., Bergstrom, G. C., Walker, L. P., & Gibson, D. M. (2009). An optimized microplate assay system for quantitative evaluation of plant cell wall–degrading enzyme activity of fungal culture extracts. *Biotechnology and Bioengineering*, *102*(4), 1033–1044. DOI: 10.1002/bit.22151

Külen, O., Stushnoff, C., & Holm, D. G. (2013). Effect of cold storage on total phenolics content, antioxidant activity and vitamin C level of selected potato clones. *Journal of the Science of Food and Agriculture*, *93*(10), 2437–2444. DOI: 10.1002/jsfa.6053

Kurek, M., Galus, S., & Debeaufort, F. (2014). Surface, mechanical and barrier properties of bio-based composite films based on chitosan and whey protein. *Food Packaging and Shelf Life*, 1(1), 56-67. DOI: 10.1016/j.fpsl.2014.01.001

Madiwale, G. P., Reddivari, L., Stone, M., Holm, D. G., & Vanamala, J. (2012). Combined effects of storage and processing on the bioactive compounds and pro-apoptotic properties of color-fleshed potatoes in human colon cancer cells. *Journal of Agricultural and Food Chemistry*, *60*(44), 11088-11096. DOI: 10.1021/jf303528p.

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. *International Journal of Food Science & Technology*, *43*(6), 951–957. DOIorg/10.1111/j.1365-2621.2006.01444.x

Martínez-Romero, D., Alburquerque, N., Valverde, J. M., Guillén, F., Castillo, S., Valero, D., & Serrano, M. (2006). Postharvest sweet cherry quality and safety maintenance by Aloe vera treatment: A new edible coating. *Postharvest Biology and Technology*, *39*(1), 93–100. DOI.org/10.1016/j.postharvbio.2005.09.006.

Meng, X., Li, B., Liu, J., & Tian, S. (2008). Physiological responses and quality attributes of table grapefruit to chitosan preharvest spray and postharvest coating during storage. *Food Chemistry*, *106*(2), 501–508. DOI: 0.1016/j.foodchem.2007.06.012.

Narwojsz, A., Borowska, E. J., Polak-Śliwińska, M., & Danowska-Oziewicz, M. (2020). Effect of different methods of thermal treatment on starch and bioactive compounds of potato. *Plant Foods for Human Nutrition*, 1-7. DOI.org/10.1007/s11130-020-00808-0

Oms-Oliu, G., Soliva-Fortuny, R., & Martín-Belloso, O. (2008). Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. *LWT-Food Science and Technology*, *41*(10), 1862–1870. DOI.org/10.1016/j.lwt.2008.01.007

Owolabi, M. S., Lajide, L., Oladimeji, M. O., & Setzer, W. N. (2010). The effect of essential oil formulations for potato sprout suppression. *Natural product communications*, *5*(4), 1934578X1000500431. DOI.org/10.1177/1934578X1000500431

Park, H. J., Chinnan, M. S., & Shewfelt, R. L. (1994). Edible coating effects on storage life and quality of tomatoes. *Journal of Food Science*, *59*(3), 568–570. DOI.org/10.1111/j.1365-2621.1994.tb05563.x

Pavlath, A. E., Gossett, C., Camirand, W., & Robertson, G. H. (1999). Ionomeric films of alginic acid. Journal of Food Science, 64(1), 61-63.

Perla, V., Holm, D. G., & Jayanty, S. S. (2012). Effects of cooking methods on polyphenols, pigments and antioxidant activity in potato tubers. *LWT-Food Science and Technology*, *45*(2), 161–171.DOI.org/10.1016/j.lwt.2011.08.005

Saha, A., Gupta, R. K., & Tyagi, Y. K. (2014). Effects of edible coatings on the shelf life and quality of potato (Solanum tuberosum L.) tubers during storage. *Journal of Chemical and Pharmaceutical Research*, *6*(12), 802-809.

Sánchez-González, L., Pastor, C., Vargas, M., Chiralt, A., González-Martínez, C., & Cháfer, M. (2011). Effect of hydroxypropylmethylcellulose and chitosan coatings with and without bergamot essential oil on quality and safety of cold-stored grapes. *Postharvest Biology and Technology*, *60*(1), 57–63. DOI.org/10.1016/j.postharvbio.2010.11.004

Sun, X. J., Yang, B. I., LI, Y. C., Han, R. F., & GE, Y. H. (2008). Postharvest chitosan treatment induces resistance in potato against *Fusarium sulphureum*. *Agricultural Sciences in China, 7*(5), 615-621.

Taşdelen, Ö., & Bayindirli, L. (1998). Controlled Atmosphere Storage and Edible Coating Effects on Storage Life and Quality of Tomatoes. *Journal of Food Processing and Preservation*, *22*(4), 303–320. DOI.org/10.1111/j.1745-4549. 1998. tb00352.x

Vokou, D., Vareltzidou, S., & Katinakis, P. (1993). Effects of aromatic plants on potato storage: sprout suppression and antimicrobial activity. *Agriculture, ecosystems & environment*, *47*(3), 223-235.

Yaman, Ö, & Bayoindirli, L. (2002). Effects of an edible coating and cold storage on shelf-life and quality of cherries. *LWT-Food Science and Technology*, *35*(2), 146–150. DOI.org/10.1006/fstl.2001.0827

Yuan, G., Chen, X., & Li, D. (2016). Chitosan films and coatings containing essential oils: The antioxidant and antimicrobial activity, and application in food systems. *Food Research International*, *89*, 117-128. DOI: 10.1016/j.foodres.2016.10.004

Zahedi, S. M., Hosseini, M. S., Karimi, M., & Ebrahimzadeh, A. (2019). Effects of postharvest polyamine application and edible coating on maintaining quality of mango (Mangifera indica L.) cv. Langra during cold storage. *Food Science & Nutrition*, *7*(2), 433–441. DOI.org/10.1002/fsn3.802

Zhuang, R., Beuchat, L. R., Chinnan, M. S., Shewfelt, R. L., & Huang, Y.-W. (1996). Inactivation of Salmonella montevideo on tomatoes by applying cellulose-based edible films. *Journal of Food Protection*, *59*(8), 808–812. DOI: 10.4315/0362-028X-59.8.808

6 Chapter 6. Skin color retention in red potatoes during long-term storage with edible coatings

6.1 Introduction

Potato (*Solanum tuberosum L.)* is one of the most consumed vegetables worldwide (Madiwale et al., 2012). The appearance is crucial for marketing fresh potatoes. A shiny bright-colored skin, which is free of blemishes and flesh color, is an essential selection criterion for the consumers. Smooth-skinned tubers, in particular reds, are vulnerable to skinning and easily noticeable. Red potatoes account for approximately 10% of the total potato production in the USA.

Red potatoes acquire skin color from the anthocyanin pigments present in the tuber periderm and peripheral cortex (Andersen et al., 2002; Brown, 2005; Lewis, 1996). The red and purple potato cultivars possess the highest concentrations of phenolic and anthocyanin compounds that exhibit antioxidant activity compared to the russet potato cultivars (Hamouz et al., 2011). During tuber bulking, the color intensity and anthocyanin concentration in red skin potatoes are reduced due to an increase in tuber size (Andersen et al., 2002).

Storage conditions greatly influence the physical and chemical properties of potatoes, as well as their nutritional value. The long-term storage requirements for potatoes are 90–95% relative humidity (RH) and an optimum temperature of 3.3-4.4°C accompanied with appropriate sprout inhibitor applications. The indicators of good quality potatoes include firmness, texture, skin color appearance, and no external defects or sprouts. Sometimes, consumers may reject the commodity if it has a faded or uncharacteristic color (Waterer 2011, Jemison et al., 2008, Busse and Bethke 2020). According to the North Dakota State University Extension article, the appearance and other quality-related issues can be accounted as one of the main reasons for the

vendors rejecting 15% or more potatoes (Understanding and Managing Blemish Problems in Fresh Market Potato — Potato Extension (ndsu.edu)).

Consumers favor tubers with bright-colored skin, and growers strive to produce and maintain red skin color at harvest, storage, and marketing (Waterer 2010; Busse and Bethke 2020). As tubers mature in the field and in storage, the amount of anthocyanin in the periderm of red-skinned potatoes decreases (Waterer 2010; Thornton et al. 2013). Application of the auxin-type plant growth regulator 2,4-D (2,4-dichlorophenoxyacetic acid) was often applied to the foliage to enhance the skin color of red-skinned potatoes (Nylund 1956; Rosen et al. 2009). In earlier days, vegetable dyes were used to enhance the color, but due to negative feedback by consumers led to finding alternative methods to maintain the color in red skin potatoes (Thonrnton et al., 2013). Besides influencing the purchaser's notion, color is also considered as an index of other quality features, such as flavor and nutrition (Nourian et al., 2003).

Natural processes, such as transpiration and respiration, continue even after the fruits and vegetables are harvested (Emragi et al., 2021; Jalali et al., 2020). Edible films and coatings limit the exchange of water vapors, oxygen, and carbon dioxide in fruits and vegetables. Coatings can be classified as food preservatives because of their ability to improve overall quality (Galus & Kadzińska, 2015). An edible coating may contain proteins, polysaccharides, lipids, or a mixture of these compounds. Much research on edible materials has recently been focused on composite or multicomponent films to take advantage of each component individually and minimize their disadvantages (Kurek et. al., 2014). A thin layer of edible coating can be directly applied to the food or commodity to form a primary envelope. Edible coatings have been used to preserve moisture and act as barriers against the gaseous exchange. Overall, they improve the sensory and

mechanical properties and prevent microbial infections, thereby extending the shelf life of the produce (Debeaufort et al., 1998; Krochta, 2002).

To the best of our knowledge, this is the first report on the use of edible coatings to maintain the skin color in red potatoes under cold storage conditions. In 2017, we conducted a preliminary study on Ciklamen and Modoc with zein, alginate, and potato starch with methyl jasmonate (100 ppm), DPA (100 ppm) and chitosan (1.5%) (Figure 7.21 and 7.22). In this study, we aimed to determine the effect of different edible coatings on two types of red skin cultivars to extend the shelf life and maintain the quality of potatoes. We also investigated the outcomes of sensory, physical, and nutritional properties upon treatment with these edible coatings.

6.2 Materials and methods

6.2.1 Tuber samples

This study was conducted during the 2018 growing season. We included two red-skin cultivars, Ciklamen and Modoc. Ciklamen is a European cultivar that is resistant to a variety of bacterial, fungal, and viral diseases. It is a short oval fresh market potato with smooth, bright red skin, and creamy-white flesh. Ciklamen has a high marketable yield, excellent taste, and a high culinary profile. Modoc is a collaborative release by the Agricultural Experiment Stations of Oregon, North Dakota, California, Idaho, and Washington. Modoc is round or oval in shape with white flesh and purplish-red skin. Freshly harvested tubers were obtained from the San Luis Valley Research Center. Tubers were harvested from mid–September to October 2018 and tubers were visually selected for uniformity in size, color, and absence of blemishes and disease. Tubers were stored in a cold room at 4°C with 95% humidity to reduce the field heat after harvest. Tubers were treated with coatings after the pulp temperature reached 4 °C. Twenty tubers were

selected for each treatment. Before the coating was applied, tubers were washed with tap water and air-dried at ambient room temperature.

6.2.2 Coating materials

Food-grade coating materials were used in this study. Zein, acid-soluble chitosan, potato starch, sodium alginate, Tween 20, acetic acid, ethanol, and glycerol were purchased from Sigma-Aldrich, Inc. (St. Louis, MO, USA). Other materials used while preparing the coating formulations, such as essential oils cinnamon, and Oregano, were purchased from Walmart.

6.2.3 Chemicals

The other chemicals, such as Folin Ciocalteu Reagent (FCR), sodium carbonate, gallic acid, aluminum chloride, calcium chloride, quercetin hydrate, dinitro salicylic acid, crystalline phenol, sodium hydroxide, sodium sulfite, potassium sodium tartrate tetrahydrate, potassium chloride, sodium acetate, and glucose were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA). All chemicals obtained were of analytical grade.

6.2.4 Preparation of coating solutions

The method described by Maftoonazad et al., (2008) was used to prepare the sodium alginate coating (F1) solution with some modification. A 1.5% (w/v) of sodium alginate powder was dissolved in water by heating at 70 °C while stirring until the solution becomes clear. Glycerol was added (50% w/sodium alginate dry weight) as a plasticizer to the coating solution. Ascorbic acid was added at a concentration of 0.75 g/100 mL of the formulation. The mixture was homogenized for 5 min at 25000 rpm using a Sorvall Omni-Mixer Homogenizer (Norwalk, Conn. USA). A 2% (w/v) solution of calcium chloride was prepared and sprayed on the tubers coated with sodium alginate to induce the cross-linking of the coating film.

The other three composite formulations prepared are as follows: 1) potato starch and alginate emulsion with the Oregano oil (F2). Potato starch (3% w/v) and sodium alginate (3% w/v) were prepared separately and then mixed at a ratio of 1:1. Glycerol was added (2% v/v formula solution) as a plasticizer. Oregano oil (0.75% v/v of formula solution) and Tween 20 (0.025 g/100 mL formulation) were added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm using Sorvall Omni-Mixer Homogenizer (Norwalk, Conn. USA). 2) zein and chitosan emulsion with the Oregano oil (F3), where the concentration in the formula was 4.5% zein and 1.5% chitosan. The acid-soluble chitosan coating solution was prepared by dissolving 1.5% (W/V) chitosan in 1% aqueous acetic acid. The mixture was homogenized for 2 min and shaken in a 60 °C water bath for 30 min, followed by cooling to room temperature. Zein (4,5% w/v) and chitosan (1.5% w/v) solutions were mixed at a ratio of 3:1. Glycerol was added (5% v/v formula solution) as a plasticizer. Oregano oil (0.75% v/v of formula solution), and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm. 3) Potato starch, chitosan, and sodium alginate with the Oregano oil (F4). Potato starch (0.5% w/v), chitosan (2% w/v), and sodium alginate (1% w/v) solutions were prepared separately and mixed at a ratio of 0.5:2:1. Glycerol was added (2% v/v formula solution) as a plasticizer. Oregano oil (0.75% v/v of formula solution), and Tween 20 was added as an emulsifier agent. The mixture was homogenized for 5 min at 25000 rpm.

6.2.5 Application of treatments and storage

Tubers were divided into several sets based on the number of formulations. They were sprayed until all tubers were covered entirely with the coatings. The coating films on the surfaces of the tubers were then dried through blowing air for 15 min. The dried samples were packaged

in plastic mesh bags. The treated tubers were stored at 4 ± 2°C and 90 ± 5% relative humidity (RH) in the dark for six months.

6.2.6 Color measurement

The colorimetric measurements of the tubers for each treatment during the storage were obtained through monitoring the color changes in the tubers at zero time, three, and six months using the method described by Manolopoulou et al., (2010). A Photovolt Instrument MiniScan Chromameter (Reston, Virginia, USA) was used to assess the color on CIE $L^*a^*b^*$ chromatic space. The L^* variable is an indicator of the darkening or lightening of the color. The a^* scale measures the degree of red ($+a^*$) color, while the b^* scale measures the degree of yellow ($+b^*$) color. The instrument was calibrated using white and black standards. Fifteen tubers were selected from each treatment group. A flat spot was marked on each tuber to minimize the external light, such that it did not interfere with the measurements. The same spot was used each time to perform the color measurement. The chroma values of the tubers were calculated by using the chroma values equation. $C^* = (a^{*2}+b^{*2})^{0.5}$. C* chroma value described the intensity of color in a sample.

6.2.7 Extraction procedure for total phenolics, total flavonoids, and reducing sugars

Potato tubers were collected from each treatment group at zero time, three, and six months. After that, all tubers were cut into small pieces, frozen, freeze-dried, and stored at -80°C for further analysis. One gram of freeze-dried material was weighed in a 10 mL falcon tube, and then 5 mL 95% methanol was added. The mixtures were vortexed for 1 min, and the tubers were incubated overnight in an orbital shaker at 150 rpm and 25°C. The homogenates were centrifuged at 5000 rpm for 25 min, followed by filtration using Whatman paper (40 nm). The

remaining tubes were re-extracted under identical conditions. The final volume was made up to 10 mL using methanol and stored at -80 °C for further analysis. The previous extraction was used to determine the levels of total phenolics, flavonoids, and reducing sugars.

6.2.8 Determination of reducing sugars

The level of reducing sugars were determined using a previously described 96-well microplate assay with slight modifications (King et al., 2009). At first, the dinitrosalicylic acid reagent was prepared (10 g/L dinitrosalicylic acid, 2 g/L crystalline phenol, 10 g/L sodium hydroxide, and 0.5 g/L fresh sodium sulfite). One hundred and twenty µL of the dinitrosalicylic acid reagent was added to each PCR tube (BioExpress, Kaysville, UT), and 20 µL of the extract was added and mixed well. The mixture was heated in a water bath at 99°C for 15 min, cooled at 4°C for 1 min, and incubated at 20°C to stop the further reaction. After thorough mixing of the contents in each tube, 100 µL of the mixture was transferred to a 96-well flat-bottom microplate with 40 µL of 400 g/L potassium sodium tartrate tetrahydrate solution. The plates were well mixed for 2 min in the plate reader, and the absorbance was measured at 570 nm. The glucose standard was prepared using 800 mL/L methanol, and reducing sugars were expressed as mg glucose per g of dry matter.

6.2.9 Anthocyanins determination

A previously described pH differential method (Madiwale et al., 2012) was used to determine the total monomeric anthocyanin content with slight modifications. One gram of freeze-dried potato sample was homogenized in 5 mL of acidified ethanol (80%, with 0.1% v/v formic acid). The mixture was vortexed for 1 min every 15 min for 1 h. Then, 3 mL of chloroform was added, and the tubes were vortexed every 10 min for 30 min. The tubes were then centrifuged at 5000

rpm for 20 min and stored overnight at 4°C. The ethanol phase was collected and stored at -20°C until further analysis. Ten microliters of the previous extract of each sample were added to 290 µL of potassium chloride (pH 1.0) and sodium acetate (pH 4.5). The absorbance was measured at 525 and 700 nm for both sets of solutions with pH 1.0 and 4.5. Total anthocyanin content was calculated using the following equation:

$$Total\ monomeric\ anthocyanin\ \left(\frac{mg}{L}\right) = \frac{(A\ x\ MW\ x\ 1000)}{\varepsilon} x\ 1$$

where $A\ =\ (A525 - A700)\ pH\ 1.0 - (A525 - A700)\ pH\ 4.5$

MW = 449.2 and ε = 26,900 are molecular weight and molar absorptivity of cyaniding-3-glucoside, respectively; 1 is the path length. The total anthocyanin was reported as mg/g dry matter.

6.2.10 Sensory evaluation

The sensory evaluation of the control and treated tubers for the color, gloss, texture, odor, and overall acceptability was performed three months after the treatments and cold storage at 4 ± 2°C and 90 ± 5% RH. A previously described method (Bai et al., 2003) was used, with minor modifications. A panel of forty judges (22 women and 18 men) with ages ranging from 21 to 55 years were randomly selected. Panelists were asked to score for color, gloss, texture, odor, and overall acceptability where 1 represents extreme dislike, 2 moderate dislike, 3 neither like nor dislike, 4 moderate liking, and 5 extreme liking for the color, gloss, texture, odors, and overall acceptability.

6.2.11 Experimental design and statistical analyses

The data on color (n = 15) were statistically analyzed using repeated measures design. While the anthocyanins, reducing sugars, total phenolics, total flavonoids, vitamin C (n = 3), and

sensory evaluation (n = 40) were analyzed using factorial design. All results were expressed as mean ± standard deviation (SD) values. The P values obtained using the ANOVA for all responses are available in supplementary table 7.3. All data were subjected to analysis of variance (ANOVA) of potato cultivars (Ciklamen and Modoc) and storage times (zero, three, and six months) separately for all coating formulations and control samples. Tukey's test was used to compare differences between treatments during storage time for both cultivars, and treatments were significant considered at $P<0.05$. All statistical analyses were performed using the R software, version 3.4.3.

6.3 Results

6.3.1 Color change

The color changes in Ciklamen and Modoc during storage are presented in Figure 1a and b. The effect of the edible coatings on the tubers was noticeable immediately after the treatment. The results of chroma value measurements revealed a significant ($P<0.05$) effect of the treatment of tubers with the edible coatings on the color at all storage periods, including zero time, three, and six months. F1 and F2 formulations were the most effective, whereas F3 formulation was less effective, during the storage period, there was no significant change in the skin color of the tubers after each treatment.

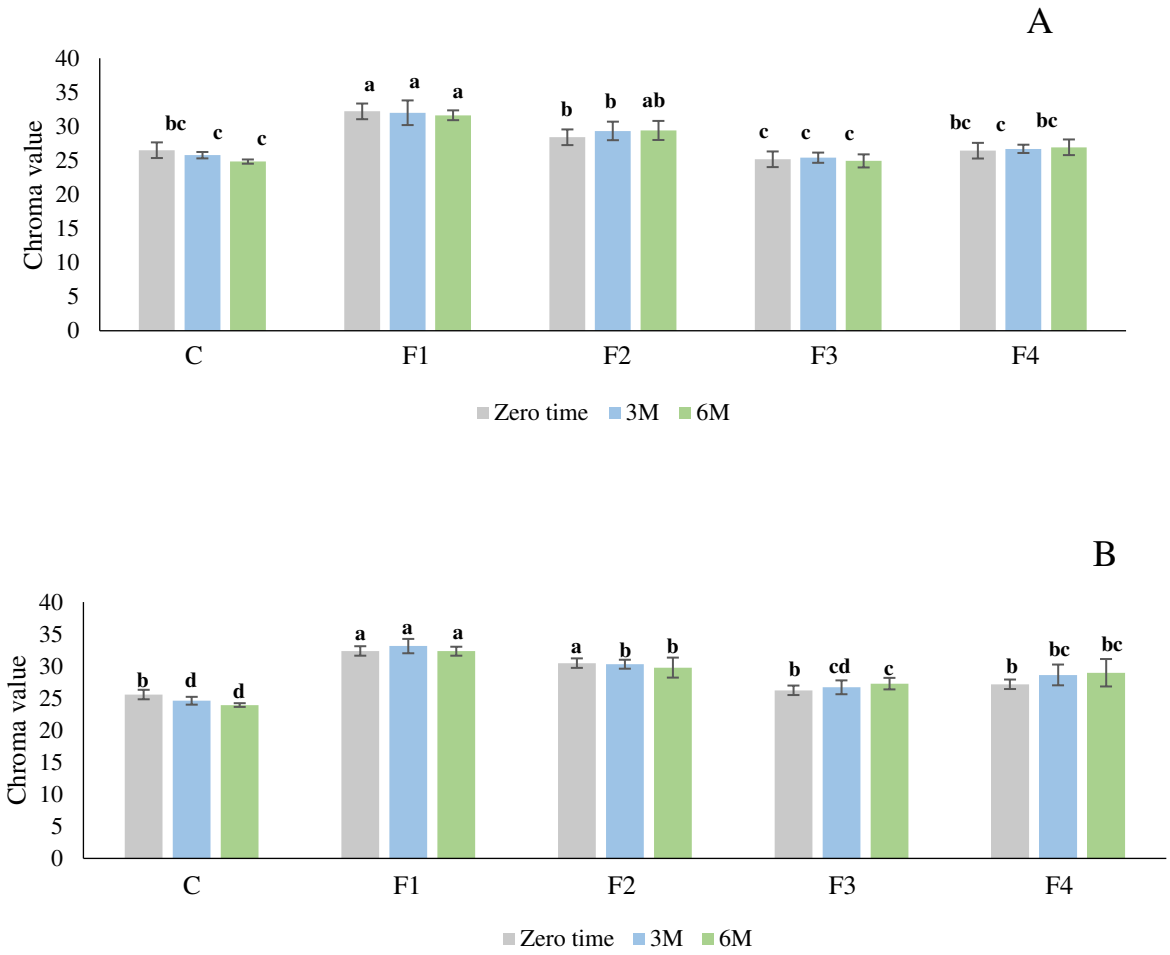


Figure 6.1. Effect of different edible coatings on the skin color of Ciklamen (a) and Modoc (b) after six months of cold storage at 4 ± 2°C and 90 ± 5% RH. Data are expressed as mean ± SD, n = 15. The different letters on the bars are indicative of statistical significance (P<0.05). C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with Oregano oil, F3: zein + chitosan emulsion with Oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with Oregano oil.

6.3.2 Reducing sugars

The levels of reducing sugars in treated tubers stored at 4 ± 2°C and 90 ± 5% RH for six months are shown in Figure 2 a and b. In case of Ciklamen cultivar, there was no significant difference in the levels of reducing sugars during the entire storage duration. However, there

were significant differences ($P < 0.05$) in case of Modoc. F4 formulation decreased the concentration of reducing sugars to the highest degree, while F2 and F3 exerted a negligible effect. Meanwhile, the concentration of reducing sugars increased in all treatment groups relative to the storage time, possibly due to the impact of low temperature.

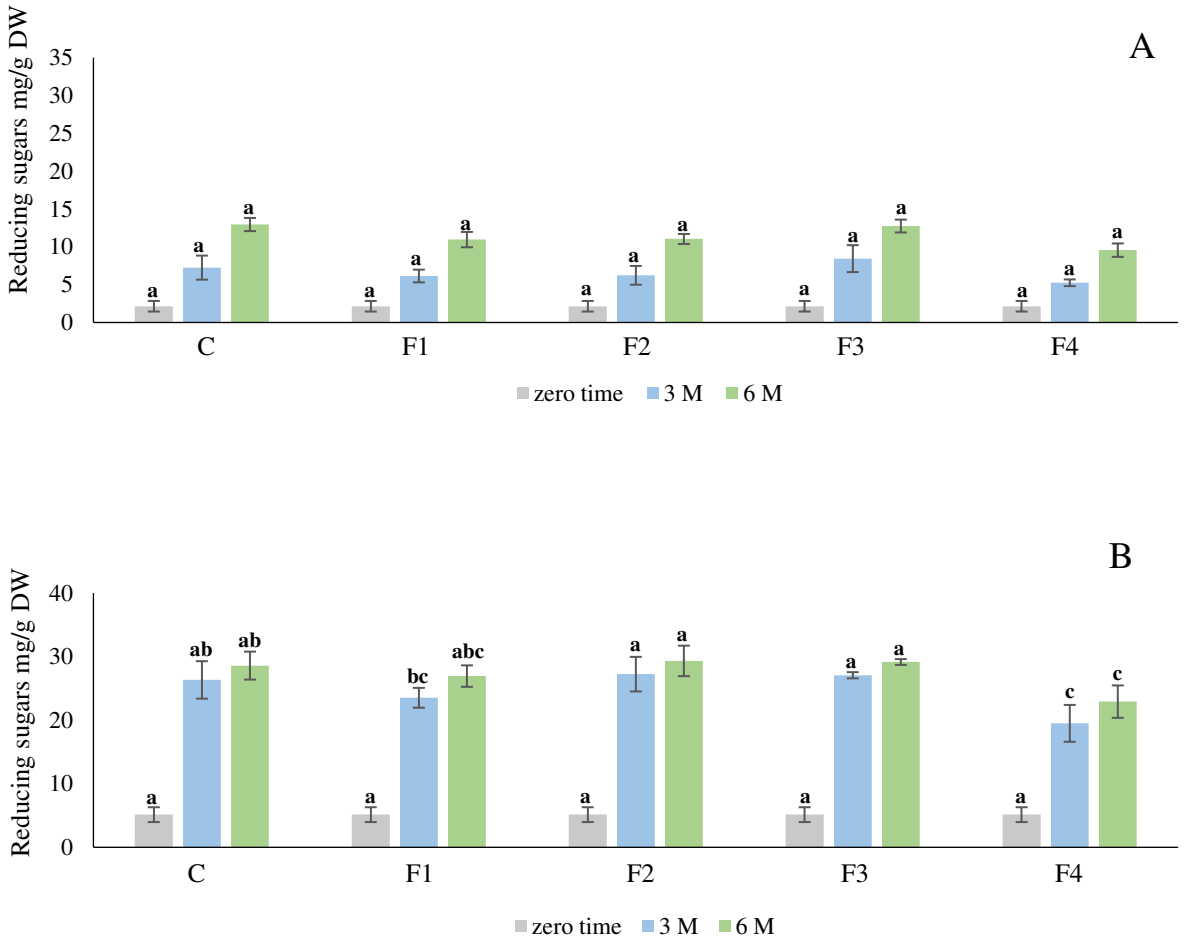
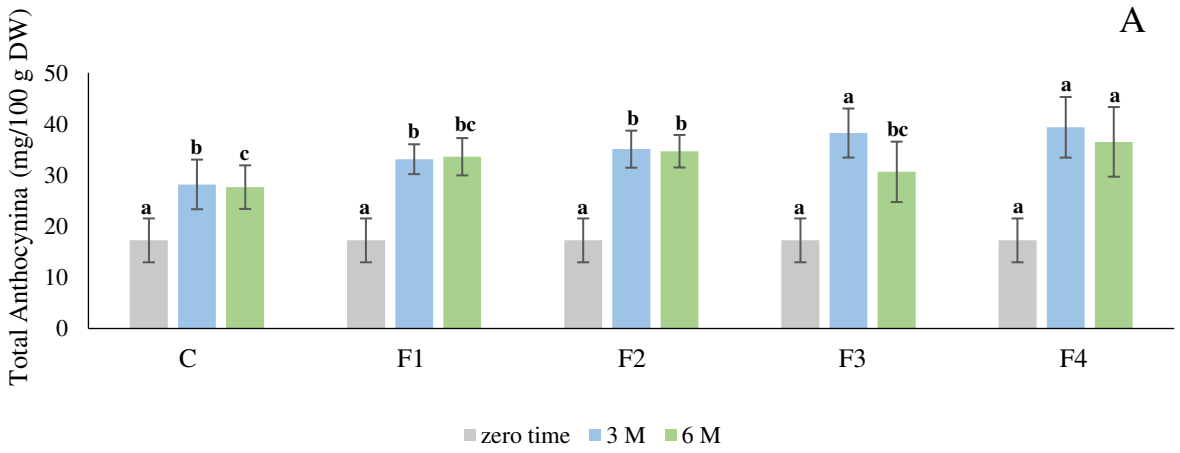


Figure 6.2. Effect of different edible coatings on the concentration of reducing sugars in Ciklamen (a) and Modoc (b) after six months of cold storage at 4 ± 2°C and 90 ± 5% RH. Data are expressed as mean ± SD, n = 3. The different letters are letters on the bars are indicative of statistical significance ($P < 0.05$). C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with Oregano oil, F3: zein + chitosan emulsion with Oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with Oregano oil.

6.3.3 Total anthocyanins

The total anthocyanin levels in treated tubers stored at 4 ± 2°C and 90 ± 5% RH for six months are shown in Figure 3 a and b. In general, the effect of the treatments with different edible coatings was limited after three months of cold storage. The only exception was in the treatment of Ciklamen with F3 and F4 formulations, where the increase in the level of total anthocyanins was significant. However, there was no significant effect (P>0.05) of other edible coatings on the anthocyanin content in Ciklamen after six months of cold storage. In case of Modoc, there was no significant difference in the anthocyanin content after three months of cold storage, while there was a significant effect after six months with F4 formulation (P<0.05). Meanwhile, the anthocyanin content decreased in most of the treatments relative to the storage duration. Occasionally, there was a slight decrease in the anthocyanins content observed after three months compared with that after six months.

Total phenolics, flavonoids, and Vitamin C levels were measured in all treated tubers along with controls at 0, 3, and 6 months of storage. The data was shown in the supplementary figures 7.25, 7.26, 7.27.



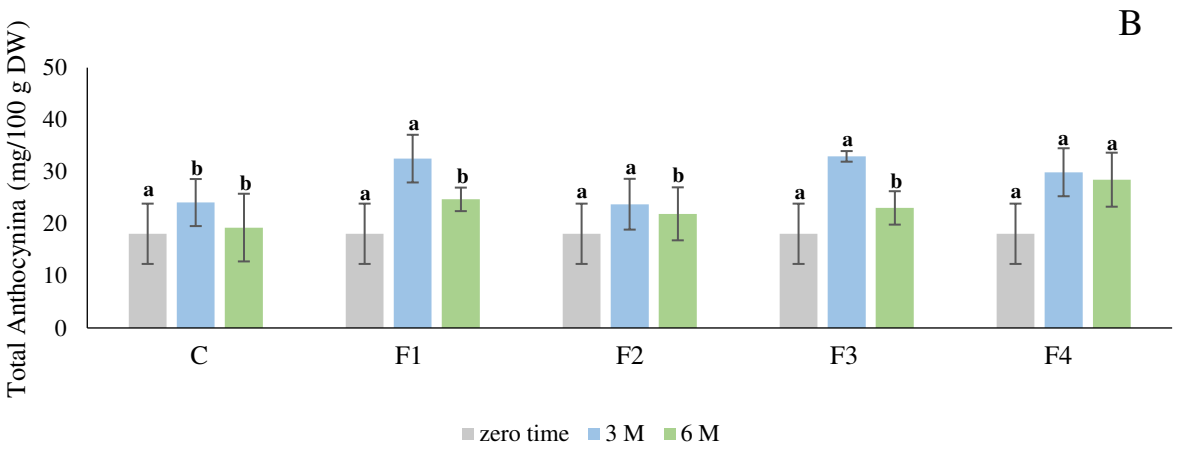
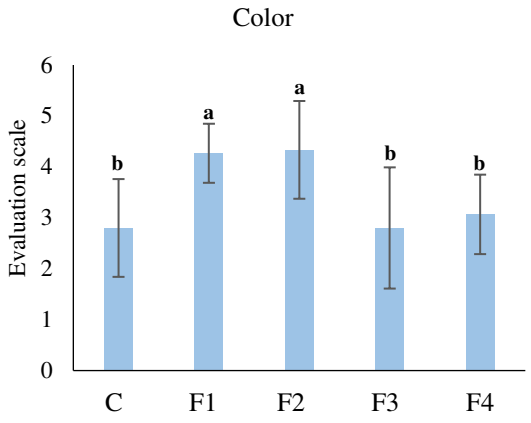
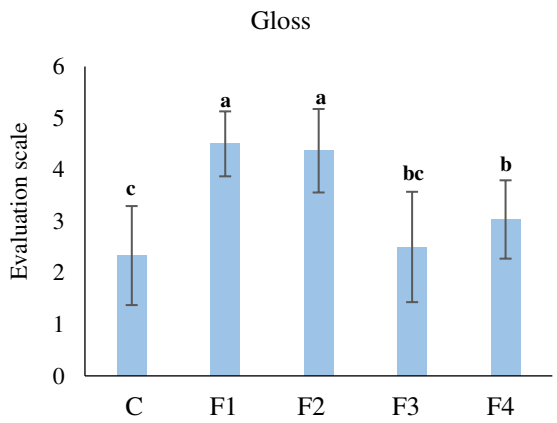


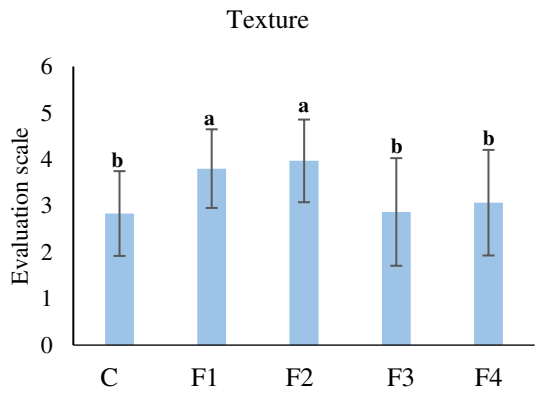
Figure 6.3. Effect of different edible coatings on total anthocyanin content of Ciklamen (a) and Modoc (b) after six months of cold storage at 4 ± 2°C and 90 ± 5% RH. Data are expressed as mean ± SD, n = 3. The different letters are letters on the bars are indicative of statistical significance (P <0.05). C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with Oregano oil, F3: zein + chitosan emulsion with Oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with Oregano oil.

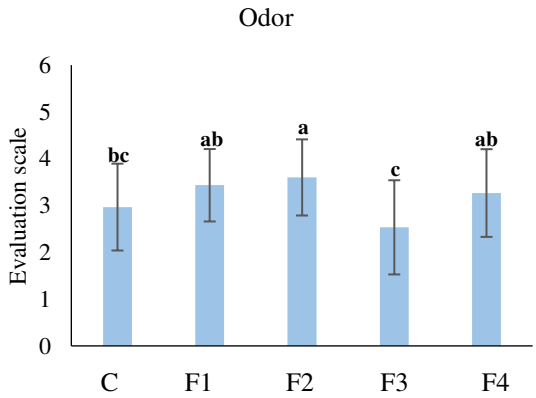
6.3.4 Sensory evaluation

Sensory evaluations were performed after three months of cold storage, and the results of the treated tubers are shown in Figures 4 and 5. F1 and F2 formulations were most effective in improving the sensory characteristics of the treated tubers, such as color, gloss, and general acceptability, compared to the control samples in both the cultivars. While F3 formulation was not acceptable by the panelists, it was significantly counterproductive when compared to the control sample.


Color
Evaluation scale
6
5
4
3
2
1
0
b
a
a
b
b
C
F1
F2
F3
F4


Gloss
Evaluation scale
6
5
4
3
2
1
0
c
a
a
bc
b
C
F1
F2
F3
F4


Texture
Evaluation scale
6
5
4
3
2
1
0
b
a
a
b
b
C
F1
F2
F3
F4


Odor
Evaluation scale
6
5
4
3
2
1
0
bc
ab
a
c
ab
C
F1
F2
F3
F4

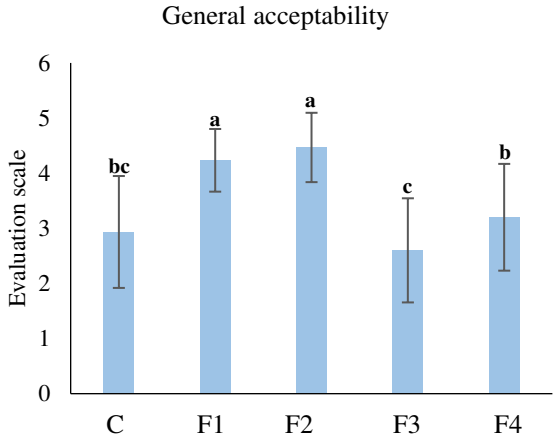

General acceptability
Evaluation scale
6
5
4
3
2
1
0
bc
a
a
c
b
C
F1
F2
F3
F4

Figure 6.4. Effect of different edible coatings on sensory evaluations of Ciklamen and Modoc after six months of cold storage at 4 ± 2°C and 90 ± 5% RH. Data are expressed as mean ± SD, n = 40. The different letters are letters on the bars are indicative of statistical significance (P <0.05). C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with Oregano oil, F3: zein + chitosan emulsion with Oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with Oregano oil.

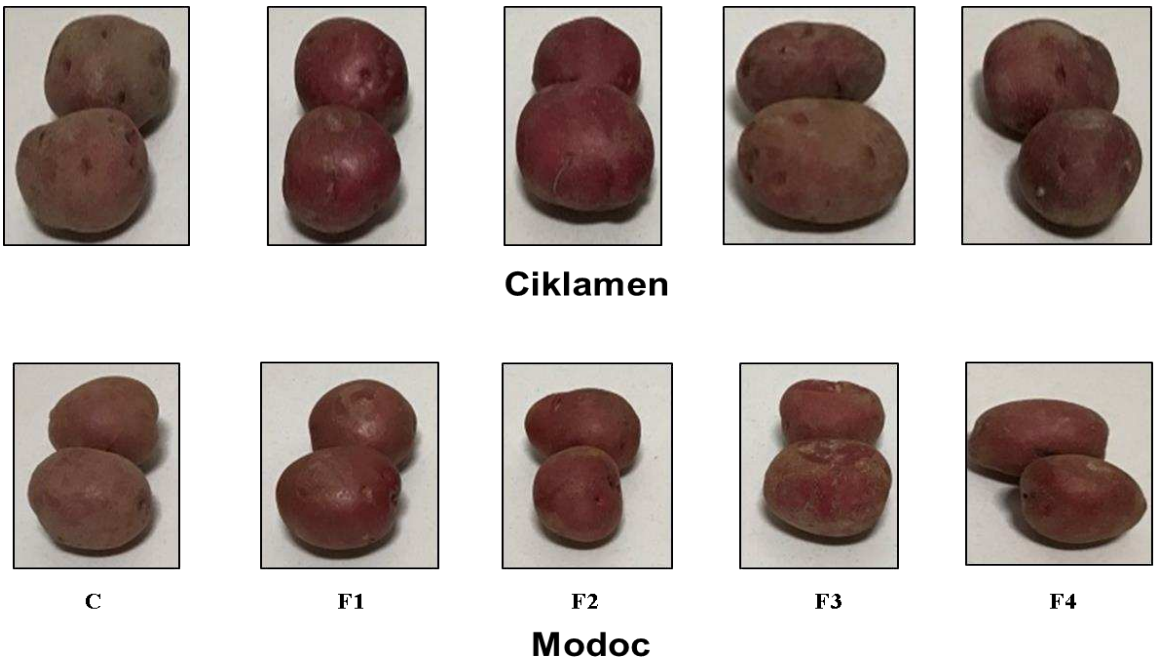


Figure 6.5. Effect of different edible coatings on the appearance of Cicklamen and Modac tubers after three months of cold storage at 4 ± 2°C and 90 ± 5% RH. C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with Oregano oil, F3: zein + chitosan emulsion with Oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with Oregano oil.

6.4 Discussion

A consumer's first decision on quality is based on the visual appearance and color of the commodity. Appearance is one of the most important attributes that influences the consumers acceptability of any product (Pedreschi et al., 2005; Pathare et al., 2013). From 2016 to 2018, we tested different formulations on three different potato cultivars (Rio Grande, Youkan Gold, and Purple Majesty) to study the effect of edible coatings on fresh potato tuber under different

storage conditions. During this study, we noticed that the application of coatings has a positive effect on the skin color of the tubers. In 2016 we tested several formulae with simple compounds and at different concentrations. A preliminary study in 2016 showed that some materials are hard to apply (due to high viscosity and difficulty to dry). Formulations containing zein showed fungal growth but acted as a good moisture barrier.

Our current studies suggest edible coatings, especially sodium alginate enhance the color of red skin potato (Fig 1). There were significant differences ($P<0.05$) in the chroma values between the control and treated tubers during cold storage. It is likely possible that these edible coatings provide a thick barrier against ethylene production and gaseous exchange between the tubers and environment, thereby delaying the natural processes, such as respiration and transpirational loss in coated tubers during cold storage. Additionally, high CO_2 levels have been shown to decrease ethylene synthesis in tomatoes, which delays changes in color (Ali et al., 2010). The presence of antioxidants (vitamin C and essential oil) in the formulation might be another reason for delaying the color changes during storage. The data on lightness (L^*) revealed an insignificant gradual decrease during storage in both treated and controlled tubers (data not shown). However, there were significant differences in lightness (L^*) between the coated samples and the control. The lowest L^* values were observed in F1, and F2 treated groups, and the highest were in control, and F3 treated groups. The presence of Zein in the formulation increased L^* value, while alginate reduced it.

Anthocyanin concentrations have been shown to decrease during tuber growth in some red skin varieties (Andersen et al., 2002). Lewis et al. (1999) demonstrated the effect of temperature on red skin potato cultivars. They revealed that anthocyanin concentration decreased when the tubers were stored at 10°C, but increased at 4°C. Our results on anthocyanin estimation were

consistent with the results obtained by Lewis et al. (1999), as the anthocyanin content increased when the tubers were stored at 4°C.

Chitosan-based coating were applied for different applications on potato tuber for reducing weight loss and maintaining firmness (Saha et al., 2014), resistance to fusarium dry rot (Sun et al., 2008), and also applied to reduce greening in potatoes (Banks 1985). Chiabrando and Giacalone (2015) reported that the application of chitosan coating on blueberry delayed the changes in anthocyanin content and antioxidant activity compared to the control. Moreover, as the duration of storage advanced, the levels of anthocyanin increased in both the treated and control blueberries. Furthermore, comparing the chitosan-treated blueberries to the other treatment groups, the increase in anthocyanin level was significantly higher (Chiabrando & Giacalone, 2015).

Cortez et al., (2017) reported that the processing and storage of strawberries without oxygen appeared as a better method for anthocyanin production and color stability. An increase in the concentration of reducing sugars during cold storage due to starch conversion may have caused an increase in anthocyanin synthesis. Reducing sugars during cold storage have been shown to provide carbon skeletons for enhanced anthocyanin biosynthesis (Andersen et al., 2002). Eddy and Mapson (1951) showed that when exogenous monosaccharides, such as glucose and fructose, were applied, the anthocyanin concentration in cress seedlings (*Lepidium sativum)* increased. However, they concluded that the effects of sugar were indirect.

The permeability of the natural skin of fruits and vegetables is essential for the respiration of living tissues. Consequently, through choosing the appropriate permeability of the coating film, gaseous exchange and respiration can be regulated to extend the product's shelf life. The oxygen permeability of a film can be regulated using antioxidants, such as citric acid or ascorbic acid, as

an additive in the film composition. The selectivity of edible coating films towards O_2, CO_2, and water vapors leads to a delay in the natural ripening process (Ayranci & Tunc, 2004). The tubers treated with F1 and F2 formulations underwent delayed color change throughout the storage period.

Panelists evaluated the visual characteristics of coated tuber samples and assigned high scores to the F1 and F2 formulations in terms of color, gloss, texture, and general acceptability (Fig. 4). Since the evaluation was performed after three months of storage, the effects of edible coatings in delaying the loss of quality in terms of texture and color could be attributed to the inhibition of water diffusion. Martínez-Romero et al. (2006) observed a similar phenomenon in sweet cherries, and a decrease in water diffusion was defined as the attributable reason. Li and Barth (1998) suggested that the edible coatings reduce dehydration by physically limiting the air-filled surface tissue. The maintenance of texture in treated tubers (F1 and F2) may be attributed to their ability to prevent water loss (Oms-Oliu et al., 2008).

The highest scores for visual characterization in terms of gloss of red skin potatoes were assigned to F1 and F2 formulations compared to the control after three months of cold storage. This is because F1 and F2 formulations imparted an attractive, natural-looking gloss to the treated red skin potatoes compared to other formulations and control. Additionally, the panelists assigned the lowest ($P<0.05$) scores in terms of odor and general acceptability to F3 treated samples. This might be due to the presence of zein in the formulation, which imparts whiteness and has a strong odor (Bai et al., 2003). Although F3 coating induced negative effects on odor and general acceptability, it still maintained the quality characteristics of the treated tubers for the longest duration. This could be attributed to chitosan's superior antioxidant and antimicrobial activities (Jiang et al., 2012)

Conclusions

In this study, we demonstrated that the treatment of red skin potatoes with edible coatings (F1 and F2) increased their chroma values compared to the control. Edible coatings F3 and F4 increased anthocyanin content in both cultivars after three months of storage. The combination of potato starch, chitosan, and alginate coating (F4) was more durable and retained tuber anthocyanin levels even after six months. The treatment with edible coatings significantly improved the sensory evaluations, especially in terms of the color, gloss, and general acceptability of red skin potatoes. Alginate-based coatings enhanced the tuber red skin color (chroma value) and increased the general acceptance based on sensory characteristics in both cultivars tested.

6.5 Reference

Ali, A., Maqbool, M., Ramachandran, S., & Alderson, P. G. (2010). Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology*, 58, 42–47. https://doi.org/10.1016/j.postharvbio.2010.05.005

Andersen, A. W., Tong, C. B. S., & Krueger, D. E. (2002). Comparison of periderm color and anthocyanins of four red potato varieties. *American Journal of Potato Research*, 79, 249–253. https://doi.org/10.1007/BF02986357

Ayranci, E., & Tunc, S. (2004). The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.). *Food Chemistry*, 87, 339–342.

Bai, J., Alleyne, V., Hagenmaier, R. D., Mattheis, J. P., & Baldwin, E. A.(2003). Formulation of zein coatings for apples (*Malus domestica* Borkh). *Postharvest Biology and Technology*, 28, 259–268.

Banks, N. H. (1985). Coating and modified atmosphere effects on potato tuber greening. *The Journal of Agricultural Science,* 105(1), 59-62.

Brown, C. R. (2005). Antioxidants in potato. *American Journal of Potato Research*, 82, 163–172. https://doi.org/10.1007/BF02853654

Busse, J. S., & Bethke, P. C. (2020). Impact of 2, 4-D and potato (Solanum tuberosum L.) tuber age on anthocyanin content of skin and phellem anatomy of Red Norland. *American Journal of Potato Research,* 97(1), 102-110.

Chiabrando, V., & Giacalone, G. (2015). Anthocyanins, phenolics and antioxidant capacity after fresh storage of blueberry treated with edible coatings. *International Journal of Food Sciences and Nutrition*, 66, 248–253.

Cortez, R., Luna-Vital, D. A., Margulis, D., & Gonzalez de Mejia, E. (2017). Natural pigments: Stabilization methods of anthocyanins for food applications. *Comprehensive Reviews in Food Science and Food Safety*, 6, 180–198.

Debeaufort, F., Quezada-Gallo, J. A., & Voilley, A. (1998). Edible films and coatings: tomorrow's packagings: a review. *Critical Reviews in food science***,** 38(4), 299-313.

Eddy, B. P., & Mapson, L. W. (1951). Some factors affecting anthocyanin synthesis in cress seedlings. Biochemical Journal, 49(5), 694–699.Galus, S., & Kadzińska, J. Food applications of emulsion-based edible films and coatings. *Trends in Food Science & Technology*, 45, 273–283.

Emragi, E., Sathuvalli, V., & Jayanty, S. S. (2021). The impact of ventilation conditions on the quality of Rio Grande Russet tubers during long-term cold storage. *Journal of Agriculture and Food Research.* 3, 100095.

Galus S, Kadzińska J. (2015). Food applications of emulsion-based edible films and coatings. *Trends in Food Science & Technology*. Oct 1;45(2):273-83.

Hamouz, K., Lachman, J., Pazderu, K., Tomášek, J., Hejtmánková, K., & Pivec, V. (2011). Differences in anthocyanin content and antioxidant activity of potato tubers with different flesh colour. *Plant Soil Environ*. 57:478–485. https://doi.org/10.17221/265/2011-pse

Jalali A, Linke M, Geyer M, Mahajan PV. (2020). Shelf life prediction model for strawberry based on respiration and transpiration processes. *Food Packaging and Shelf Life*. Sep 1;25:100525.

Jemison Jr, J. M., Sexton, P., & Camire, M. E. (2008). Factors influencing consumer preference of fresh potato varieties in Maine. *American Journal of Potato Research*. 85(2), 140-149.

Jiang, T., Feng, L., & Li, J. (2012). Changes in microbial and postharvest quality of shiitake mushroom (*Lentinus edodes*) treated with chitosan–glucose complex coating under cold storage. *Food Chemistry*. 131, 780–786.

King, B. C., Donnelly, M. K., Bergstrom, G. C., Walker, L. P., & Gibson, D. M. (2009). An optimized microplate assay system for quantitative evaluation of plant cell wall–degrading enzyme activity of fungal culture extracts. *Biotechnology and Bioengineering*. 102, 1033–1044.

Krochta JM. (2002). Proteins as raw materials for films and coatings: definitions, current status, and opportunities. *Protein-based films and coatings*.1:1-40.

Kurek M, Galus S, Debeaufort F. (2014). Surface, mechanical and barrier properties of bio-based composite films based on chitosan and whey protein. *Food Packaging and Shelf Life.* Mar 1;1(1):56-67.

Lewis, Christine E. (1996). Anthocyanins and related compounds in potatoes (*Solanum tuberosum* L.). Ph.D. Thesis, University Canterbury, Christchurch, New Zealand. https://doi.org/10.26021/8459

Lewis, Christine E., Walker, J. R. L., & Lancaster, J. E. (1999). Changes in anthocyanin, flavonoid and phenolic acid concentrations during development and storage of coloured potato (*Solanum tuberosum* L) tubers. *Journal of the Science of Food and Agriculture***.** 79, 311–316. https://doi.org/10.1002/(SICI)1097-0010(199902)79:2<311::AID-JSFA199>3.0.CO;2-Q

Li, P., & Barth, M. M. (1998). Impact of edible coatings on nutritional and physiological changes in lightly-processed carrots. *Postharvest Biology and Technology*. 14, 51–60. https://doi.org/10.1016/S0925-5214(98)00020-9

Madiwale, G. P., Reddivari, L., Stone, M., Holm, D. G., & Vanamala, J. (2012). Combined Effects of Storage and Processing on the Bioactive Compounds and Pro-Apoptotic Properties of Color-Fleshed Potatoes in Human Colon Cancer Cells. *Journal of Agricultural and Food Chemistry.* 60 11088–11096. https://doi.org/10.1021/jf303528p.

Maftoonazad N, Ramaswamy HS, Marcotte M. (2008). Shelf-life extension of peaches through sodium alginate and methyl cellulose edible coatings. *International journal of food science & technology*. Jun;43(6):951-7.

Manolopoulou H, Xanthopoulos G, Douros N, Lambrinos G. (2010). Modified atmosphere packaging storage of green bell peppers: Quality criteria. *Biosystems engineering*. Aug 1;106(4):535-43.

Martínez-Romero, D., Alburquerque, N., Valverde, J. M., Guillén, F., Castillo, S., Valero, D., & Serrano, M. (2006). Postharvest sweet cherry quality and safety maintenance by Aloe vera treatment: A new edible coating. *Postharvest Biology and Technology*. 39,93–100. https://doi.org/10.1016/j.postharvbio.2005.09.006

Nourian, F., Ramaswamy, H. S., & Kushalappa, A. C. (2003). Kinetics of quality change associated with potatoes stored at different temperatures. *LWT - Food Science and Technology*. 36, 49–65. https://doi.org/10.1016/S0023-6438(02)00174-3

Nylund, R. E. (1956). The use of 2,4-D to intensify skin colour of Pontiac potatoes. *Amer. Potato J.* 33: 145-154.

Oms-Oliu, G., Soliva-Fortuny, R., & Martín-Belloso, O. (2008). Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. *LWT-Food Science and Technology.* 41, 1862–1870.

Pathare PB, Opara UL, Al-Said FA. (2013). Colour measurement and analysis in fresh and processed foods: a review. *Food and bioprocess technology*. 6(1):36-60.

Pedreschi F, Moyano P, Kaack K, Granby K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*. Jan 1;38(1):1-9.

Rosen, C. J., Roessler, J. A., Petracek, J. D., Englemann, S. and Tong, C. S. (2009). 2,4-dichlorophenoxyacetic acid increases peonidin derivativesin red Norland periderm. *Amer. J. Potato Research*. 86: 15-23.

Saha, A., Gupta, R. K., & Tyagi, Y. K. (2014). Effects of edible coatings on the shelf life and quality of potato (Solanum tuberosum L.) tubers during storage. *Journal of Chemical and Pharmaceutical Research*. 6(12), 802-809.

Sun, X. J., Yang, B. I., LI, Y. C., Han, R. F., & GE, Y. H. (2008). Postharvest chitosan treatment induces resistance in potato against Fusarium sulphureum. *Agricultural Sciences in China.* 7(5), 615-621.

Thornton MK, Lee J, John R, Olsen NL, Navarre DA. (2013). Influence of growth regulators on plant growth, yield, and skin color of specialty potatoes. *American journal of potato research.* 90(3):271-83.

Waterer, D. (2010). Influence of growth regulators on skin colour and scab diseases of red-skinned potatoes. *Canadian Journal of Plant Science*. 90 (5), 745-753.

7 Appendices

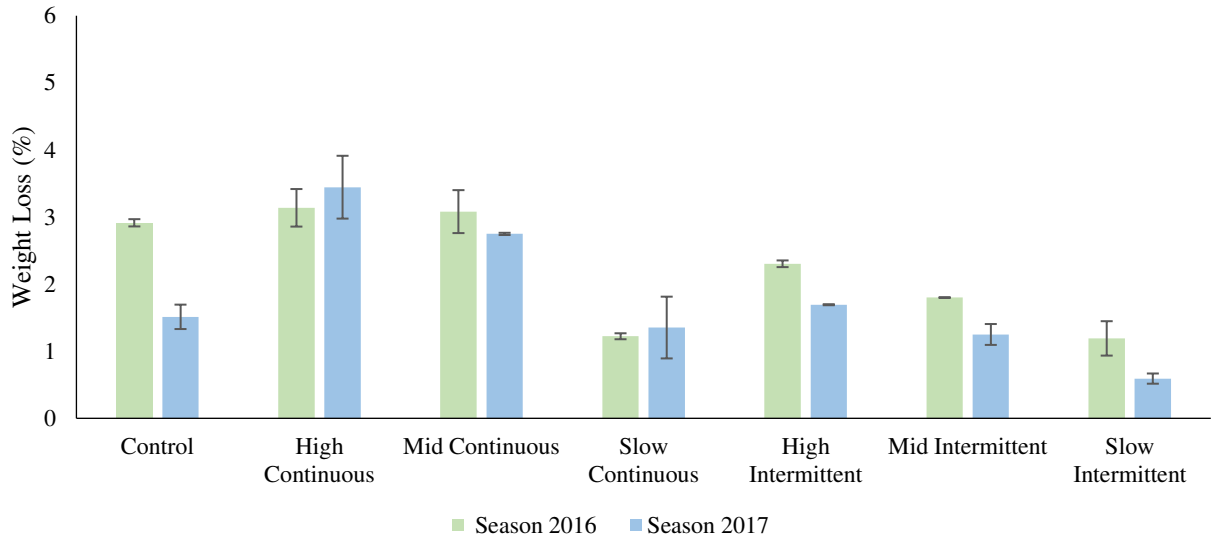


Figure 7.1. Effect of ventilation conditions on tuber weight loss (%) of the Rio Grande Russet potatoes after three months of cold storage at 5 °C ± 2 and 95 % RH ± 5 in 2016 and 2017 season. Data expressed as mean ± S.D., n = 2.

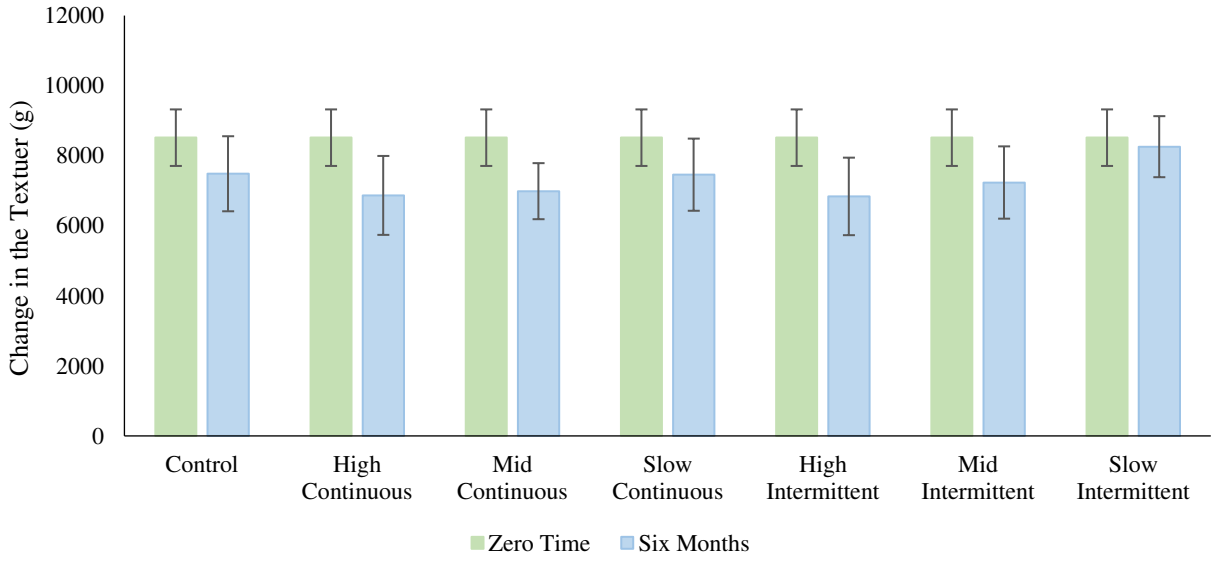


Figure 7.2. Effect of ventilation condition on texture (g) of the Rio Grande Russet at zero time and after six months of cold storage at 5 °C ± 2 and RH 95 % ± 5 in 2016 season. Data expressed as mean ± S.D., n = 30.

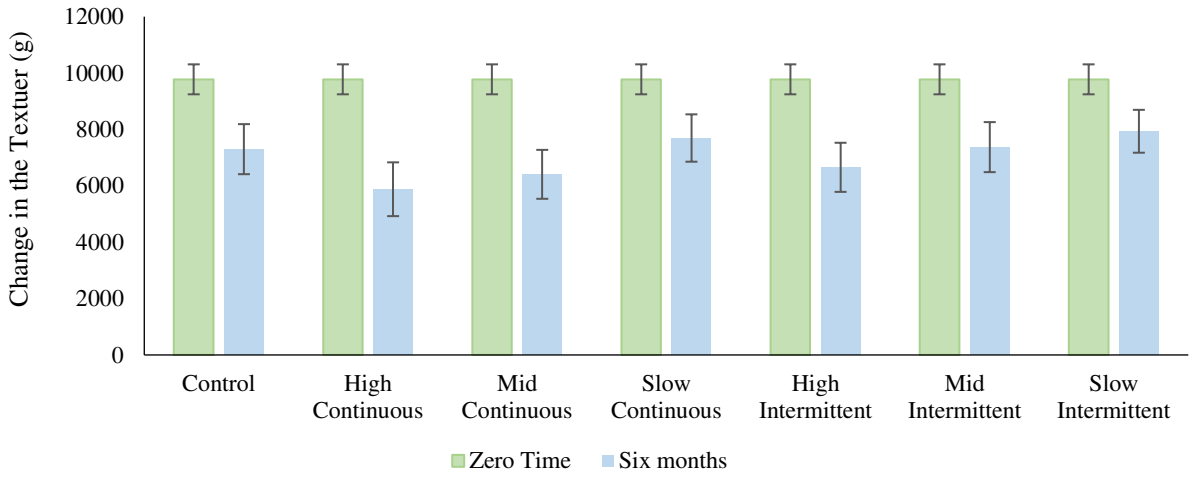


Figure 7.3. Effect of ventilation condition on texture (g) of the Rio Grande Russet at zero time and after six months of cold storage at 5 °C ± 2 and RH 95 % ± 5 in 2017 season. Data expressed as mean ± S.D., n = 30.

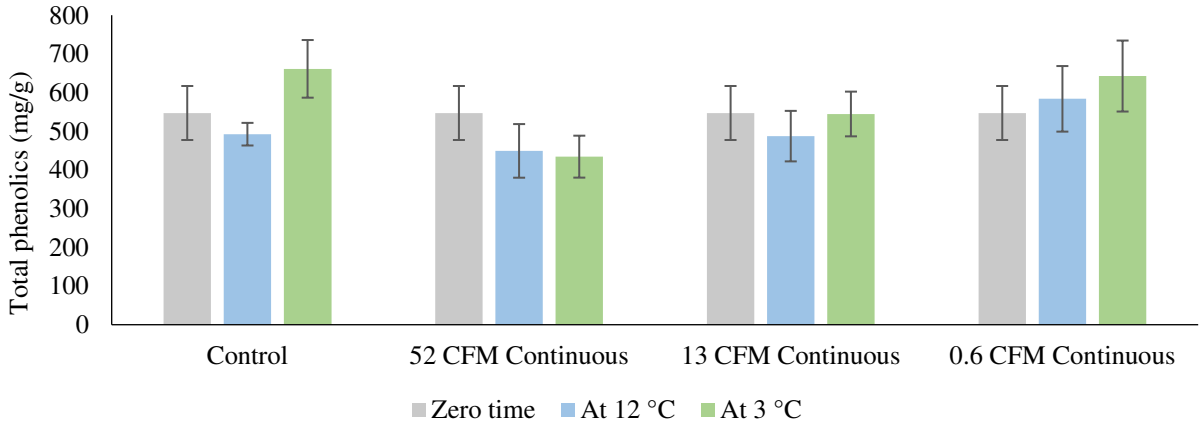


Figure 7.4. Effect of ventilation conditions on the total phenolics (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLG method of field heat reduction. Data expressed as mean ± S.D., n = 3.

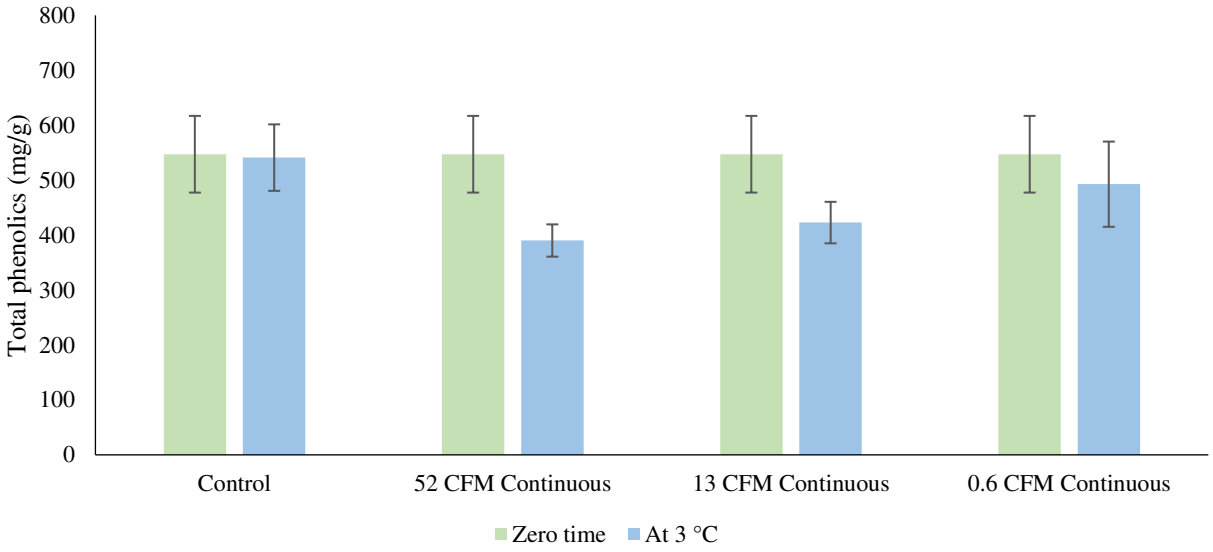


Figure 7.5. Effect of ventilation conditions on the total phenolics (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLS method of field heat reduction. Data expressed as mean ± S.D., n = 3.

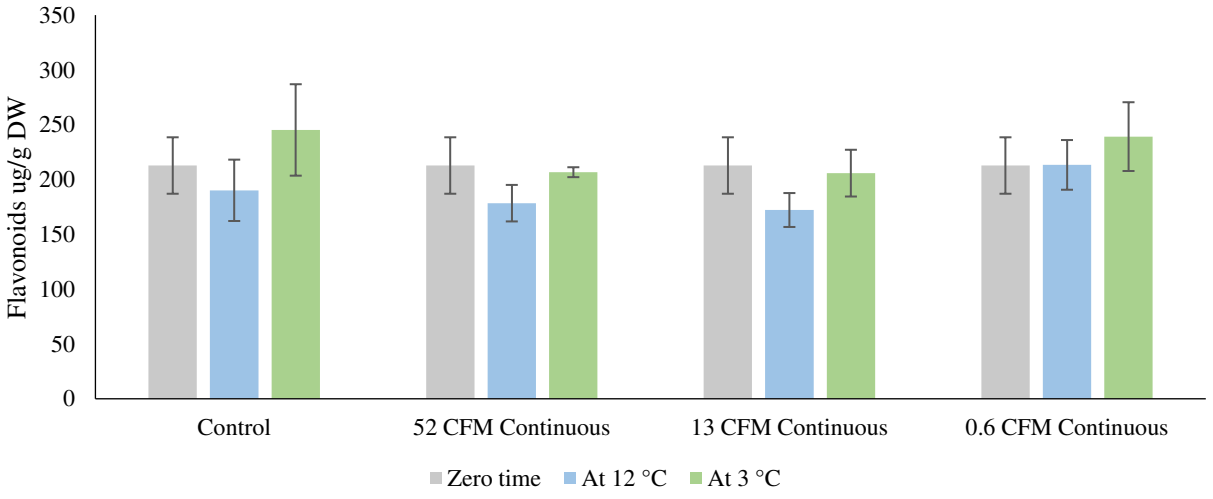


Figure 7.6. Effect of ventilation conditions on the flavonoids (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLG method of field heat reduction. Data expressed as mean ± S.D., n = 3.

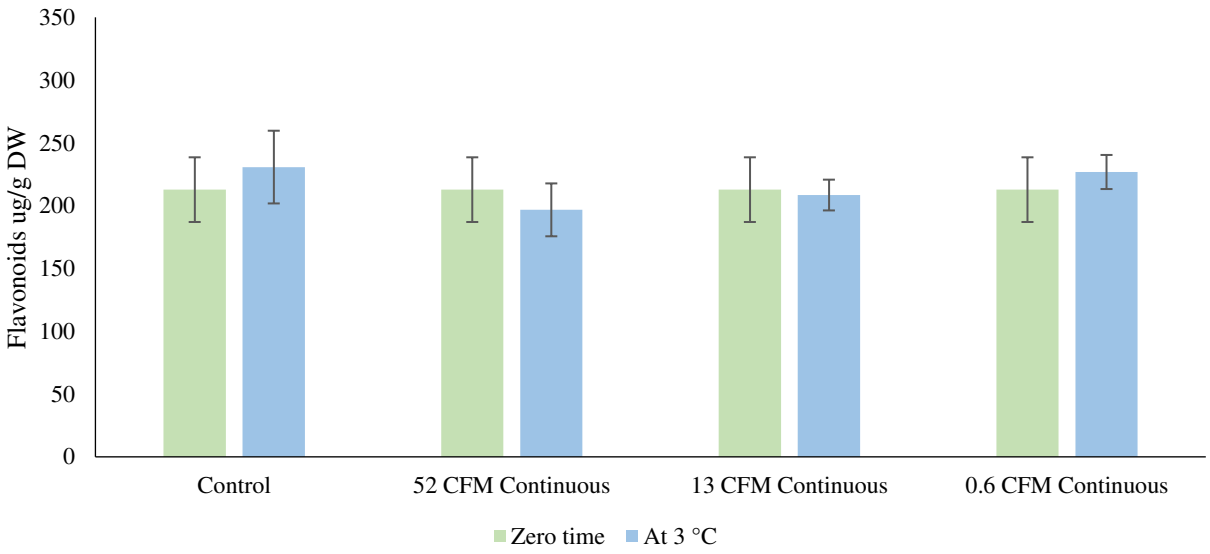


Figure 7.7. Effect of ventilation conditions on the flavonoids (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLS method of field heat reduction. Data expressed as mean ± S.D., n = 3.

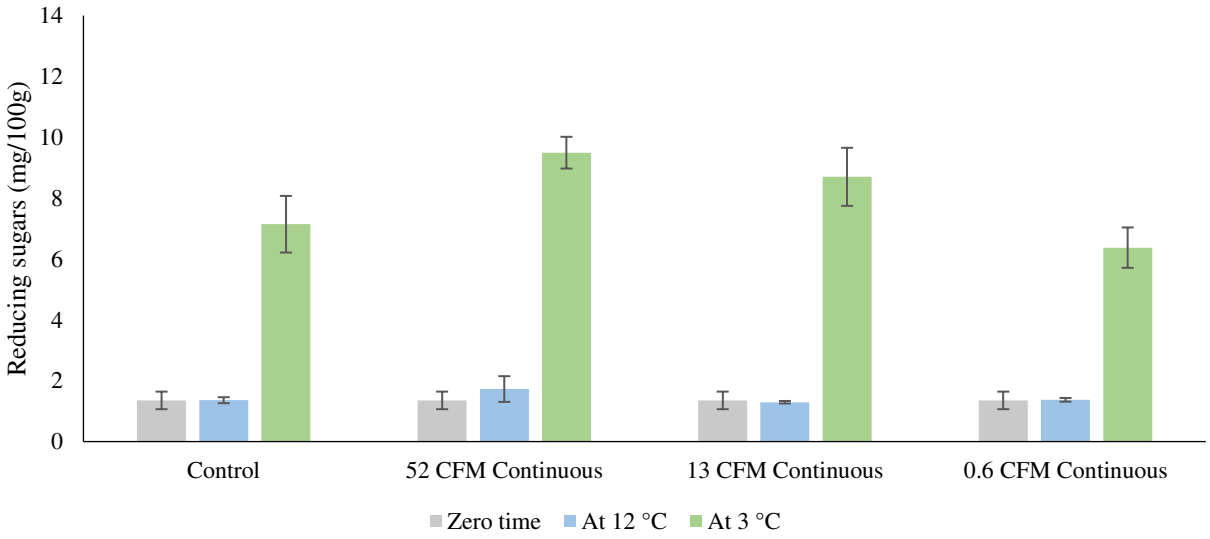


Figure 7.8. Effect of ventilation conditions on the reducing sugars (mg/100 g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLG method of field heat reduction. Data expressed as mean ± S.D., n = 3.

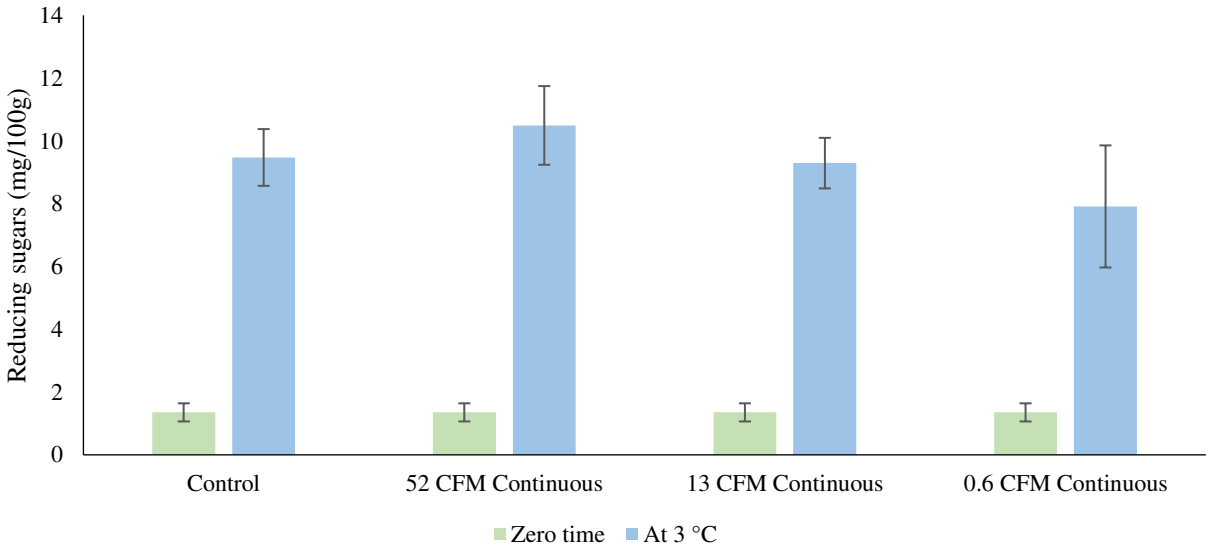


Figure 7.9. Effect of ventilation conditions on the reducing sugars (mg/100 g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLS method of field heat reduction. Data expressed as mean ± S.D., n = 3.

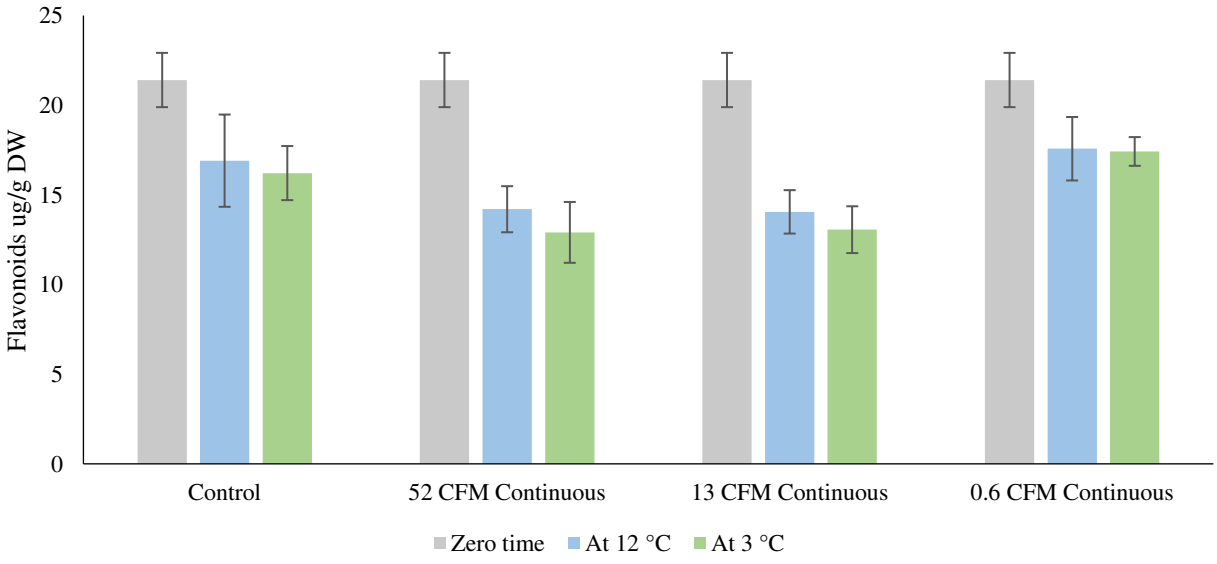


Figure 7.10. Effect of ventilation conditions on the Vit C (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLG method of field heat reduction. Data expressed as mean ± S.D., n = 3.

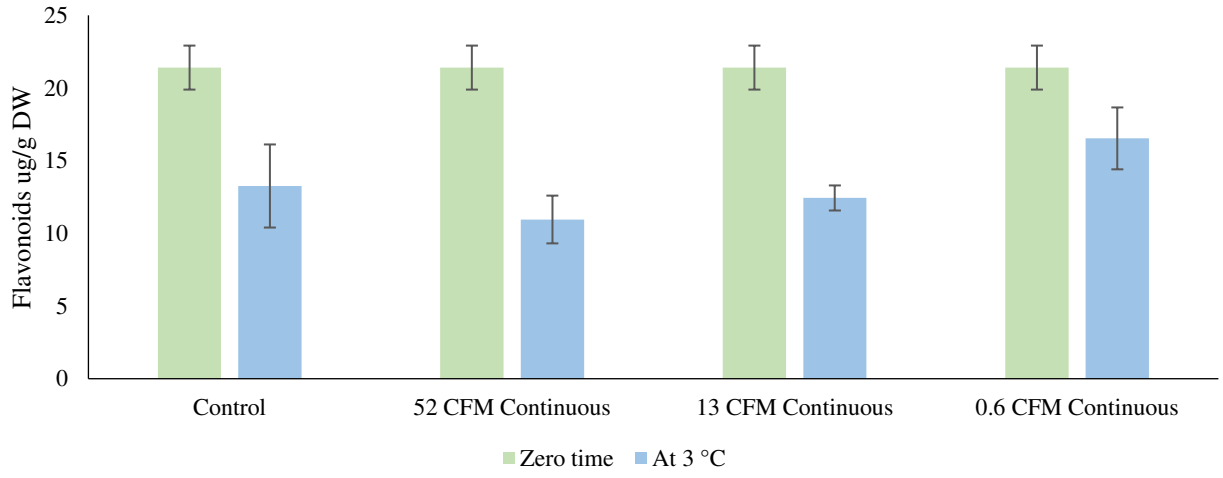
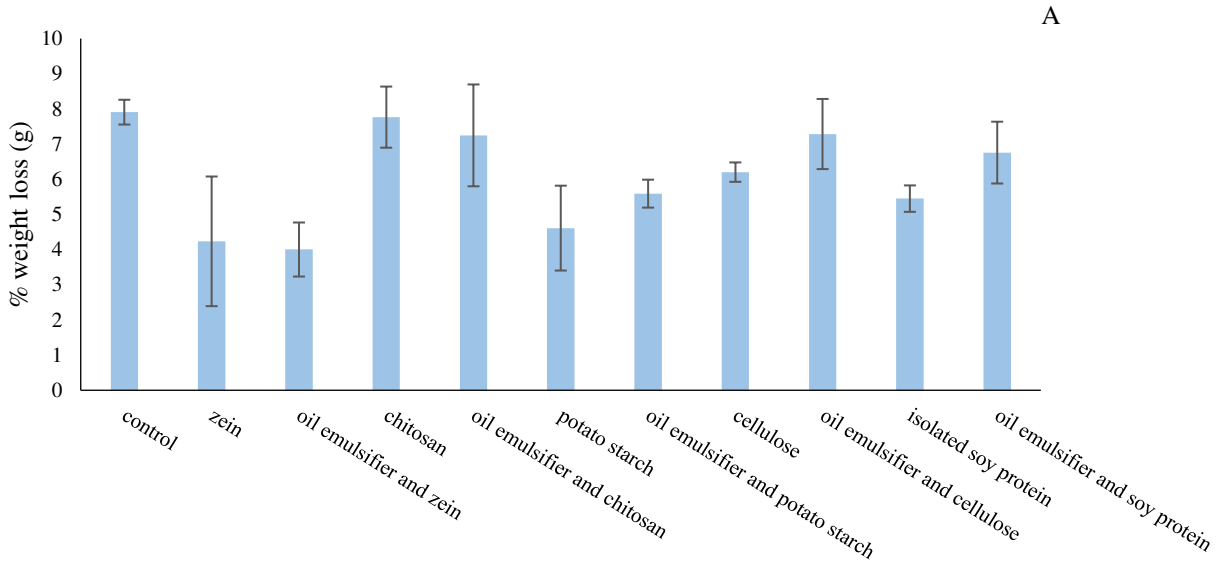


Figure 7.11. Effect of ventilation conditions on the Vit C (mg/g) of Rio Grande Russet potato tubers after 3 °C was reached using the TLS method of field heat reduction. Data expressed as mean ± S.D., n = 3.



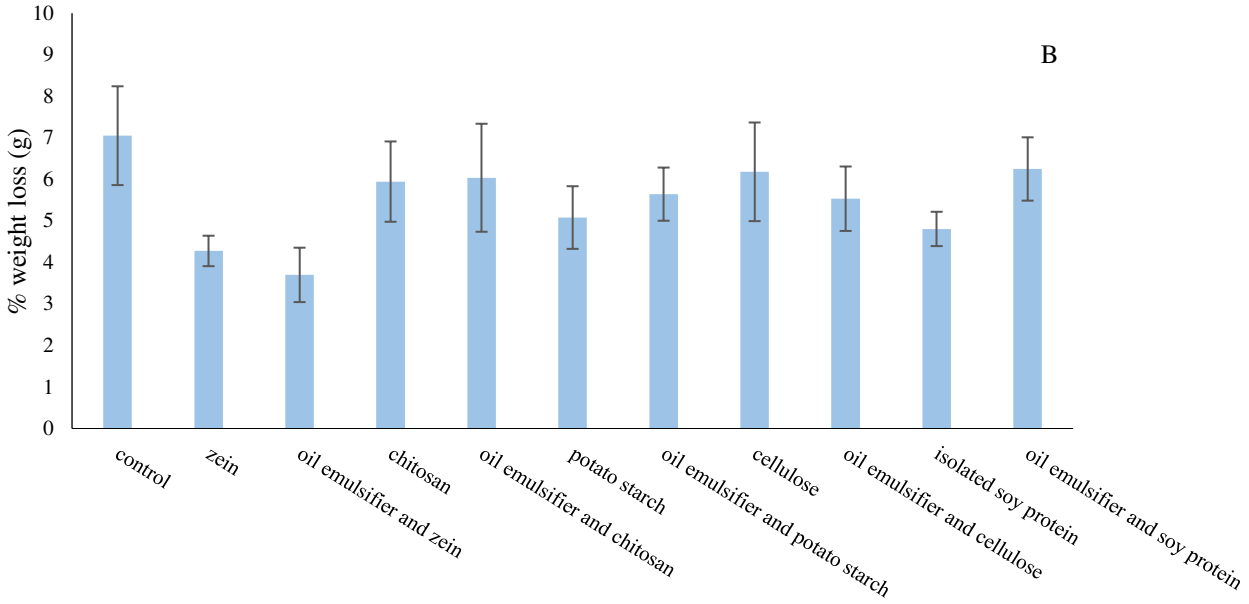
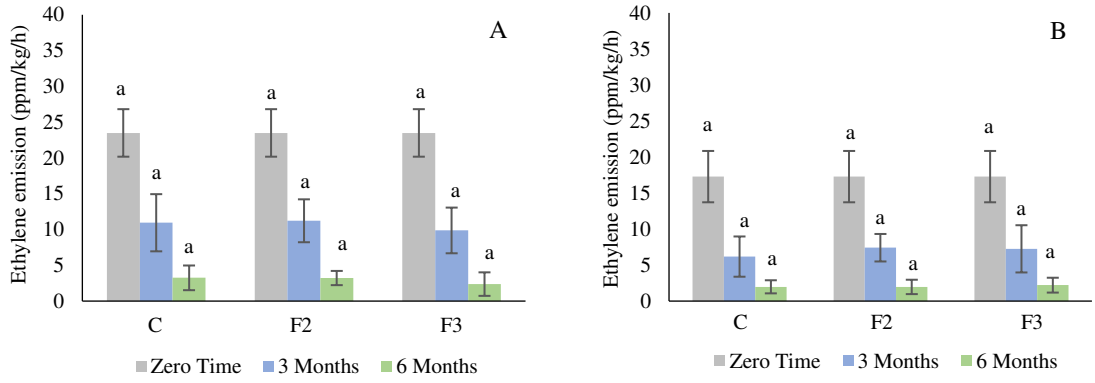


Figure 7.12. a and b. Effect of edible coatings on tuber weight loss (%) in the 2016 season in Rio Grande Russet (a) and Purple Majesty (b) at the end of storage at room temperature 18 °C±2 and 45-55% RH. Data are expressed as the mean±S.D., n = 10.



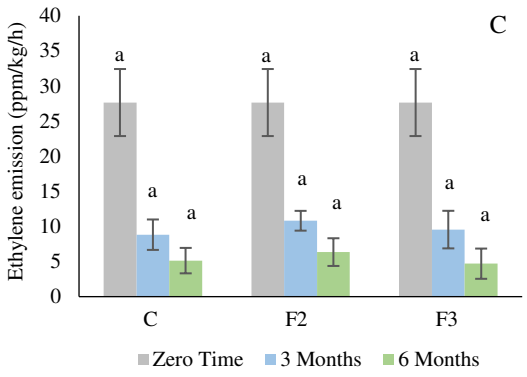
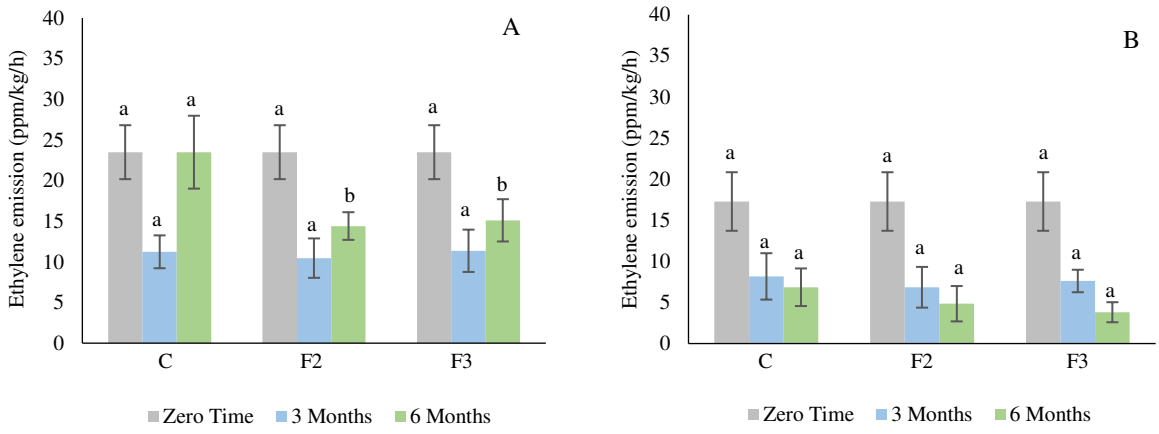


Figure 7.13.a, b, and c. Effect of edible coating on tuber ethylene production (ppm/kg/h) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C control, F2 sodium alginate, and F3 potato starch emulsion with oregano essential oil.



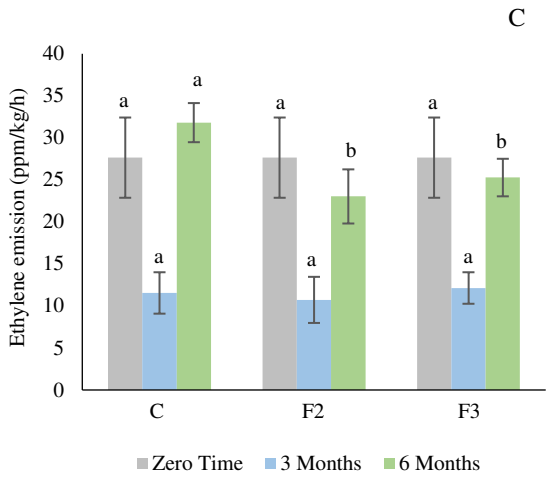
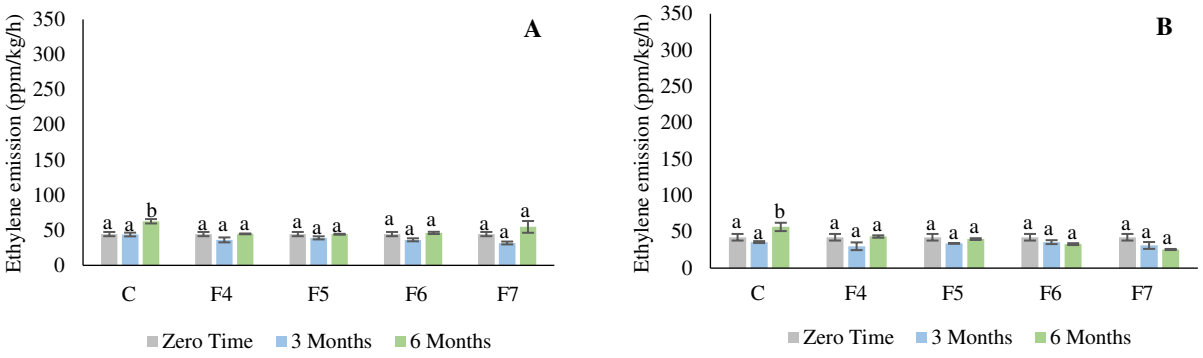


Figure 7.14. a, b, and c. Effect of edible coating on tuber ethylene production (ppm/kg/h) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 55 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C control, F2 sodium alginate, and F3 potato starch emulsion with oregano essential oil.



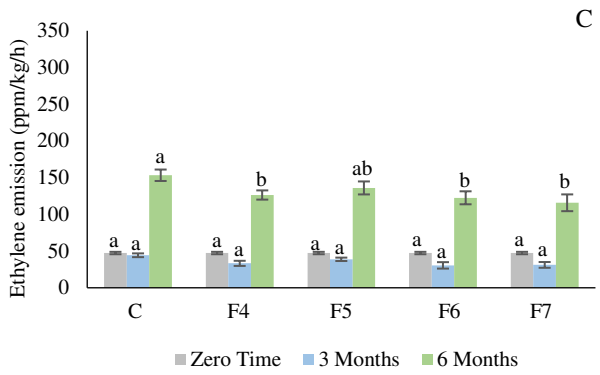
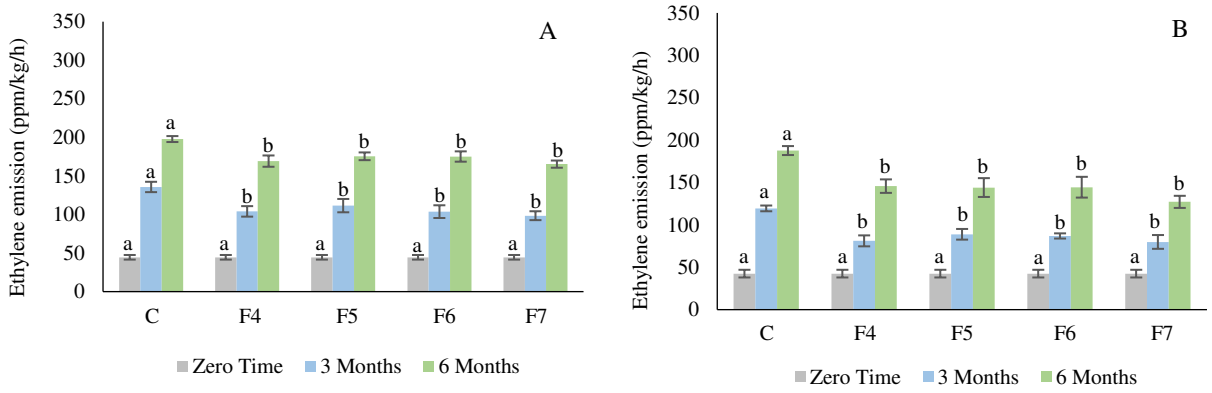


Figure 7.15. a, b, and c. Effect of edible coating on tuber ethylene production (ppm/kg/h) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 90 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.



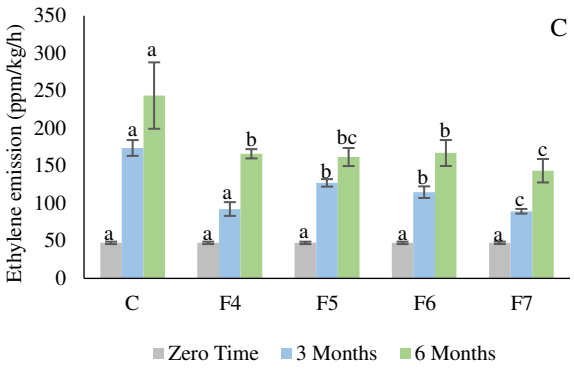
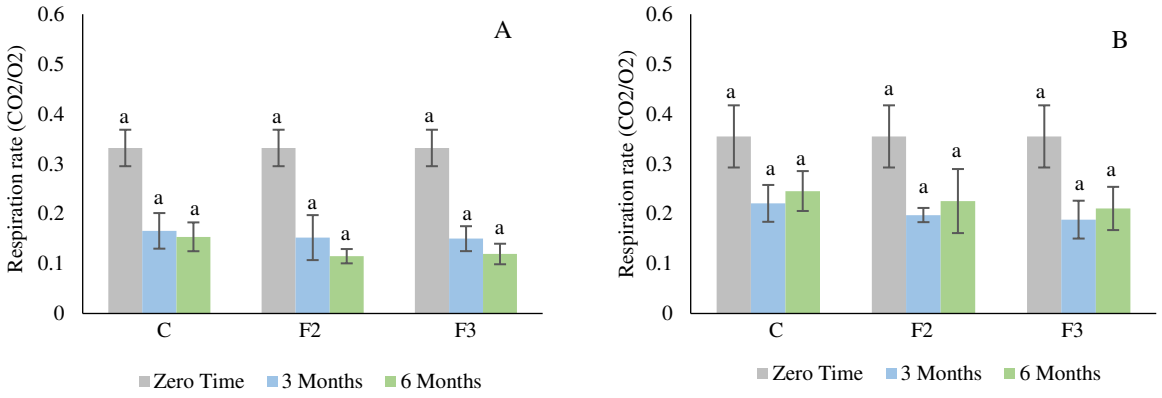


Figure 7.16. a, b, and c. Effect of edible coating on tuber ethylene production (ppm/kg/h) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 55 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.



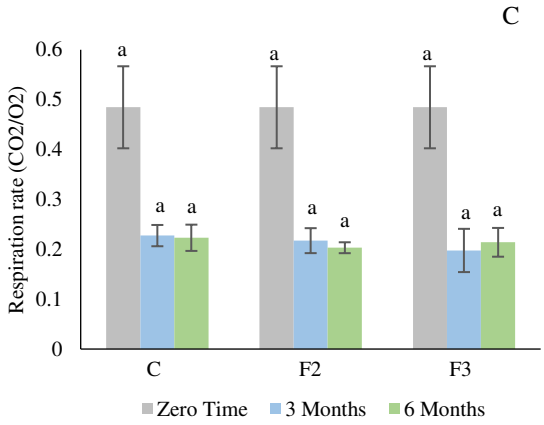
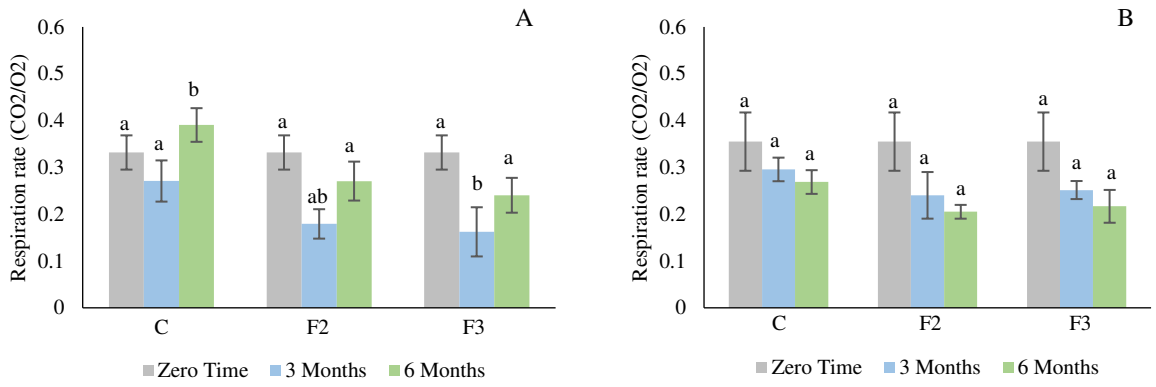


Figure 7.17. a, b, and c. Effect of edible coating on tuber respiration rate (CO_2/O_2) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$).

C control, F2 sodium alginate, and F3 potato starch emulsion with oregano essential oil.



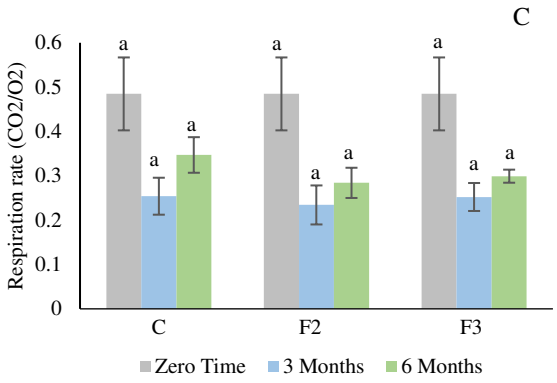
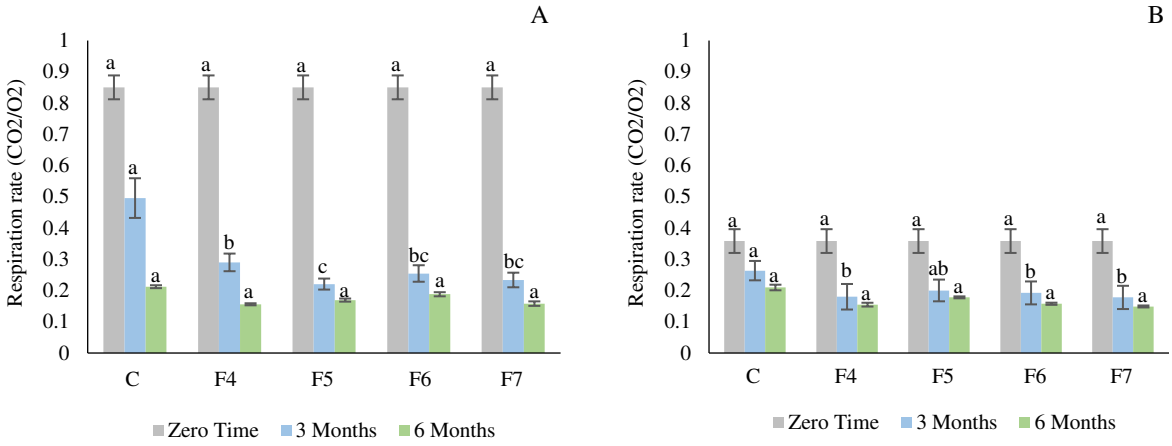


Figure 7.18. a, b, and c. Effect of edible coating on tuber respiration rate (CO_2/O_2) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 55 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$).

C control, F2 sodium alginate, and F3 potato starch emulsion with oregano essential oil.



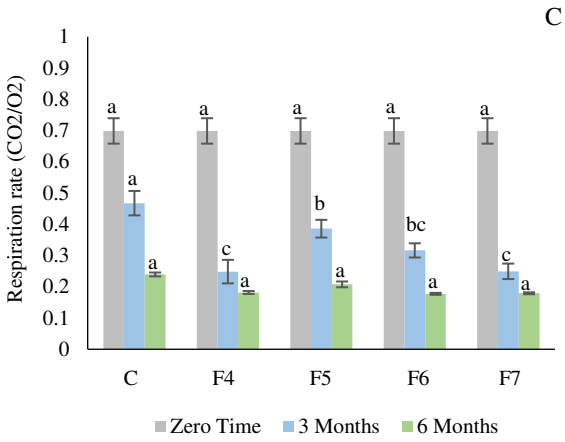
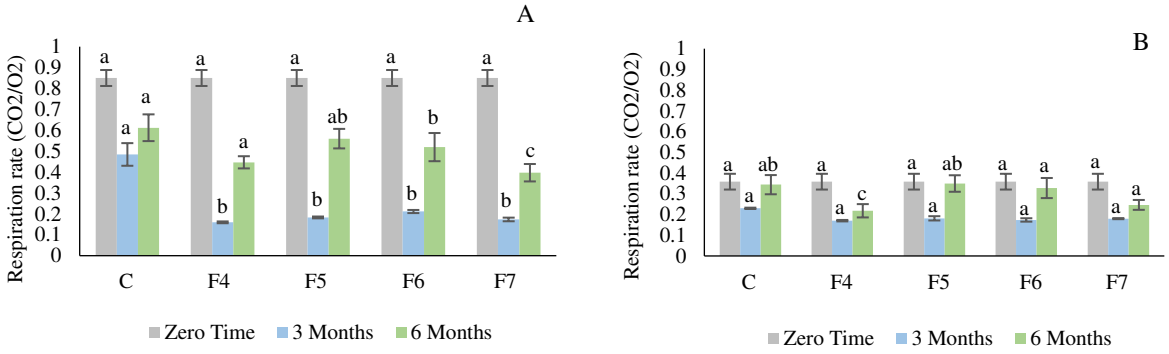


Figure 7.19. a, b, and c. Effect of edible coating on tuber respiration rate (CO_2/O_2) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 90 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.



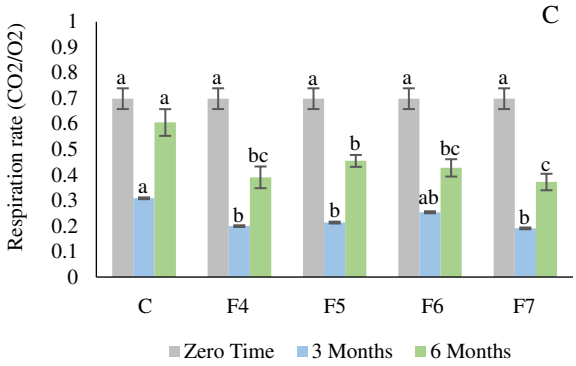


Figure 7.20. a, b, and c. Effect of edible coating on tuber respiration rate (CO_2/O_2) of the RG (a), YG (b), and PM (c) after six months of storage at 5 °C ± 1 and 55 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

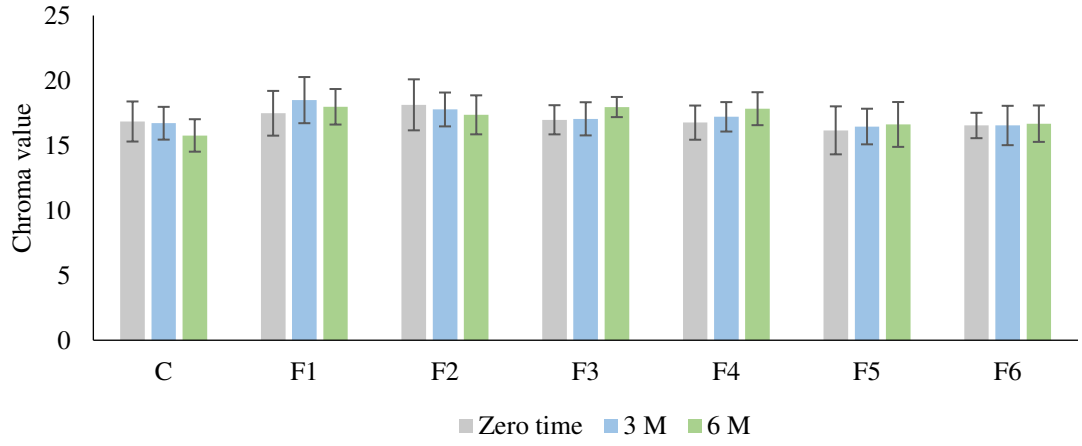
Table 7.1.Effect of edible coating on the total flavonoids (mg/g) of the RG, YG, and PM after six months of storage at 5 °C ± 1and 90% RH (HRHSC) and 55% RH (HRHSC) in the 2017 and 2018 seasons. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

Season	Treatment	Rio Grande					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	59.66±7.51	14.24±6.36^{a}	35.03±4.67^{a}	59.66±7.51	7.31±1.76^{a}	13.09±2.91^{a}
	F2	59.66±7.51	14.24±3.33^{a}	50.42±3.53^{a}	59.66±7.51	8.08±1.15^{a}	24.63±4.06^{a}
	F3	59.66±7.51	13.09±2.91^{a}	50.42±9.82^{a}	59.66±7.51	8.08±1.15^{a}	31.23±2.24^{a}
2018	C	165.39±45.26	226.41±10.65^{a}	112.91±24.48^{a}	165.39±45.26	204.52±22.45^{a}	95.05±9.08^{a}
	F4	165.39±45.26	221.77±36.69^{a}	113.71±16.55^{a}	165.39±45.26	270.17±17.46^{b}	121.03±7.45^{a}
	F5	165.39±45.26	201.19±12.22^{a}	121.2±25.67^{a}	165.39±45.26	241.48±19.6^{ab}	101.34±24.87^{a}
	F6	165.39±45.26	230.17±7.58^{a}	119.62±27.17^{a}	165.39±45.26	209.01±1.81^{ab}	75.54±10.04^{a}
	F7	165.39±45.26	221.48±18.26^{a}	112.61±24.97^{a}	165.39±45.26	226.99±26.72^{ab}	99.84±16.09^{a}
		Yukon Gold					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	45.03±1.15	10.39±2^{a}	23.09±6.43^{a}	45.03±1.15	10.01±0.67^{a}	33.1±1.76^{a}
	F2	45.03±1.15	8.12±1.97^{a}	28.87±4.62^{a}	45.03±1.15	9.24±1.15^{a}	23.09±3.46^{a}
	F3	45.03±1.15	10.8±2.9^{a}	24.63±6.36^{a}	45.03±1.15	11.16±2.91^{a}	26.17±3.33^{a}
2018	C	103.94±12.65	167.28±12.67^{a}	100.01±21.99^{a}	103.94±12.65	131.04±13.8^{a}	74.1±9.94^{a}
	F4	103.94±12.65	160.46±6^{a}	104.2±15.59^{a}	103.94±12.65	154.96±8.66^{b}	83.68±7.31^{a}
	F5	103.94±12.65	175.68±28.96^{a}	108.42±34.35^{a}	103.94±12.65	167.57±11.3^{b}	86.62±8.06^{a}
	F6	103.94±12.65	167.28±11.87^{a}	103.34±19.49^{a}	103.94±12.65	169.88±14.92^{b}	84.61±6.09^{a}
	F7	103.94±12.65	167.57±13.39^{a}	107.3±34.16^{a}	103.94±12.65	171.62±9.38^{b}	80.35±8.61^{a}
		Purple majesty					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	403.77±5.46	288.3±22.04^{a}	341.42±23.84^{c}	403.77±5.46	314.09±11.02^{a}	342.19±14.44^{c}
	F2	403.77±5.46	288.68±18.15^{a}	279.45±29.46^{a}	403.77±5.46	308.7±22.67^{a}	305.62±14.62^{b}
	F3	403.77±5.46	284.83±20.99^{a}	305.23±24.69^{b}	403.77±5.46	311.39±9.26^{a}	259.43±26.67^{a}
2018	C	446.7±29.37	446.7±9.16^{a}	340.12±19.37^{a}	446.7±29.37	412.35±15.04^{ab}	252.45±20.38^{a}
	F4	446.7±29.37	452.2±13.02^{ab}	343.96±16.84^{a}	446.7±29.37	476.55±22.43^{cd}	260.99±17.38^{a}
	F5	446.7±29.37	457.13±8.7^{ab}	346.89±21.82^{a}	446.7±29.37	498.58±3.51^{d}	268.02±27.04^{a}
	F6	446.7±29.37	499.45±5.52^{b}	353.54±17.06^{a}	446.7±29.37	455.97±6.53^{bcd}	265.41±21.68^{a}
	F7	446.7±29.37	449.85±23.79^{a}	359.27±39.04^{a}	446.7±29.37	396.55±16.32^{a}	262.66±10.69^{a}

Table 7.2.Effect of edible coating on the vitamin C (mg/g) of the RG, YG, and PM after six months of storage at 5 °C ± 1and 90% RH (HRHSC) and 55 % RH (HRHSC) in the 2017 and 2018 seasons. Data expressed as mean ± S.D., n = 3. The different letters are significantly different ($P < 0.05$). C: control, F4: sodium alginate emulsion with cinnamon oil, F5: potato starch + sodium alginate emulsion with cinnamon oil, F6: zein + chitosan emulsion with cinnamon oil, and F7: potato starch + chitosan + sodium alginate emulsion with cinnamon oil.

Season	Treatment	Rio Grande					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	89.41±4.94	48.55±2.35[a]	49.65±3.06[a]	89.41±4.94	41.83±2.24[a]	35.99±2.52[a]
	F2	89.41±4.94	46.32±6.25[a]	47.76±3.09[a]	89.41±4.94	48.62±2.47[a]	41.29±2.59[a]
	F3	89.41±4.94	46.99±3.06[a]	46.1±3.34[a]	89.41±4.94	46.29±4.05[a]	42.08±3.64[a]
2018	C	59.2±9.5	39.88±5.73[a]	37.91±2.63[a]	59.2±9.5	31.8±2.11[a]	30.59±3.66[a]
	F4	59.2±9.5	45.23±2.36[a]	41.67±1.7[a]	59.2±9.5	39.86±4.28[a]	35.65±3.01[a]
	F5	59.2±9.5	39.52±4[a]	38.15±5.15[a]	59.2±9.5	40.98±3.11[a]	36.59±4.96[a]
	F6	59.2±9.5	40.02±3.6[a]	39.3±1.47[a]	59.2±9.5	34.98±3.38[a]	32.26±2.94[a]
	F7	59.2±9.5	41.98±6.68[a]	38.74±4.92[a]	59.2±9.5	38.19±2.69[a]	34.91±3.28[a]
		Yukon Gold					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	173.15±4	59.99±7.09[a]	61.66±5.03[a]	173.15±4	51.44±8.38[a]	44.44±4.15[a]
	F2	173.15±4	58.32±6.77[a]	60.32±7.55[a]	173.15±4	56.92±7.12[a]	48.68±4.06[a]
	F3	173.15±4	61.94±8.17[a]	59.53±7.24[a]	173.15±4	55.72±3.42[a]	46.68±4.49[a]
2018	C	115.23±16.01	94.71±4.47[a]	62.62±3.55[a]	115.23±16.01	77.08±4.35[a]	60.41±7.17[a]
	F4	115.23±16.01	95.53±4.26[a]	67.61±6.25[a]	115.23±16.01	88.35±3.16[b]	69.32±6.47[a]
	F5	115.23±16.01	87.62±5.98[a]	61.98±6.4[a]	115.23±16.01	87±4.43[ab]	67.96±6.93[a]
	F6	115.23±16.01	92.79±2.86[a]	67.41±4.37[a]	115.23±16.01	84.48±3.87[ab]	67.98±8.92[a]
	F7	115.23±16.01	95.18±3.35[a]	65.51±2.35[a]	115.23±16.01	87.63±4.29[a]	70.56±7.78[a]
		Purple majesty					
		HRHSC			LRHSC		
		Zero time	3M	6 M	Zero time	3M	6 M
2017	C	77.44±4.83	47.33±5.27[a]	44.62±3.85[a]	77.44±4.83	32.35±3.05[a]	30.09±3.61[a]
	F2	77.44±4.83	46.99±5.04[a]	42.73±5.01[a]	77.44±4.83	38.72±2.16[a]	32.45±5.41[a]
	F3	77.44±4.83	46.47±4.7[a]	42.73±3.63[a]	77.44±4.83	36.85±5.5[a]	31.85±6[a]
2018	C	49.69±4.01	25.66±2.53[a]	24.64±3.96[a]	49.69±4.01	19.13±1.95[a]	16.04±2.53[a]
	F4	49.69±4.01	28.4±3.36[a]	27.08±1.39[a]	49.69±4.01	24.6±2.29[a]	21.94±2.03[a]
	F5	49.69±4.01	25.83±2.55[a]	24.85±1.1[a]	49.69±4.01	22.16±3.19[a]	19.66±4.11[a]
	F6	49.69±4.01	27.31±4.44[a]	26.86±3.43[a]	49.69±4.01	20.93±1.85[a]	19.57±2.56[a]
	F7	49.69±4.01	29.12±3.37[a]	26.41±4.43[a]	49.69±4.01	25.12±2.86[a]	23.01±3.35[a]

A



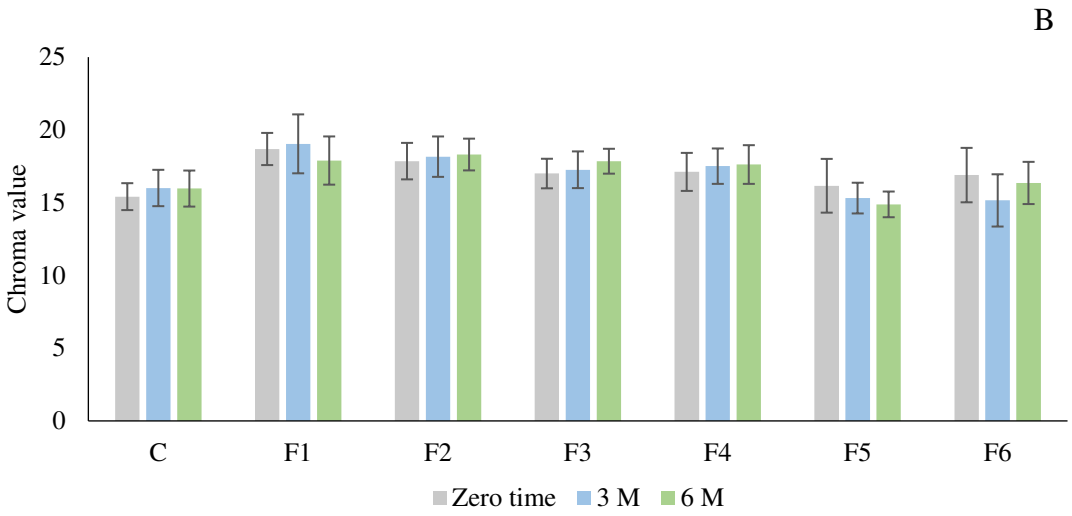
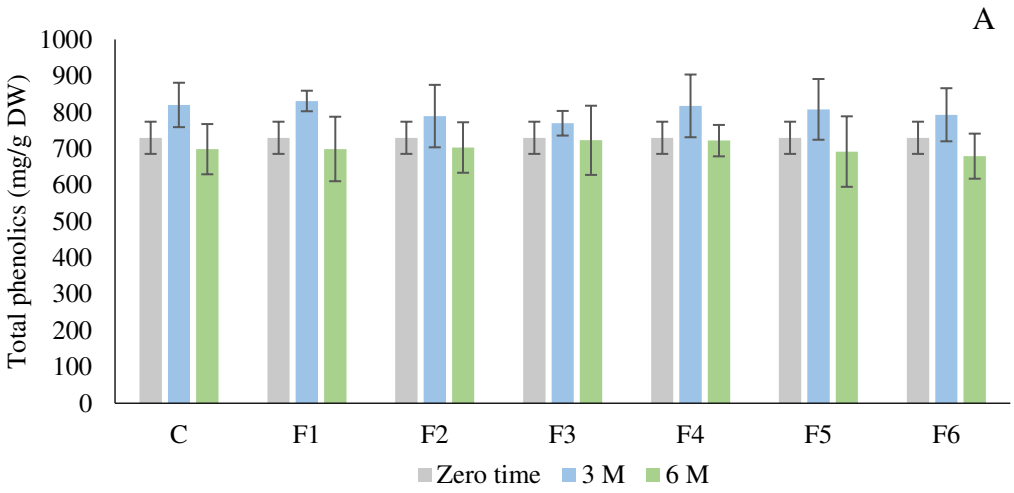


Figure 7.21. a and b. Effect of coating on tuber chroma value of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. C: control, F1: zein, F2: sodium alginate, F3: potato starch, F4:100 ppm methyl jasmonate, F5: chitosan, and F6 100 ppm Diphenylalanine.



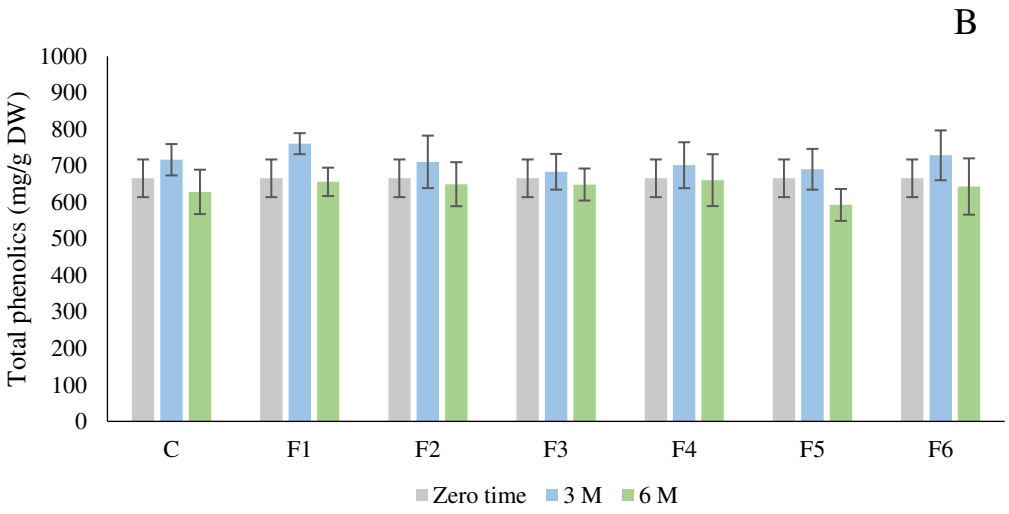
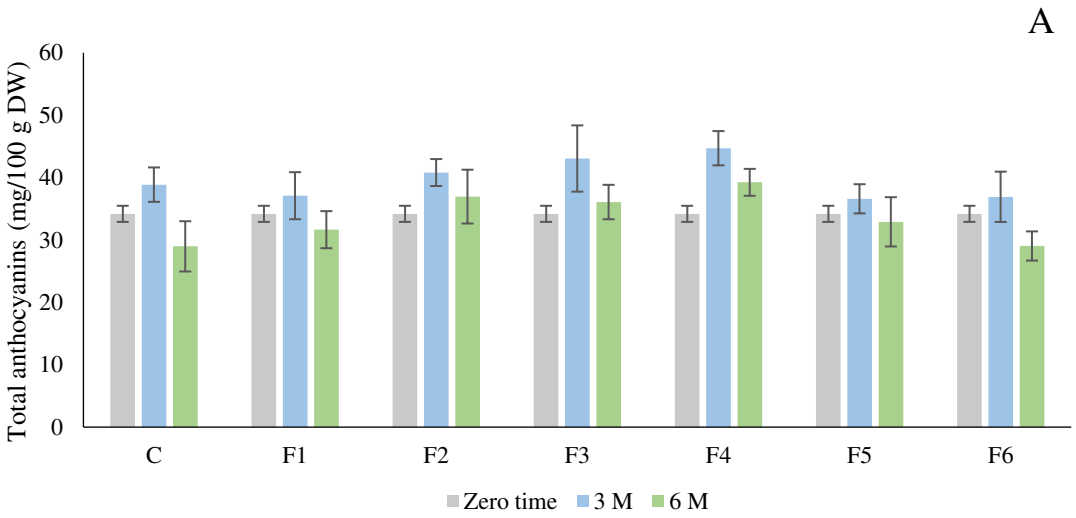


Figure 7.22. a and b. Effect of coating on tuber total phenolics (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3 C: control, F1: zein, F2: sodium alginate, F3: potato starch, F4:100 ppm methyl jasmonate, F5: chitosan, and F6 100 ppm Diphenylalanine.



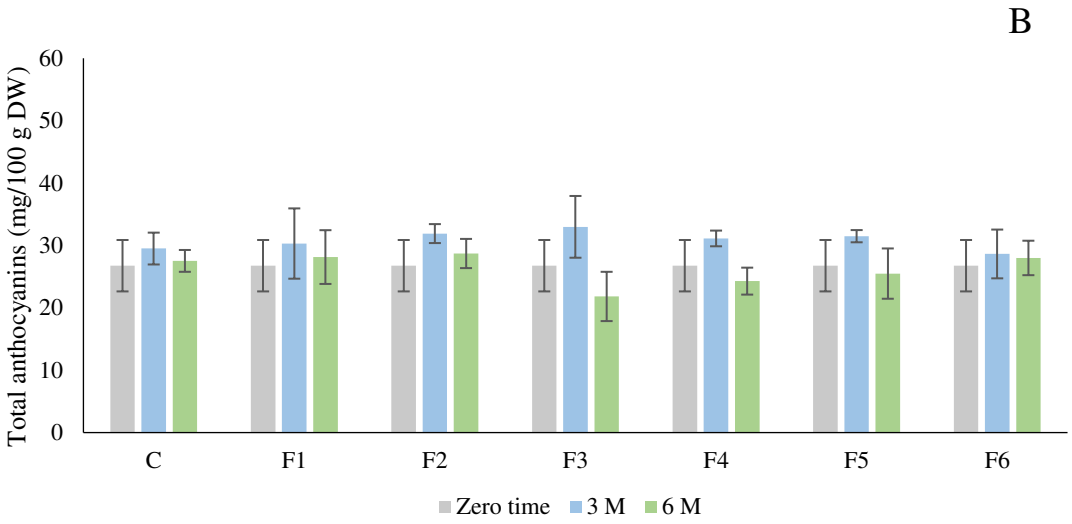
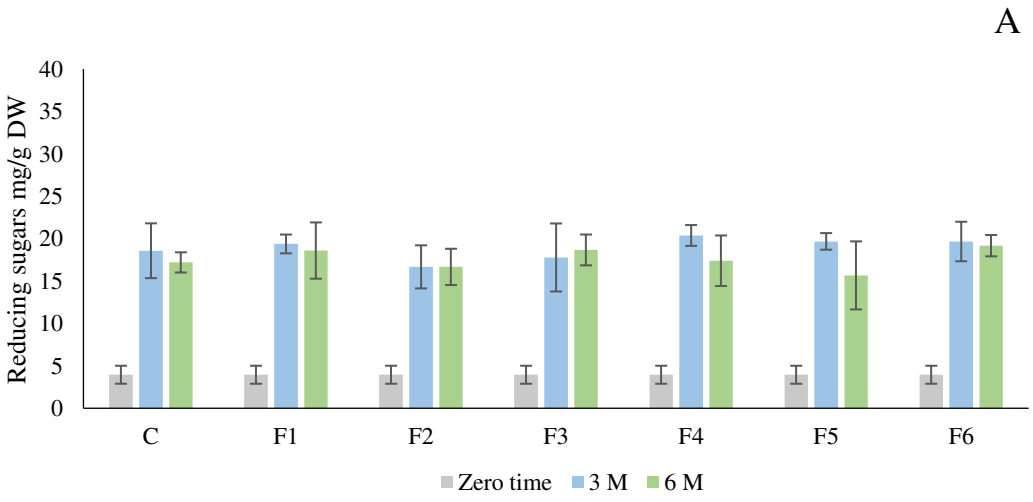


Figure 7.23. a and b. Effect of coating on tuber total anthocyanins (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3 C: control, F1: zein, F2: sodium alginate, F3: potato starch, F4:100 ppm methyl jasmonate, F5: chitosan, and F6 100 ppm Diphenylalanine.



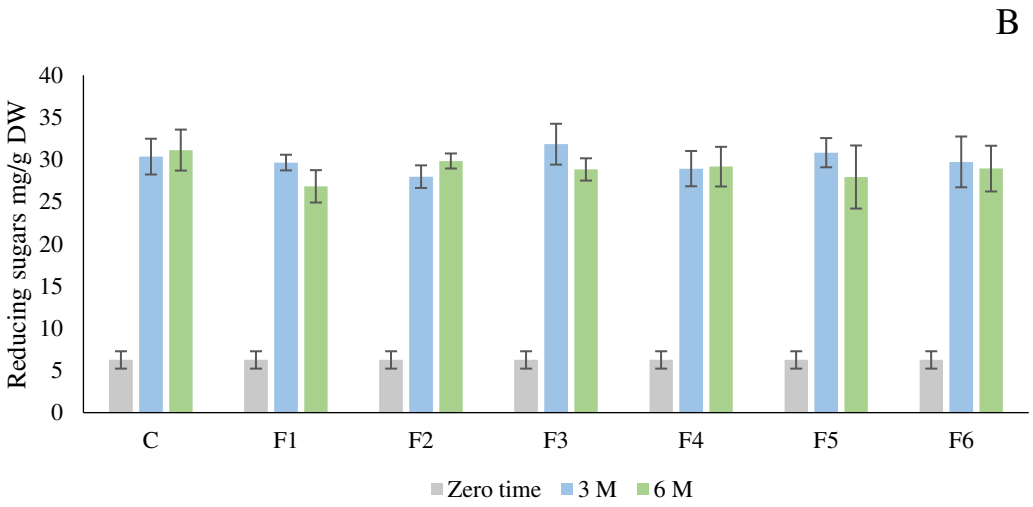
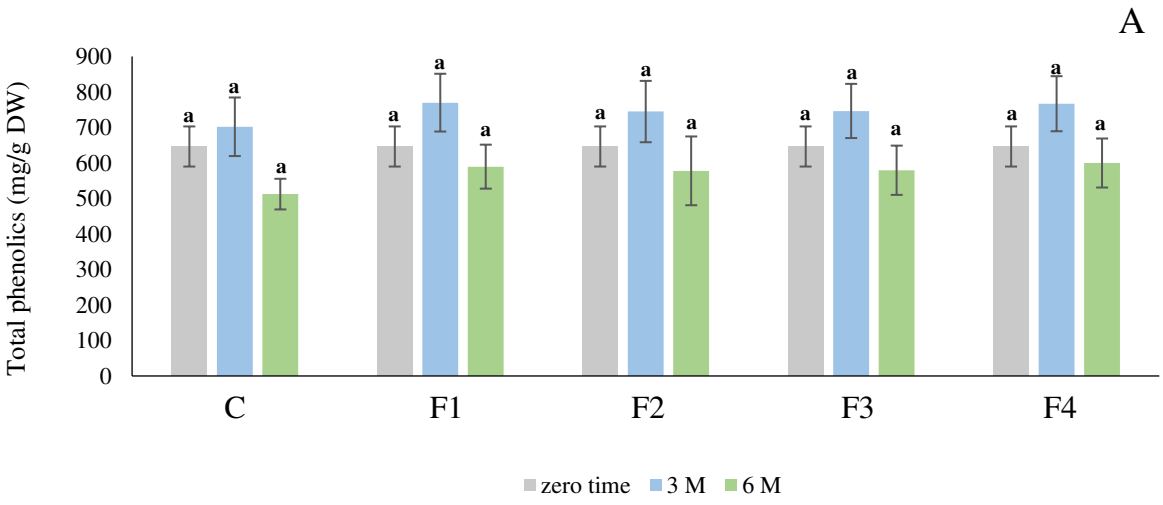


Figure 7.24. a and b. Effect of coating on tuber reducing sugars (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2017 season. Data expressed as mean ± S.D., n = 3. C: control, F1: zein, F2: sodium alginate, F3: potato starch, F4:100 ppm methyl jasmonate, F5: chitosan, and F6 100 ppm Diphenylalanine.



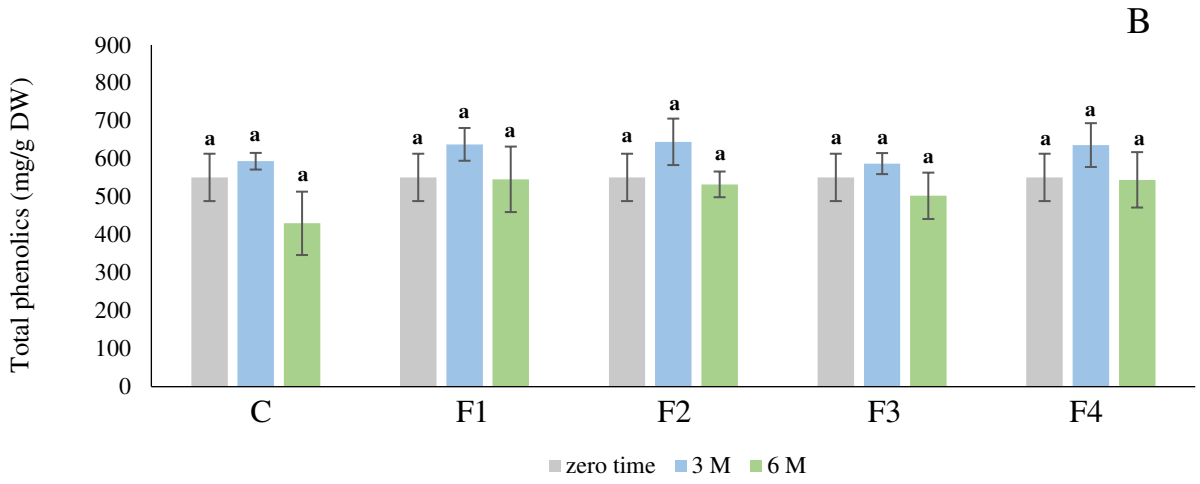
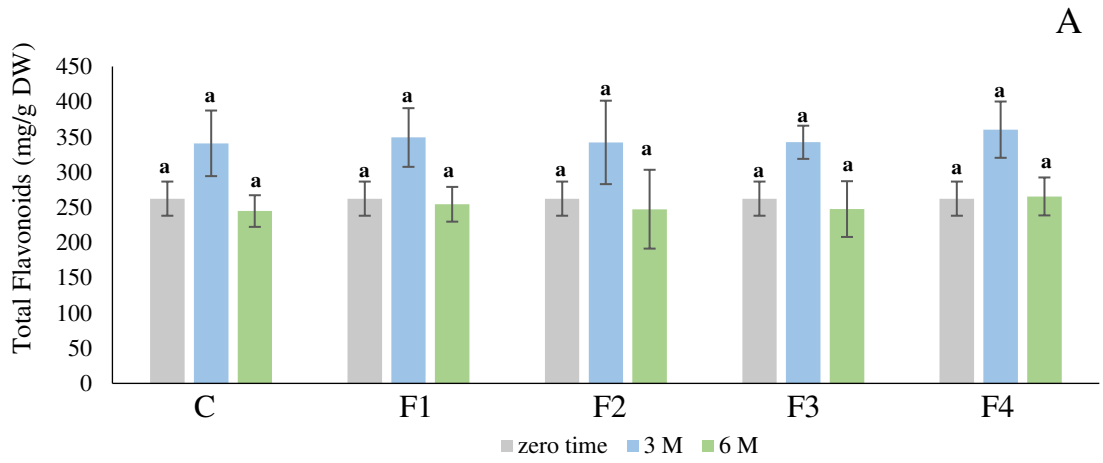


Figure 7.25. a and b. Effect of coating on tuber total phenolics (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with oregano oil, F3: zein + chitosan emulsion with oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with oregano oil.



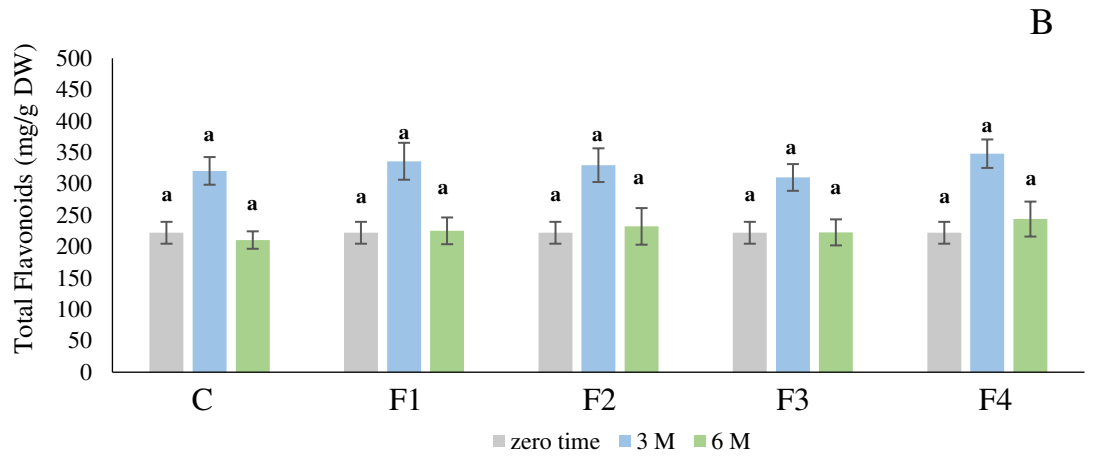
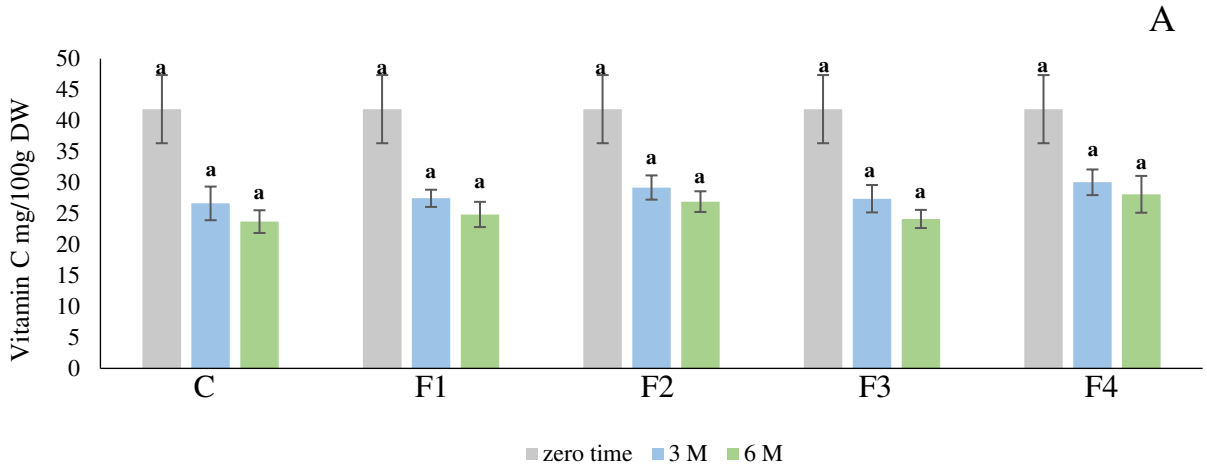


Figure 7.26. a and b. Effect of coating on tuber total flavonoids (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with oregano oil, F3: zein + chitosan emulsion with oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with oregano oil.



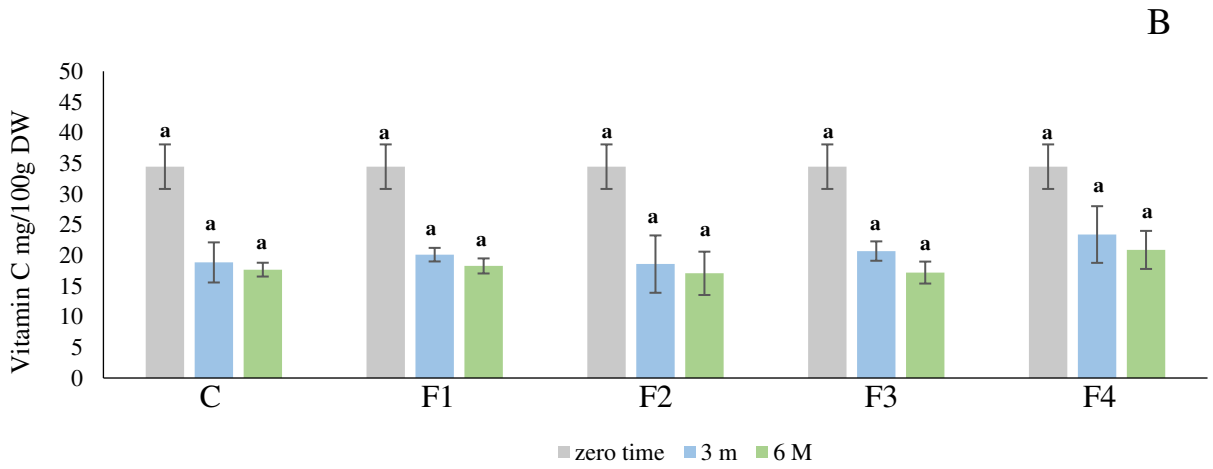


Figure 7.27. a and b. Effect of coating on tuber vitamin C (mg/g DW) of the Ciklamen (a) and Modoc (b) after six months of storage at 5 °C ± 1 and 90 % RH in the 2018 season. Data expressed as mean ± S.D., n = 3. C: control, F1: sodium alginate, F2: potato starch + sodium alginate emulsion with oregano oil, F3: zein + chitosan emulsion with oregano oil, and F4: potato starch + chitosan + sodium alginate emulsion with oregano oil.

Table 7.3 Analysis of Variance for color, anthocyanins, total phenolics, total flavonoids, reducing sugars, and Vit C. Table presents P values obtained using the ANOVA, General Linear Model function of R software, version 3.4.3.

Source	Color	Anthocyanin	Total phenolics	Total flavonoids	Reducing sugars	Vit C
Variates	0.571	0.237	0.062	0.483	0.000	0.000
Storage time	0.303	0.043	0.002	0.001	0.000	0.186
Treatments	0.000	0.030	0.856	0.992	0.132	0.476
Variates x Storage time	0.541	0.384	0.752	0.732	0.064	0.186
Variates x Treatments	0.000	0.486	0.956	0.992	0.012	0.686
Storage time x Treatments	0.000	0.536	0.992	0.903	0.967	0.997
Variates x Storage time x Treatments	0.000	0.048	0.993	0.907	0.970	0.989