AN ABSTRACT OF THE THESIS OF

Weena Mekwatanakarn for the degree of Doctor of Philosophy in Horticulture presented on December 11, 1998.

Title: Modified Atmosphere Packaging of Vegetables

Abstract approved:

Daryl G. Richardson

Modified atmosphere packaging (MAP) has considerable potential to extend fresh produce postharvest life. Physiological properties of produce (e.g. variety, respiration rate, mold resistance), storage temperature, and film permeability are keys to success. While appearance may be good, off-odors from mold or anaerobiosis may limit quality of MAP produce.

Four CRYOVAC films (PD940, PD941, PD955 and PD961), one microperforated film (Stepac XTEND120), and two controls: perforated bags (eight 6 mm holes) and bulk boxes were evaluated at two temperatures for passively creating MAP to extend storage life/quality of green beans, sweet corn and cauliflower. Five bean and two sweet corn varieties in MAP were evaluated for genetic factors on storage quality.

PD941 was most effective, followed by PD961compared to other films in retaining green bean storage quality at 5°C, and sweet corn and cauliflower at 0°C. XTEND120 film and vented controls had twice the weight loss of other films. Control green beans retained good quality for 7 days, whereas PD941 film had

good quality after 21 days at 5°C. 'Hialeah' and 'Prosperity' were superior to 'Bronco', 'Derby' and '91G' green beans in PD941 at 5°C for 21 days.

Sweet corn in PD941 film retained quality (sweetness) for two weeks. While sugars decreased during storage, values were still high after 14 days in both 'Sugar Buns' and 'Supersweet Jubilee'. Packages and temperature had little effect on sugars in 'Sugar Buns' sweet corn (se), but 'Supersweet Jubilee' sweet corn(sh2) was significantly affected by film type and temperature and had higher sugar concentration. Off-odors were detected in XTEND120 packaged 'Sugar Buns' stored 14 days at 0°or 5°C, but none in 'Supersweet Jubilee'.

Cauliflower retained quality longer in PD941 film at 0°C than other treatments, and no off-odors were detected up to 21 days. Cauliflower packed in PD955, PD961 and vented controls had off-odors 7 days at 5°C storage, but none at 0°C. Controls showed decay after 14 days storage at 0° and 5°C.

Modified Atmosphere Packaging of Vegetables

by

Weena Mekwatanakarn

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed December 11, 1998

Commencement June 1999

Doctor of Philosophy thesis of Weena Mekwatanakarn presented on
11 December 1998

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My Signature below authorizes release of my thesis to any reader upon request.

Weena Mekwatanakarn, Author

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to my major professor, Dr. Daryl Richardson, for his guidance, encouragement, understanding and friendship during my Ph.D.program.

I would like to express my sincere thank to my committee members, Dr. Ronald Wrolstad, Dr. Michael Burgett, Dr. Bill Mansour and Dr. Jack Stang for serving on my committee and their valuable suggestions.

Special thanks go to Dr. James Baggett and Deborah Kean for their help in producing green beans and sweet corn used in the first year of experiments; Dr. Jack Stang for providing sweet corn used in the second year experiments.

The financial support from The Royal Thai Government for my Ph.D. program is highly appreciated.

Finally, my heartful gratitude goes to my husband, Poonsak, my son, Mew for their love, understanding, support and fun. My deepest appreciation goes to my parents and my aunt for their support and encouragement during my studies.

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MODIFIED ATMOSPHERE PACKAGING OF VEGETABLES

CHAPTER 1

INTRODUCTION

Vegetables are living, respiring and perishable products with active metabolism even after harvest from the parent plant. The storage life and quality of vegetables can be extended by slowing down the deterioration process or by inactivating the physiological processes of both the commodity and storage pathogens. Postharvest handling of vegetables involves a number of problems due to the diversity of shape, size and nature of vegetables. Immature fruit vegetables (green beans and sweet corn) and floret vegetables (cauliflower) pose more problems in postharvest handling as these tissues are still physiologically very active and respire rapidly. Consumers also demand produce to be in a condition almost as fresh as at harvest time. Therefore, postharvest technologists are challenged to develop methods to prolong the storage life and retention of vegetable quality of these high respiring commodities.

Temperature is the most important environmental factor in maintaining storage quality of horticultural products because of its dramatic effects on respiration rates and other biological reactions (Robertson, 1993). Low temperature contributes to decrease the respiration rate, retards or prevents microorganism growth and reduces the metabolic activity of plant tissues (Riquelme et al., 1994) and moisture loss. Exposure of produce to low temperature immediately after harvest is very useful but may not be sufficient for maintaining quality during all the marketing steps. For this reason, other techniques such as protective packaging in conjunction with cold storage is an active area of research.

Controlled atmosphere (CA) requires precise control of O_2 and CO_2 concentration around fresh produce, as supplements to temperature and relative humidity management during storage and transport. The beneficial effect of CA in prolonging the postharvest life of produce has been demonstrated and reviewed in many papers. This technology, which involves large specialized storage buildings and sophisticated operating equipment, is capital intensive and expensive to operate, and it is more appropriate for long term storage. A positive return on investment in CA storage has been demonstrated for many commodities such as apples, pears, bananas, cabbages and Chinese cabbages. Commercial application of CA to vegetables has not been widely adopted. The major reason for this has been economic and related to short storage duration. It has been uneconomical to build a CA facility for a commodity which may only be stored for a few months. Moreover, entry of Mexico into the North America Free Trade Act (NAFTA) has meant that fresh vegetables can be supplied to the US market nearly year round. There is still need, however, for a storage technology to smooth market supply and demand, and to serve markets at greater distances. Such a technology may include some application of in-transit CA or MA.

Modified atmosphere packaging (MAP), an adaptation of controlled atmosphere technology, offers a less expensive alternative approach. The basic principle of MAP is to match the respiration of the product with the O_2 and CO_2

permeability of packages in order to modify the O_2 and CO_2 concentrations of the atmosphere to desired levels within the package (Beaudry and Lakakul, 1995). MAP ideally generates an atmosphere sufficiently low in O_2 and high in CO_2 to reduce the metabolism of packaged product and/or the activity of decay-causing organisms resident on that product. Reduced O_2 and elevated CO_2 atmosphere within MAP extends the storage life of fresh produce by reducing commodity respiration rates and slowing rate of use of the finite energy supplies present in the living tissue (Gorney, 1997). Passive modification of atmosphere, which creates an appropriate atmosphere by matching commodity respiration with film permeability, presents a much more economical alternative approach to CA to extend storage life. The keys to the successful application of this approach is knowing what type of environment will be most beneficial to the produce inside the package and then determining which packaging materials can be used to create such an atmosphere. In addition, physiological properties (eg. variety, respiration rate, mold resistance), temperature, mold control and film permeability are key components for success.

Many types of films from CRYOVAC Company (division of W.R.Grace & Co) have shown promise for packaging of fresh produce such as broccoli florets (Cabezas, 1995 and Cabezas and Richardson, 1997), lemons (Eaks, 1986), and potatoes (Shetty et al., 1989). Furthermore, microperforation technology in which the film is perforated with uniformly distributed minute holes can potentially open up new applications in fresh produce packaging technology, particularly for high respiring produce (Frey, 1997) or for produce intolerant of high relative humidity.

Microperforated films (XTEND, Stepac, L.A.) also showed promise for prolonging fresh sweet corn storage life by 30 to 40 % at 0 °C and 5 °C compared to ice - packed controls (Aharoni and Richardson, 1997).

There were two major objectives of this research. The first objective was to determine the effect of different MAP packaging films and temperature on storage life and quality of green beans, sweet corn and cauliflower. The second objective was to evaluate five green bean culitivars and two corn cultivars for possible varietal differences in storage life and quality under MAP.

CHAPTER 2

LITERATURE REVIEW

Postharvest handling, packaging, transport, storage and marketing of vegetables involve a number of factors, mainly because of the diverse shape, size and nature of vegetables. There is an express need to present produce to the consumer in almost the same physiological state and condition as at harvest time. Therefore, manipulation of the postharvest factors independently or in combination which influence the storage life and quality, forms the basis of postharvest technology for prolonging storage life and retention of vegetable quality (Moleyar and Narasimham, 1994).

Unlike meat, fish and other chilled perishable food, fresh produce continues to respire after harvesting. Therefore, respiratory activities of fresh produce must be taken into account for prolonging storage life. The primary factors in maintaining quality and extending the postharvest life of fresh fruits and vegetables are harvesting at optimum maturity, minimizing mechanical injuries, using proper sanitation and packaging procedures and providing optimum temperature and relative humidity during all marketing steps (Kader et al., 1985,1989; Shewfelt, 1986). Secondary factors include modification of O_2, CO_2 and/or C_2H_4 concentration in the atmosphere surrounding the commodity to levels different from those in air, referred to as controlled atmosphere (CA) or modified atmosphere packaging (MAP) (Kader et al., 1989; Kader, 1995).

CA implies a greater degree of precision and continual adjustment than MAP in maintaining specific levels of O_2, CO_2 and other gases.

2.1. Basic Principles of Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) of fresh fruits and vegetables refers to the still evolving technique of matching the respiration of the product with the O_2 and CO_2 permeability (breathability) of packages in order to modify the O_2 and CO_2 concentrations of the atmosphere to desired levels within the package (Beaudry and Lakakul, 1995). One important goal of MAP is to generate an atmosphere sufficiently low in O_2 or high in CO_2 to influence the metabolism of the product being packaged or the activity of decay causing organisms resident on that product such that storage life is prolonged. In addition to atmosphere modification, a sealed package vastly conserves and improves moisture retention which, probably more than O_2 and CO_2 modification, helps preserve food quality (Beaudry and Lakakul, 1995). Moreover, maintaining a product in a container sealed off from the external environment helps ensure conditions to reduce exposure to airborne pathogens (plant and human) compared to uncovered produce.

During the past 50 years, uses of controlled atmosphere and modified atmosphere packaging to supplement, not substitute for temperature and relative humidity management, has increased steadily and contributed significantly to extending the storage life and maintaining quality of several fruits and vegetables (Kader, 1995). This trend is expected to continue as technological advances are made in attaining and maintaining CA and MAP during transport, storage and marketing of fresh produce. MAP can facilitate maintenance of the desired atmosphere during the entire postharvest handling time between harvest and use. However, temperature abuse conditions or wrong film choices may create highly unfavorable atmospheres, leading to losses.

Recent advances in the design and manufacture of polymeric films with a wide range of gas diffusion characteristics have stimulated renewed interest and increased the use of flexible plastic film for MAP of fresh produce (Kader, 1989; Riquelme et al., 1997). Furthermore, microperforation technology in which the film is perforated with consistent, minute holes can potentially open up new applications in fresh produce packaging technology, particularly for high respiring produce (Frey, 1997). Incorporation of the microperforation technology and passive modified atmosphere effectively extend the shelf life of fresh produce. In addition, increased availability of various absorbers and adsorbers of O_2, CO_2, C_2H_4 and water vapor provide possible additional tools for manipulating the microenvironment within MAP units.

2.2. Beneficial and Detrimental Effect of MAP

2.2.1. Beneficial Effects

MAP is capable of extending the storage life of fresh produce by 1.5 to 4 fold under refrigeration depending on the commodity (Zagory and Kader, 1988; Day 1989). Incorporation of MAP and low temperature management can further increase storage life of fresh produce. Generally, the effect of reduced O_2 and/ or elevated CO_2 on reducing the respiration rate has been assumed to be the primary reason for the beneficial effects of MAP on fresh produce (Kader et al., 1989; Kader 1995; Gorny, 1996; Riquelme et al., 1997). MAP conditions can effectively reduce or inhibit C_2H_4-induced senescence and physiological disorders in harvested fruits and vegetables (Kader, 1985; Lougheed, 1987; Herner,1987; Gorny and Kader, 1997).

Prevention of ripening and associated changes in fruits is one of the main benefits of MAP (Kader, 1980). Oxygen concentration has to be less than 8 % to have a significant effect on fruit ripening and the lower the O_2 concentration, the greater the effect (Kader, 1989). Elevated CO_2 levels above 1% also retard fruit ripening and their effects are additive to those of reduced O_2 atmospheres. For some commodities which can tolerate high CO_2, $CO_2 > 12$ % has shown added effectiveness in control of same fungal pathogens (El - Goorani and Sommer, 1981) and this has led to commercialization of MAP. Cherries, strawberries, blueberries and several other small fruits have been shown to benefit from high CO_2 treatments. In addition, the effects of MAP on delay or inhibition of ripening are greater at higher temperature. Therefore, use of MAP may provide handling of ripening climacteric fruits at temperatures higher than their optimum holding temperature so that chilling-sensitive fruits could benefit by avoiding their exposure to chilling temperatures.

Kader (1989) indicated that MAP conditions reduce respiration rates provided that the levels of O_2 and CO_2 are within the range that is tolerated by the commodity. This, combined with decreased C_2H_4 production and reduced sensitivity to C_2H_4 action, results in delayed senescence as indicated by retention of chlorophyll, textural quality (decreased lignification), and sensory quality of non - fruit vegetables. The incidence and severity of certain physiological disorders which are induced by C_2H_4 and chilling injury of some commodities can be reduced under low O_2 and high CO_2 concentrations.

El - Goorani and Sommer (1981) concluded that delaying senescence by MAP reduces susceptibility of fruits and vegetables to pathogens. Therefore, use of some postharvest fungicides and fumigants can be reduced or eliminated in those cases where MAP provides adequate control of pathogens. Oxygen level below 1 % and/or CO_2 level above 10 % are needed to significantly suppress fungal growth (El - Goorani and Sommer, 1981). Moreover, elevated CO_2 levels (10 to 15 %) can be used to provide fungistatic effects on commodities that can tolerate such high CO_2 levels. MAP conditions can facilitate picking and marketing more mature or riper (better flavored) fruits by slowing down their postharvest deterioration rate to permit transport and distribution (Kader, 1995).

2.2.2. Detrimental Effects

Exposure of fresh fruits and vegetables to O_2 levels below their tolerance limits or to CO_2 levels above their tolerance limits may increase anaerobic respiration and the consequent accumulation of ethanol and acetaldehyde and other metabolites causing off-flavors (Kader et al.,1989; Richardson and Kosittrakun, 1995). In addition, anoxic modified atmosphere conditions can favor the growth of facultative anaerobes and obligate anaerobes compared to aerobic spoilage organisms. Fruits present few public health risks due to their relatively low pH (Church and Parsons, 1995). However, a risk does exit with vegetables from both mesophilic and psychrotrophic pathogens in both ambient and chilled stored products (Church and Parsons, 1995). The possibility of potentially fatal toxigenesis by psychrotrophic (*Clostridium botulinum*) theoretically exists in anaerobic atmosphere caused by O_2 depletion arising from either the use of incorrect packaging material (Day 1993 as cited by Church and Parsons, 1995) or temperature abuse (O'Beirne, 1990). There is little evidence of a real threat in practical usage (Church and Parsons, 1995) because O_2 levels don't become zero. However, accumulation of *C. botulinum* toxin without sensory indication has not been demonstrated in vegetable products (Zagory and Kader, 1988). Further research is needed to estimate the potential for public health problems and the need for including indicators of temperature abuse and/or anaerobic conditions within packages, and particularly minimally processed vegetables and fruits packed alone or in combination with other ready to eat food, which may increase bacterial contamination (Kader et al., 1989).

2.3. Methods of Creating Modified Atmosphere Packaging

Modified atmosphere within polymeric film packages can be created either **passively** by the commodity or **actively** by introducing an atmosphere upon sealing (Zagory and Kader, 1988).

2.3.1. Commodity Generated or Passive Modified Atmosphere

Modification of the atmosphere is achieved through a combination of the commodity 's respiration and gas permeation through the packaging film (Smith et al., 1987). If commodity respiration characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can be passively created within a sealed package as a result of the O_2 consumption and the production of CO_2 through commodity respiration (Smith et al., 1987). In order to achieve and maintain a satisfactory atmosphere within a package, the gas permeability of the selected film (see Table 2.1) must be such that it allows O_2 to enter the package at a rate about equal to the consumption of O_2 by the commodity (Zagory and Kader, 1988). Similarly, CO_2 must permeate from the package to offset the production of CO_2 by the commodity. They also suggested that the atmosphere must be established rapidly and without danger of the creation of anoxic condition or injurious high levels of CO_2. The challenge in creating a passive atmosphere is to provide sufficient oxygen to keep the produce from going anaerobic while reducing oxygen well below the 21 % normally found in the earth's atmosphere (Frey, 1997). However, sometimes passive atmosphere generation may require a relatively long period to establish.

2.3.2. Active Modified Atmosphere

Because of the limited ability to regulate a passively established modified atmosphere, it is likely that same atmospheres within MAP will need to be actively established and adjusted (Zagory and Kader, 1988, Frey, 1997). Although this active approach clearly provides the potential for maintaining the ideal package atmosphere, it is inherently expensive (Frey, 1997). The active modified atmosphere can be accomplished by pulling a slight vacuum and replacing most of the package atmosphere with the desire gas mixture just prior to sealing (Kader et al., 1989). Additionally, absorbers or adsorbers may be included in the package to scavenge O_2, CO_2 or C_2H_4 to control the concentration of these gases. Although active modification requires some additional costs, the main advantage is that the equilibrium atmosphere can be modified immediately during packaging rather than several hours or days later as may occur in passive atmosphere generation. Kader et al., 1989 demonstrated the potential of O_2, CO_2 and C_2H_4 absorbers as follow:

2.3.2.1. Oxygen Absorbers

Most commercially available O_2 absorbers use iron powder as the main active ingredient. These products often utilize powdered FeO which becomes Fe_2O_3, Fe_3O_4 and their hydroxide forms after absorption of O_2. It is possible to calculate the right type, size, and amount of FeO needed to lower the concentration of O_2 to approximate desired pre - determined values. The lower the temperature, the slower the rate of O_2 absorption.

2.3.2.2. Carbon Dioxide Absorbers

Some of the absorbers that are currently being used to remove excess CO_2 from controlled atmosphere rooms that could be adapted for their utilization in MAP include a) slaked lime :freshly hydrated high calcium lime, $Ca(OH)_2$ b) activated charcoal and c) magnesium oxide

2.3.2.3. Ethylene Absorbers

Some materials that can and are being used for C_2H_4 absorption within polymeric film packages are

1) Potassium permanganate ($KMnO_4$). Permanganate absorbed on celite, vermiculite, silica gel or alumina pellets. A commercial product called Purafil is widely available and is in common use.
2) Builder clay powder. Its principle component is cristobalite (> 87 % SiO_2, >5 % AlO_2, > 1 % Fe_2O_3), with traces of other crystals. It absorbs ethylene and many other gases and is nontoxic and may be incorporated into plastic films but it results in a brownish cloudy appearance
3) Brominated activated charcoal (Abeles, et al., 1992)
4) Other compounds like hydrocarbons (Squalene, Apiezon) and silicones (Phenylmethylsilicone) might have some potential use, but none have been commercialized.

Kader et al. (1989) also pointed out an alternative method for quickly developing a modified atmosphere within a package which involves the use of an appropriately sized sachet of ferrous carbonate. The amorphous material oxidizes in moist air according to following equation

$$4\ FeCO_3 + O_2 + 6\ H_2O \rightarrow\rightarrow\rightarrow\rightarrow\rightarrow 4\ Fe\ (OH)_3 + 4\ CO_2$$

Therefore, CO_2 content of the package builds up while the O_2 content reduces. Commercially suitable absorbers for any gas should satisfy the following requirements:

1) must be effective and exhibit an appropriate rate of absorption of the specified gas
2) must be harmless to humans by direct or indirect contact
3) must have good storage stability
4) must be small in size but have large capacity for gas absorption
5) it should also be inexpensive, recyclable or easily disposable

2.4. Factors Affecting Modified Atmosphere Packaging

2.4.1. Commodity Factors

2.4.1.1. Respiration

Respiration in fresh produce is the oxidative breakdown of starch, sugars, organic acids and other complex molecules to simpler molecules including CO_2 and H_2O with a concurrent production of energy (Kader, 1987;Zagory and Kader, 1988). One of the primary effects of MAP is a lower rate of respiration which reduces the rate of substrate depletion, CO_2 production, O_2 consumption and release of heat (Zagory and Kader,1988; Riquelme et al., 1994). As a result, potential storage life can be extended. The decrease in respiratory activity shown by fruits and vegetables exposed to MAP is proportional to O_2 concentration (Riquelme et al., 1994). They pointed out that the concentration should not fall below 1 to 3 % otherwise anaerobic metabolism could begin with the decarboxylation of the pyruvic acid to acetaldehyde, CO_2 and ethanol. However, this critical O_2 level depends on the species, variety, temperature and preservation time. The rate of respiration is indicative of the rapidity with which compositional changes are taking place within plant material, and thus indicates the potential storage life of fruits or vegetables (Day, 1988). Fruits and vegetables with extremely high respiration rates and correspondingly extremely high degree of perishability will have a very short storage life (Day, 1993). The respiration rate of a commodity inside a polymeric film package, as measured by the rate of CO_2 production, will depend upon size and type of commodity, variety, maturity stage, physical condition, concentrations of O_2, CO_2 and C_2H_4 within the package, commodity mass in the package, temperature and possibly light (Kader et al., 1989; Day, 1993; Riquelme et al., 1994). A small potato has higher respiration rate than a larger one of the same variety (Day, 1993). He proposed that this phenomenon is probably due to the larger surface area of the smaller potato exposed to the atmosphere allowing more diffusion of O_2 into the tissues. In addition, different varieties of the same commodity exhibit widely different respiration rates and vary between different parts of a commodity. Similarly, different parts of the same plant differ in respiration rate. The peel, flesh and seed of mango all demonstrate different rates of respiration (Day, 1993). In addition, respiration rates change during a commodity's natural process of ripening, maturity and senescence. Certain climacteric fruits (e.g., apple, kiwifruit, pear and tomato) exhibit a marked and transient increase in respiration during their ripening which is associated with production and sensitivity to ethylene (Zagory and Kader, 1988; Kader et al., 1989). The ratio of CO_2 produced to O_2 consumed, known as the respiratory quotient (RQ), is normally close to 1.0, but can range from 0.7 to 1.3 depending on the metabolic substrate utilized (Forcier et al., 1987; Zagory and Kader, 1988). Some researchers suggested that MAP can alter the RQ, which will in turn affect the atmosphere created by the respiration of the commodity within the package (Tomkins, 1965; Kader et al., 1988). However, if the RQ is increased above 1.0, this may signify the transition from aerobic to anaerobic respiration.

2.4.1.2. Diffusion Characteristics of the Commodity

Gas exchange between a plant organ and its environment can be considered in four steps as follows (Kader et al., 1989):

1) Diffusion in the gas phase through the dermal system
2) Diffusion in the gas phase through the intercellular system
3) Exchange of gases between the intercellular atmosphere and the cellular solution (cell sap) which is a function of the distribution of the intercellular spaces and respiratory activity
4) Diffusion in solution within the cell to centers of O_2 consumption or from centers of CO_2 and C_2H_4 production

CO_2 and C_2H_4 are produced in the mitochondria and cytoplasm, and this local increase in concentration will activate diffusion outward and toward the cell wall surface adjacent to the intercellular space (Kader et al., 1989). These gases then move into the intercellular space under the skin or epidermis. From there, CO_2 and C_2H_4 diffuse through the openings in the surface of the commodity to the ambient atmosphere (Wolfe, 1980; Burton, 1982; Kader et al., 1989). On the other hand, O_2 diffuses inward from the ambient air into the centers of consumption inside the cells by the reverse pattern of that for CO_2 and C_2H_4. CO_2 moves much more readily through the skin than O_2 (Hall et al., 1954, Burton, 1974). CO_2 and C_2H_4 diffusion rate were very similar in a number of bulky organs (Burg and Burg, 1965). The rate of movement of gases through bulky plant organs in response to a pressure gradient has been used to measure diffusion characteristics (Kader et al., 1989). However, resistance to mass flow and resistance to diffusive flow are not equivalent (Stannett, 1978 as cited by Kader, et al., 1989).

Gas diffusion within a fruit or vegetable is determined by respiration rate, maturity stage, physiological stage, commodity mass and volume, pathways and barriers of diffusion, properties of the gas molecule (such as polarity & relative solubility in H_2O), concentration of gases in the atmosphere surrounding the commodity, magnitude of gas concentration gradient across barriers and temperature (Kader et al., 1989). Three different routes are available for the gas exchange between commodities and their surrounding atmosphere: lenticels and stomata, the cuticle and the pedicel opening or floral end (Kader et al, 1989). Theoretically, a gas will diffuse most quickly through that pathway which offers least resistance, that is mainly through gaseous space such as channels filled with air (Burton, 1974,1982; Solomos, 1987).

Bulky organs have a much lower surface to volume ratio than leaves; therefore the distance over which gases must diffuse in the tissue is very large, and respiration accounts for the major metabolic source of CO_2 and sink for O_2 (Kader et al., 1989). In these organs, there is no evidence for the presence of functional stomata or other active control of gas exchange (Adams, 1975; Kader, 1989). The majority of gas diffusion in these organs occurs through the lenticels (Burg and Burg, 1965; Burton, 1965 and Wigginton, 1973). The calyx opening of apples (Markley and Sando, 1931; Cameron and Reid, 1982) and the stem scar of tomatoes (Clendening, 1941; Burg and Burg, 1965 and Cameron and Reid, 1982) contribute significantly to gas exchange.

Many studies on gas exchange of plant tissues showed that the skin (epidermis and cuticle) represents the main significant barrier to gas diffusion (Burton, 1950; Burg and Burg, 1965; and Ben-Yehoshua, 1969). The skin barrier is the primary factor regulating the internal concentration of gases within a commodity. In addition, the effects of films on diffusion or resistance to gases moving across the skin are additive.

The resistance to CO_2 diffusion out of fruits or vegetables has been indicated to increase during the maturation period (Kidd and West, 1949; Ben-Yehoshua, 1969). When the fruit is still immature, there is less resistance to gas diffusion (Marcellin,1974 after Kader et al., 1989). Generally a marked increase in resistance to O_2 and CO_2 diffusion occurs shortly after harvest (Trout et al., 1942; Burton, 1965) and continues to increase during maturation (Ben-Yehoshua,1987). This may relate to progressive skin wax synthesis and the obturation of lenticels accompanying maturation. Studies in a number of fruits also found that as the fruit ripened, the resistance to CO_2 diffusion increases whereas resistance to C_2H_4 diffusion decreases (Vaz,1982 after Kader et al., 1989). Large fruits were more resistant to CO_2 diffusion than smaller ones.

Reduced external O_2 levels result in lower diffusion resistance to CO_2 and higher resistance to C_2H_4 (Kader et al., 1989). In addition, elevated external CO_2 levels increased both the C_2H_4 and CO_2 diffusion resistance. This may have been the result of purely physical viscosity effects of these higher molecular weight gases.

2.4.2. Environmental factors

2.4.2.1. Temperature

Maintaining proper temperature control after harvesting is probably the most important factor affecting the quality of modified atmosphere packed produce (Day, 1993). Low temperature contributes to decrease the respiration rate, to control microorganism growth and to retard the metabolic activity of plant tissues (Riquelme et al., 1994). They pointed out that for packed products to be preserved as long as possible, exposure to low temperature should last the longest time possible. The optimal temperature can be described as that which delays senescence and maintains quality without causing damage by cold or freezing (Zagory and Kader, 1988 as cited by Riquelme et al., 1994). This temperature will depend on the type of fruits or vegetables, the permeability of the plastic used and the tolerance of the fruits and vegetables to different gaseous concentrations (Riquelme et al., 1994). During the marketing of MAP products, the optimum temperature must be kept constant to prevent deterioration. Temperature fluctuation may produce condensation of water vapour inside the package, modify the plastic's permeability and increase the respiration rate of the product (Riquelme et al., 1994). A decrease in the internal concentration of O_2 and an increase in the internal concentration of CO_2 within bulky plant organs in response to an increase in temperature have been shown for almost all commodities (Kader et al., 1989). At constant relative humidity, an increase in temperature causes an immediate increase in transpiration rate of bulky plant organs (Pieniazek, 1943). On the whole, respiration is roughly doubled or tripled for every rise of 10°C (Kader et al., 1989) although respiration response may be 5 to 7 fold in the 0 – 10°C range.

While the optimum low storage temperature are generally known for nearly all commodities, it is equally important to recognize that these ideal temperatures are not always adhered to and temperature abuse occurs more frequently than many care to admit. Thus in practice, and this is even more important in MAP studies, one must know how the system will react to temperature abuse conditions. Therefore, instead of performing these experiments at a single optimal temperature, we have included in the design, storage temperature trials 5°C higher than the optimum to represent likely temperature abuse conditions. It is likely that abuse temperature even 10°C higher than optimum may be encountered in countries without consistent access to refrigeration. Temperature is also an extremely important consideration in package design (Beaudry and Lakakul, 1995). As temperature increases, the permeability of the packaging film to O_2 and CO_2 increases markedly (Beaudry and Lakakul, 1995). They reported that the permeability of O_2 and CO_2 through low-density polyethylene (LDPE) increases approximately 2.5 fold between 0 and 15 °C. However, Kader et al., (1989) reviewed that the permeability of some films has been reported to rise from two to five times with every 10°C increase in temperature. However, in most practical uses, films do not thermally respond as rapidly as the increase in commodity respiration and we have frequently made that observation in the OSU Postharvest lab. In addition, CO_2 permeability responds more to increase in temperature than O_2 permeability. Therefore, commodities packed in a film resulting in a favorable atmosphere at a low temperature may result in a harmful atmosphere at higher temperatures (Kader et al., 1989). This again reinforces the importance of careful temperature management of packaged produce. Temperatures in the range 0 – 5°C are generally chosen for storage and distribution of most modified atmosphere packed produce (Day, 1993) except those tropical commodities which require higher storage temperatures (above risk of chilling injury) to be safe. He pointed out that at these low temperatures, respiration rates are significantly lowered and the growth of spoilage and food poisoning microorganisms is restricted. Temperatures less than 10 –12°C should be maintained throughout the preparation for MAP of fresh produce prior to chilling below 5°C for storage and distribution (Day, 1992).

2.4.2.2. Relative Humidity

Relative humidity appears to have little effect on permeability of most film packages unless actual condensation occurs on the film (Zagory and Kader, 1988), in which case permeability may be greatly reduced. The plastics used in MAP are of low permeability to water vapour and so water is accumulated inside the package creating a high humidity, low oxygen environment which may be favorable to pathogenic microorganisms such as *Botrytis spp* and *Geotrichum spp* which increase the possibilities of product deterioration (Zagory and Kader, 1988; Riquelme et al., 1994). For this reason, fungicidal treatment of packaged fruits and vegetables is very important (Zagory and Kader, 1988). However, consumer expectations of reduced use of chemicals, especially postharvest applications make such chemical treatments increasingly difficult to accept by the consuming public. However, high relative humidity decreases weight loss and maintains produce firmness over longer periods of time (Riquelme et al., 1994). Shirazi and Cameron (1987) suggested ways to control relative humidity inside the package by using water absorbing chemicals such as CaSiO4, KCl, NaCl, Xylitol and sorbitol. This has not been practically applied to date, however the inclusion of surfactants in the polymeric formulation of the film was also suggested to act as antimisting or anti-fogging agents (Shore, 1978 as cited by Riquelme et al., 1994).

2.4.2.3. Light

For most commodities, light is not an important factor for postharvest handling. However, green vegetables in the presence of sufficient light could potentially consume substantial amounts of CO_2 and produce O_2 through photosynthesis (Zagory and Kader, 1989). These reactions could counteract the processes of respiration which are helping in the maintenance of a specified MAP. Little information is available whether ambient light passing through a plastic film is sufficient enough to cause substantial photosynthesis. Day (1989, 1990) suggested that the influence of light should not be ignored. In addition, some commodities may be adversely affected by excessive light such as the chlorophyll bleaching of Brussels sprouts and watercress (Day, 1993), and greening of potatoes and Belgian endive can cause serious loss of quality unless light is excluded (Zagory and Kader, 1989). Therefore, opaque films may be appropriate for these commodities.

2.4.3. Films Available and Suitable for MAP of Fresh Produce

The desirable characteristics of plastic films for MAP of fresh produce (Kader et al., 1989) are:

1) Required permeabilities for the different gases
2) Good transparency and gloss
3) Light weight
4) High tear strength and stretchability, resistance to puncture
5) Low temperature heat sealability
6) Nontoxic
7) Nonreactive with produce
8) Thermal and ozone resistance
9) Weatherability

10) Commercial suitability

11) Ease of handling

12) Ease of printing for labeling purposes

Day (1993) mentioned that the main characteristics to consider when selecting film for MAP for fruits and vegetables are gas permeability, water vapor transmission rate, mechanical properties, type of package, transparency, sealing reliability and microwaveability. He proposed three packaging scenarios of MAP namely, a) Barrier film: undesirable anaerobic conditions b) Fully permeable film: no desirable atmospheric modification c) Intermediate permeable film: desirable equilibrium modified atmosphere and he concluded that packaging films of correct intermediate permeability can create desirable MAP of respiring fruits and vegetables. Another type of film called Ultra - low barrier, microperforated films are being developed that have air permeability of about 60,000 $ml/m^2 \cdot day \cdot atmosphere$ (Gorris and Peppelenbos, 1992, Frey, 1997). They proposed that these films are probably well suited for packaging produce with extremely high respiration rates such as asparagus, broccoli, mushrooms, mungbean sprouts and shredded vegetables.

However, due to differences in the respiration rates of individual fruits or vegetables and the effect of temperature on both respiration and gas permeability, the type of plastic film required to achieve any specific equilibrium modified atmosphere must be defined for each commodity at a specific storage temperature or for a narrow temperature range (Day, 1988). The permeability of packaging films, particularly to CO_2 is directly proportional to temperature

(Ooraikul, 1991; Beaudry and Lakakul, 1995) and rise from two to five times with every 10°C increase in temperature (Kader et al., 1989). Thus, a film that creates a near optimum atmosphere at a given temperature will create a sub-optimal atmosphere if the temperature is increased. In other words, a film resulting in favorable atmosphere at a low temperature will likely result in a harmful atmosphere at higher atmospheres.

For most commodities (except those which tolerate high CO_2 levels), a suitable film must be much more permeable to CO_2 than to O_2 (Kader et al., 1989). The CO_2 permeability should be somewhere in the range of 3 - 5 times greater than the oxygen permeability, depending upon the desired atmosphere (Zagory and Kader, 1988). In fact, most commercially available films meet this criterion (Table 2.1, (Kader et al., 1989)).

Of these, low density polyethylene and polyvinyl chloride are the main films used in packaging fruits and vegetables (Kader, 1992).

Gas diffusion across a film is determined by film structure, film permeability to specific gases, film thickness, surface area, concentration gradient across the film, temperature and differences in pressure across the film (Kader et al. 1989). Other variables which can affect gas diffusion into and out of polymeric film packages are free volume inside the package, effectiveness of closure of the package, condensation of water vapor and air velocity around the package (Kader et al., 1989). Changes in temperature will affect gas diffusion

Table 2.1. Permeabilities of available polymers used for film formulation

Film type	Permeabilities (cc/m^2 / mil / day at 1 atm)			
	CO_2	O_2	$CO_2 : O_2$ Ratio	WVTR*
Polyethylene: (Low density)	7,700–77,000	3,900-13,000	2.0-5.9	
Polyvinyl chloride	4,263-8,138	620-2,248	3.6-6.9	
Polypropylene	7,700-21,000	1,300-6,400	3.3-5.9	
Polystryrene	10,000-26,000	2,600-7,700	3.4-3.8	
Saran™	52-150	8-26	5.8-6.5	
Cellulose acetate	13,330-15,500	1,814-2,325	6.7-7.3	1,613-1,395
Polyvinylidine chloride	59	15.5	3.8	3.1
Rubber Hydrochloride	4,464-209,250	589-50,375	4.2-7.6	7.8-10.9
Nylon	31	15.5	2.0	126
Polycarbonate	23,250-26,350	13,950-14,725	1.7-1.8	10.9-17.1
Ethylcellulose	77,500	31,000	2.5	310
Methylcellulose	6,200	1,240	5.0	3,100
Polyvinyl alcohol	Near 0	Near 0	-	1,240
Polyester	180-390	52-130	3.0-3.5	-
Polyvinyl fluoride	171	50	3.4	-
Polychlorotrifluoroethylene	124	11.8	10.5	0.3
Cellulose triacetate	13,640	2,325	5.9	74-93
Vinyl chlorideacetate	853	233	3.7	62

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* Water vapor transmission rate

between cell sap and intercellular spaces and across films (Kader et al., 1989). This is because solubility of gases in a liquid matrix decreases with increasing temperatures.

The packaging film should ideally give equilibration of relative humidity not exceeding 90 % (Geeson, 1990), However, the use of films with high water vapor transmission rates (WVPR) could result in shriveling and wilting whereas low WVPR result in excessively high relative humidity levels (>98 %) which may cause condensation and encourage fungal decay (Geeson et al., 1985; Geeson, 1990). Many films with favorable CO_2 and O_2 permeability characteristics have a rather low permeability for water vapor (Gorris and Peppelenbos, 1992). The high relative humidity formed within the package can cause condensation and favor development of molds/ bacteria. In addition, even small fluctuations in the storage temperature can result in condensation inside the package which would greatly increase the proliferation and spread of spoilage microorganisms (Gorris and Peppelenbos, 1992).

Especially in fruits, high relative humidity can cause heavy losses due to microbial decay. In package relative humidity may be controlled by using packaging materials with high water vapor permeabilities, or by including sachets with water absorbers like $CaCl_2$, sorbitol or xylitol in the package or by using packaging material with suitable gas permeability that has been coated with these dessicants (Barmore, 1987; Shirazi and Cameron, 1992: Gorris and Peppelenbos, 1992).

The phytohormone ethylene poses another complicating factor that is involved in the ripening or maturation of fresh produce. In MAP, the ethylene produced by the packaged produce may accumulate to some extent since the permeability of most packaging films for ethylene is intermediate between that for CO_2 and O_2 (Gorris and Pepplenbos, 1992). Alternatively, ethylene may enter a package from the outside when there is a prominent source such as vehicle exhaust or ripening climacteric fruits. Therefore, inclusion of ethylene scrubbers like potassium permanganate may counteract the effect of ethylene although the capacity of such gas scavengers is finite and limited.

Many types of plastic films used for MAP display a wide range of characteristics in terms of gas permeability, water vapor transmission rates, anti-fogging properties, strength and stretch shrink properties. In addition, gas permeability is sensitive to changes in temperature and relative humidity (Prince et al., 1986). Gas permeability specifications given by film manufacturers are usually determined under conditions that are quite different from the high humidity, refrigerated storage conditions of fresh produce. In addition, most data on film permeability are generated at a single temperature (20°C) and often at very low relative humidity. Therefore, the responses of film permeability to temperature between 0 and 20°C and to relative humidity between 85 and 95 % need to be determined (Kader et al., 1989). At present, it is impossible to tell from the specifications provided by packaging film manufacturers whether a specific film would provide for an in package gas atmosphere with tolerable O_2 and CO_2 levels when applied in practice (Kader et al., 1989). Therefore, the suitability of a film must be tested with the product under the correct practical conditions.

The polyolefins are the predominant plastics used for packaging (Goddard, 1980). This group includes polyethylene, polypropylene and polybutylene as well as their copolymers (Goddard, 1980). In general, the polyolefin films are typified by their good water vapor barrier properties, their relatively high gas permeability, product visibility and their favorable response to heat sealing (Kader et al., 1989). Most of the polyolefin films can be oriented to allow heat shrinkage (Kader et al., 1989). They also pointed out that heat shrink films could be used in MAP because the headspace around the produce can be greatly reduced after the film has been shrunk to fit. As a result, more rapid modification of internal atmosphere can be obtained. Several types of polyethylene films are available and are among those most commonly used in packaging of fresh produce (Kader et al., 1989). Polyethylene film is generally described as having high (0.941 - 0.965), medium (0.926 - 0.940) or low density (0.910 - 0.925) specific gravity (g/cc) which can also be used to describe their water barrier properties (Heuer,1987). In addition, polyethylene displays excellent tear strength, high resistance to chemical degradation and relatively high gas permeability. Moreover, the particular importance for MAP is that polyethylene, particularly low density polyethylene, tends to have a high ratio of CO_2 to O_2 permeability (Kader, 1989). This is important in allowing O_2 concentration to decrease without an associated excessive buildup of CO_2 inside the package.

Some PVC films are well suited for MAP and already in use for over-wrapping trays of fresh produce (Hall et al., 1975) and are widely used as shrink film for fresh produce (Preston, 1967). This is because PVC films typically have moderate levels of water vapor permeability and they can be soft, clear, non-fogging and durable (Preston, 1967; Hall et al., 1975). In addition, they can have fairly high CO_2 / O_2 permeability ratios as well. Rij and Ross (1987) determined that packaging broccoli in selected PVC films with proper gas permeabilities could serve to generate an appropriate equilibrium atmosphere to retard spoilage. Hoever, Aharoni et al. (1985) found that PVC film wrapped broccoli heads were unsaleable whereas polyethylene film bags used during simulated prolonged transit (3 days at 15°C + 2 days at 20°C or 14 days at 0.5°C + 2 days at 20°C) allowed broccoli heads to be kept in high quality.

Polystyrene is another polymer which has been used extensively to wrap lettuce and tomatoes and is available as a heat shrink film (Sacharow and Griffin, 1980). It has high gas transmission rates and relatively high CO_2 / O_2 permeability ratio (Kader et al., 1989). Moreover, it is relatively inert chemically and has a high degree of clarity.

Many types of films from CRYOVAC Company were developed and tested for fresh produce packaging. Lemons, wrapped with CRYOVAC D-955 were found to have reduced weight loss and respiratory rates (Eaks, 1986). Potatoes packed in polyolefin film (Cryocvac D950 and D955) stored at 24°C or room temperature lost less weight and showed minimal physical changes compared to controls (Shetty et al., 1989). Moggia-Lucchini (1991) tested

CRYOVAC D940 and D955 on blackberries and found that moisture loss was extremely low (0.1 to 0.3 %) compared to control (3 %). However, packed blackberries developed almost 40% more rot than the control, due to excessively high relative humidity inside the packages. Broccoli MAP using three CRYOVAC polyolefin flims (PD941, PD961 and PD900) and perforated polyethylene bags were stored at 0, 5 and 10°C (Cabezas, 1995; Cabezas and Richardson, 1997). They found that cut broccoli florets in PD941 film developed no off-odors during 28 days storage at 0, 5 and even under 10°C. In addition, color (hue angle and chroma) and chlorophyll retention was better in MAP of broccoli florets than perforated bag controls. Loss of ascorbic acid was also delayed. Controls in perforated bags became unsaleable in only 14 days.

Some new microperforated packaging films (XTEND, Stepac, L.A.) which reduce in - package moisture to the 95 - 98 % RH range and yet raises CO_2 to 15 - 18 % and lowers O_2 to 7 - 5 % have shown promise for prolonging fresh sweet corn storage life by 30 -40 % at 0 and 5°C compared to ice packed controls (Aharoni and Richardson, 1997). They found that XTEND 100 and XTEND 130 were more suitable for bulk packaging than the XTEND 120. However, XTEND 120 maintained fresh sweet corn quality in the consumer package, which contained two cobs. This was because the lower RH in the consumer packages of XTEND 100 and XTEND 130 caused some drying and denting of the kernels (Aharoni and Richardson, 1997). Othieno and Thompson (1995) assessed the use of microperforated film for extending shelf-life in simulated commercial marketing of sweet corn (cv. Super sweet). The best results were obtained with unperforated film or film with minimum perforation (one 0.4 mm hole/6.5 cm^2). Cobs packed in non-perforated polypropylene film had a reduced rate of toughening, weight loss and loss of sweetness but they tended to produce off-odors. Packing the cobs with the sheath still attached but partly cut away to reveal the kernels was the best treatment for both storage and visual presentation. Microperforated films theoretically could use any type of barrier film type, but creating an array of micro-perforations specifically designed for the needs of the commodity.

Another aspect which is at present receiving serious interest is the use of films that can modify their own permeability in response to changes in the external environment, or to modifications in the composition of the internal atmosphere (Riquelme et al., 1994). Therefore, if these ‘intelligent" or “smart” films can really adapt their characteristics to temperature changes, then the influence of such changes that occur in the long marketing process can be reduced to a minimum. Landec Corporation has developed a polymer capable of preserving the freshness and taste of packaged fresh cut produce (Anonymous, 1997). The unique properties of this polymer help the product maintain its freshness as the temperature changes. By using a membrane consisting of a unique and proprietary polymeric coating on a porous substrate, the required atmosphere can be manipulated by changing the polymer used to coat the substrate which changes the CO_2 / O_2 permeability ratio and the size of the membrane. By utilizing a crystalline polymer, it is possible to increase the permeability substantially as the temperature rises, thereby reducing the chance of the package becoming anaerobic if the cold chain is broken (Anonymous, 1997). However, to the present, little technical data is available to verify this claim.

2.5. Equilibrium Gas Concentration in MAP

Kader et al. (1989) described that oxygen inside the package is consumed by the produce as it respires and an approximately equal amount of CO_2 is produced. The reduction in O_2 concentration and increase in CO_2 concentration creates a gradient causing O_2 to enter and CO_2 to exit the package. Initially, however, the gradient is small and the flux across the package is not sufficient to replace the O_2 that was consumed or to drive out all of the CO_2 that was generated. Therefore, inside the package, the O_2 content decreases and the CO_2 increases. As this modified atmosphere is created inside the package, respiration rate falls in response to the new atmosphere, resulting in less O_2 utilization and less CO_2 production. Therefore, new equilibrium concentrations of the gases surrounding the fruit are eventually attained (Geeson et al., 1985; Smith et al., 1987). When O_2 consumption equals O_2 diffusion into the package and CO_2 production equals CO_2 diffusion out of the package, a steady state equilibrium is achieved (Kader et al., 1989; Beaudry and Lakakul, 1995). They reported that accumulation of CO_2 and C_2H_4 and the depletion of O_2 occurred faster at 10°C than at 5°C, and the equilibrium gas concentrations were different at 10°C than at 5°C.

Since modified atmosphere conditions generated within a package may fluctuate slightly, the practical optimal atmosphere should be one that is not too close to an injurious MA (Day,1993). He suggested that an optimal MAP should minimize respiration rate without danger of physiological damage to the commodity. In addition, different commodities vary widely in their tolerance to different atmospheres (see Table 2.2 and 2.3). Moreover, the effect of low O_2 and high CO_2 levels on respiration are additive, therefore, optimal concentrations of both gases in combination are difficult to predict without actual measurements in a variety of atmospheres (Zagory and Kader, 1988; Zagory, 1990). However, as a generalization, MAP containing 2 - 5 % O_2 and 3 - 8 % CO_2 have been shown to extend the shelf life of a wide variety of fruits and vegetables (Day, 1988). Day (1993) concluded that determination of the optimal MAP of a particular produce item is complicated because of the numerous variables involved. Thus, if the effect of simultaneous variations in CO_2 and O_2 levels on the quality of a vegetable held at 5°C were to be assessed, then a critical quality parameter would have to be assessed by a trained sensory panel.

2.6. Relative Tolerance to Low O_2 and Elevated CO_2 concentration

The lower O_2 limit which commodities can tolerate has been the important issue of numerous inquiries over the past several decades. If O_2 levels decline below the tolerance level of a particular plant organ, fermentation, tissue browning and off-flavors occur (Beaudry and Gran, 1993; Richardson and Kosittrakun, 1995), although some of these off-flavors may be reversible. However, lower O_2 levels have been shown to yield a number of benefits for apple fruit (Lau, 1989). A number of factors can potentially impact the lower O_2 limit of fruits and vegetables in storage. Cultivar, temperature and CO_2 level are three very commonly altered factors and each are known to interact with storage temperature (Beaudry and Gran, 1993). They used an MAP approach to determine cultivar, temperature and CO_2 effects on the lower O_2 tolerance of various commodities including apples and blueberries. The lower O_2 limit for apple fruit was found to be cultivar dependent, ranging from a low of approximately 0.8 kPa for 'Northern Spy' and 'Law Rome' to a high of approximately 2.0 kPa for 'McIntosh'. For blueberry fruit (cv. 'Bluecrop'), the lower O_2 limit increased with temperature and CO_2 partial pressure. Increasing the temperature from 0 to 25°C caused the lower O_2 limit to increase from 1.8 to 4 kPa. Increasing the CO_2 levels from 5 to 60 kPa increased the lower O_2 limit for blueburry fruit from 4.5 to > 16 kPa. High CO_2 level can enhance storage life of a number of commodities by helping the product to resist decay (Brooks et al., 1932; Thornton, 1930 after Beaudry and Gran, 1993; El - Goorani and Sommer, 1981). However, if the CO_2 partial pressure exceeds the tolerance level of plant tissues, then fermentation occurs, resulting in off - flavors and physical damage (Beaudry and Gran, 1993), although as Richardson and Kosittrakun (1995) have been shown, these may be reversible.

Subjecting fresh fruits and vegetables to O_2 levels below and/or CO_2 levels above their tolerance limits at a specific temperature time combination will result in stress to the living plant tissue such as irregular ripening, development of off flavors and increased susceptibility to decay initiation and/or aggravation of certain physiological disorders (Kader et al., 1989). Some physiological disorders are brown stain on lettuce, internal browning and surface pitting of pome fruits and blackheart of potato. Fresh fruits and vegetables vary greatly in their relative tolerance to low O_2 concentration and elevated CO_2 concentration (Kader, 1986; Kader et al, 1989; Weichmann, 1986 and Kader, 1995). Tables 2.2 and 2.3 show classifications of fruits and vegetables according to their relative tolerances to low O_2 or elevated CO_2 concentrations when kept at or near their optimum storage temperature and relative humidity (Kader et al., 1989). These are the levels below which O_2 or above which CO_2, physiological damage would be expected. These limits of tolerance can be different at temperatures above or below those recommended for each commodity. In addition, a given commodity may tolerate even higher levels of CO_2 or lower levels of O_2 for a short duration. Boersig et al. (1988) proposed that the tolerance to low O_2 would be lower as storage temperature and/ or duration increases since O_2 requirements for aerobic respiration of the tissues increase with higher temperature. Tolerance limits to CO_2 decrease with a reduction in O_2 level and, similarly, the tolerance limits to low O_2 concentrations increase with an increase in CO_2 level (Kader et al., 1989) and this has been especially appreciated for pears stored under CA (Richardson and Kupferman, 1997).

For some commodities, maturity stage can alter susceptibility to low O_2 and/or high CO_2 stress (Kader et al.,1989). Ripe fruits often tolerate higher levels of CO_2 than mature green fruits. Minimally processed fruit and vegetables have fewer barriers to gas diffusion and consequently they tolerate higher concentrations of CO_2 and lower O_2 than intact commodities. The effects of

Table 2.2. Classification fruits and vegetables according to their tolerance to low O_2 concentrations. (Kader, et al., 1989)

Minimum O_2 concentration tolerated (%)	Commodities
0.5	Tree nuts, dried fruits, and a few vegetables, some pears if CO_2 is less than 0.1 %
1.0	Some cultivars of apples and pears, broccoli, mushroom, garlic, onion, most cut or sliced fruits and vegetables
2.0	Most cultivars of apples and pears, kiwifruit, apricot, cherry, olive, cantaloupe, sweet corn, green bean, celery, lettuce, cabbage, cauliflower, Brussels sprouts
3.0	Avocado, persimmon, tomato, pepper, cucumber, artichoke
4.0	Citrus fruits, green pea, asparagus, potato, sweet potato

Table 2.3. Classification of fresh fruits and vegetables according to their tolerance to elevated CO_2 concentrations. (Kader, et al. 1989)

Maximum CO_2 concentration tolerated (%)	Commodities
2	Apple (Golden Delicious), Asian pear, European pear, Apricot, grape, olive, tomato, pepper sweet, lettuce, endive, Chinese cabbage, celery, artichoke, sweet potato
5	Apple (most cultivars), peach, nectarine, plum, orange, avocado, banana, mango, papaya, kiwifruit, cranberry, pea, pepper(Chili), eggplant, cauliflower, cabbage, Brussels sprouts, radish, carrot
10	Grapefruit, lemon, lime, persimmon, pineapple, cucumber, summer squash, snap bean, okra, asparagus, broccoli, parsley, leek, green onion, dry onion, garlic, potato
15	Strawberry, raspberry, blackberry, cherry, fig, cantaloupe, sweet corn, mushroom, spinach, kale, Swiss chard

stress resulting from exposure to undesirable MAP conditions can be additive to other stresses (such as chilling injury, wounding or ionizing radiation) in accelerating the deterioration of fresh produce (Kader et al., 1989). They concluded that successful MAP must maintain near optimum O_2 and CO_2 levels to attain the beneficial effect of MAP without exceeding the limits of tolerance that may increase the risk of physiological disorders and other detrimental effects.

2.7. Effects of Modified Atmosphere Packaging on the Quality of Fruits and Vegetables

The modification of the compounds responsible for the color, taste and odor determine the final fruit and vegetable quality. Low O_2 concentrations and/or high CO_2 concentrations can alter the metabolism of some constituents and/or the rate at which they are broken down or formed (Riquelme et al., 1994). In addition, anaerobic respiration or the physiological damage caused by CO_2 alters the composition of the product and considerably alters its quality.

Green beans quality changed minimally when stored in low density polyolefin film package during 16 days storage at 5°C (Trail et al., 1992). Many researchers found that broccoli maintained its quality longer in both perforated and sealed polyethylene packages at three temperatures than did unpackaged controls (Wang and Hruschka, 1977; Aharoni et al., 1981; Elkashif et al., 1983; Cabezas and Richardson, 1997). Aharoni et al. (1981) indicated that both high CO_2 (5 to 20 %) and low O_2 (1%) concentrations retard respiration and senescence of broccoli heads. In addition, increasing CO_2 seems to be more effective than decreasing O_2. Microperforated film (XTEND120) was found to maintain sweet corn quality in the consumer package for 7 days but was less suitable for bulk pack (Aharoni and Richardson, 1997). Previous researchers also found that reduced O_2 and CO_2 created by MAP can reduce deterioration in sweet corn (Kader, 1989; Othieno and Thompson, 1995). Sweet corn cobs can be transported for sale in distant markets after being sealed in PVC films to delay quality loss through the reduction of water loss and shrivelling (Aharoni et al., 1996). However, this package had decay at the cut ends of the corn, therefore, they tested two polyolefin films as substitutes for PVC. They found that these films can reduce decay and maintain quality during 12 days storage at 10°C and 2 days at 20°C.

2.7.1. Color

Consumers rarely choose fruits and vegetables according to their nutritional value; rather their choices are strongly influenced by appearance and price considerations (Weichmann, 1986). Thus, color and general appearance strongly influence the decisions of buyers to purchase particular fresh produce. Low O_2 concentration and/or high CO_2 concentration delay maturation and strongly affect color (Riquelme et al., 1994). High CO_2 concentration can also reduce the formation of phenolic compounds, phenoloxidase activity and phenol oxidation (Siriphanich and Kader, 1985). If O_2 and CO_2 are not within the tolerance limits, browning phenomena usually occur (Riquelme et al., 1994).

Loss of chlorophyll and biosynthesis of carotenoids (red and yellow) and anthocyanins (blues) are slowed in fruits and vegetables as a result of MAP (Isenberg, 1979; Smock, 1979; Riquelme et al., 1994). As expected, chlorophyll content is associated with greenness in green vegetables (Shewfelt, 1986) and maintained by high CO_2 level (Herner, 1987). Degradation of chlorophyll is the visible characteristic metabolic change of senescence and constitutes a good marker of the physiological condition of green plant tissues (Yamauchi and Watada, 1991). Degradation of chlorophyll by ethylene has been reported to be due to increased chlorophyllase activity (Amir - Shapira et al., 1987). Rolle and Chism (1987) also pointed out that chlorophyll change may result from the loss of membrane integrity, which occurs with senescence stimulated by ethylene. Chlorophyll degradation pathway probably differs among plant species (Watada et al., 1990). Ballantyne et al (1988) proposed that conversion of chlorophylls into pheophytins may be caused by acidification of cellular cytoplasm which is responsible for the degreening of broccoli.

Lebermann et al. (1968) reported that increased CO_2 and decreased O_2 levels in the storage atmosphere reduced the rate of color changes, mainly from green to yellow in vegetables as a result of chlorophyll breakdown. This effect has been well documented for broccoli (Leberman et al., 1968; Kasmire et al., 1974; Barth et al., 1993). They stated that an increase in CO_2 is more effective than a reduction in O_2 in slowing color changes as they obtained the same results whether 21 or 3 % O_2 was combined with increased CO_2. However, Lipton and Harris (1974) found that O_2 less than 1 % reduced the breakdown of chlorophyll and this inhibiting effect remained even during subsequent aeration. In addition, a combination of increased CO_2 and decreased O_2 preserved color of broccoli packed in polymeric film (Barth et al., 1993) and reduced yellowing of Brussels sprouts much more effectively than either alone (Lyons and Rappaport, 1962 after Weichmann, 1986). Zhuang et al. (1994) also reported a 30 % increase in chlorophyll content of broccoli florets within 6 days of storage at 5 °C.

The color of cauliflower after cooking is also influenced by the composition of the storage atmosphere (Weichmann, 1986). Lipton et al. (1967) pointed out that color changed to grayish or yellowish when cauliflower heads were cooked immediately after being stored 7 days at 5°C in 15 % CO_2. However, this discoloration was less pronounced after storage in 10 or 5 % CO_2. In addition, darkening did not develop in cooked heads held in air for 24 hr after removal from high CO_2.

Trail et al. (1992) pointed out that the most obvious indicator of quality of snap beans is color which changes from a desirable bright green to an objectionable yellowish color. In addition, chlorophyll content of snap beans stored in low density polyolefin film packages at 5°C was not influenced by storage period up to 16 days whereas snap beans stored at 10°C showed significantly better maintenance of chlorophyll after 4 days storage followed by a decline as time in storage increased. They concluded that hue angle and tristimulus a* corresponded more closely to chlorophyll content and were better indicators of snap bean color than chroma or tristimulus L* and b*. Resurreccion et al. (1987) also found that hue angle was the most important objective measures of postharvest quality in snap beans. CO_2 at 5 - 10 % was found to retard yellowing in snap beans (Groeschel et al., 1966). In addition, enhancement of CO_2 levels by respiration of snap beans packed in sealed bags was apparently sufficient to prevent quality loss (Buescher and Adams, 1979). Monreal and Alique (1997) also found that color loss of green beans was reduced by low O_2 levels in combination with moderate CO_2 concentrations. In their work, controlled atmosphere storage of green beans (cv. 'Perona') in 1 % O_2 and 3 % CO_2 prolonged the shelf life 22 days by maintenance of pigment content and the visual score. Saltviet (1993) also pointed out that low O_2 levels in combination with moderate CO_2 typically reduce color loss of many green tissues.

Increased CO_2 was also found to reduce browning and other discolorations of cut or broken surfaces of Brussels sprouts (Pelleboer, 1982; Weichmann, 1983), green beans (Buescher and Henderson, 1977; Herner 1987), lettuce (Singh et al., 1972) and sweet corn on the cob (Spalding et al., 1978). CO_2 at 10 - 30 % delayed brown discoloration of mechanically damaged tissue in green beans by decreasing phenolic content, phenolase activity and oxidation of phenolics (Buescher and Henderson, 1977). In addition, elevated CO_2 inhibited phenolic production and polyphenol oxidase activity in lettuce (Siripanich and Kader, 1985). More than 10 % CO_2 and less than 1 % O_2 is used effectively in fresh cut lettuce for inhibiting browning reaction (Gorney, 1997). On the other hand, browning of mushrooms was increased at elevated CO_2 levels and prevented only in O_2 free atmosphere (Murr and Morris, 1974).

2.7.2. Flavor

The effect of modified atmosphere on the flavor of fruits and vegetables depends on the crop involved. Off flavors can develop in any fresh fruit or vegetable if it is exposed to O_2 and /or CO_2 levels beyond tolerance limits that result in anaerobic respiration and formation of ethanol and acetaldehyde (Kader, 1986). Even though the accumulated ethanol and acetaldehyde can be removed from plant tissues by aeration, the extent of removal depends on the duration of exposure to anaerobic respiration, and the subsequent aeration time (Richardson and Kosittrakun, 1995). And, of course, molds themselves can generate off-odors.

Changes in carbohydrates, organic acids, proteins, amino acids, lipids and phenolic compounds can influence the flavor of fresh fruits and vegetables (Kader, 1986). He concluded that elevated CO_2 can also decrease the rate of sugar to starch conversion which is otherwise undesirable in peas and sweet corn. Snap beans stored in 20- 30 % CO_2 at 27°C for 24 hr had better flavor than those held in air, however 10 % CO_2 had no effect on flavor (Buescher and Henderson, 1977). On the other hand, sweet corn stored in 25 % CO_2 combined with 21 % O_2 developed an off - flavor, but in 2 % CO_2 no off-flavor developed (Spalding, 1978 as cited in Weichmann,1986). Sweet corn (cv. 'Super sweet') packed in non-perforated polypropylene film had a reduced rate of loss of sweetness but they tended to produce off-odors (Othieno and Thompson, 1995). Moreover, controlled atmosphere slowed down the losses of sugars and organic acids in tomatoes during storage at 12.5°C for up to 2 months (Goodenough and

Thomas, 1981). Goodenough (1982) also observed an increase in glucose and fructose and citric acid and a decrease in starch and malic acid in tomatoes stored in 5 % O_2 and 5 % CO_2. In addition, fruits of various apple cultivars have a better flavor after storage in 3 % CO_2 and 4 % O2 than after equal duration storage in air (Bangerth 1973).

In cauliflower, storage in 1 % O_2 or less also resulted in off-odors and off-flavor, but the latter was noticeable only after the samples were cooked (Lipton and Harris, 1976 as cited by Weichmann, 1986). An off-flavor following cooking also was found after storage of cauliflower in 15 % CO_2. However, when the crop was aerated sufficiently before cooking, the taste was found to be normal (Lipton et al., 1967 as cited in Weichman, 1986). Off-odors and off-flavors have also been noted after high CO_2 storage in celery, sweet corn and onions (Morris and Kader, 1977). By contrast, the taste of chinese cabbage as well as of lettuce was not negatively influenced by 1 % O_2 (Parsons et al., 1964; Wang, 1983). The offensive odors due to high CO_2 disappeared after aeration, but those due to low O_2 were still detectable (Kasmire et al., 1974). They recommended that if high CO_2 is used, the O_2 level should be greater than 1 %. Richardson and Kosittrakun (1995) showed that low O_2 (< 1 %) could produce off-flavors in cold-stored pears, apples, plums, red raspberries and blueberries, but this was largely reversible after 3 – 7 days aeration. The cause of the off-flavor could not be correlated with acetaldehyde or ethanol levels, which remained high after the aeration.

2.7.3. Texture

Cold storage in controlled atmosphere (CA) will inhibit ripening and texture change to a greater extent than is possible in air alone (Herker et al., 1997). There are three ways in which controlled atmosphere can influence fruit texture: first, a positive effect of CO_2 on tissue strength; second, a general inhibition of metabolic processes which often minimize texture change over long periods of storage: and third, a deterioration in quality and texture associated with use of injurious atmospheres (Herker et al., 1997). Changes in the texture of most fruits involve softening whereas vegetables usually involves toughening. The influence of modified atmosphere storage on the texture of vegetables varies with the commodity (Weichmann, 1988). The texture of green beans was not changed by storage in 0 to10 % CO_2 with 2 % O_2 for 1 or 2 weeks at 7°C (Groeschel, et al., 1966). The same result was also found in green beans stored in 0 - 30 % CO_2 in air for 24 hr at 27°C (Buescher and Henderson, 1977). In addition, no textural changes were demonstrated in raw broccoli stored in 0 - 20 % CO_2 with 2, 5, 10 or 20 % O_2 for 14 days at 1 or 7°C (Leberman et al., 1968). However, broccoli stored in high CO_2 was softer (after cooking). Lipton (1975) also found that 10 % or more CO_2 prevented toughening of broccoli and as a result, tissue became more tender when cooked than it was at the time of harvest. He pointed out that this tenderization may be a direct result of CO_2 mediated decrease in tissue pH. The same result was also found in cauliflowers (Lipton and Harris, 1976) and asparagus (Lougheed and Dewey, 1966). In asparagus, tenderness of the cooked asparagus spear increased at CO_2

concentrations of 3 - 30 % with an optimum at 15 %. Reduced O_2 had little effect on tenderness of asparagus or broccoli (Lipton, 1975).

A rapid and direct influence of CO_2 on tissue strength has only been reported in strawberry (Plocharski, 1982; Smith, 1992: Smith and Skog 1992; Larsen and Watkins 1995). Firmness was enhanced by storage in elevated CO_2 concentration in strawberry. The maximum firmness enhancement was generally achieved at 15 - 20 % CO_2 when storage temperature was 0 °C. Plocharski (1982) suggested that CO_2 was responsible for the induction of change in pectic substances. However Smith (1992) did not verify this. The effect of CO_2 on increased firmness has not been published in other fruits (Harker et.al., 1997), who also point out that strawberry has a unique interaction with CO_2. Alternatively, in other fruits, the effect may have been too small to detect with the devices used or the experiment not held long enough. The mechanism of modified atmosphere effect on texture of fresh fruits and vegetables is not fully understood and merits further investigation (Kader, 1986).

CHAPTER 3

A: THE EFFECT OF MAP FILM TYPES AND STORAGE TEMPERATURE ON QUALITY OF GREEN BEANS (*Phaseolus vulgaris* L.)

Key Index Words: *Phaseolus vulgaris* L., snap beans, modified atmosphere packaging, off–odors, headspace gas composition

3.1. ABSTRACT

Although modified atmosphere packaging has potential to extend the postharvest life of most fresh produce, physiological properties (e.g., variety, respiration rate, mold resistance), film permeability, temperature and mold control are the key components for success of this approach. The objective of these studies was to test the effectiveness of different plastic films and two temperatures on storage life and quality of green beans (cvs. 'Strike' and 'Jade'). Green beans packed in four CRYOVAC polyolefin films, one microperforated film and a control perforated film (vented bags) stored at 5° or 10°C were sampled initially and at one week intervals for quality evaluation. Sensory evaluation was performed at 14 and 21 days after storage for the 1997 green bean experiment. In package CO_2 and O_2 concentrations were measured throughout the storage period.

In the 1996 preliminary experiment, green beans packed in vented bags and unpackaged control showed poor quality ratings as early as 7 days after storage. Green beans (cv. 'Strike') packed in PD941 and PD961 were of acceptable quality for up to 21 days at 5°C. They were superior to other

treatments in mean quality rating, minimum weight loss and color change. However, slight off-odors developed in PD961 packages after 21 days storage. Green beans packed in PD955 did not maintain satisfactory market quality (quality rating score <3) after 7 days storage at 10°C and after 14 days storage at 5°C. Weight loss was less than 1% in all CRYOVAC films tested and showed a similar pattern at 5 and 10 °C. Green beans packed in vented bags and unpackaged had more than 7% weight loss after 21 days storage.

In the1997 experiment, control packaged 'Jade' green beans retained good quality for only 7 days whereas those packed in PD941 film gave the best overall quality after 21 days storage at both temperatures; which confirmed the 1996 preliminary result. However, a high off-odors score was detected by panelists for beans in PD941 stored at 10°C after 21 days storage. The highest off-odor scores were rated in green beans packed in XTEND120 at 10°C for both 14 and 21 days storage. The development of off - odors was associated with very high CO_2 concentration (25 – 30%) inside packages. Green beans packed in PD961 also had high off-odor scores at both temperatures. Weight loss of green beans packed in XTEND120 and vented bags (controls) were three to eight times greater than those in either CRYOVAC films (PD941 and PD961) (less than 1 %). Green beans packed in PD941 gave the highest retained hue angle, which indicated greener bean pods, compared to other films at both 5 and 10 °C. The tristimulus a* values indicated that beans were significantly greener (became more negative, $p \leq 0.05$) at 10°C than at 5°C, especially after 7 and 14 days storage. At 5°C the trend in a* became less negative as the storage period increased. However, no significant change in hue angle over time was found throughout the entire 21 days storage period for PD941 at 5°C. Although not statistically significant, control beans (vented bags) indicated some tendency to lose chlorophyll compared to other treatments.

3.2. INTRODUCTION

Green beans *(Phaseolus vulgaris* L.*)* also known as snap, string or French beans are one of the most important vegetable crops in the United States (Lewis, 1958). Fresh market green beans are usually marketed in bulk without packaging or other preparations. At optimal storage temperatures (4 to 7°C), green beans should be stored only for short periods up to 10 days (USDA Handbook # 66). Often they are in poor condition and have many blemishes when they reach retail markets. Ceponis and Butterfield (1984) surveyed green bean losses at retail and consumer levels in metropolitan New York and found that retail losses were 14 % in bulk compared to 3 % in prepackaged beans. They concluded that desiccation was the leading cause of retail loss, while mechanical and physical injuries caused most of the losses in consumer samples. Visible loss of quality after harvest arises through rotting, shriveling and color changes (Ryall and Lipton, 1979). In addition, because green beans are harvested at an immature developmental stage, they have a high respiration rate and short storage life. Although some extension in storage life can be achieved through decreasing the temperature, the development of chilling injury at temperatures less than 4°C becomes a limiting factor in temperature reduction (Wills and Kim, 1996).

Therefore, postharvest handling and management strategies, including MAP, are very important to reduce deterioration and preserve green bean quality.

Exposure of fresh fruits and vegetables to low O_2 and high CO_2 atmosphere can reduce deterioration and influence quality and storage life by reducing metabolic activity (Kader, 1986, Kader, 1995; Riquelme et al., 1994). Modified atmosphere packaging in sealed plastic films (MAP) provides such an approach to improve the storage life and quality of several horticultural products (Calderon and Barkai-Golan, 1990; Day, 1993). Groeschel et al. (1966) concluded that in order to reduce respiration rate of green beans by 40 %, the O_2 level had to be reduced to 2 %. Carbon dioxide had little or no effect on respiration, but green color losses were minimized with the use of 10 % CO_2 because chlorophyll breakdown was retarded (Groeschel, 1966). Buescher and Adams (1979) reported that elevation of carbon dioxide levels in packages due to respiration of green beans appeared sufficient to prevent quality loss. Green beans (cv. 'Opus') may be held for up to 21days at 4°C in 2% O_2 plus 6% CO_2 or at 1°C in 2% O_2 plus 6% CO_2 or 8% CO_2 (Costa et. al., 1994). They concluded that at 1°C, 8% CO_2 was the maximum level tolerated with 2% O_2; 18 % CO_2 caused injury at 4°C, but not at 8°C. The change in color of green beans from a desirable bright green to an objectionable yellow is the most obvious indication of quality loss (Trail et al., 1992). They found that storing green beans at 5°C for 16 days had no significant influence on chlorophyll indicating slow down in chlorophyll degradation. Another study reported that polyethylene bags could be used to prevent water loss and maintain total sugar of green beans (Sistrunk et al., 1989). The quality of vegetables stored in sealed packages is affected by permeability of the plastic film to O_2 and CO_2, storage time and storage temperature. This current study was undertaken to determine the effects of different package films on the quality of green beans during storage at 5° (optimum temperature) and 10°C (mild temperature abuse).

3.3. MATERIALS AND METHODS

3.3.1. Plant materials and Films Used

Experiments were conducted in 1996 and 1997. In the1996 preliminary experiment, green beans (cv: 'Strike' from Asgrow Seed Company) were grown at Oregon State University Vegetable Research Farm in Corvallis, OR. They were harvested by hand at the commercial maturity stage (defined by sieve size) and immediately brought to the laboratory and kept overnight at 5°C. The next morning, the green beans were visually inspected and the defective and blemished pods were removed. The experiment was a 6 x 2 factorial (6 package films, 2 temperatures) in a completely randomized design. Four polymeric films manufactured by CRYOVAC Company were used as packaging films (Table 3.1). Treatments were as follows:

1) PD940
2) PD941
3) PD955
4) PD961
5) Control (Vented bag, eight 6 mm holes per bag)
6) Control (Unpackaged)

PD940 and PD941 are essentially the same film, the only difference being that PD940 is the doubled over folded sheet form of PD941. Two storage temperatures were tested (5° and 10°C). Green beans (300 g each) were obtained randomly, placed into 7" x 8 " polyolefin film bags and sealed in an impulse heat sealer (Model CD 500, DEA LUN CO LTD, Taiwan R.O.C.). There were fourteen packages per treatment. The CO_2 and O_2 gas concentrations and weight loss were measured from the same eight replications (packages) throughout the experiment. However, destructive measurements (2 packages per treatment at each evaluation time) were performed for color change and subjective quality evaluations.

Table 3.1. Carbon dioxide, oxygen and water vapor transmission rates of CRYOVAC films used in experiments (CRYOVAC Technical Information).

Film	Permeability rate (cc/ m^2 / 24 hr)		Water vapor transmission rate (g / 100 in^2/ 24 hr)
	CO_2	O_2	
PD940	50,000	16,500	5.2
PD941	31,000	16,544	5.0
PD955	27,000	8,900	1.48
PD961	19,000 - 22,000	6,000 - 8,000	0.90 - 1.10

-Data for XTEND120 was not available (proprietary information of Stepac Company).

In 1997, green beans (cv. 'Jade' from Rogers Seed Division, Novartis) were harvested by hand from the Davis family farm near Corvallis, Oregon. The same packaging procedure was used essentially as in the 1996 experiment but we concentrated on the superior films and a new type microperforated film was added. The experiment was a 4 x 2 factorial (4 package films, 2 temperatures) in a completely randomized design. Two polymeric films manufactured by CRYOVAC Company were used as packaging films, namely PD941 and PD961. A microperforated film (XTEND120) from Stepac Company was tested and a perforated bag control. Packaging treatments in the 1997 experiments were as follows:

1) PD941
2) PD961
3) XTEND120
4) Control (Vented bag, eight 6 mm holes per bag)

Two storage temperatures (5° and 10°C) were also tested. We have included in the design, storage temperature trials 5 °C higher than optimum to approximate likely temperature abuse conditions. Green beans (300 g each) were obtained randomly and placed in 7 " x 9 " bag and sealed in an impulse heat sealer (Model CD 500, DEA LUN CO LTD, Taiwan R. O. C.). There were eighteen packages per treatment. Headspace CO_2 and O_2 gas concentration and weight loss were measured from the same four packages throughout the experiment. However, destructive measurements (4 packages per treatment at each evaluation time) were done for color change and subjective quality evaluations by panelists.

3.3.2. Headspace CO_2 and O_2 Analysis

Headspace CO_2 and O_2 concentrations were analyzed using gas chromatography. Samples (1 ml, 8 replicates for 1996 experiment and 4 replicates for 1997 experiment) for each treatment were drawn one day after packing, then every 1 – 3 days. Gas samples were withdrawn through the film by using a 1 ml gas tight syringe fitted with 27 gauge needle and packages were immediately resealed with 2 cm^2 Scotch tape after each sampling. CO_2, O_2 and N_2 measurements of headspace were made by injecting the 1 ml gas sample into a Carle Model 311 Gas Chromatograph equipped with a HayeSep R column (2 m x 3 mm OD, 80 / 100 mesh) and a Molecular Sieve 5 A column (2m x 3 mm OD, 80 / 100 mesh) at 55 °C with manual column switching. Separated gases were detected by a thermal conductivity detector (TCD). Helium carrier gas flow was 30 ml / min. An HP model 3395 digital integrator (Hewlett - Packard Co., USA) quantified TCD detector response. External calibration standards containing 17 % O_2, 3 % CO_2 and 80 % N_2 were supplied by Scott Gases, Inc. Oxygen, carbon dioxide and water transmission rates of these tested films are presented in Table 3.1. Control bags with large perforation have O_2 and CO_2 concentration that are essentially the same as surrounding atmosphere (this is well known among postharvest researchers) and therefore were not measured.

3.3. Quality Evaluation

All quality evaluations were performed at ambient temperature (~ 20°C) within 1 hr of removal from storage. The following quality attributes were monitored: weight loss, subjective quality evaluation, and color change. Weight was measured to determine loss with time and percentage of weight loss was calculated from the difference between initial and final weight at each time interval.

In the 1996 experiment, subjective visual evaluations were made by the authors at one-week intervals (7, 14 and 21 days after storage) on all beans in each replicate. Samples were evaluated for loss of quality, particularly loss of green color, development of browning and microbial growth. An overall mean was calculated for the 2 replicates in each treatment. A quality score of 1 to 5 was assigned to each bean (5 = very good; 4 = good; 3 = just satisfactory or marginally acceptable; 2 = poor; 1 = very poor) (Wills and Kim, 1992). While this scoring gave some indication of quality loss, it was obvious that a more expanded sensory panel was needed next year.

In the 1997 experiment, a sensory panel of 15 untrained panelists was conducted at 14 and 21 days after storage. A 10 cm line-scaling test was used. The ballot is shown in Fig. A.1. Samples of whole beans (300 g) from the treatments were assigned a random one digit code number and presented to the judges in random order on a white paper plate. Two samples for each treatment were used for sensory evaluation, one with beans in the package and another with package film removed. Panelists rated green beans for general appearance, crispness (by bending to break the bean pod) and off aroma intensity. The panelist response marks on the 10-cm line scale were converted to numbers for statistical analysis.

Colorimetric measurements were made before packing and at one-week storage intervals thereafter using a Minolta Chroma Meter CR - 300. The instrument was calibrated with a white tile before use (L = 97.78, a = -0.69, b = 23). The L* a * b * color space has been used successfully in quantifying color change in green vegetables (Shewfelt et al., 1988; Gnanasekharan et al., 1992) and many other fruits and vegetables. Values of tristimulus L* a* and b* were measured at 5 cm from the stem end of beans (Pomeranz and Meloan, 1978; Francis, 1980 after Trail et al., 1992). L* represents the lightness index ranging from 0 for black to 100 for white. The a* value represents red - green (+ to -) and the b* value represents yellow - blue (+ to -). The L* a* b* readings were used to calculate the hue angle (arc tan b* / a*) and chroma $(a^{*2} + b^{*2})^{1/2}$. In green vegetables, the tristimulus a* value was less than 0, therefore the hue angle was calculated by $180 + \tan^{-1} b^* / a^*$ (Minolta, 1988). A decrease in hue angle indicated a color change from green to yellow in green beans.

3.3.4. Data Analysis

Data were statistically analyzed using the generalized linear models in STATGRAPHICS Plus version 3.0 statistical software. The model consisted of two class independent effects (packaging and storage temperature) arranged as a factorial completely randomized design measured repeatedly over time. Analysis of variance was used to evaluate the effects of independent variables on in-package percentage of CO_2 and O_2, color measurement and on sensory quality evaluations. Sensory evaluation data were analyzed as a factorial randomized block design by using each panelist as a block so that variations between panelists could be taken into account. Fisher protected LSD test (FPLSD) was used for mean separation when appropriate. A p value $\leq$ 0.05 was used to establish significance. ANOV tables are shown in Table A.3 through Table A.8.

4.4. RESULTS AND DISCUSSION

4.4.1. Preliminary Experiment on Green Bean

4.4.1.1. CO_2 and O_2 Concentration within the Package

Similar patterns of CO_2 accumulation and O_2 reduction were shown at 5° and 10°C storage temperature for all sealed films tested (Fig. 3.1). PD941 gave the lowest CO_2 accumulation at all storage times. In addition, PD941 gave the highest in - package O_2 percentage almost all storage times and temperatures. This film provided some moderate CO_2 accumulation and O_2 reduction inside packages. Packages of PD961 and PD940 did not much differ in O_2 concentration after 3 days storage when near equilibrium was reached, and gave the lowest O_2 concentration compared to PD955 and PD941. In addition, they showed the same pattern at both 5 and 10 °C. However, CO_2 accumulation in PD961 packages was about 1 - 2 % higher than that of PD940 at all storage times regardless of storage temperature (Fig. 3.1). PD955 gave the highest CO_2 concentration at both temperatures.

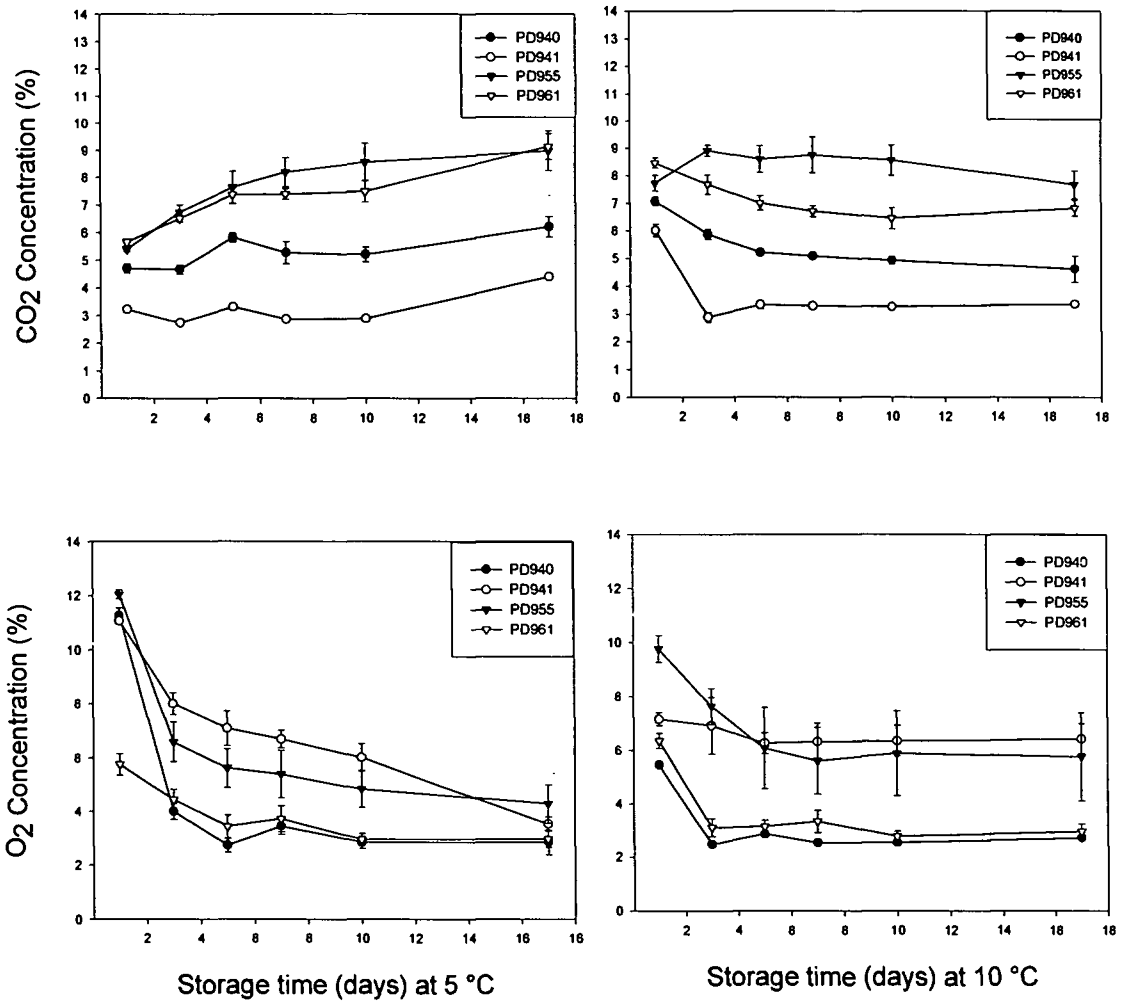


Figure 3.1. Concentrations of CO_2 and O_2 over time in sealed bags of four film types containing 300 g of green beans (cv. 'Strike') stored at 5° and 10°C. Each value is the mean of 8 replications. Vertical bars represent standard error of the mean. SE bars may be obscured by line symbols.

4.4.1.2. Quality Evaluations

Vented bags and unprotected bulk beans were only marginally acceptable at 7 days at either 5 °C or 10 °C. Quality loss was initially mostly due to moisture loss. Green beans (cv. 'Strike') in PD941 film MAP held acceptable quality for at least 21 days at 5°C storage (Fig. 3.2). Beans in PD961 were almost as good, but when both PD941 or PD961 packaged beans were held at 10°C, the quality was only acceptable (quality rating ≥ 3) up to 14 days, and PD941 maintained better quality than PD961. While PD940 and PD955 were satisfactory for 7 and 14 days at 5°C, they were not acceptable even at 7 days under 10°C storage.

4.4.1.3. Weight Loss

All CRYOVAC films tested reduced weight loss to less than 1% at both 5° and 10°C (Fig. 3.3). Green beans in control (unpackaged) had the highest weight loss, which was about 10% already after 7 days storage at both 5° and 10°C. Green beans packed in the vented bag control also demonstrated more weight loss compared to CRYOVAC films but the weight loss was about a third of the unpackaged controls (Fig. 3.3).

4.4.1.4. Color Change

The tristimulus L* value increased (the color became lighter) as the storage period increased and a similar trend occurred at both 5° and 10°C storage temperatures and in all tested films (Fig. 3.4). At 14 days and 21 days after storage, temperature had a significant ($p \leq 0.05$) effect on the tristimulus L* values. Green beans stored at 10°C had a significantly ($p \leq 0.05$) higher L* values compared to that at 5°C. Green bean pods in the two controls (vented bag and unpackaged controls) had the highest L* value which indicated lighter colored pods.

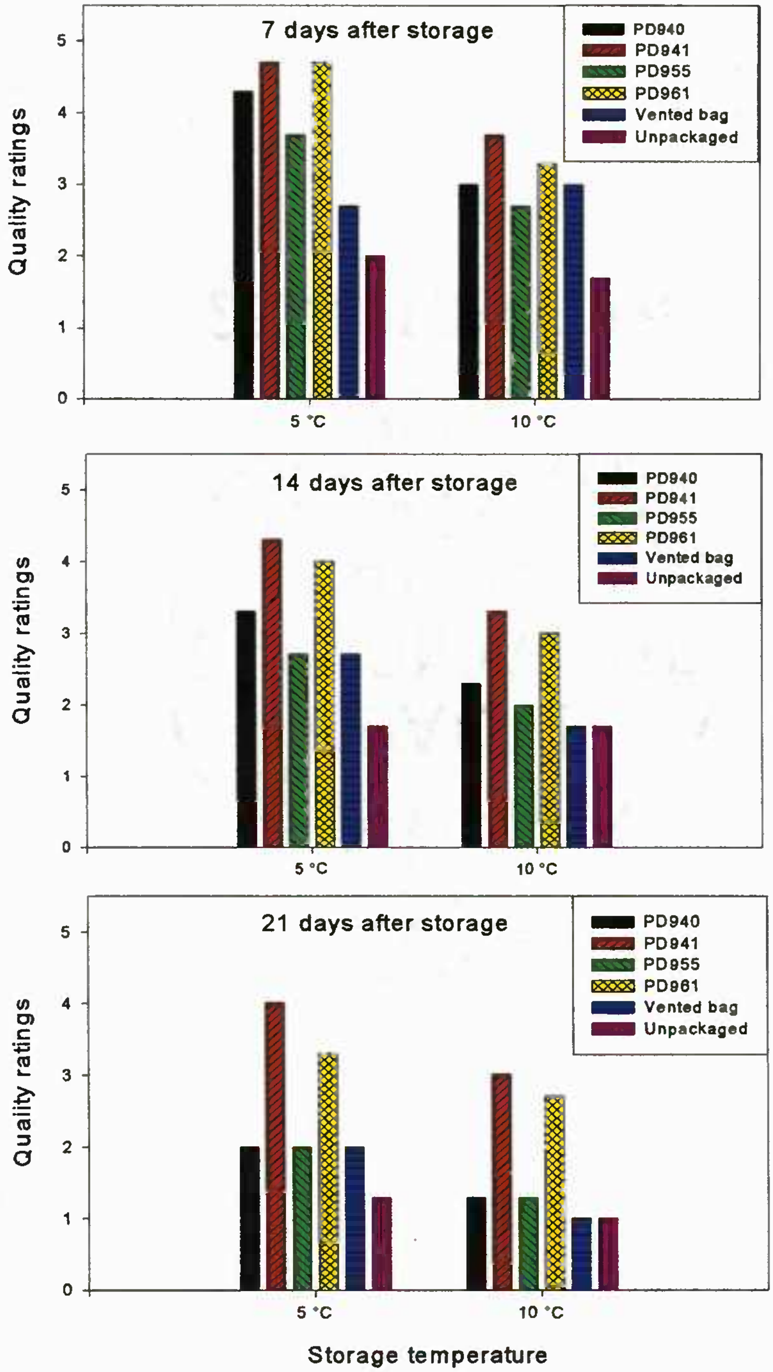


Figure 3.2. Mean quality ratings of 'Strike' green beans from each of the twelve treatments (2 temperatures X 4 packaging film types + 2 controls). A 1 to 5 scale (1 = poor; 5 = very good) was used to rate the beans. Samples were evaluated after 7, 14 and 21 days storage at 5°and 10°C. Each value is the mean of 2 replications.

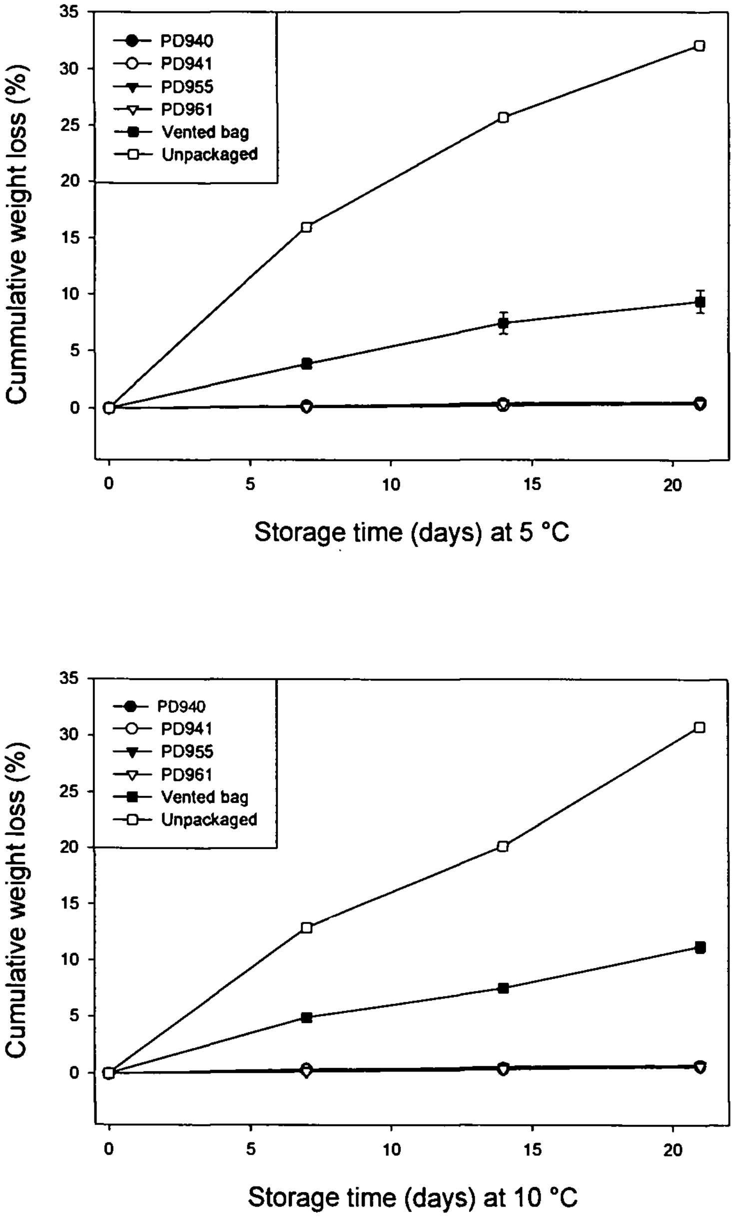
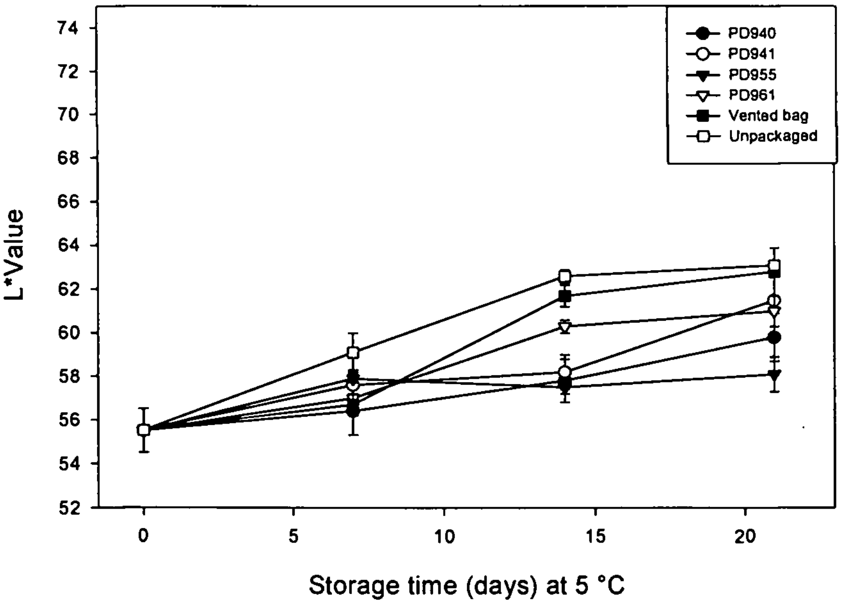


Figure 3.3. Cumulative weight loss of 'Strike' green beans affected by film types and 5° and 10°C storage temperatures. Vertical bars represent standard error (SE) of the mean (n=8). SE bars may be obscured by line symbols.



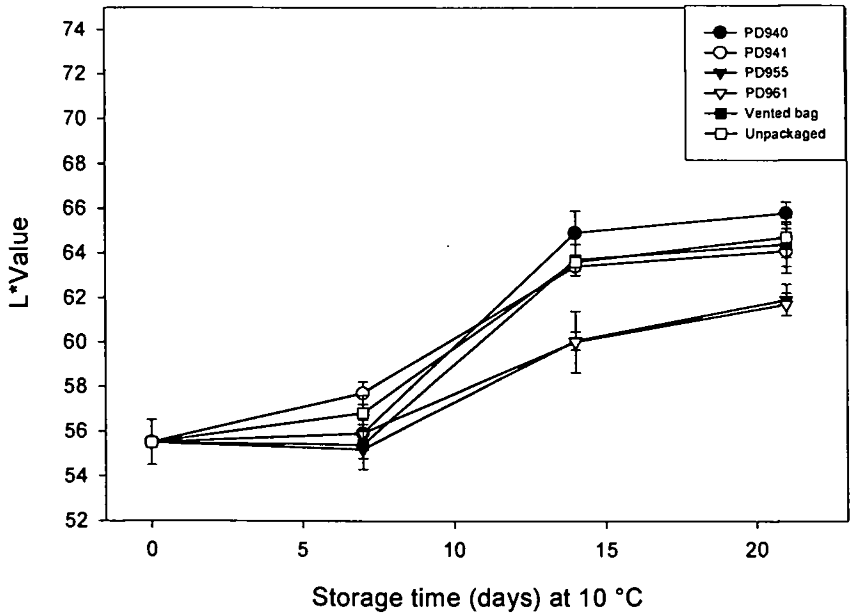
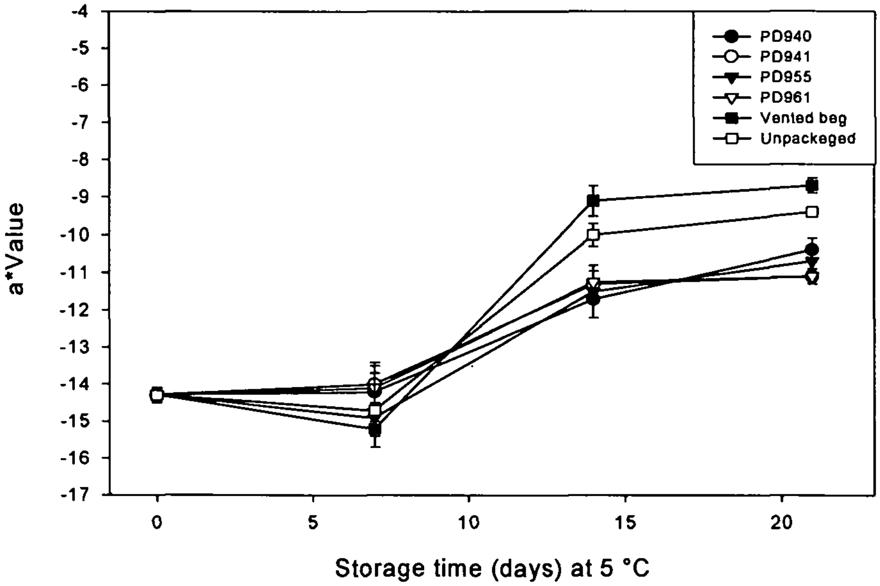


Figure 3.4. Color change (Minolta CR-300 L*value) of 'Strike' green beans packed in different film types at 5° and 10 °C. Vertical bars represent standard error of the mean (n=20). SE bars may be obscured by line symbols. Larger L* value represent lighter ("whiter") colored green beans.

The tristimulus a* value increased significantly ($p \leq 0.05$) (became more negative) after 7 days storage at 5°C which indicated greener pods (Fig. 3.5). This change might have indicated an early chlorophyll breakdown product, pheophytin, an oxidized form, rather than chlorophyll. No significant differences between film type were found at 7 days. However, after 14 and 21 days storage, the trend became less negative as the storage period increased indicating degradation of chlorophyll. The tristimulus a* value of green beans in the two control treatments (vented bag and unpackaged controls) was least negative particularly at 5°C.

No consistent differences or trends were found in the tristimulus b*values among packaging and storage temperature treatments except that the control treatment (unpackaged controls) of green bean pods stored at 10°C had significantly higher values throughout the entire storage period (Fig. 3.6). This result suggested the tristimulus b* value was not a good indicator for measurement of color in green beans. Trail et al (1992) also reported the same result on this same variety of green beans (cv. 'Strike') packed in polyolefin film. The saturation or chroma showed some irregular increases and decreases at 5°C but a more general decrease at 10°C. There was no significant difference in chroma of beans packed in PD941 at either 5° or 10°C (Fig. 3.7). However, the chroma of some treatments increased after 7 days storage and then decreased significantly after 14 days storage at 5 °C, but this may have been due to small sample sizes.

No significant differences in Hue angle were found among treatments at 7 days storage either at 5°C or 10°C (Fig. 3.8). However, after that Hue angle decreased significantly ($p \leq 0.05$) and became smaller as the storage time exceeded 7 days. The two controlled treatments (vented bags and unpackaged controls) had the lowest Hue angle compared to other treatments at both 5° and 10°C (Fig. 3.8).



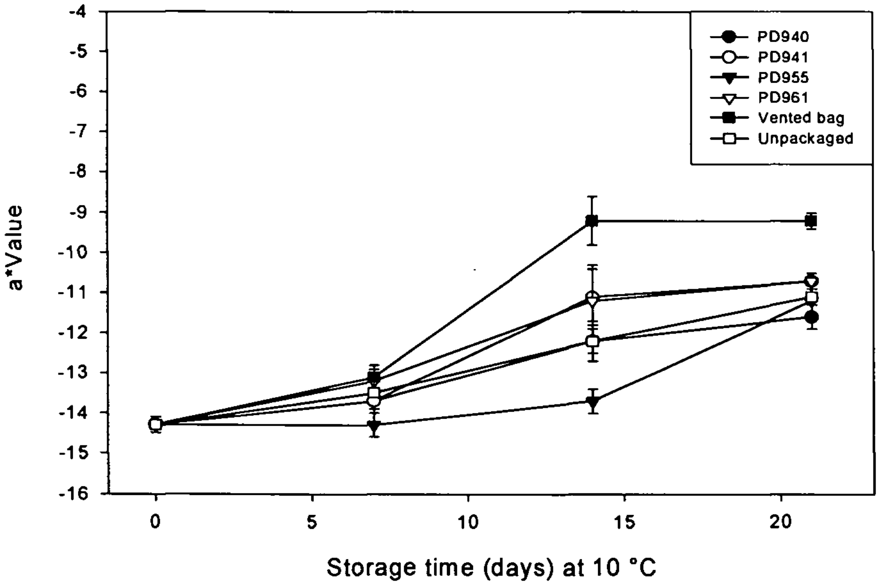
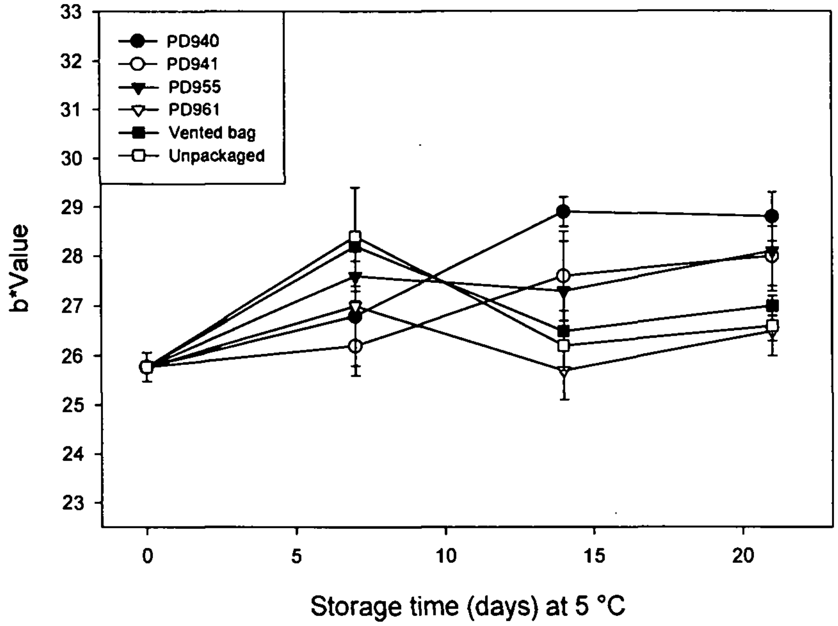


Figure 3.5. Color change (Minolta CR-300 a*value) of 'Strike' green beans packed in different film types at 5°and 10°C. Vertical bars represent standard error of the mean (n=20). SE bars may be obscured by line symbols. The a*value indicates relative greenness : the more negative, the greener the color.



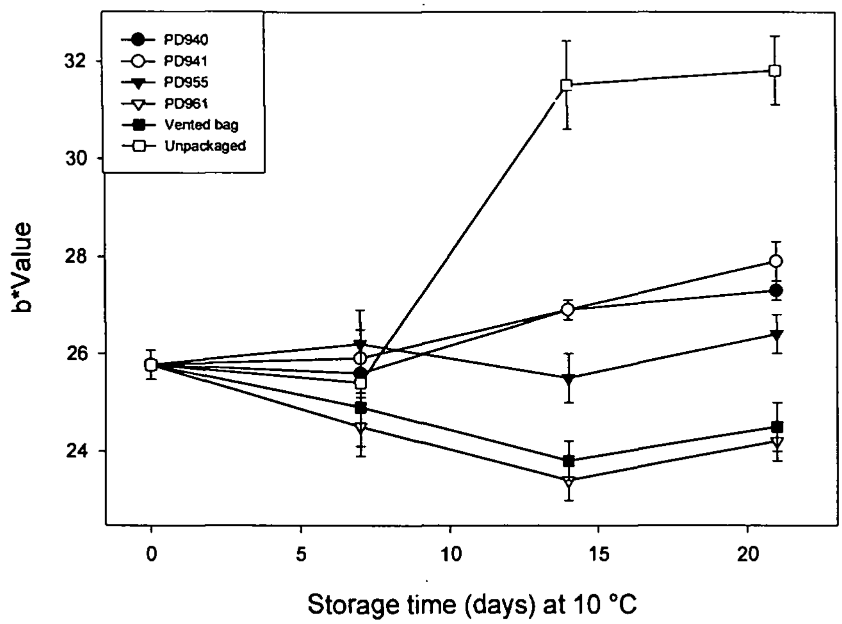
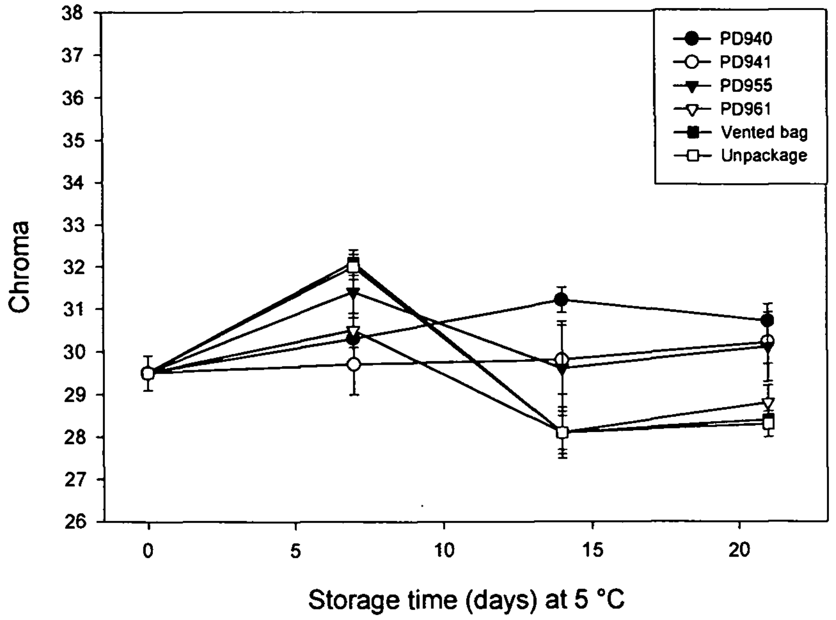


Figure 3.6. Color change (Minolta CR-300 b*value) of green bean (cv. 'Strike') packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20). SE bars may be obscured by line symbols. Larger b*values indicate a color change toward more yellow.



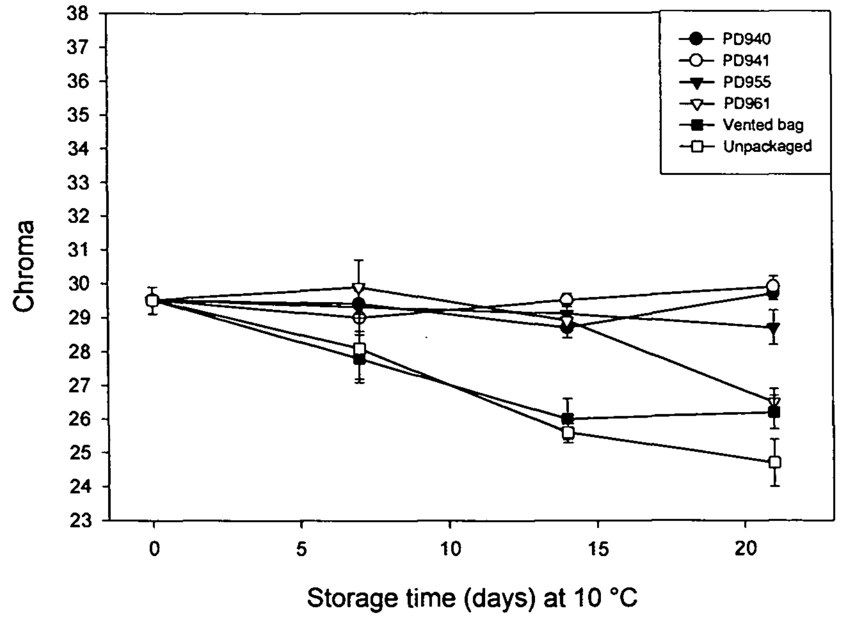
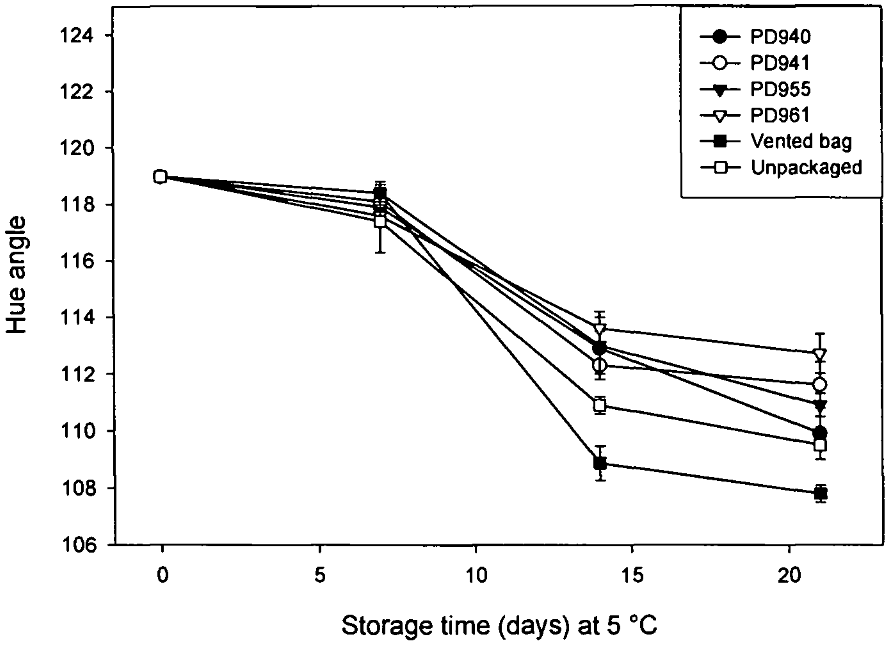


Figure 3.7. Color change (Minolta CR-300 Chroma) of green bean (cv. 'Strike') packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20). SE bars may be obscured by line symbols.



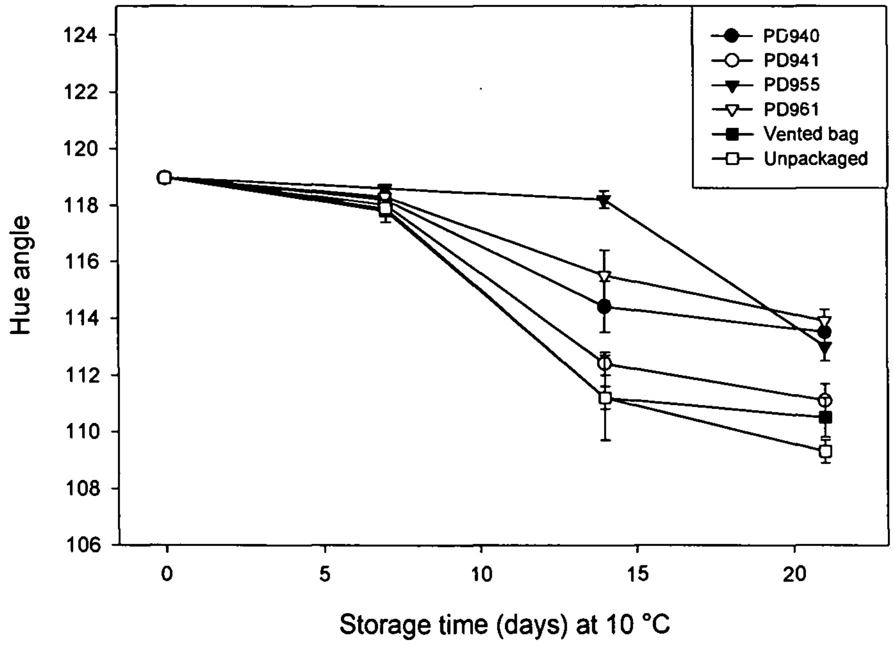


Figure 3.8. Color change (Minolta CR-300 Hue angle) of 'Strike' green beans packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20). SE bars may be obscured by line symbols.

3.4.2. Green Bean MAP Experiment

3.4.2.1. CO_2 and O_2 Concentration within the Package

As is characteristic of sealed MAP packages, O_2 decreased and CO_2 increased to equilibrium values over several days. Equilibrium was achieved in 2 to 4 days at 10°C and in 3 to 6 days at 5°C. Interestingly, O_2 came to equilibrium earlier than did CO_2. CO_2 concentration in the packages increased more rapidly at 10°C than at 5°C (Fig. 3.9), particularly, in microperforated film (XTEND120) in which CO_2 reached 26% at 10°C compared to 9% CO_2 at 5°C during the first 2 days storage. During these first two days at 5°, CO_2 concentration was 3 % in PD941 and 4 % in PD961, and at 10°C was 10.7 % CO_2 in PD941 and13 % in PD961, respectively. However, from 4 days to 14 days of storage, CO_2 concentrations were not different between 5°and 10°C in both PD941 and PD961 packages. In other words, a similar pattern was found for CO_2 concentration in these two film types (Fig. 3.9). However, XTEND120 differed in CO_2 concentration between 5°and 10°C storage temperature.

At 10 °C, CO_2 concentration in XTEND120 was very high (26%) the first 2 days of storage and equilibrated thereafter to about 24%. Likewise, CO_2 concentration at 5°C was also high (20 %) during the first 4 days of storage and equilibrated thereafter to about 24%. CO_2 accumulation within PD941 film package was less compared to PD961 at all tested temperatures. This is because PD941 has a higher CO_2 transmission rate than PD961 (Table 3.1).

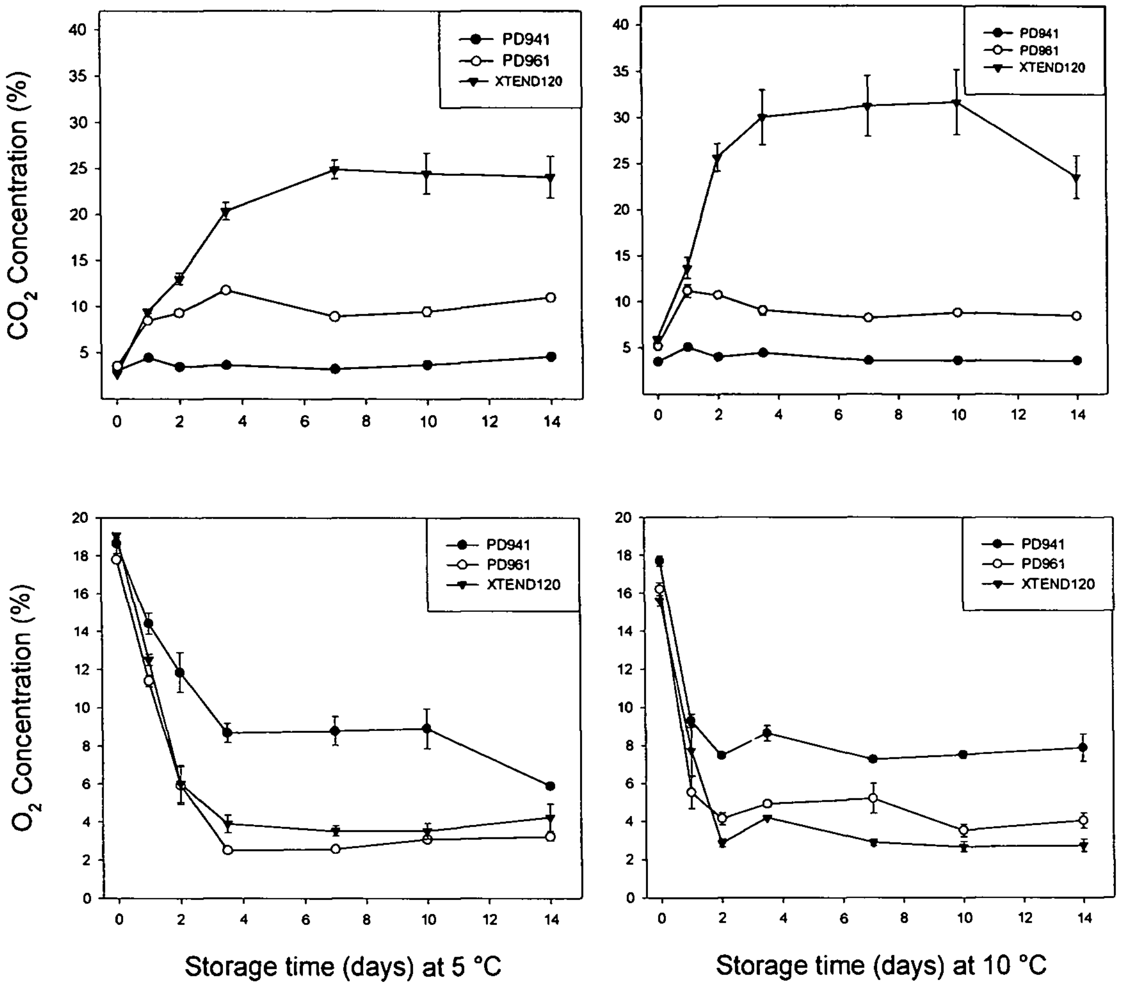
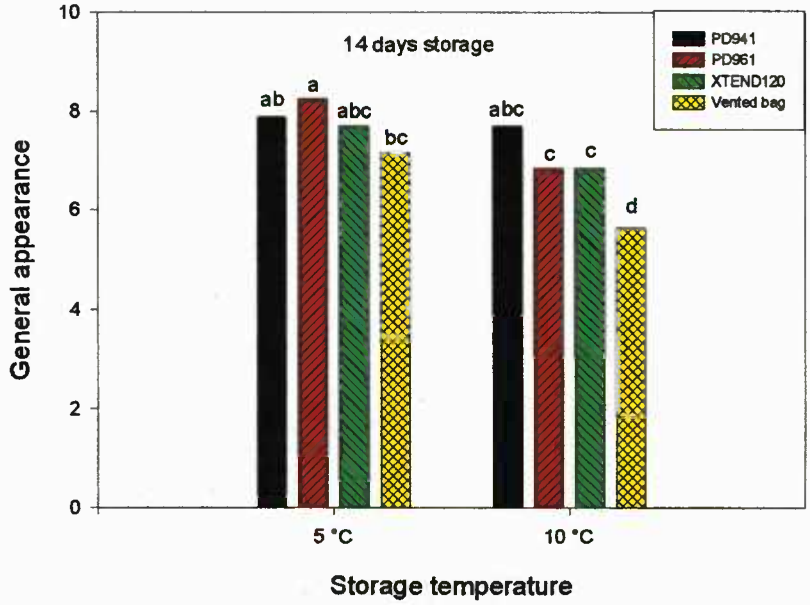


Figure 3.9. Concentrations of CO$_2$ and O$_2$ over time in sealed bags of three film types of green beans (cv. 'Jade') stored at 5° and 10°C. Vertical bars represent standard error (SE) of the mean (n=4) and may be obscured by symbols.

PD941 gave a higher O_2 concentration at both 5° and 10°C throughout the entire storage period compared to PD961 and XTEND120 (Fig. 3.9). At two days storage, O_2 inside the package showed a large decrease in PD961 and XTEND120 (ranging from 2.9 to 6.0 %) whereas a slight decrease occurred inside PD941 package (ranging from 7.5 to 11.9) at both temperatures. At 14 days after storage, O_2 concentrations of PD961 and XTEND120 were not significantly different and equilibrated to 3% at 5° and 4% at 10°C storage for PD961 whereas those of XTEND120 were 4% O_2 at 5°C and 2.7% O_2 at 10°C. However, the concentration of O_2 within PD941 packages was almost twice that of PD961 & XTEND120 being 5.9 % and 7.9 % at 5° and 10°C, respectively, and significantly different ($p \leq 0.05$).

4.2.2 Sensory Evaluation

Sensory evaluations made after 14 days storage indicated that there was no significant interaction between film types and temperature on general appearance and crispness. Green beans at 5°C had significantly ($p \leq 0.05$) better general appearance than those at 10 °C (Fig. 3.10). Beans packaged in PD941, PD961 and XTEND120 performed similarly in general appearance and were significantly ($p \leq 0.05$) better than controls (vented bags) at 10°C. The two panels for the 14 and 21 day evaluations were composed of different individuals and this likely contributed to some of the unexpected higher ratings of the 21 day stored samples compared to the 14 day stored samples. It would be unlikely that



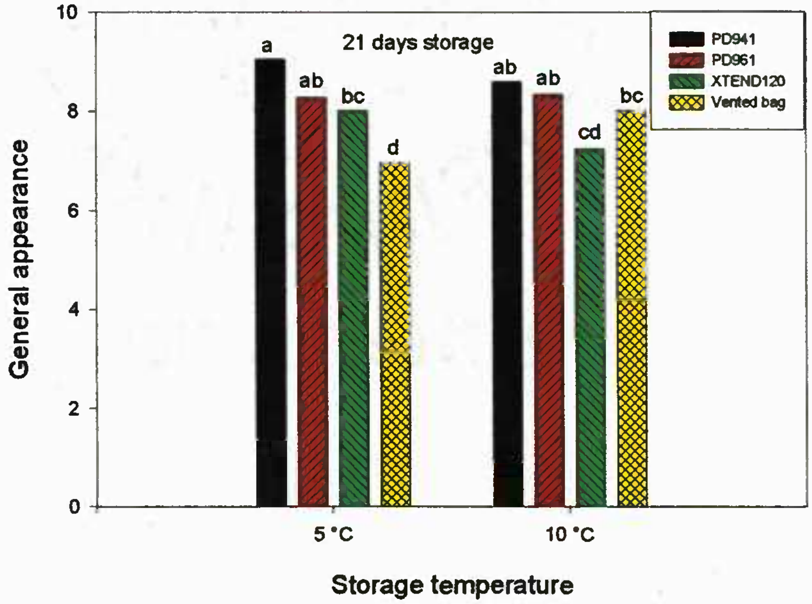


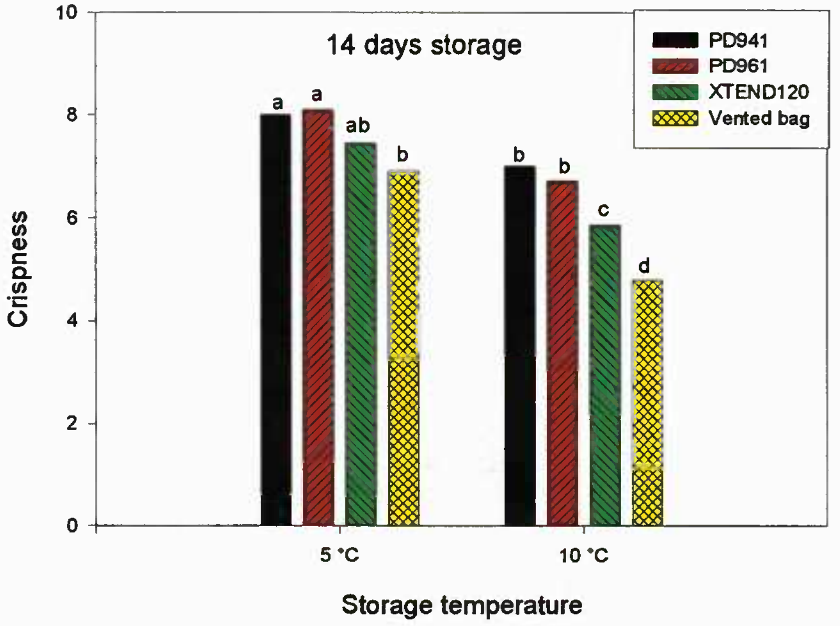
Figure 3.10. Sensory evaluation of general appearance of MAP green beans (cv. 'Jade') stored at 5° and 10°C for 14 and 21days. Means with the same letter are not significantly different at $p < 0.05$ by FPLSD (each value is the mean of 15 replications).

the same samples after 21 days would have quality ratings better than 14 day samples.

No significant temperature by film interactions were found for crispness. Therefore, as with general appearance, temperature and package film effects on crispness were interpreted separately. Green beans at 5°C also showed significantly better crispness ($p \leq 0.05$) compared to that at 10°C. Green beans packed in PD961 gave the best crispness score (8.1 out of 10) but were not significantly different from PD941 (8.0) at 5°C (Fig. 3.11). Control simulated bags had the lowest crispness score (4.8).

However, significant ($p \leq 0.05$) temperature by film interactions were found for off-odors. Green beans packed in PD941 film at 5°C gave the lowest off-odors score and did not significantly differ from that at 10°C (Fig. 3.12). In addition, no significant difference in off-odor score was found in green beans packed in XTEND120 and controls at 5°C. However at 10°C, the highest off-odor score (8.3) was observed in green beans packaged in XTEND120 film. Green beans packed in PD961 at 10°C had significantly ($p \leq 0.05$) higher off-odor score (6.2) ($p \leq 0.05$) compared to that at 5°C (3.7).

At 21 days storage, the result of sensory evaluation showed a significant interaction ($p \leq 0.05$) between film types and temperatures in general appearance, crispness and off-odor scores. Green beans packed in PD941 and held at 5°C had the best general appearance, crispness and lowest off-odor scores. There was no significant difference in general appearance scores for PD941 at 5° and 10°C, being 9 and 8.6, respectively. These scores indicated



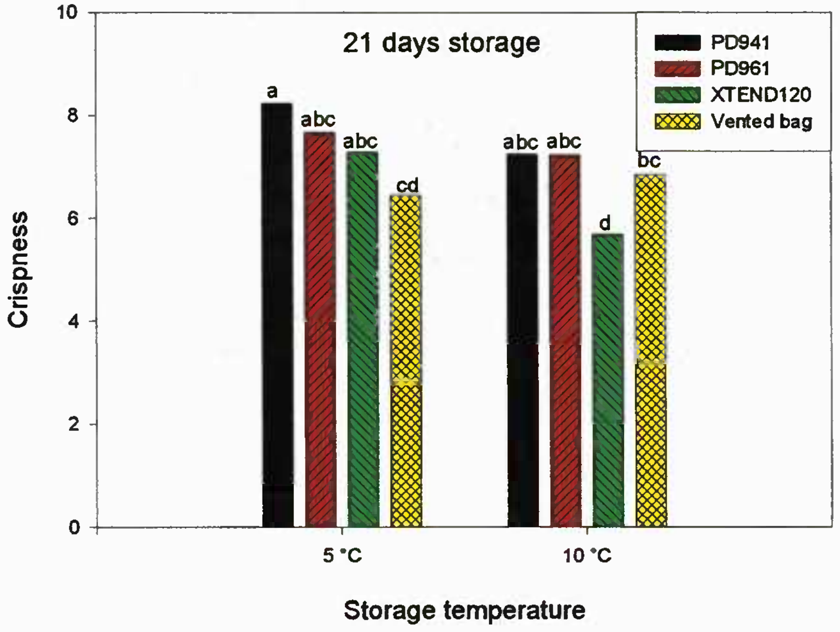


Figure 3.11. Sensory evaluation of crispness of MAP green beans (cv. 'Jade') stored at 5° and 10°C for 14 and 21 days. Means with the same letter are not significantly different at $p < 0.05$ by FPLSD (each value is the mean of 15 replications).

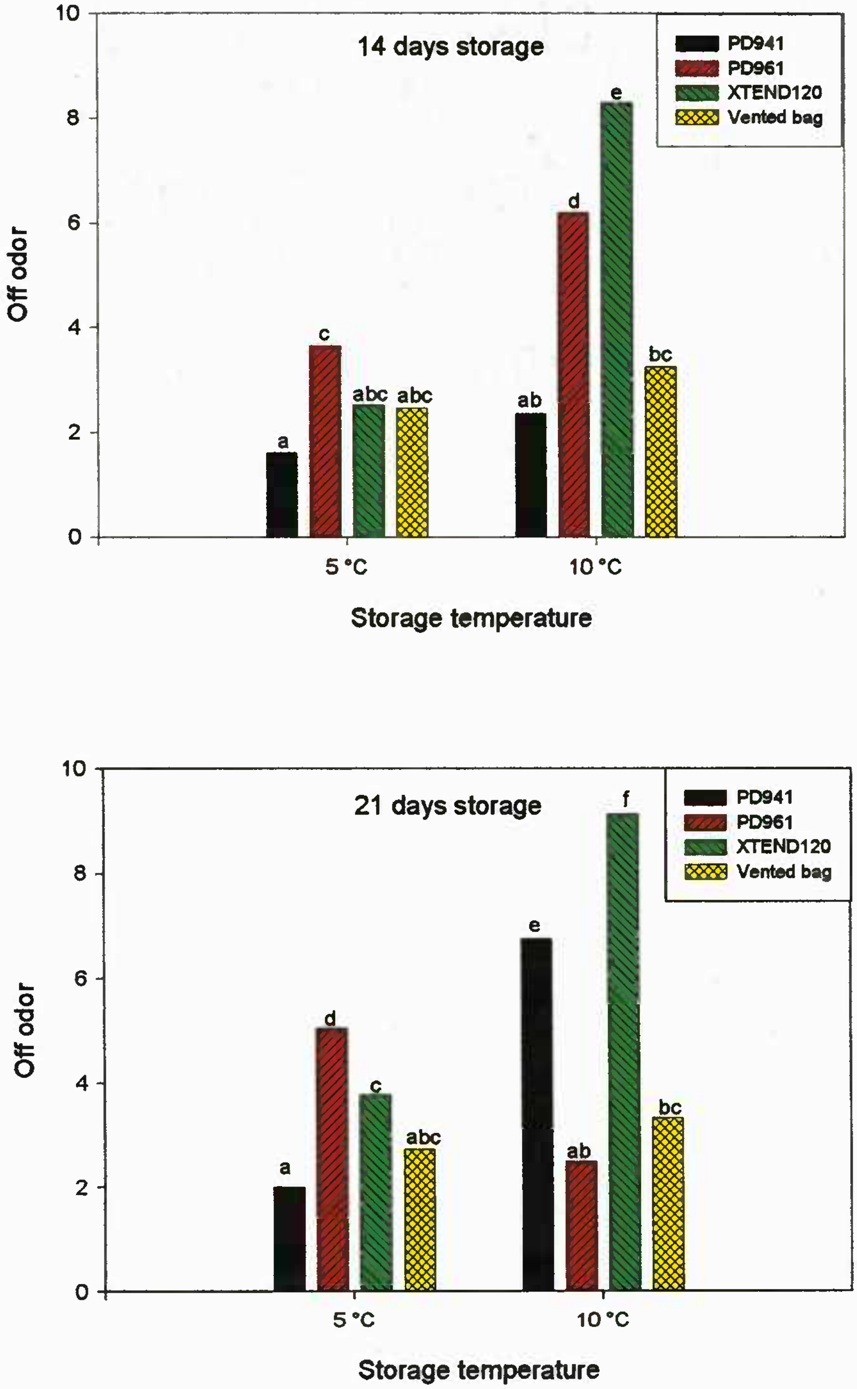


Figure 3.12. Sensory evaluation of off-odor of MAP green beans (cv. 'Jade') stored at 5° and 10°C for 14 and 21 days. Means with the same letter are not significantly different at $p < 0.05$ by FPLSD (n=15).

high quality (Fig. 3.10). PD961 and XTEND120 also showed similar results in general appearance between 5° and 10°C. At 5°C storage temperature, crispness of green beans packed in PD941, PD961 and XTEND120 were not significantly different (Fig. 3.11). Green beans packed in XTEND120 at 10°C showed the lowest crispness score (5.7) and highest off-odors score of 9.1 (Fig. 3.12). The result paralleled the off-odors score data after 14 days storage. However, off-odor scores found in PD961 after 21 days at 10°C showed some contradictory results with those at 14 days storage. A high off-odor score (6.7) was also found in PD941 at 10°C.

It is important to state that these two panels on 14 and 21 days were different in that 7 of the 15 panelists were different people. Thus while treatment comparisons within a panel may be valid, comparisons between panel data on the different storage times may be more variant. Also, since a rather small number of packages were presented to panelists, package to package variance could account for some of the unexpected results.

4.2.3 Weight Loss

Green beans packed in XTEND120 and in vented bags (control) showed a similar pattern in weight loss at both 5° and 10°C (Fig. 3.13). As storage time increased, the weight loss of pods increased more or less linearly. Green beans stored at 10°C in vented bags or in XTEND120 bags exhibited greater weight loss than those stored at 5°C. At 10°C, weight loss was 8 % whereas only 4 %

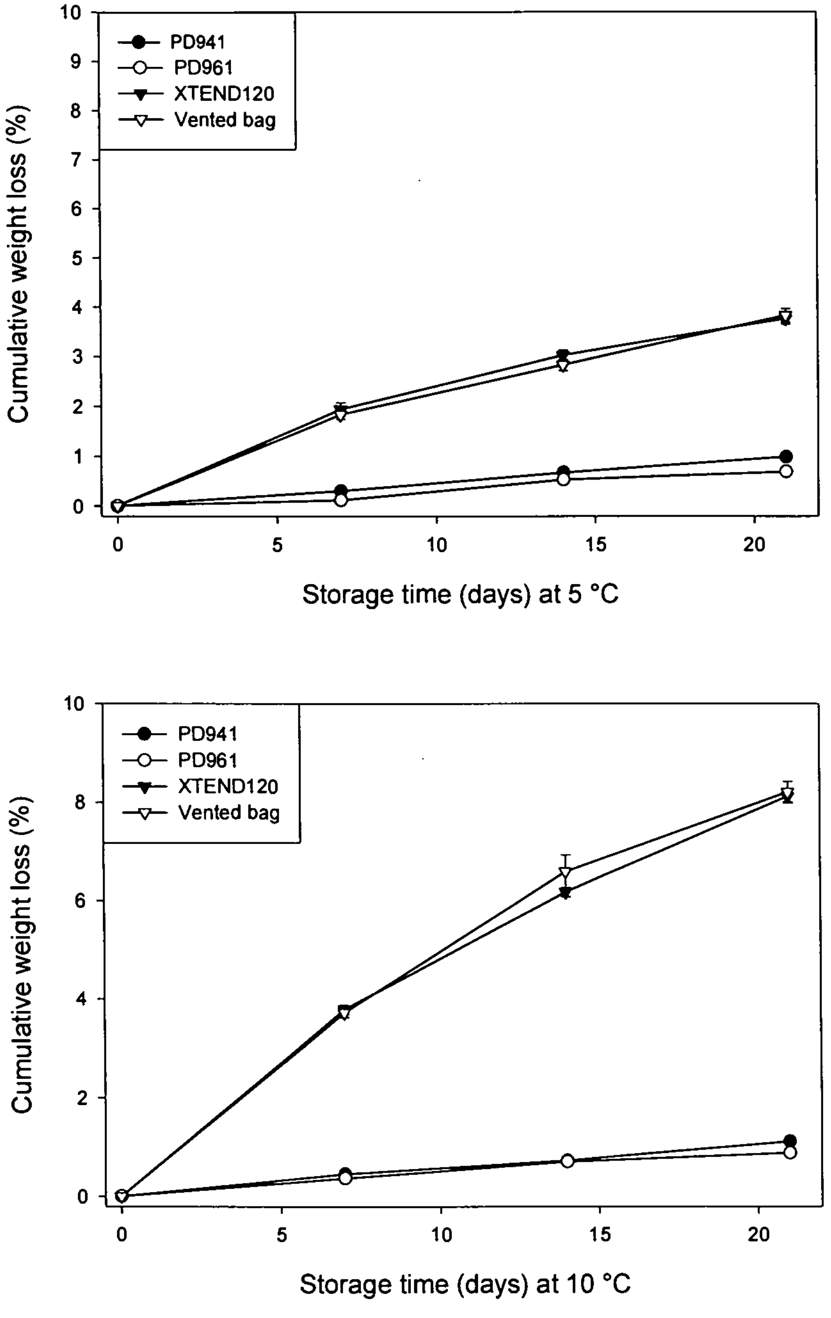


Figure 3.13. Cumulative weight loss of green bean (cv. 'Blue light') affected by film types and storage temperature at 5° or 10°C. Vertical bars represent standard error of the mean (n=4).

were found at 5°C at 21 days storage. On the other hand, weight losses of green beans packed in either CRYOVAC films (PD941 and PD961) were less than 2 % at both 5° and 10°C (Fig. 3.13).

4.2.4 Color Changes

After 7 days storage, green bean pods were significantly lighter (higher L*) ($p \leq 0.05$) at 10°C than at 5 °C (Fig. 3.14). However, after 21 days storage no significant differences in L* values were found between 5° and 10°C as beans had visually lost similar amounts of chlorophyll in both cases. The same trend was demonstrated in all treatments in that L* values increased as storage time increased regardless of package film used.

In the tristimulus a* no significant temperature by film interaction was found at all measured times. The tristimulus a* values were significantly greener (become more negative) ($p \leq 0.05$) at 10°C than at 5 °C, especially at 7 and 14 days storage (Fig. 3.15). This was probably because higher CO_2 concentration was attained in packages at 10°C compared to that at 5°C. CO_2 may help to prevent chlorophyll degradation. On the contrary, at 5 °C the trend became less negative as the storage period increased. However, green bean pods packed in vented bag (control) showed less green compared to other tested packages at both 5 and 10 °C.

There was no significant difference in tristimulus b* reading in green beans after 21 days storage period in all tested treatments, even though, the tristimulus b* reading was significantly higher ($p \leq 0.05$) in all treatments compared to initial b* value (Fig. 3.16).

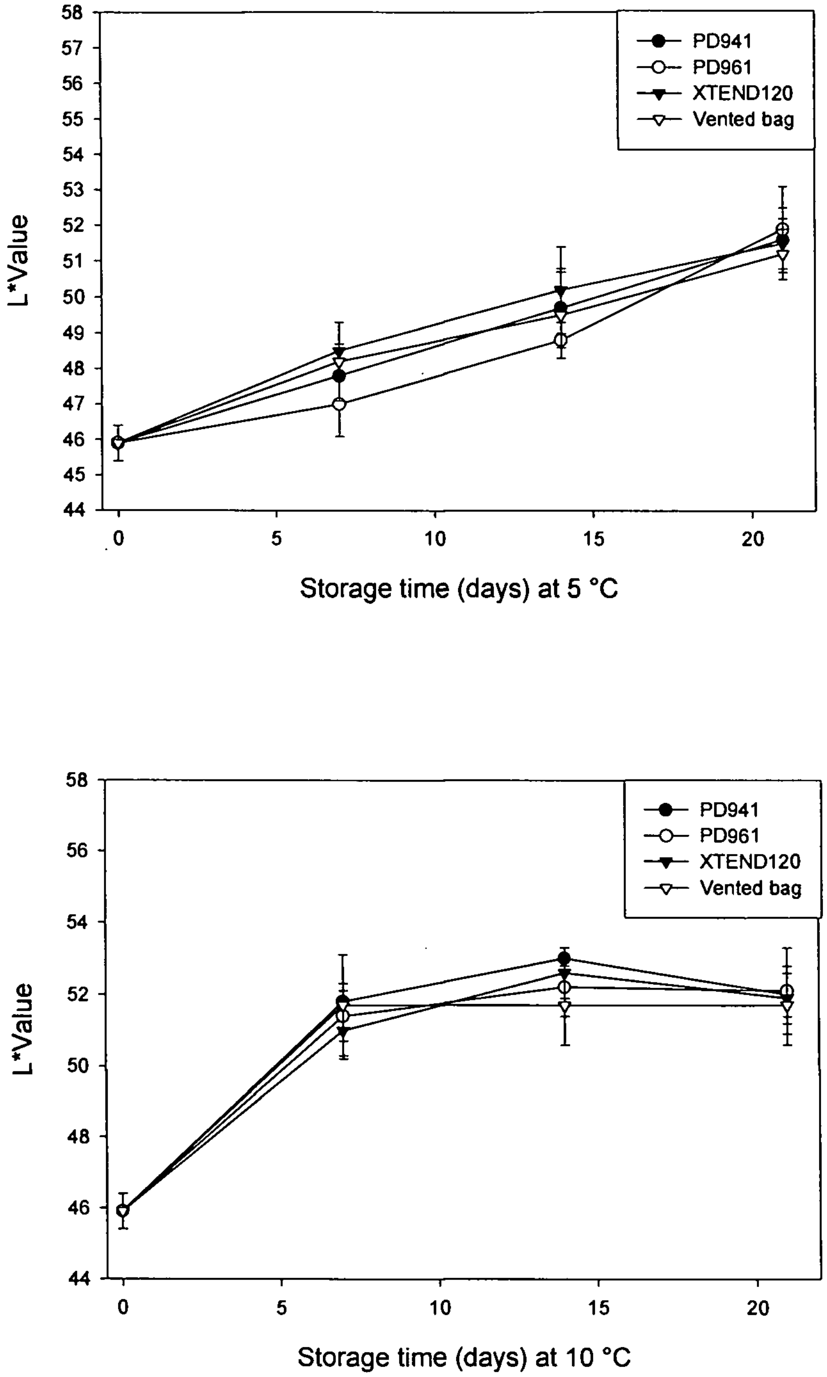
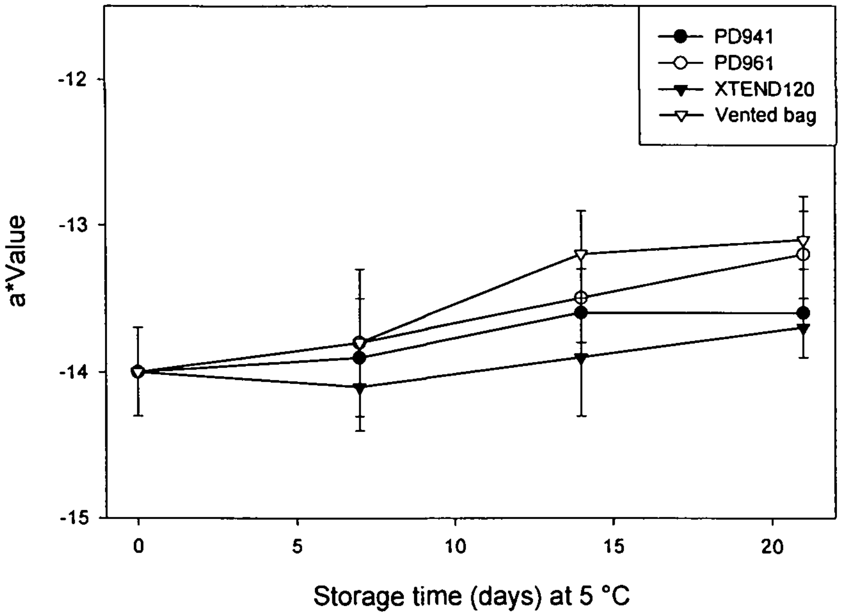


Figure 3.14. Color change (Minolta CR-300 L*value) of green bean (cv. 'Jade') packed in different film types at 5 and 10 °C. Vertical bars represent standard error of the mean (n=20).



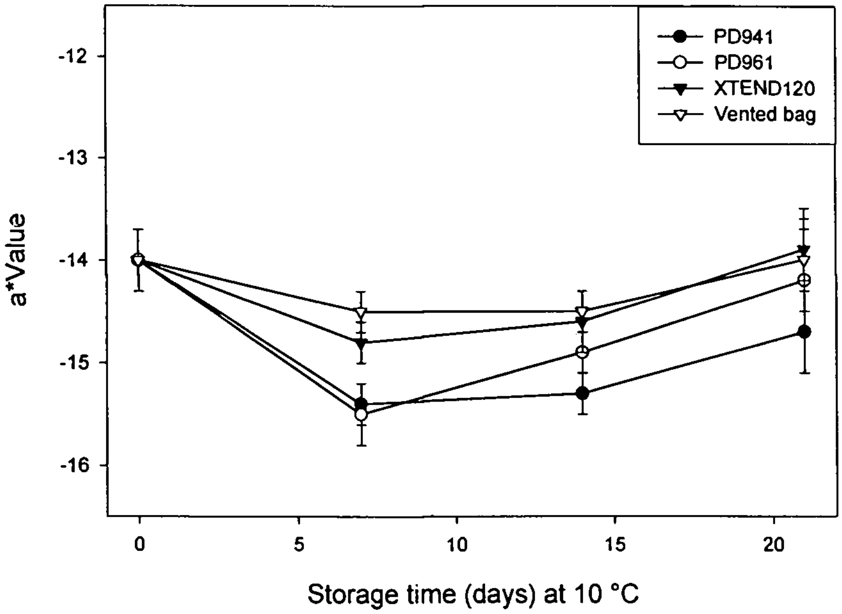


Figure 3.15. Color change (Minolta CR-300 a* value) of green bean (cv. 'Jade') packed in different film types at 5 and 10 °C. Vertical bars represent standard error of the mean (n=20).

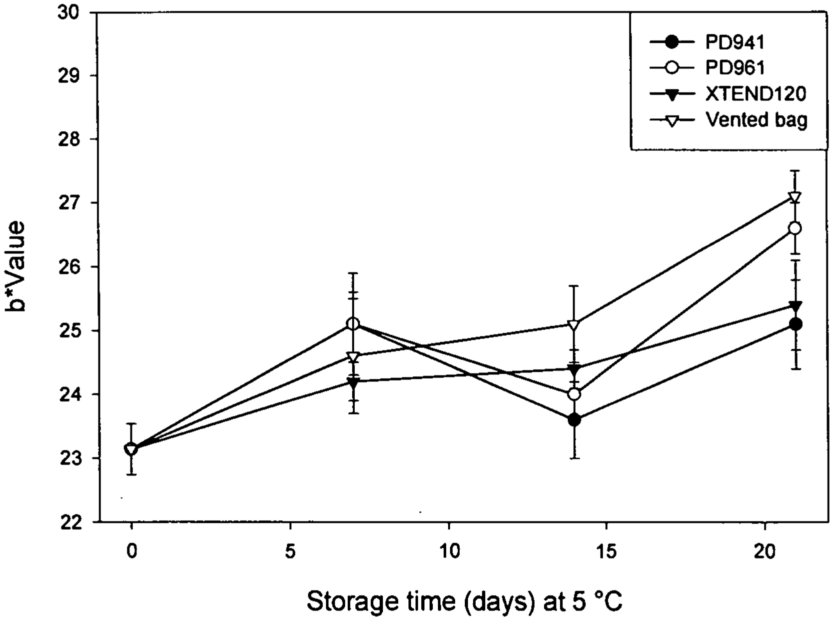
This indicated that bean pods were more yellow, contrary to actual general appearance of green beans. Therefore, the tristimulus b* measurement was not considered to be a good indicator for measurement of color in green beans. Trail et al, 1997 also reported this result with their green beans (cv. 'Strike') packed in polyolefin film.

Chroma (arc tan b* / a*) increased gradually after storage until 7 days in both 5° and 10°C and decreased after that in all treatments (Fig. 3.17). Trail et al (1997) reported similar results on green beans and by Gnanasekharan et al. (1992) on green vegetables. However, after 14 days storage, chroma values trended to increase in all treatments and were not significant.

Hue angle $(a^{*2}+b^{*2})^{1/2}$ became smaller as the storage time increased, no significant difference was found between treatments at 7 days after storage (Fig. 3.18). However, at 14 days storage, hue angle at 10 °C was significantly ($p \leq 0.05$) higher than that at 5 °C but no differences between packages were found. A significant ($p \leq 0.05$) temperature by film interaction was found after 21 days storage. Green beans packed in PD941 and stored either at 5° or10°C gave the highest hue angle value compared to other treatments. No significant change in hue angle was found throughout the entire 21 days storage period for PD941 at 5°C.

3.4.2.5. Summary

Vented bag (control) 'Jade' beans were only marginally acceptable at 7 days stored at either 5 °or 10 °C. 'Jade' green beans packed in PD941 films and stored at 5°C storage had the best overall quality after 21 days storage. Similar results of sensory analysis at 14 and 21 days after storage demonstrated that PD941 MAP beans showed highest general appearance and crispness scores and the lowest off-odors scores. Although green beans packed in XTEND120 showed acceptable general appearance after 21 days in storage, but they had the highest off-odor scores even after 14 days storage which was associated with very high CO_2 concentration (about 25 – 30 %) inside packages. XTEND120 film had less permeability to CO_2 and this was too high to be beneficial.



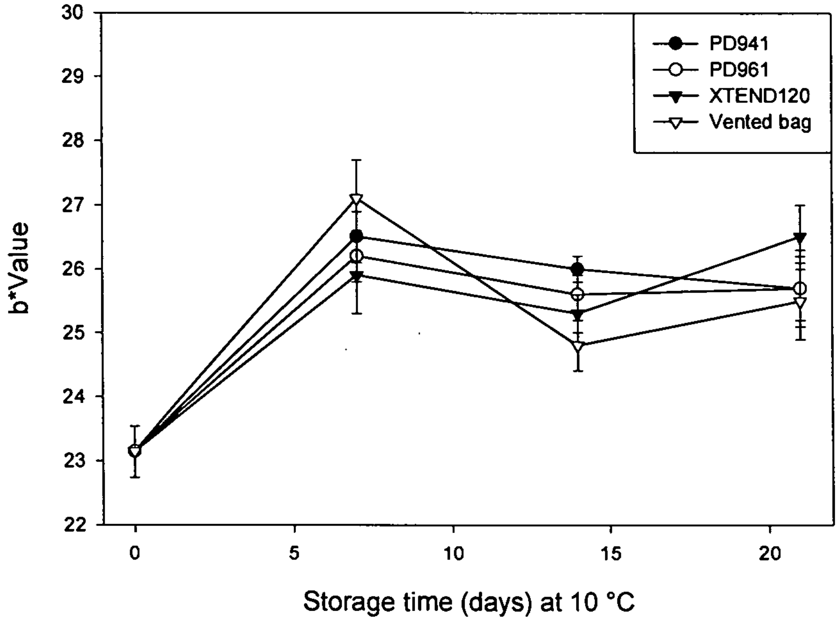
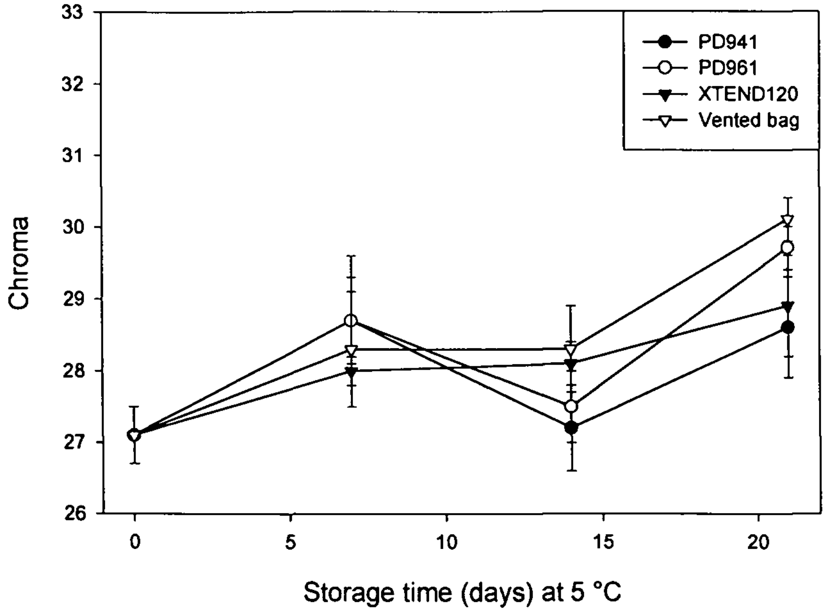


Figure 3.16. Color change (Minolta CR-300 b* value) of green bean (cv. 'Jade') packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20).



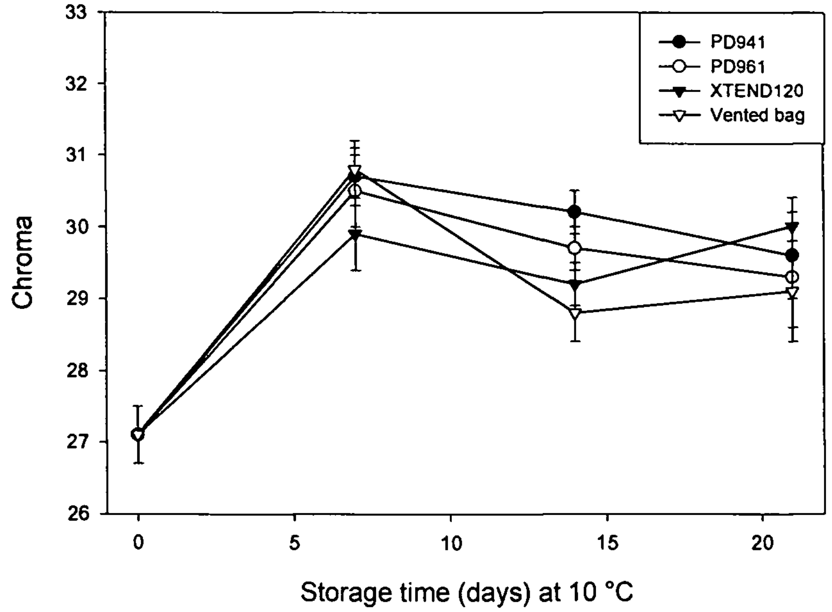
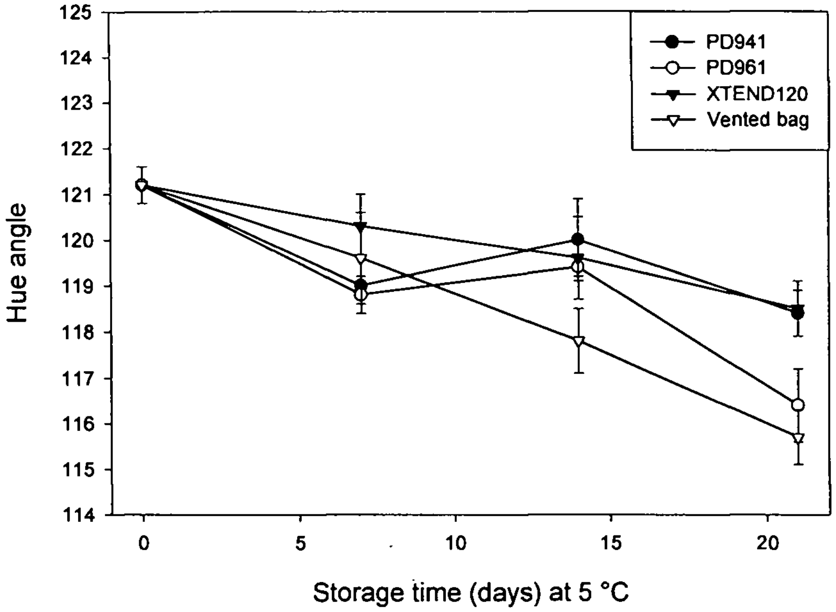


Figure 3.17. Color change (Minolta CR-300 Chroma) of green bean (cv. 'Jade') packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20).



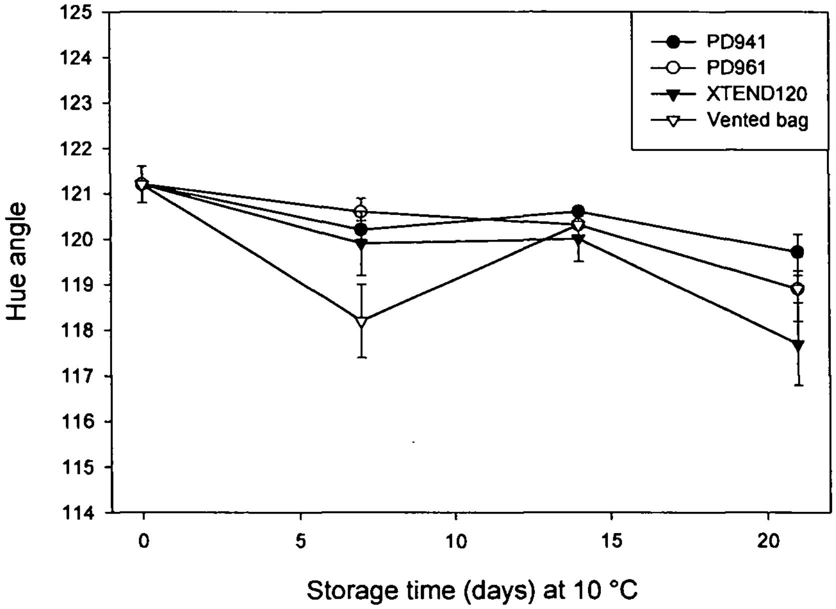


Figure 3.18. Color change (Minolta CR-300 Hue angle) of green bean (cv. 'Jade') packed in different film types at 5° and 10°C. Vertical bars represent standard error of the mean (n=20).

B: GREEN BEAN VARIETAL COMPARISON IN MODIFIED ATMOSPHERE PACKAGES *

3.1. ABSTRACT

Although modified atmosphere packaging has potential to extend the shelf life of fresh produce, physiological properties (e.g., variety, respiration rate, mold resistance), temperature, mold control and film permeability are key components for success. This study tested five varieties of green beans ('91G', 'Derby', 'Bronco', 'Hialeah', and 'Prosperity') packed in CRYOVAC PD941 polyolefin film (a film known to give MAP benefits to green beans) and stored at 5°C optimal temperature on storage life quality, color retention and gas composition. Four of the five tested green bean varieties can be kept for three weeks at 5°C using CRYOVAC film PD941. Cultivar '91G' was the exception and developed chilling injury symptoms 7 days after packing. CO_2 and O_2 within packages were not different between varieties and equilibrated within four days at about 4% CO_2 and 5% O_2. There were significant differences in color measurements between varieties after storage. 'Hialeah' and 'Prosperity' showed better general appearance compared to 'Bronco' and 'Derby' after 21 days storage. Weight loss was low (< 1 % after 21days) with only slight varietal differences. Sensory evaluation by panelists will need to be performed before conclusive results can be made, although our initial quality assessments were favorable.

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* This paper has been published in the Proceedings of CA'97 (Mekwatanakarn and Richardson, 1997) 4:59 – 65.

3.2. INTRODUCTION

Consumption of fresh green beans has increased in the United States while that of canned green beans has decreased (Judge and Sons, 1989). This change in demand for fresh green beans has increased the importance of postharvest handling. Moreover, green beans are harvested at an immature developmental stage, have a high respiration rate, and a short storage life. Although modified atmosphere packaging (MAP) has potential to extend the storage life of fresh produce, physiological properties (varieties, respiration rate, mold resistance), temperature, film permeability and mold control are important components for success. Many researchers have pointed out that quality of green beans is related to varieties and postharvest handling (Gonzalez et al., 1986; Stone and Young, 1985; Varseveld et al., 1985). The most obvious indicator of quality of green beans is color which changes from a desirable bright green to an objectionable yellowish color (Trail et al., 1992). They concluded that hue angle and tristimulus a* corresponded more closely to chlorophyll content and were better indicators of green bean color than chroma or tristimulus L* or b*. Another researcher also found that hue angle was the most important objective measure of postharvest quality in green beans (Resurreccion et al., 1987). Groeschel et al. (1966) demonstrated that 5-10 % carbon dioxide retarded yellowing in green beans. In addition, enhancement of carbon dioxide levels from respiration of green beans packed in sealed bags was apparently sufficient to prevent quality loss (Buescher and Adams, 1979). The objective of our study was to evaluate five green bean varieties under near optimal MAP for possible differences in storage life and quality (color attributes).

3.3. MATERIALS AND METHODS

Five varieties of green beans ('91G', 'Derby', 'Bronco', 'Hialeah' and 'Prosperity') were harvested by hand and sorted visually. Defective and blemished pods were discarded. Sixty samples of green beans (300 g each) were obtained randomly. The samples were weighed and packed in CRYOVAC PD941 polyolefin film, sealed with a heat impulse sealer and stored at 5°C. CRYOVAC PD941 film was selected based upon good performance with broccoli and other produce of similar high respiration rate (See, for example, the paper by Cabezas & Richardson, 1997). Gas composition (CO_2 and O_2) within packages was monitored by Carle Model 311 Gas Chromatography one day after packing and then every three days. Samples were weighed weekly and the percentage of weight loss was determined. General appearance of each variety was assessed initially and at one week intervals.

Colorimetric measurements were recorded using a Minolta Chroma Meter series CR-300 calibrated with a white standard tile prior to packing and at one week intervals. Values of tristimulus L* a* b* were measured at 5 cm from the stem end of beans (Pomeranz and Meloan, 1978; Francis, 1980 after Trail et al., 1992). The L* a* b* readings were used to compute chroma and hue angle. The tristimulus a* value is less than 0 in green vegetables, therefore the hue angle was calculated by 180 + tan-1 b*/a* (Minolta, 1988). Chroma value was calculated by $(a^2 + b^2)^{1/2}$. The L* a* b* color space was used because of its successful representation in quantifying color changes in green vegetables (Shewfelt et al., 1988; Gnanasekharan et al., 1992).

3.4. RESULTS AND DISCUSSION

Four of the five green bean varieties (except '91G') can be stored at 5°C for three weeks with minimal weight loss and color change under MAP with CRYOVAC film PD941. Cultivar '91G' develop visual chilling injury symptoms, randomized light tan russet spots 1-2mm, and pitting which appeared one week after packing but this was not reflected in any color measurement. Weight loss was low with no varietal difference and a maximum weight loss of 1.2% after 21 days' storage. As the storage period increased, the weight loss of bean pods increased (Fig. 3.19). CO_2 and O_2 concentrations within packages were not different between varieties and equilibrated at about 4% CO_2 and 5% O_2 after 14 days (Fig. 3.20).

Storing green beans at 5°C for 14 days had no significant effect on hue angle of '91G', 'Hialeah' and 'Prosperity' (Table 3.2). However, at 21 days of storage of these three varieties, the hue angle decreased significantly indicating a change from green to yellow. Similar results were obtained by Trail et al. (1992) with 'Strike' green beans. 'Derby' and 'Bronco' in MAP showed no significant changes in hue angle after 21 days storage.

The tristimulus a* value became more negative until 14 days after storage for '91G', 'Derby' and 'Prosperity' indicating greener green bean pods (Fig.3.21). The trend reversed and became less negative as the storage period increased beyond two weeks indicating degradation of chlorophyll. Similar results were obtained by Trail et al., (1992) with green beans (cv. 'Strike'). However, a* values for 'Hialeah' and 'Bronco' became slightly less negative but were not significantly different as storage time increased to 21 days.

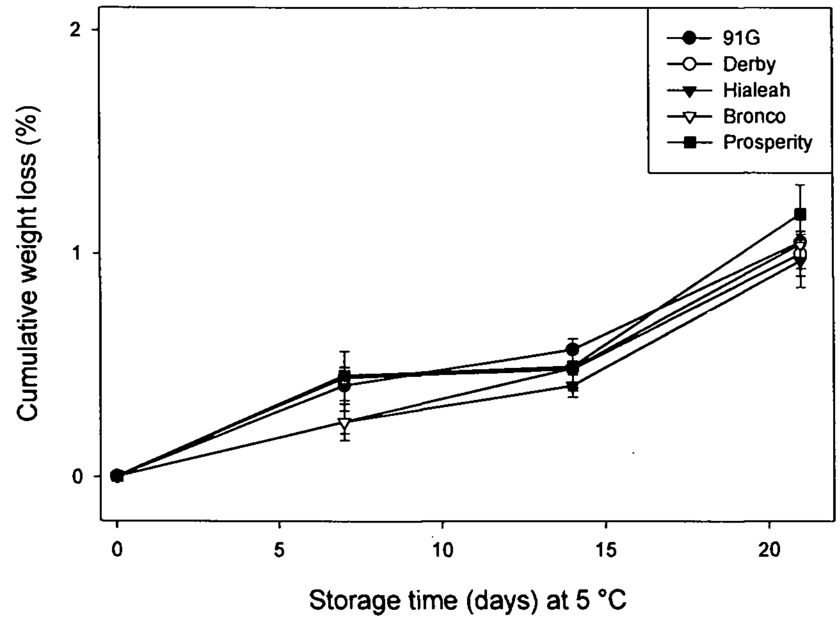
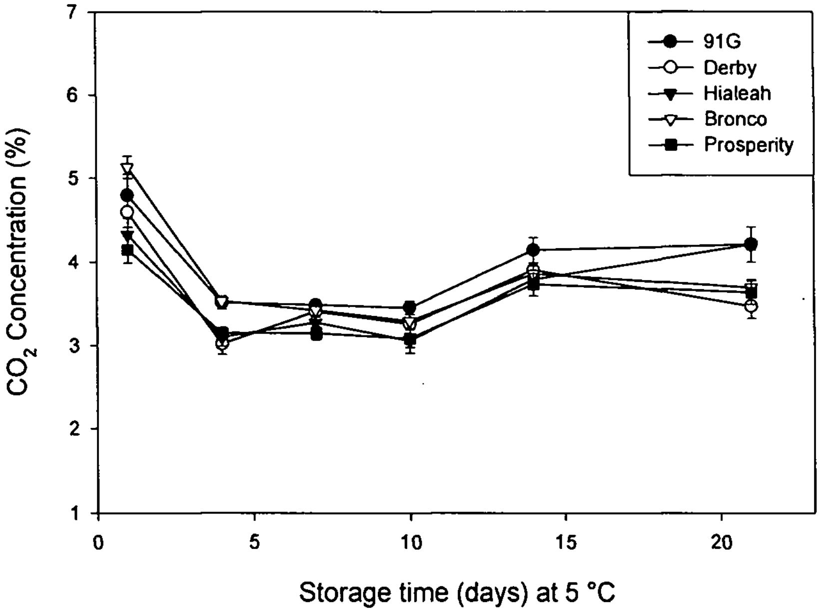


Figure 3.19. Cumulative weight loss percentage of five green bean varieties packaged in PD941 film at 5°C storage.



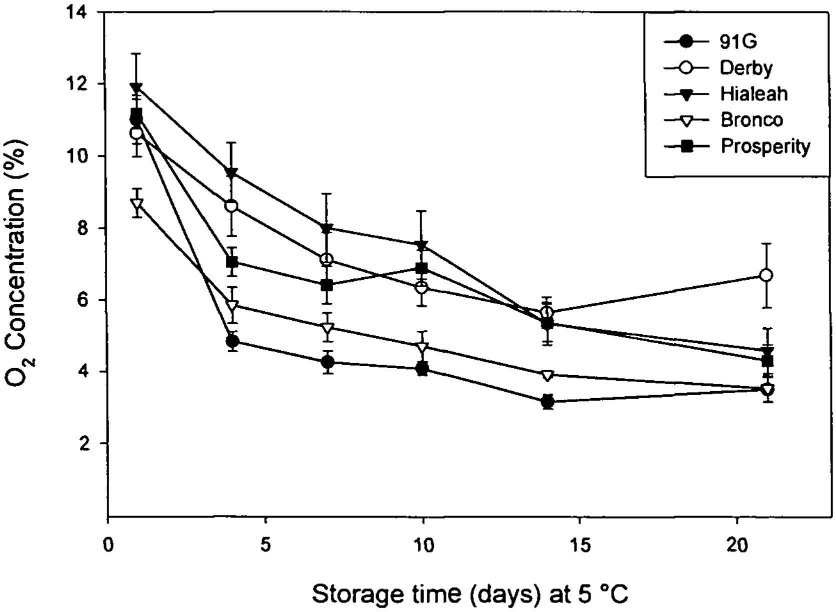


Figure 3.20. Concentrations of CO_2 and 0_2 over time in sealed bags (PD941) of five green bean varieties stored at 5°C. Vertical bars represent standard error of the mean (n=8) and may be obscured by symbols.

Table 3.2 Color change (Hue angle = $\tan^{-1} b^* / a^*$) of green bean varieties seal packaged in CRYOVAC PD941 film during storage at 5°C. Each value is the mean of 20 observations.

Green Bean Variety	Time in 5 °C Storage (days)			
	1	7	14	21
91G	120.90 ± 0.5	120.10 ± 0.4	120.00 ± 0.5	116.81*± 1.1
Derby	117.64 ± 0.2	119.52 ± 0.2	119.04 ± 0.3	118.63 ± 0.3
Hialeah	117.72 ± 0.2	117.53 ± 0.4	117.46 ± 0.3	115.38*± 0.6
Bronco	119.09 ± 0.4	119.84 ± 0.2	120.08 ± 0.4	120.46 ± 0.5
Prosperity	119.32 ± 0.7	118.63 ± 0.2	118.09 ± 0.2	116.35*± 0.5

* = Means within a row are statistically different (FPLSD $p \leq 0.05$)

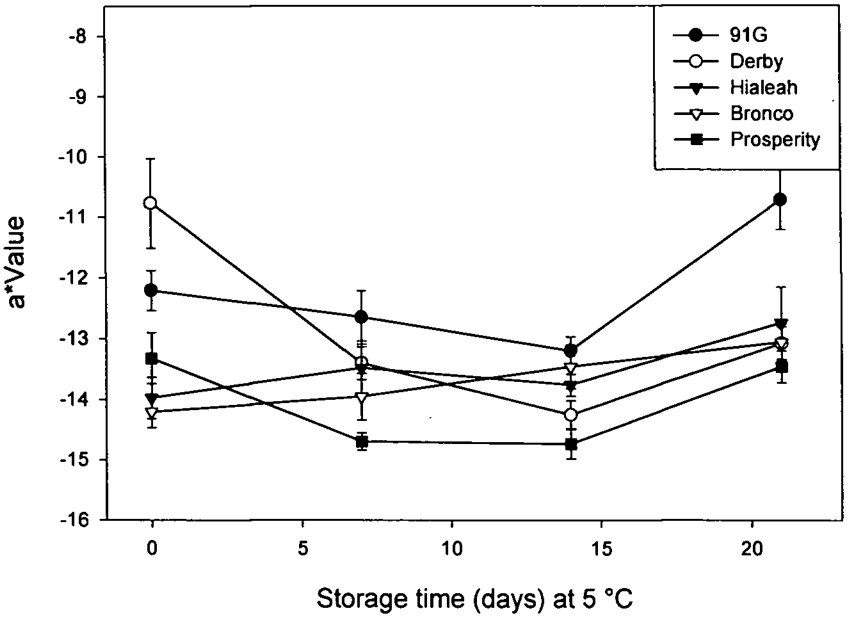


Figure 3.21. Color change (Minolta CR-300 a* Value) of five green bean varieties packaged in PD941 film at 5°C storage. Vertical bars represent standard error of the mean (n=20).

C: CONCLUSIONS

1. Vented bags (control) and unpackaged (control) beans were only marginally acceptable after 7 days at either 5° or 10°C.
2. Green beans packed in PD941 CRYOVAC MAP at 5°C retained the best overall quality three times longer compared to control. However, a high off-odor score was detected by panelists in PD941 packages at 10°C storage temperature after 21 days storage.
3. Green beans packed in PD941 and PD961 had acceptable appearance quality during 21 days storage at 5°C in terms of mean quality rating, minimum weight loss and color change. However, off-odors developed in PD961 packages after 14 days storage at 5°C and very strong off odor occurred especially at 10 °C after 14 days storage.
4. Green beans packed in PD955 and PD940 were satisfactory for 7 and 14 days at 5°C and they were not acceptable even for 7 days at 10°C.
5. Green beans packed in XTEND120 showed an acceptable general appearance after 21 days in storage. But the highest off-odors score was rated even after 14 days storage which was associated with very high CO_2 concentration (about 25 – 30 %) inside packages. XTEND120 film had less permeability to CO_2 and did not provide beneficial atmospheres for either 'Jade' or 'Strike' cultivars.

6. Weight loss in green beans packed in XTEND120 and vented bags (control) were similar and were three to eight times higher than beans in either CRYOVAC films (PD941 and PD961) (less than 1 %).
7. Green beans packed in PD941 gave the highest hue angle color compared to other films in both 5° and 10°C, which indicated greener bean pods. In addition, no change in hue angle was found throughout the entire 21 days storage period for PD941 at 5°C.
8. The tristimulus a* value and hue angle corresponded more closely to visual observations and were better indicators of green bean color than chroma, L*, or b* value.
9. 'Hialeah' and 'Prosperity' were superior followed by 'Bronco', 'Derby', and '91G' the only cultivar which developed chilling injury symptoms after only 7 days at 5°C.

CHAPTER 4

THE EFFECT OF FILM TYPES AND STORAGE TEMPERATURE ON QUALITY OF MAP SWEET CORN (*Zea mays)*

Index words: *Zea mays*, modified atmosphere packaging, storage life, anaerobic metabolism, respiration, weight loss, off-odors, O_2, CO_2, .

4.1. ABSTRACT

A major postharvest problem of fresh sweet corn quality is a rapid decrease in sugar level shortly after harvest especially at high temperature. Quickly refrigerating sweet corn immediately after harvest is very useful but may not be sufficient for maintaining quality during all the marketing steps. Plastic films that modify the atmosphere by lowering O_2 and increasing CO_2 have the potential to extend the storage life and quality of vegetables and may be used to supplement low temperature. In addition, using sugary enhanced sweet corn (*se*) and supersweet sweet corn (*sh_2*) which are sweeter and may retain quality longer compared to normal sweet corn, may further help to maintain sweet corn quality. Therefore, experiments were conducted to test the effectiveness of film types and storage temperatures in extending the postharvest life and quality of sugary enhanced (*se*) sweet corn (cv. 'Sugar Buns') and supersweet (*sh_2*) sweet corn (cv. 'Supersweet Jubilee').

Two CRYOVAC polyolefin films (PD941 and PD961), a microperforated film (XTEND120) and a perforated polyetylene film (control) were tested for their suitability in packaging of sweet corn stored at 0° (optimum) and 5°C (mild abuse). The changes in CO_2 and O_2 concentration inside packages were

monitored by GC throughout the storage period. Quality parameter such as sucrose concentration, soluble solids, weight loss and color change were determined initially and at one week intervals. In addition, sensory analysis by panelists was conducted after 14 days storage.

PD941 appeared to be the most effective film in retaining quality (sweetness), better general appearance and lowest weight loss in both sweet corn cultivars when stored at 0°C. Although sugar concentration decreased over storage time, sugar values of sweet corn were still high in this film after 14 days storage. No significant difference in sugar concentration was found between treatments after 14 days storage for 'Sugar Buns'. 'Supersweet Jubilee' had twice the sucrose concentration of 'Sugar Buns', however, 'Supersweet Jubilee' lost significant sucrose during 14 days of 0° and 5°C storage. Weight loss of sweet corn packed in PD941 and PD 961 was low (about 1 – 1.5 %) after 14 days storage at both temperatures, whereas weight loss from XTEND120 was about 2.5 – 3%. Even though water condensation was found in all packages of PD941 and PD961, no decay was observed after 14 days storage. During this time, very strong off odor was evident in sweet corn (cv. 'Sugar Buns') packaged in XTEND120 even at 0°C. However, very few off odors were detected in XTEND120 packages of 'Supersweet Jubilee'. Films PD961 and XTEND120 were not sufficiently permeable to CO_2 and severe off odors were detected especially in 'Sugar Buns' packaged in XTEND120 at both temperatures. Even though moderate CO_2 concentration (about 8 to 10 %) was attained in PD941 packages at 5°C, severe off odors (mostly caused by mold, in this case) were also detected by panelists in both tested cultivars.

4.2. INTRODUCTION

The most important quality characteristic of sweet corn is its sweetness. Sweetness rapidly decreases after harvest due to a decline in sugar levels which is due to both respiratory loss of carbohydrate and conversion to starch (Huelsen, 1954). Previous research showed a 50 % decrease in total sugar within 24 hrs after harvest at 25°C and 10 % decrease at 10°C (Spalding et. al., 1978). Evensen and Boyer (1986) also found that the quality of normal sweet corn (*su*) deteriorates rapidly within 3 days after harvest, especially at 10°C storage temperature. In addition, total sugar declined more quickly during storage at 10°C than at 0°C. Sugar depletion after harvest may be reduced by prompt cooling, storage at low temperature (near 0°C), and by the use of cultivars with genetic modifications of carbohydrate metabolism (Evensen and Boyer, 1986). Lutz and Hardenburg (1968) emphasized that even under cold storage conditions standard sugary (*su)* sweet corn quality should not be expected to remain acceptable for more than 4 - 8 days. However, this was prior to the use of the new mutant varieties of sweet corn had been developed. In addition, genetic limitations of normal (*su*) sweet corn in consumer quality and postharvest storage properties have led plant breeders to incorporate other gene mutations in normal (*su*) sweet corn (Olsen et al., 1990) such as sugary enhanced sweet corn (*se*) and super sweet corn (sh_2). This is because sweet corn that had these recessive genes often was sweeter and may retain quality longer compared to normal sweet corn (*su*). Olsen and Jordan (1989) and Olsen et al., (1990) concluded that the highest rating for both sweetness and general appearance was usually recorded for the supersweet (*sh*$_2$) and the lowest rating for normal (*su*) sweet corn. Quality scores for sugary enhanced (*se*) cultivars usually fell between the supersweet and normal sweet corn.

Plastic films can be used to passively modify atmosphere around fresh produce inside packages to provide an environment which can delay the deterioration of many crops. Reduced O_2 and increased CO_2 created by modified atmosphere packaging have been shown to reduce deterioration in sweet corn (Kader et al., 1989, Othieno and Thompson, 1995). Aharoni and Richardson (1997) found that XTEND120 microperforated film maintained fresh corn quality in the consumer package for 7 days but this film was less suitable for bulk pack. CRYOVAC PD941 film was also shown to be promising for other vegetables such as broccoli florets (Cabezas and Richardson, 1997), or green beans (Mekwatanakarn and Richardson, 1997) and in our preliminary results of sweet corn conducted in 1996.

Usually the time from harvest to consumers is often many days for sweet corn. Therefore, it would be useful to incorporate the advantages of improved genetic cultivars and the available postharvest technology; modified atmosphere packaging and low temperature management in order to maintain quality of sweet corn for longer periods. This would be particularly useful for long distance transport. The objective of this study was to evaluate the effect of different film types and temperature on quality of sugary enhanced sweet corn (*se*) and supersweet corn (*sh*$_2$).

4.3. MATERIALS AND METHODS

4.3.1. Plant Materials and Films Used

Two experiments were conducted on fresh sweet corn (*Zea mays* cultivar 'Sugar Buns' (*se*) and 'Supersweet Jubilee' (*sh*$_2$). Sweet corn was harvested from field experiments at Oregon State University Vegetable Research Farm, Corvallis, OR. Sweet corn husks were removed and the cobs with kernels immediately placed in 0°C storage temperature. A standard commercial " pillow pack" (5.5" x 10") was used containing two corncobs in each package. The average weight ranged from 400 – 470 g per package for 'Sugar Buns' and 620 – 700 g per package of 'Supersweet Jubilee'. Two CRYOVAC polyolefin films designated as PD941 and PD961 were used as MAP packaging films. One new microperforated film (XTEND ™, Stepac, LA) labeled XTEND120 was also tested for suitability. A control using vented bags (eight 6-mm holes per bag) was also tested to simulate consumer bags in retail grocery stores. All types of packages were sealed with a heat impulse sealer (Model CD 500, DEA LUN CO LTD, Taiwan R.O.C.) and immediately placed in 0° or 5°C storage temperature. We have included in the design, storage temperature trials 5°C higher than the optimum to represent likely temperature abuse conditions.

The experiment was a 4 x 2 factorial (4 packages and 2 temperatures) in a completely randomized design. Each package represented a replicate and there were four replicates per treatment combination.

4.3.2. Headspace CO_2 and O_2 Analysis

Four packages were used for headspace analysis of CO_2 and O_2 using gas chromatography. The methods for analysis were the same as that described for green beans in Chapter 3.

4.3.3. Quality Evaluation

Four packages were weighed initially and at five day intervals to determine weight loss over time. Weight loss was calculated as the difference between initial and final weight at each time interval and presented as a cumulative weight loss percentage. Four replicates per treatment were evaluated initially and after 7 and 14 days of storage for soluble solids and sugar analysis. Color was measured (n = 20 observations for each treatment) from two opened packages by a Minolta Chroma Meter CR -300 as previously described in Chapter III. Soluble solids were measured by placing a drop of juice expressed from the kernels onto an Atago model NL - 1 hand - held refractometer and measuring its refractive index.

Frozen corncobs were stored at -30°C until analysis. The sugar content of kernels by position on the ears were in decreasing order from basal, middle and top parts of the ears as these were shown to have significant differences (Park et al., 1994). Therefore, kernel samples from basal, middle and top parts of the ears were extracted with 80% ethanol, filtered, and used for sugar analysis. Reyes, et al. (1982) reported a correlation between sweetness intensity and sugar content in the corn which indicated that sensory perception of sweetness was more closely related to sucrose content ($r = 0.80$) than with levels of either fructose or glucose ($r = 0.19$ to 0.23). Sucrose was found to be the major sugar present in sweet corn, comprising at harvest 82, 80 and 90 % of total sugar from 'Aussie Gold 12', 'Rosella 425' and 'Sucro', respectively (Olsen et al., 1990). Sugar concentration of the 80% ethanol extracts was measured by using the phenol – sulfuric acid micro-method described by DuBois et al., (1956). A Bausch & Lomb Spectronic 2000 Spectrophotometer measuring absorbance at 490 nm was used to quantify soluble carbohydrate (sucrose concentration) (see Appendix A.3 for the DuBois – sucrose standard curve).

4.3.4. Headspace Acetaldehyde and Ethanol

Headspace acetaldehyde and ethanol concentrations (indicators of possible anaerobic metabolism) withdrawn by 1.0 ml syringe, were measured with the same gas chromatograph used for CO_2 and O_2 determinations. However, for ethyl alcohol and acetaldehyde, the GC was equipped with a Porapak Q column (2m x 3 mm, 80/100 mesh) operated isothermally at 130°C and with a flame ionization detector. Helium carrier gas flow and hydrogen were 30 ml / min. Compressed air flow was 300 ml / min. Peak areas were quantified with a Shimadzu CR3A digital integrator and calibrated with standard curves prepared from authentic acetaldehyde and ethanol as external standards. It was critical to prepare standards in the cold room because the boiling point of acetaldehyde is only 21°C (Windholz et al., 1983 as cited by Kosittrakun, 1989). The values reported are the means of four replications (packages).

4.3.5. Sensory Evaluation

Sensory evaluation was conducted 14 days after storage using 15 untrained panelists. A linear scale of a 10 cm horizontal line was used for quality evaluation (general appearance, mold, corn aroma intensity and off aroma). Quality values less than "5" were arbitrarily chosen as "marginally acceptable". The sensory ballot used is shown in Appendix A.2. Samples were assigned a random one digit code number and presented to judges in random order on a white paper plate. Two packages of each treatment were used for sensory evaluation, one with package intact and another with package removed. Marks on the 10-cm line scale were converted to numbers for statistical analysis.

4.3.6. Data Analysis

Data were statistically analyzed using the generalized linear models in STATGRAPHICS - Plus statistical software, version 3.0. The model consisted of two class independent effects (packaging and storage temperature) arranged as a factorial completely randomized design measured repeatedly over time. Analysis of variance was used to evaluate the effects of independent variables on color measurement and on sensory quality evaluations. However, sensory evaluation data were analyzed as a factorial randomized block design by using each panelist as a block so that variations between each panelist can be taken into account. Fisher protected LSD (FPLSD) test was used for mean separation when appropriate. A p value ≤ 0.05 was used to establish significance. ANOVA tables are shown in Table A.9 through Table A.24.

4.4. RESULTS AND DISCUSSION

4.4.1. 'Sugar Buns' Sweet Corn MAP

4.4.1.1. Headspace CO_2 and O_2

CO_2 accumulation in packaged 'Sugar Buns' Sweet Corn stored at 0°C for 14 days is shown in Figure 4.1. PD941 packed sweet corn had equilibrated to almost 10% within one day. PD961 steadily increased to 25 – 30% CO_2 in 9 days, whereas XTEND120 also increased steadily to 55% CO_2 in 9 days, then decreased to about 45% CO_2 at 14 days.

CO_2 in packages at 5°C showed similar trends (Figure 4.1), but to generally high levels for XTEND120 reaching 70% CO_2 in 9 days. PD961 and PD941 had about the same pattern as at 0°C.

O_2 concentration at 0°C storage leveled to about 4% for PD941 within 3 days, and to about 2% for PD961 and XTEND120 in 9 days. At 5°C storage, all three films, PD941, PD961 and XTEND120 had O_2 equilibrated at 2.5 % within 6 days. Vented bags were not shown as they are essentially the same as air: 21% O_2 and about 0.05% CO_2.

4.4.1.2. Sensory Evaluation

Appearance: sensory evaluations of 'Sugar Buns' Sweet Corn appearance after 14 days **under 0 °C storage** showed that the controls

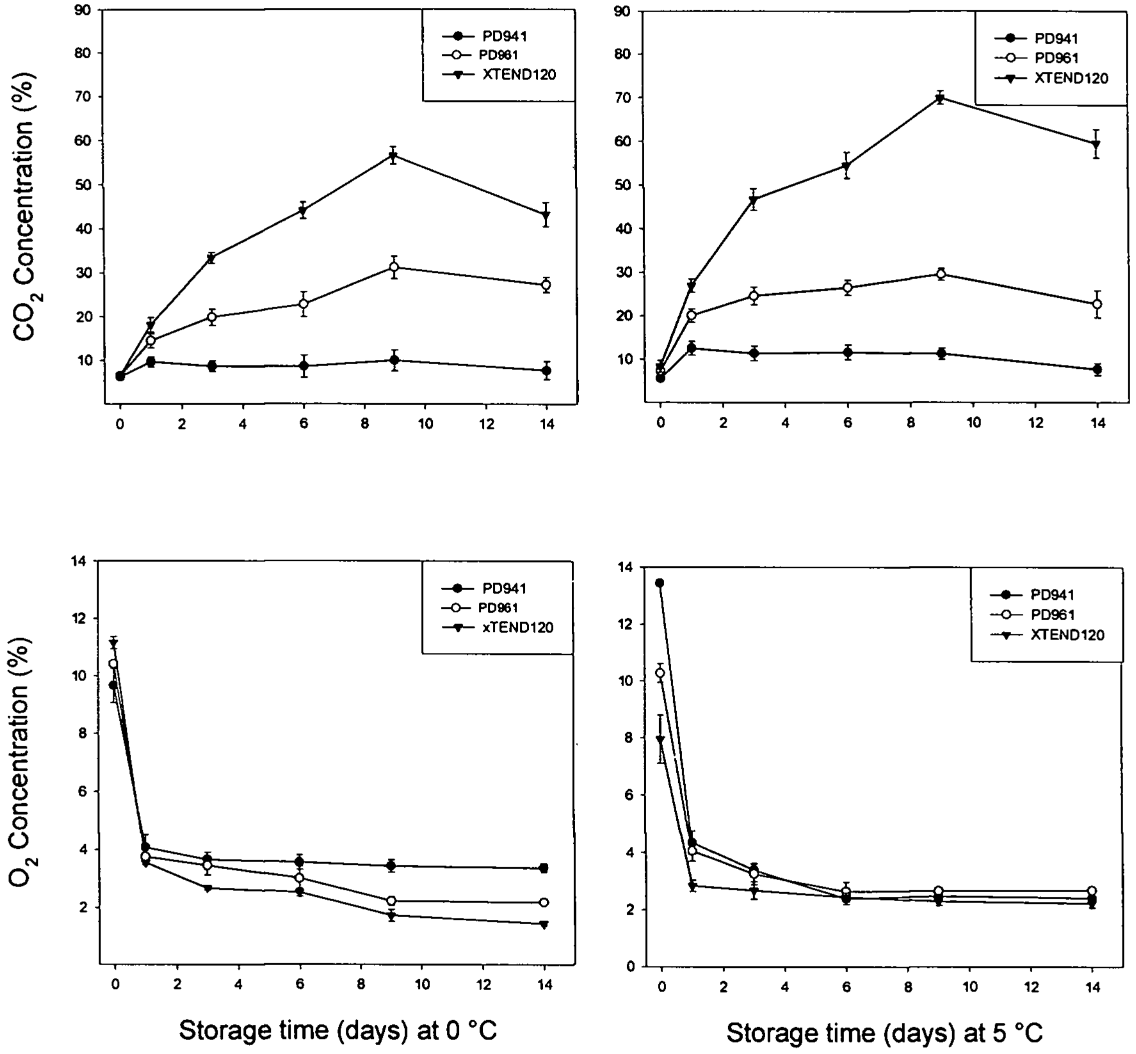


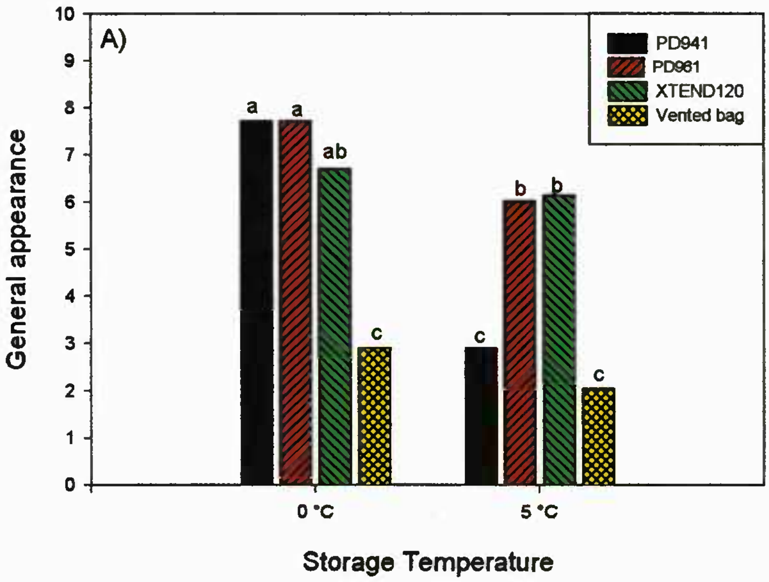
Figure 4.1. Concentrations of CO_2 and O_2 over time in sealed bags of three film types of sweet corn (cv. 'Sugar Buns') stored at 0° or 5°C. Vertical bars represent standard error of the mean (n=4). Symbols may obscure error bars.

(vented bags) had a low rating of 3 compared to the 7.8 ratings of PD941 and PD961, and the 6.6 rating of XTEND120 microperforated film (Figure 4.2 A). **Under 5°C** storage, controls were judged very low (2) and PD941 only slightly better at 3. PD961 and XTEND120 scored about 6. While panelists were not asked to define a minimal score for acceptability or for purchase, a score of 4 is perhaps a reasonable estimate of minimal acceptability based upon our rather arbitrary experience. The higher appearance scores of PD961 and XTEND120 at 5°C is noteworthy since these treatments also had the highest CO_2 in the headspace which may have suppressed mold. Under both 0°C and 5°C storage, the low appearance scores of corn in vented bags reflects both desiccation and mold as discussed next.

Mold: Mold score after 14 days at **0°C storage** were very low for PD941, 961 and XTEND120 (Figure 4.2 B). The exception was the controls, which had high (6.5) mold scores. **At 5°C storage**, both the controls and PD941 corn mold scores were quite high about 6 to 7. PD961 and XTEND120 mold scores were slightly greater, but still quite acceptable.

Corn Aroma Intensity: under **0°C storage** for 14 days, corn aroma of 'Sugar Buns' packed in PD961 was rated better than controls, but not statistically better than PD941 or XTEND120 (Figure 4.3 A). However, **at 5°C storage**, PD961 aroma was statistically better than PD941 and XTENd120, which were better than controls.

Off – Aroma: While this category reflects off–aromas arising from either



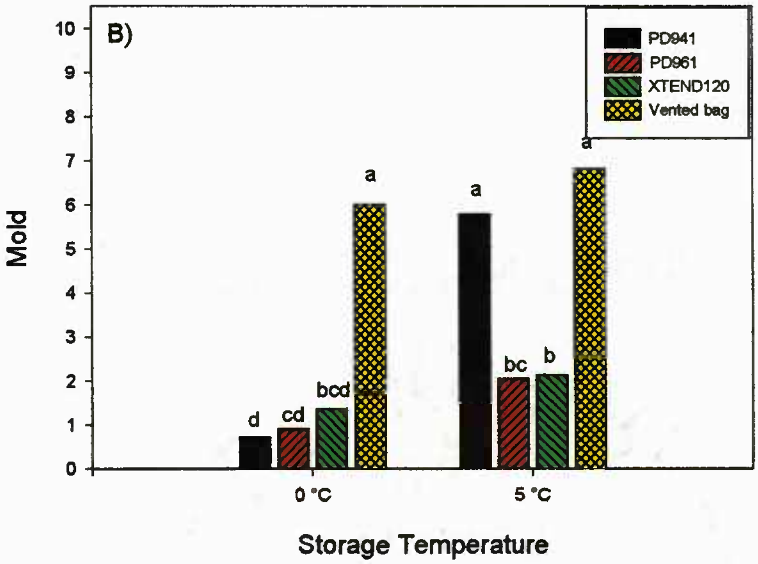


Figure 4.2. Sensory evaluation of general appearance (A) and mold (B) of sweet corn (cv. 'Sugar Buns') after 14 days storage at 0° and 5°C. No mold was observed at 7 days. Each value is the mean of 15 observations. Bars with a different letter are significantly different at $P < 0.05$ by FPLSD

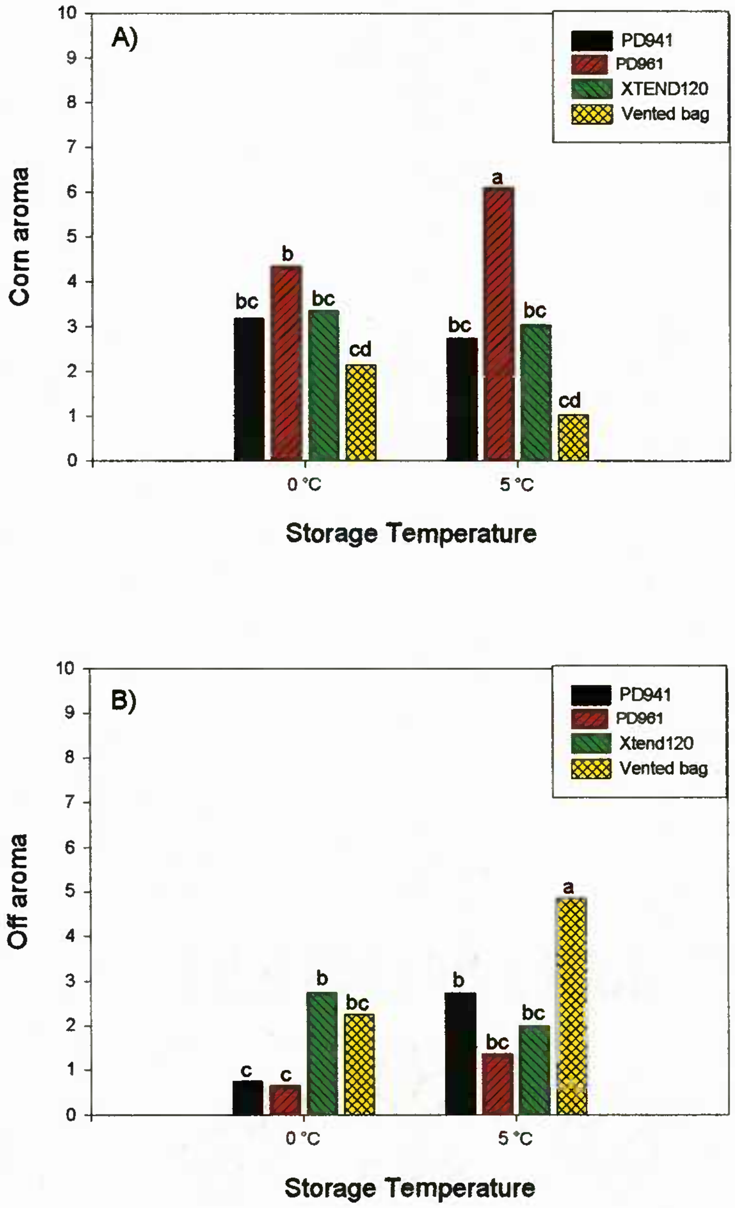


Figure 4.3. Sensory evaluation of corn aroma intensity (A) and off aroma (B) of sweet corn (cv. 'Sugar Buns') after 14 days storage at 0° and 5°C. Each value is the mean of 15 observations. Bars with a different letter are significantly different at P < 0.05 by FPLSD.

mold or from anaerobic metabolism, panelists were not asked to make that distinction. However, based upon a rather large body of information on low O_2, high CO_2 effects on quality, coupled with mold incidence scores discussed above, probable sources of off–aromas can be discussed. Under **0°C storage**, off–aroma scores were low, reflecting less metabolic activity of both the corn and mold pathogens. However, the higher off–aroma of the controls can be assigned to fungal causes (Figure 4.3 B), and not anaerobic metabolism since these vented bag controls have atmospheres essentially that of surrounding air. Even a small package leak can cause complete loss of MAP atmosphere. Off–aroma of XTEND120 packaged corn is most likely due to anaerobic metabolism (Figure 4.1) of the corn, rather than mold (Figure 4.3 B). Under **5°C storage**, control off–aroma was very high due to fungal activity. Corn off–aroma in PD941 was also high, most likely due to mold incidence (Figure 4.2 B), and less likely from anaerobic metabolism (Figure 4.1). Since O_2 was about 2.5 %, and CO_2 was only 8 – 10 %, apparently not sufficient to inhibit mold growth. CO_2 in PD 961 and XTEND120 apparently was high enough to suppress mold, yet not too high to trigger anaerobic off–aromas at 5°C.

4.4.1.3. Headspace Acetaldehyde and Ethanol

Up to 7 days storage at 0° and 5°C, no headspace acetaldehyde or ethanol were detected in any tested treatment (Table 4.1). After 14 days storage, headspace acetaldehyde was still not found at all in packages of PD941 at 0°C but a small amount of ethanol (0.06 ug /ml) was detected. This paralleled the results from off-odor sensory analysis. However, headspace acetaldehyde and

Table 4.1. Effect of film types and temperature on headspace acetaldehyde and ethanol concentration of sweet corn (cv. 'Sugar Buns') after 14 days storage in 0° and 5 °C (each value is the mean of 4 replications).

Temperature (°C)	Film types	Acetaldehyde (ug/ml)	Ethanol (ug/ml)
0	PD941	0 ± 0	0.06 ± 0.06
	PD961	0.95 ± 0.06	1.66 ± 0.43
	XTEND120	0.13 ± 0.08	0.58 ± 0.21
	Control (Vented bags)	0.02 ± 0.01	0.04 ± 0.05
5	PD941	0.11 ± 0.09	3.14 ± 0.94
	PD961	0.06 ± 0.06	2.37 ± 0.85
	XTEND120	0.19 ± 0.13	2.29 ± 0.54
	Control (Vented bags)	0.05 ± 0.01	0.45 ± 0.21

- No acetaldehyde and ethanol were found at 7 days after storage for any of the treatments

ethanol were found in all other treatments after 14 days storage. Sampling for headspace acetaldehyde and ethanol underestimates tissue levels of these substances due to the higher partitioning of these into tissue water compared to air. As a result, headspace acetaldehyde and ethanol might be less meaningful in term of off aroma detection. Tissue acetaldehyde and ethanol, as measured enzymatically, would provide more useful data on off aroma development .

4.4.1.4. Soluble Carbohydrate (Sucrose Concentration)

There were no significant differences in 80% ethanol soluble carbohydrate concentrations (DuBois micromethod) among treatments after 14 days storage but a significant difference ($p \leq 0.05$) was found after 7 days storage (Table 4.2).

Kernel sucrose concentration decreased over storage time in all polymeric films at 0°C. However, sucrose appeared to increase slightly in all polymeric films tested at 5°C after 7 days storage, but decreased after 14 days storage.

A similar result was reported by Evensen and Boyer (1986), who showed that the sucrose concentration in three out of six cultivars actually increased but at the 0°C storage temperature, as reducing sugar concentration decreased. In addition, Olsen et al (1990) also reported a slight increase in sucrose concentration in "Sucro" (14%) which occurred after 4 days storage at 1°C, but this did not occur in the other two cultivars studied.

Table 4.2. Effect of film types and temperature on soluble carbohydrate (mainly sucrose) concentrations of sweet corn (cv. 'Sugar Buns') stored at 0° and 5°C.

Temperature (°C)	Film types	Soluble carbohydrate (mg/g fresh wt.) Storage time (days) 7	14
0	PD941	37.5 bc	34.2 a
	PD961	32.7 c	32.3 a
	XTEND120	37.6 bc	33.1 a
	Control (Vented bags)	36.8 c	33.4 a
5	PD941	42.1 ab	34.4 a
	PD961	46.1 a	33.9 a
	XTEND120	44.5 a	34.9 a
	Control (Vented bags)	34.4 c	31.5 a

-Initial value for soluble carbohydrate was 42.0 ± 2.1

-The above value based on sucrose standard equivalence.

-Means within the columns followed by the different letters are significantly different at $p \leq 0.05$ by FPLSD (each value is the mean of 4 replications).

4.4.1.5. Soluble Solids

Storing sweet corn in four different polymeric films had no significant effect on soluble solids content (by refractometer) at 0°and 5°C after 7 days storage (Table 4.3). However, a significant ($p \leq 0.05$) temperature by films interaction was found after 14 days storage. Both CRYOVAC films (PD941 and PD961) showed the same trend at 0 and 5 °C storage temperature.

4.4.1.6. Weight Loss

Packaging sweet corn in polyethylene bags of these three film types reduced weight loss compared with controls at both temperatures (0° and 5°C) (Figure 4.4). Sweet corn packed in PD941 and PD961 showed the least weight loss (about 1% and 1.5%) after 14 days storage in both 0° and 5°C. Weight loss in XTEND120 was two fold (about 2.5 - 3%) that of PD941 and PD961. During 7 days storage at 5°C, weight loss of sweet corn packed in XTEND120 was about 2 % and the same as that of control (vented bags), but at 0°C less weight loss was seen in XTEND120 compared to controls.

4.4.1.7. Color Change

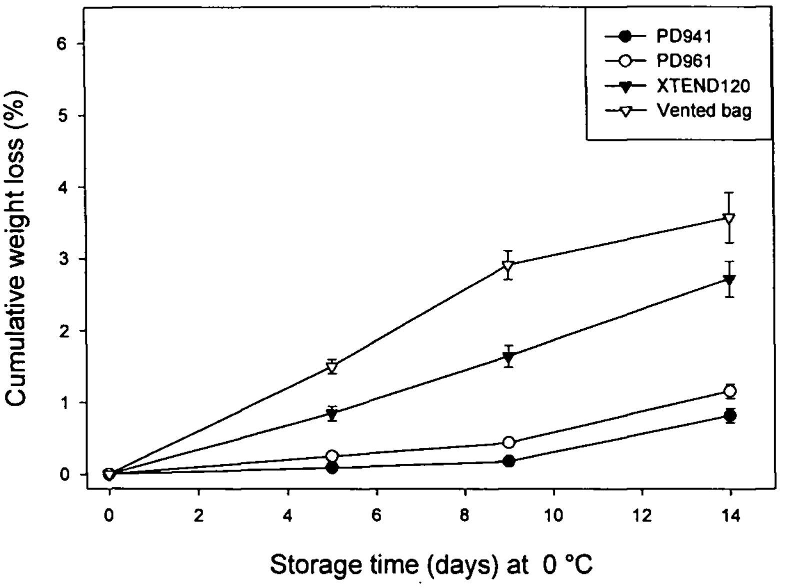
A slight darkening in color of sweet corn and a trend to turn more yellow with time was observed and expressed in terms of L values, hue angle and chroma (Figure 4.5, 4.6 and 4.7). However, no significant difference was noted between treatments in L values and hue angle after 7 days storage. A significant ($p \leq 0.05$) temperature by films interaction was found in color parameters after 14 days storage.

Table 4.3. Effect of film types and temperature on refractometer soluble solids contents of sweet corn (cv. 'Sugar Buns') stored at 0° and 5°C.

Temperature (°C)	Film types	% Soluble solid Storage time (days) 7	 14
0	PD941	26.3 a	25.8 a
	PD961	25.8 a	24.3 a
	XTEND120	23.8 a	20.0 b
	Control (Vented bags)	26.0 a	22.3 b
5	PD941	24.8 a	20.3 b
	PD961	25.3 a	24.2 b
	XTEND120	25.8 a	25.3 a
	Control (Vented bags)	24.5 a	25.0 a

-Initial value for soluble solids was 25.0

-Means within the columns followed by different letters are significantly different at $p \leq 0.05$ by FPLSD (each value is the mean of 4 replications).



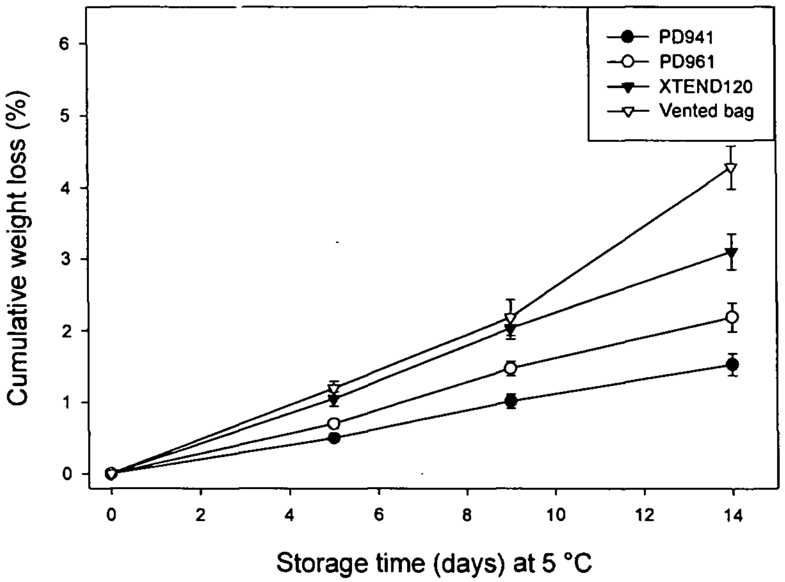
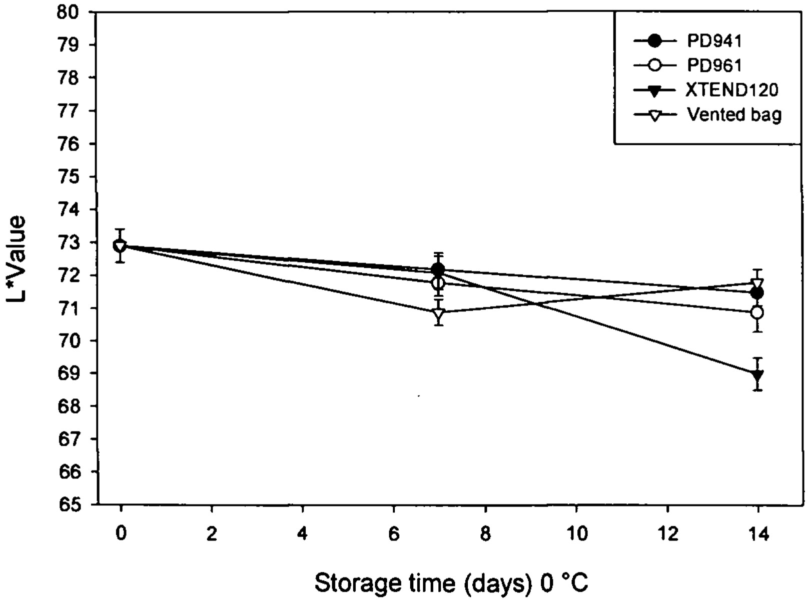


Figure 4.4. Cumulative weight loss percentage of 'Sugar Buns' sweet corn affected by film types and storage at 0° or 5°C. Vertical bars represent standard error of the mean (n=4). Symbols may obscure error bars.



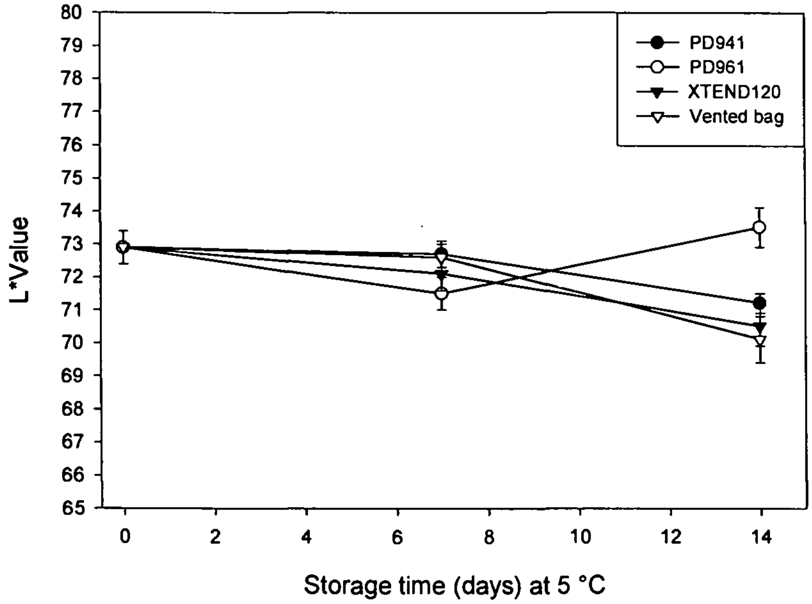
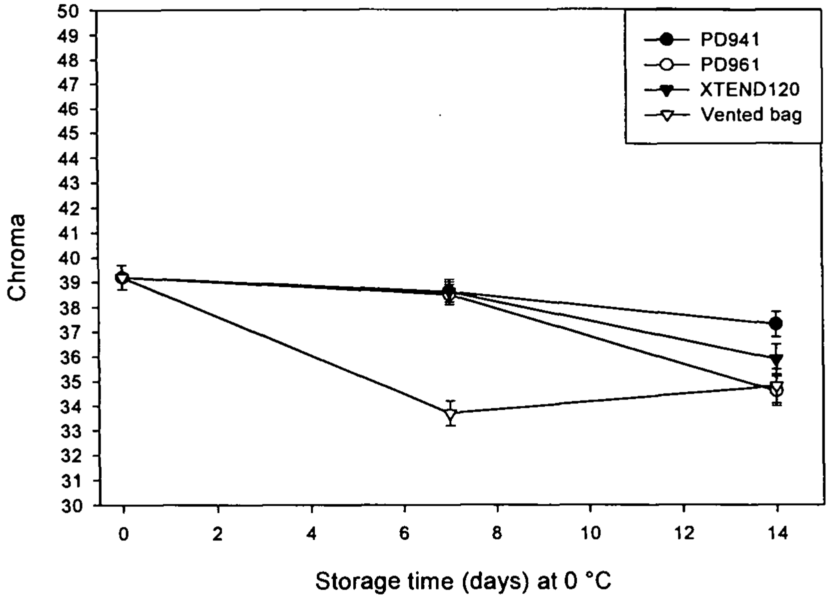


Figure 4.5. Color change (Minolta CR-300 L*value) of sweet corn (cv. 'Sugar Buns') packed in different film types and stored at 0°or 5°C. Vertical bars represent standard error of the mean (n=20).



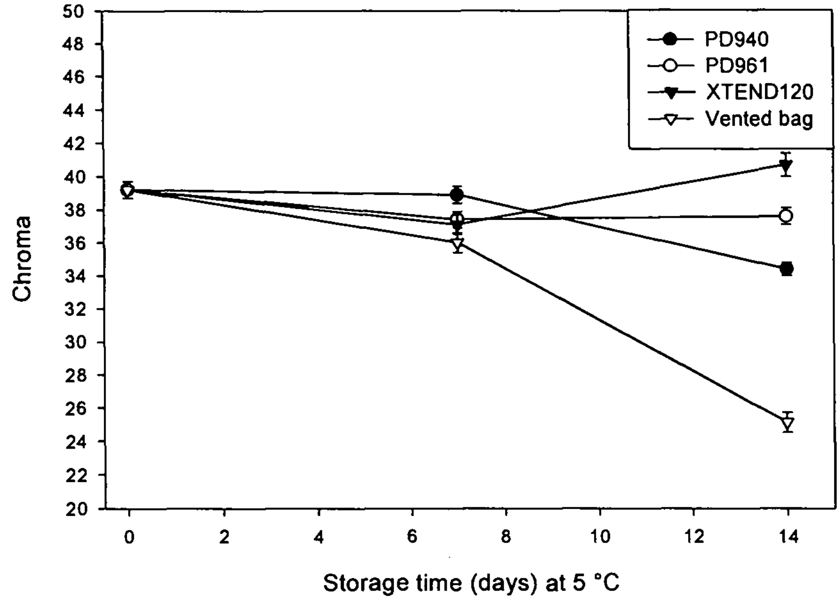
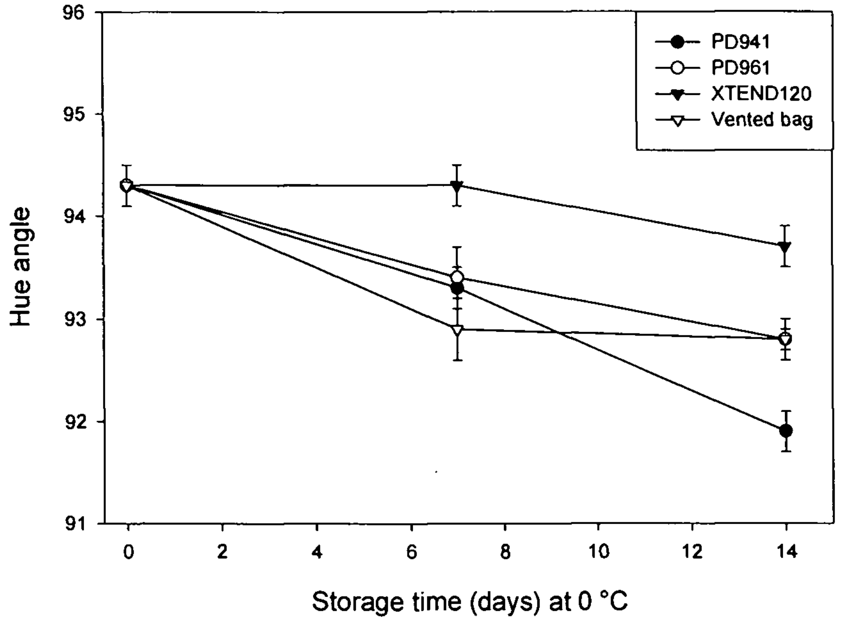


Figure 4.6. Color change (Minolta CR-300 Chroma) of 'Sugar Buns' sweet corn packed in different film types at 0°or 5°C storage. Vertical bars represent standard error of the mean (n=20).



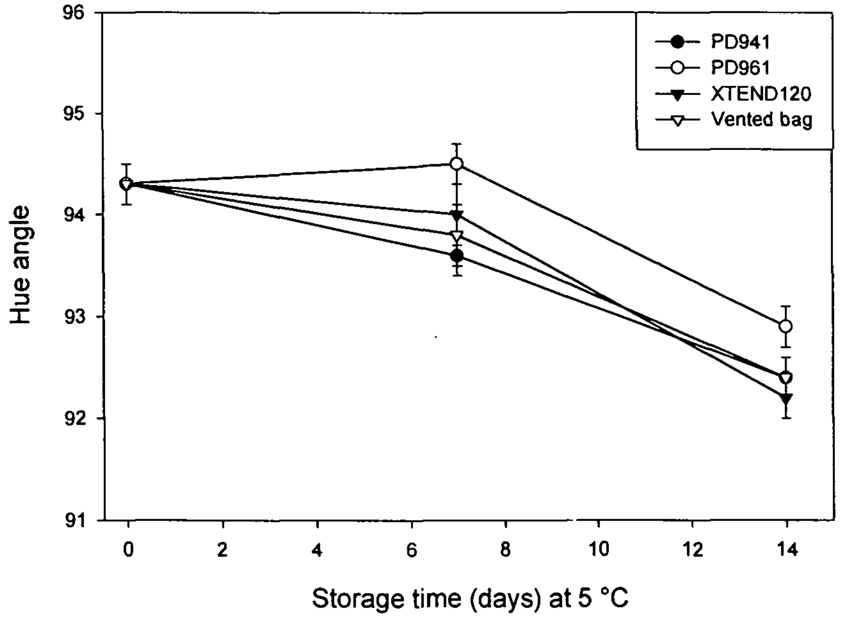


Figure 4.7. Color change (Minolta CR-300 Hue angle) of sweet corn (cv. 'Sugar Buns') packed in different film types at 0 °or 5 °C storage. Vertical bars represent standard error of the mean (n=20).

4.4.1.8. Summary

Sugary enhanced (*se*) sweet corn (cv. 'Sugar Buns') had higher soluble carbohydrate (sucrose) concentration to start with compared to normal sweet corn (*su*). Thus, even though sucrose concentration decreased over storage time, this sweet corn was still sweet after 14 days storage (Table 4.1). Package film and temperature tested had no significant effect on sucrose concentration. This could be because the temperature range tested (0°and 5°C) might be too small to see differences. PD941 film appeared to show some promise in terms of moderate CO_2 and O_2 concentration (10 % and 2 % respectively), the least weight loss, better general appearance and lower headspace acetaldehyde and ethanol compared to other films tested at 0°C storage temperature. Very little off odor was observed at 0°C after 14 days storage. Water condensation was found in all packages of PD941 and PD961, but no decay was observed during 14 days of storage. Even though XTEND120 packages had more weight loss compared to that of PD941 and 961 and no condensation was evident, the kernels were still in good general appearance and fresh with no denting. This might have been due to fairly high CO_2 in the packages. However, very strong off odor was present in XTEND120 even at 0 °C, which indicates anaerobic metabolism. Mold incidence usually started at the base where the leaf bract was removed. This suggests the need for some protective treatment to control fungal attack.

4.4.2. 'Supersweet Jubilee' Sweet Corn MAP

4.4.2.1. CO_2 and O_2 Concentration within the Package

The in – package CO_2 concentrations of 'Supersweet Jubilee' sweet corn stored up to 14 days at 0°C are shown in Figure 4.8. PD941 showed CO_2 rising to 15% at 2 days, then dropping to 12% equilibrium after 7 days. This rise and fall pattern has been observed before (Cabezas and Richardson, 1997) and is associated with a temporary "overshoot" of rapid CO_2 accumulation as O_2 is still decreasing to equilibrium. PD961 equilibrated to 22% CO_2 and XTEND120 package equilibrate to 32% CO_2. The same package stored at 5°C, had similar patterns (Figure 4.8) but the equilibrium values for PD941, PD961 and XTEND120 were 12%, 32% and 45% CO_2, respectively. At this higher storage temperature, the equilibrium was reached earlier, within about 2 days, compared to about 7 days for 0°C storage.

'Supersweet Jubilee' sweet corn packages stored at 0°C equilibrated to about 4% O_2 in about 3 days. XTEND120 film packages were slightly lower by about 0.5 %. Under 5°C storage, the pattern was the same, but equilibrated in 1 to 2 days at levels about 3.0 to 3.5% O_2. Normally, these levels of O_2 would be considered quite safe under regular CA conditions. However, the CO_2 levels attained by these packaging systems rise well above 30 %. High CO_2 may well disturb aerobic pathways of respiration. Thus under high CO_2, the minimum level of O_2 should be higher to avoid quality losses.

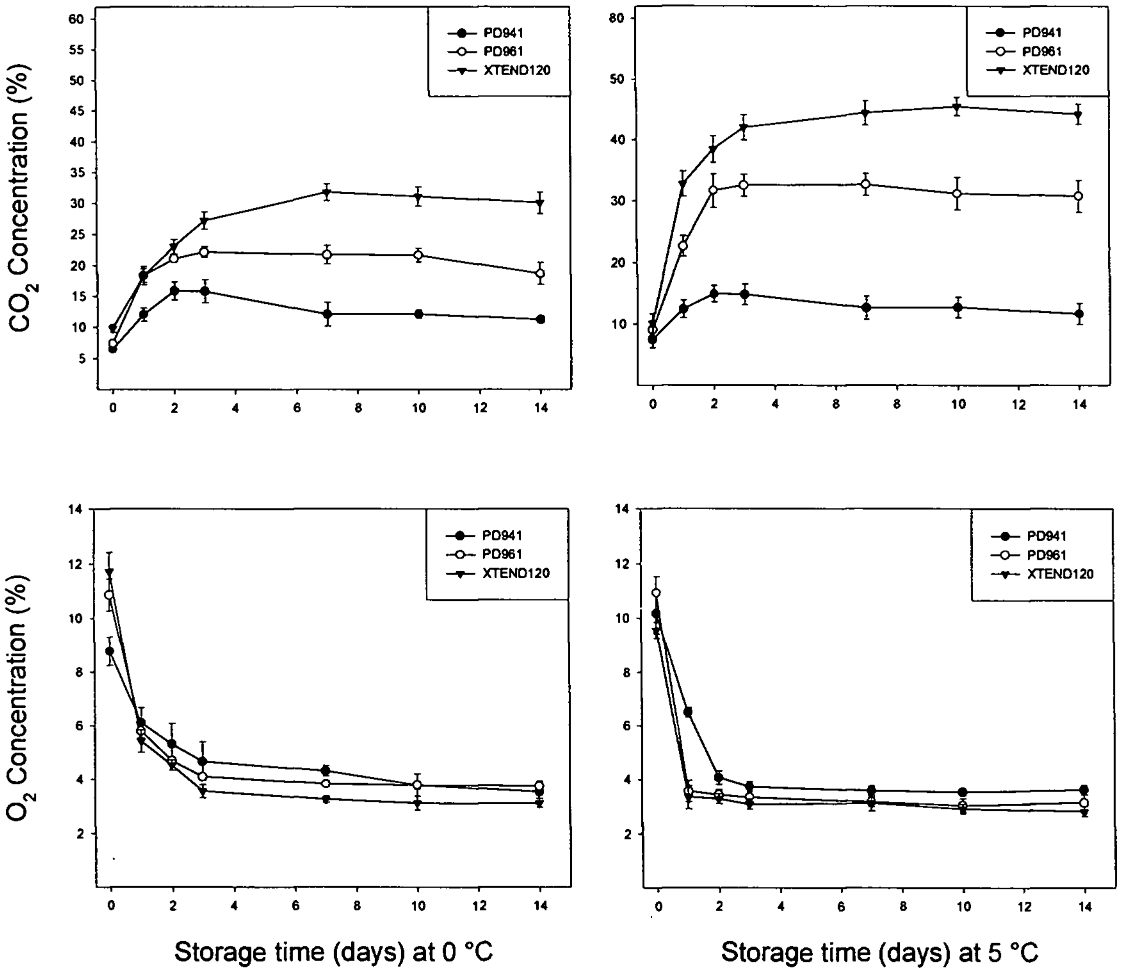


Figure 4.8. Concentrations of CO_2 and O_2 over time in sealed bags of three film types of 'Supersweet Jubilee' sweet corn stored at 0° or 5°C. Vertical bars represent standard error of the mean (n=4).

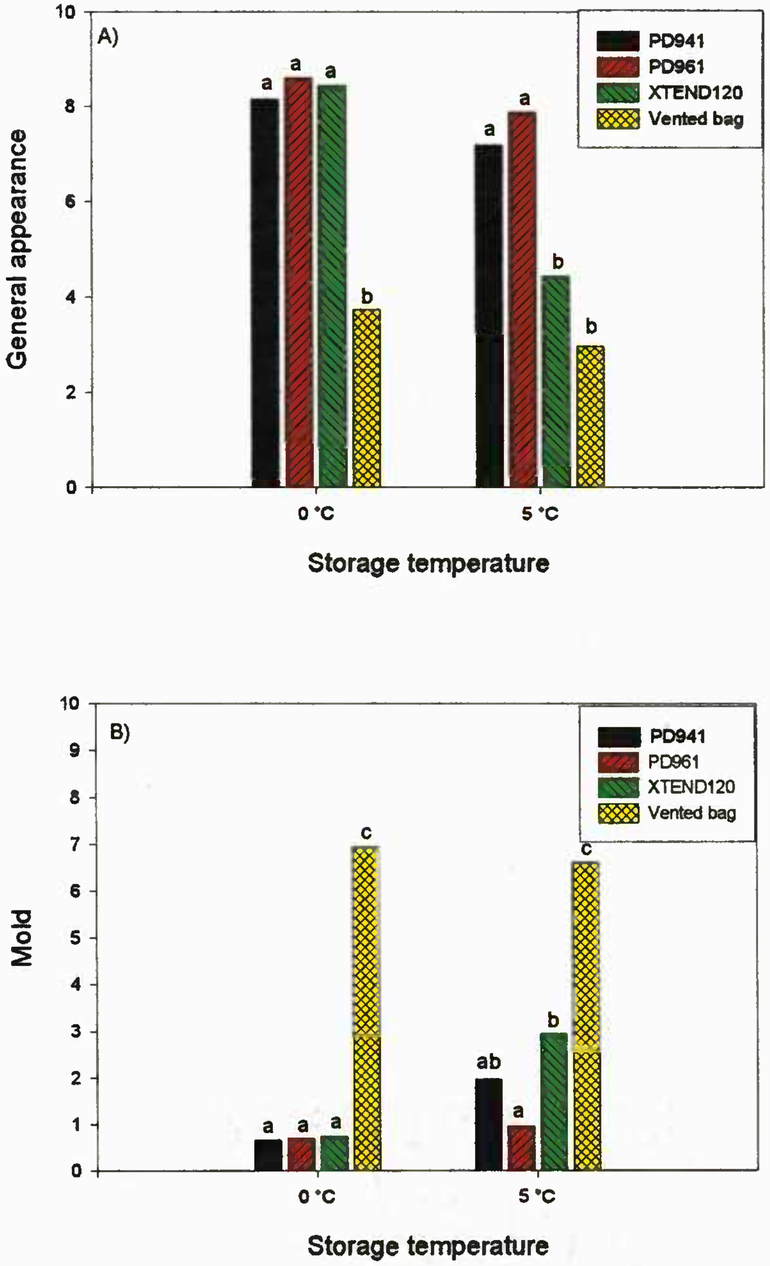


Figure 4.9. Sensory evaluation of (A) general appearance and (B) mold of 'Supersweet Jubilee' sweet corn after 14 days storage at 0° and 5°C. Each value is the mean of 15 replications. Bars with the different letter are significantly different at $P < 0.05$ by FPLSD.

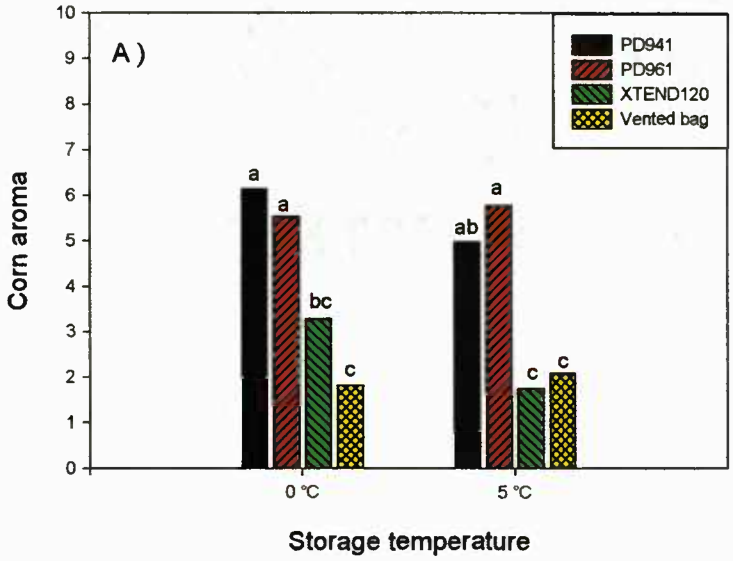
4.4.2.2. Sensory Evaluation

Appearance: At 0°C ‘Supersweet Jubilee’ sweet corn appearance was excellent for all MAP packages (Figure 4.9 A). The exception was the vented bag controls, which were rated poor, mostly due to visible desiccation and mold. At 5°C storage, PD941 and PD961 also had excellent appearance, but XTEND120 and control packages were both rated poor in appearance, mostly due to mold.

Mold: At both 0°and 5°C, vented bag controls had high levels of mold and this detracted from appearance scores discussed above (Figure 4.9 B). At 0°C and 5°C, PD941 and PD961 had minimal mold. Xtend120 packages had low mold scores at 0°C, but were significantly greater ($p \leq 0.05$) at 5°C.

Corn Aroma: Panelists rated PD941 and PD961 corn aroma very good at both 0°and 5°C (Fig. 4.10 A). XTEND120 and controls were rated lower at 0°C and 5°C.

Off-Aromas: Panelists were not asked nor trained to differentiate off-odors, which could arise either from mold or from anaerobic metabolism. At 0°C storage, off-aromas were generally low and there were no significant differences between packages (Fig. 4.10 B). At 5°C, XTEND120 packages had significantly lower off-aroma, and this was despite having the highest CO_2, the lowest O_2 , and fairly high mold. This is very hard to explain. However, the packages used for the sensory panel were not the very same ones sampled for CO_2 and O_2. Even so, the 5°C XTEND120 off-aromas score is difficult to rationalize. One would certainly expect that the mold incidence would have contributed to off-aroma, although not all types of mold would produce off-aromas.



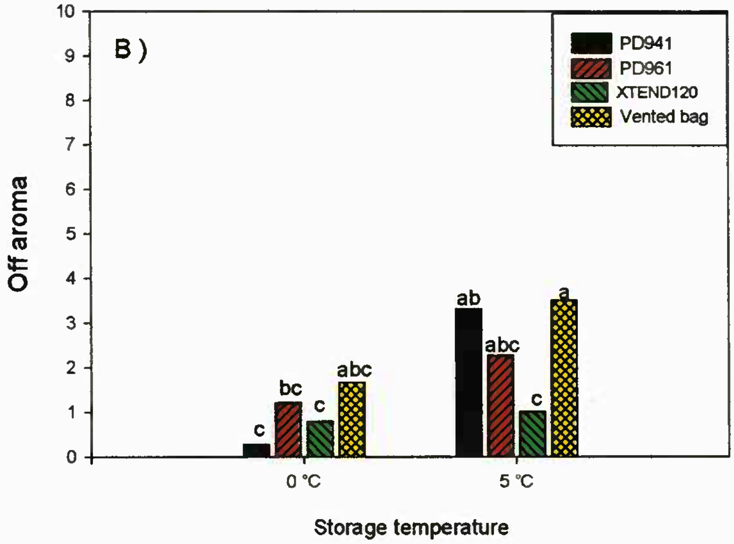


Figure 4.10. Sensory evaluation of corn aroma (A) and off aroma (B) of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage at 0 and 5 °C. Each value is the mean of 15 replications. Bars with the different letter are significantly different at $P < 0.05$ by FPLSD.

Still another possible explanation is that aromas, including off-aromas, may be quickly lost once packages are opened.

4.4.2.3. Headspace Acetaldehyde and Ethanol

After 7 days storage, no headspace acetaldehyde was found in any treatments except that a very small amount was detected in packages of PD941 at 5°C (Table 4.4). However, headspace ethanol was not present in XTEND120 film but was found in other treatments at both temperatures. After 14 days storage, headspace acetaldehyde was detected in all treatments but none was found in sweet corn packaged in PD961 stored at 5°C. In addition at 5°C, headspace ethanol was detected in all treatments, particularly packages of PD941 and XTEND120.

4.4.2.4. Soluble Carbohydrate (Sucrose Concentration)

Supersweet sweet corn (sh_2) (cv. 'Supersweet Jubilee') had two fold higher sugar concentration (101 mg/g fresh weight) compared to sugary enhanced sweet corn (*se*) 'Sugar buns' (42 mg/g) which was tested in the first experiment. Sugar concentration also decreased over storage times in all treatments but values were still high after 14 days storage (Table 4.5). Sweet corn packed in PD941 retained higher sugar concentration compared to other films tested in both 0° and 5°C storage temperature. No temperature by films interaction was demonstrated. Therefore, only main effects of film and temperature were considered. Sugar concentration was significantly lower ($p \leq$

0.05) in sweet corn held at 5°C storage temperature than that at 0°C. Significant effects ($p \leq 0.05$) on sugar concentration were noted between films tested after 7 and 14 days storage (Table 4.5). Sweet corn packed in PD941 retained higher sugar concentration than other package films in both 0° and 5°C storage temperatures.

4.4.2.5. Soluble Solids

No significant effect was found in all treatments (Table 4.6) of 'Supersweet Jubilee' sweet corn, which was contrary to the first experiment on 'Sugar Buns' in this Chapter.

4.4.2.6. Weight Loss

Generally, sweet corn packed in all three films tested had less weight loss compared to control (vented bags) at both temperatures (Figure 4.11). Sweet corn in PD941 showed the least weight loss (less than 1 %) after 14 days storage at both temperatures. Weight loss of sweet corn packed in PD961 was the same as that of PD941 at 0°C but almost 1 % greater weight loss was found at 5°C after 14 days storage. Weight loss of sweet corn in XTEND120 film was about twice (2.5 – 3 %) that of PD941.

4.4.2.7. Color Change

A trend to turn more yellow with time of sweet corn was observed as expressed in terms of L values, hue angle and chroma (Figs. 4.12, 4.13, 4.14). However, no significant differences were noted between treatments in L*-values

Table 4.4. Effect of film types and temperature on headspace acetaldehyde and ethanol concentration of sweet corn (cv. 'Supersweet Jubilee') at 7 and 14 days after storage in 0 and 5 °C (each value is the mean of 4 replications).

Temp	Film types	Acetaldehyde (ug/ml)		Ethanol (ug/ml)	
		7 days	14 days	7 days	14 days
0°C	PD941	0	0.2 ± 0.1	0.8 ± 0.7	0.8 ± 0.8
	PD961	0	0.4 ± 0.3	0.6 ± 0.6	1.2 ± 0.7
	XTEND120	0	0.2 ± 0.1	0	1.1 ± 0.7
	Control (Vented bags)	0	0.1 ± 0.03	0	0.3 ± 0.2
5 °C	PD941	0.2 ± 0.2	0.3 ± 0.2	0.4 ± 0.3	4.1 ± 2.1
	PD961	0	0	0.04 ± 0.04	1.2 ± 0.7
	XTEND120	0	0.4 ± 0.4	0	1.0 ± 0.7
	Control (Vented bags)	0	0.1 ± 0.06	0.09 ± 0.06	0.3 ± 0.1

Table 4.5. Effect of film types and temperature on extracted soluble carbohydrate (mainly sucrose) concentrations of sweet corn (cv. 'Supersweet Jubilee') stored at 0 and 5 °C.

Temp (°C)	Film types	Soluble carbohydrate (mg/g fresh wt.) Storage time (days)	
		7	14
0	PD941	96.5 a	92.6 a
	PD961	94.7 ab	89.2 a
	XTEND120	92.4 abc	80.7 b
	Control (Vented bags)	93.2 ab	75.5 b
5	PD941	93.6 ab	80.4 b
	PD961	90.8 bc	75.5 b
	XTEND120	88.6 c	67.3 c
	Control (Vented bags)	94.6 ab	61.4 d

-Initial value for soluble carbohydrate was 101.1. Values based on sucrose standard equivalence in DuBois Phenol-H_2SO_4 method.

Means within the columns followed by the different letters are significantly different at $p \leq 0.05$ by FPLSD (each value is the mean of 4 replications).

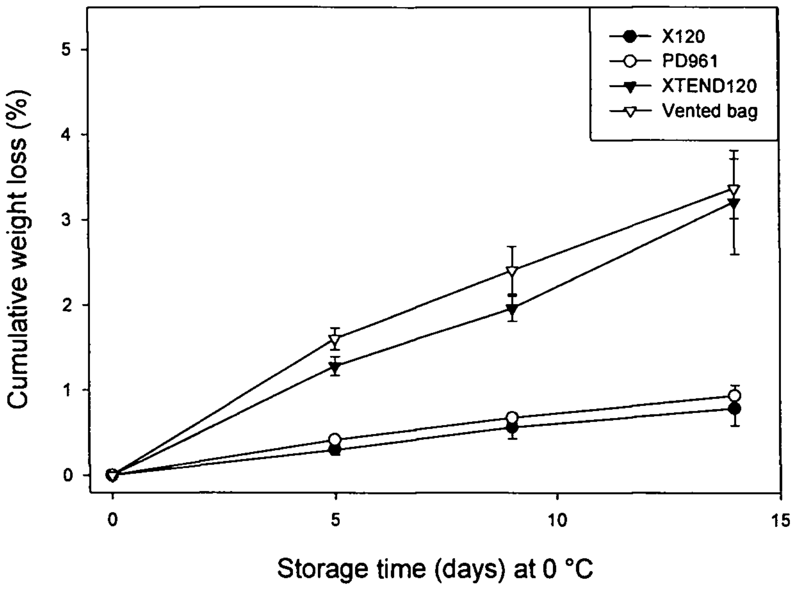
Table 4.6. Effect of film types and temperature on soluble solid contents (by refractometer) of sweet corn (cv. 'Supersweet Jubilee') stored at 0 and 5 °C.

Temp (°C)	Film types	% Soluble solids Storage time (days) 7	 14
0	PD941	15.4 ± 0.2	15.0 ± 0.2
	PD961	15.1 ± 0.1	15.1 ± 0.2
	XTEND120	15.2 ± 0.1	15.0 ± 0.3
	Control (Vented bags)	15.5 ± 0.2	14.5 ± 0.2
5	PD941	14.6 ± 0.2	14.7 ± 0.1
	PD961	14.8 ± 0.1	14.4 ± 0.2
	XTEND120	15.0 ± 0.2	14.7 ± 0.2
	Control (Vented bags)	14.1 ± 0.1	14.2 ± 0.1
		NS (all)	NS (all)

-Initial value for soluble solids was 16.4 ± 0.2

-Means within the columns are not significantly different at $p \geq 0.05$ by FPLSD.

-Each value is the mean of 4 replications



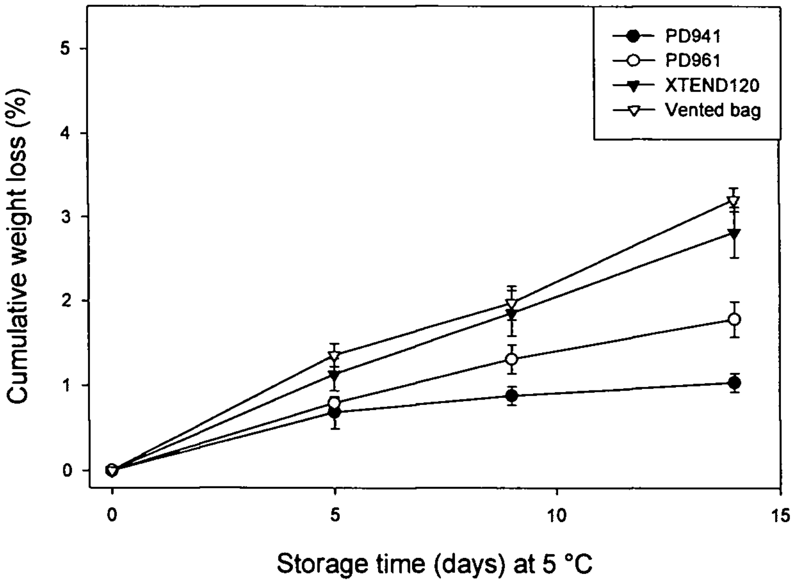
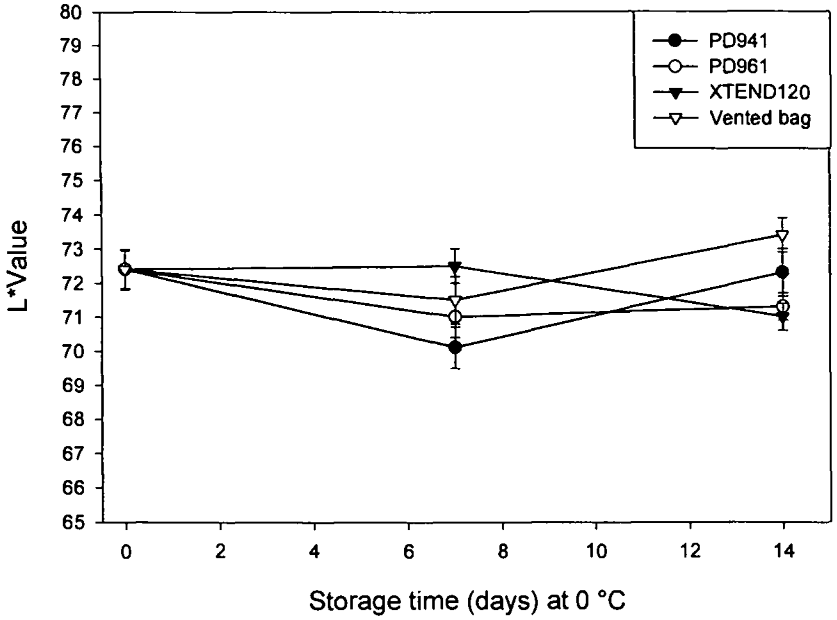


Figure 4.11. Cumulative weight loss percentage of 'Supersweet Jubilee' sweet corn affected by film types and storage at 0 or 5 °C. Vertical bars represent standard error of the mean (n=4).



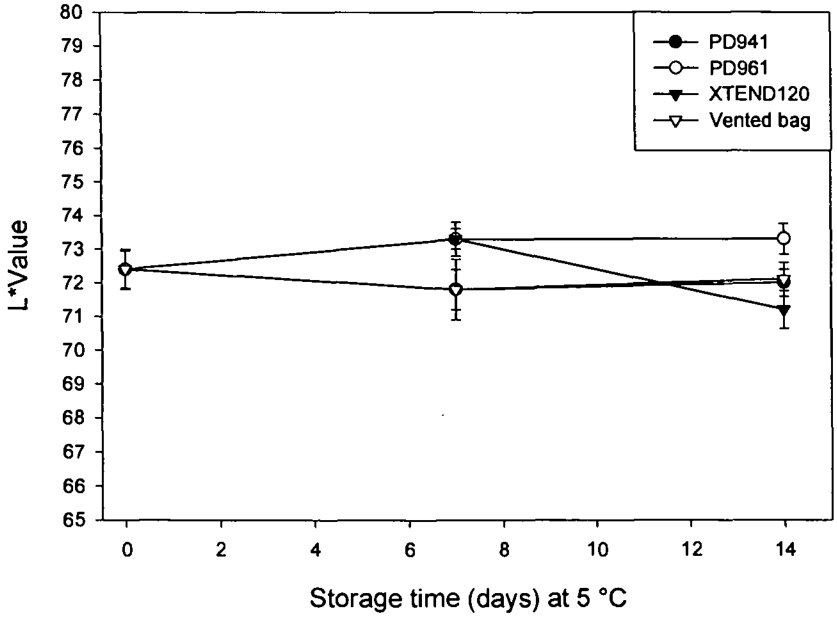
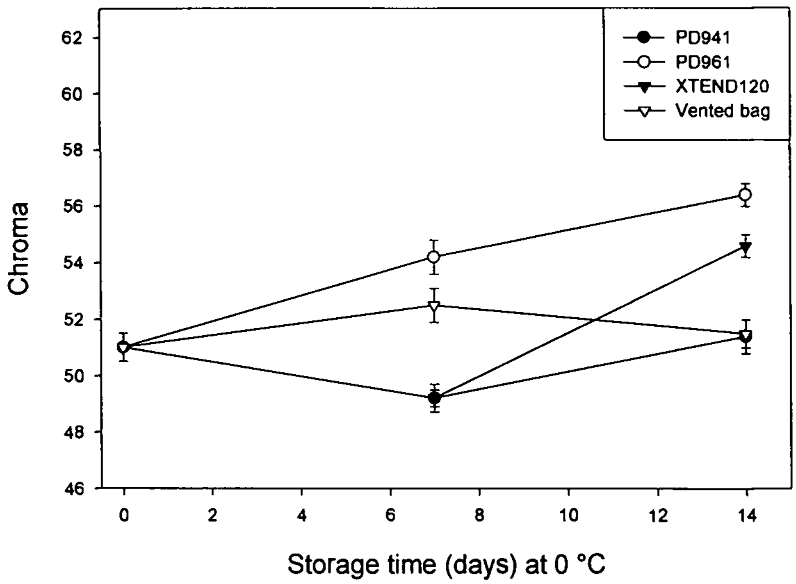


Figure 4.12. Color change (Minolta CR-300 L*value) of 'Supersweet Jubilee' sweet corn packed in different film types at 0° or 5°C. Vertical bars represent standard error of the mean (n=20).



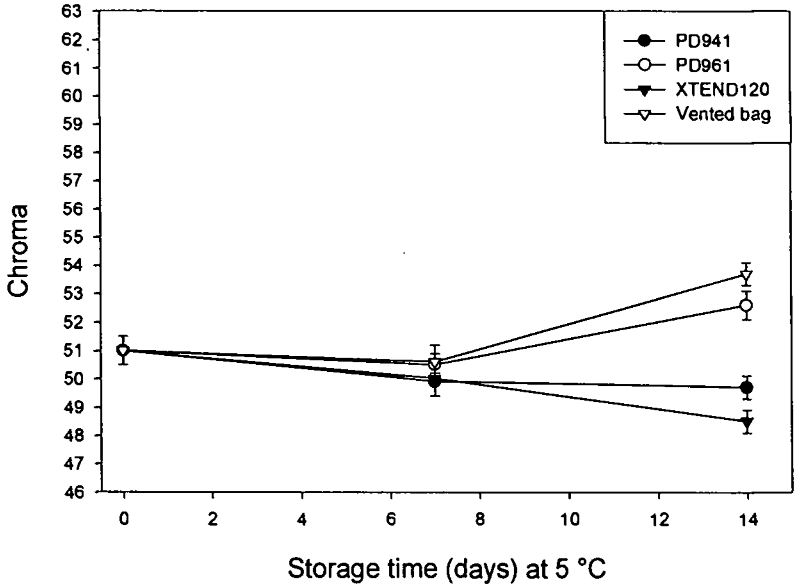


Figure 4.13. Color change (Minolta CR-300 Chroma) of 'Supersweet Jubilee' sweet corn packed in different film types at 0° or 5°C. Vertical bars represent standard error of the mean(n=20).

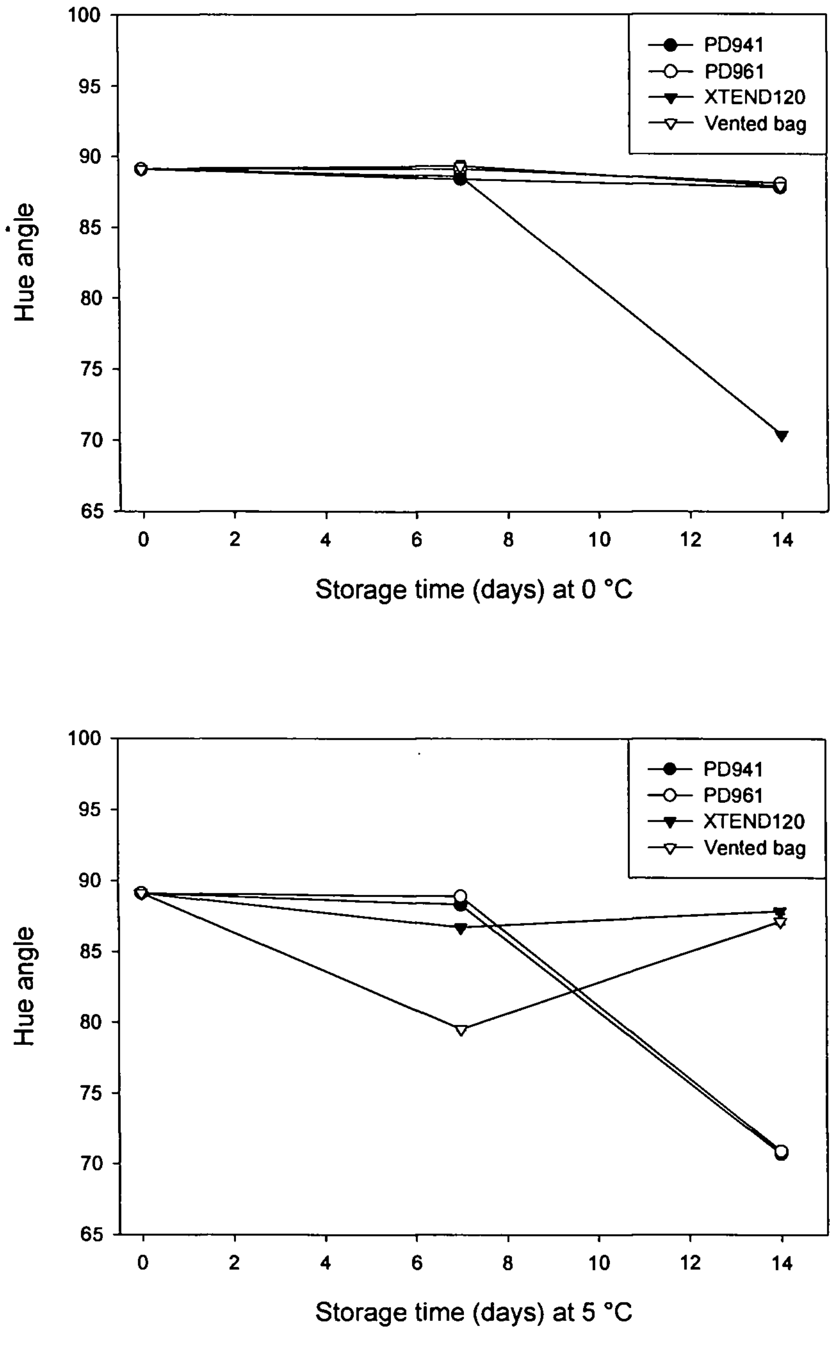


Figure 4.14. Color change (Minolta CR-300 Hue angle) of 'Supersweet Jubilee' sweet corn packed in different film types at 0° or 5°C. Vertical bars represent standard error of the mean (n=20).

and hue angle. Temperature exerted an effect only on hue angle in that lower storage temperature (0 °C) retarded the rate of loss of the hue angle, particularly sweet corn packed in PD941 and PD961.

4.4.2.8 Summary

PD941 film packaged 'Supersweet Jubilee' sweet corn at 0°C also showed some promise as in 'Sugar Buns' cultivar, in terms of creating moderate CO_2 and O_2 concentration inside packages, retaining high sugar content, the lowest weight loss, better general appearance, least mold incidence and corn aroma. According to Saltviet, (1997), the recommended CO_2 and O_2 concentrations which have a beneficial effect on sweet corn was 5 – 10 % for CO_2 and 2 – 4 % for O_2. In this experiment, PD941 provided such atmospheres in CO_2 and O_2 particularly at 0°C. In contrast to the first experiment with the 'Sugar Buns' cultivar, headspace ethanol was present in almost all treatments after 7 days of storage. However, off-odor was not detected by the panel during this time. After 14 days storage, some off-odor was noted by panelists which corresponded to the increased headspace acetaldehyde and ethanol detected during the same period (Table 4.6). As pointed out in the first experiment, results from headspace acetaldehyde and ethanol might present some error in identifying off aroma and off flavor development. Tissue rather than headspace acetaldehyde and ethanol might be a better indicator of off aroma and off flavor.

4.5. CONCLUSIONS

1. PD941 appeared to be the most effective film in retaining quality (sweetness), better general appearance and least weight loss in both sweet corn cultivars tested at 0°C.
2. Sugar concentration decreased over storage time but values were still high after 14 days storage in both cultivars tested. Packages and temperature (0° and 5°C) had no significant effect on sugar concentration in sweet corn (cv. 'Sugar Bun'). However, a significant difference ($p \leq 0.05$) in sugar concentration was found in sweet corn (cv. 'Supersweet Jubilee').
3. 'Supersweet Jubilee' has about twice sugar concentration of 'Sugar Buns'.
4. After 14 days storage, weight loss of sweet corn packed in PD941 and PD961 was low (about 1 – 1.5 %) at both 0°and 5°C whereas that of XTEND120 and controls were two fold (about 2.5 – 3 %).
5. Water condensation was found in all packages of CRYOVAC film (PD941 and PD961) but no decay was observed after 14 days at 0°and 5°C storage. Very little condensation was noticed in XTEND120 packages and this may be an advantage for some type of produce.
6. Strong off odors were detected in XTEND120 packages stored at 0° or 5°C from 'Sugar Buns' sweet corn but scarcely any off odors were detected in 'Supersweet Jubilee'.

7. Very strong off odors were also noticed in vented bags at both temperatures but especially at 5°C and in PD941 packages at 10°C. This was associated with a high incidence of mold in these packages which generated one type of an off odor.
8. High CO_2 can be a strong inhibitor of fungal activity as very few mold incidences occurred in packages with high CO_2. In contrast, very high mold incidence occurred in vented bags (these have atmospheres only slightly different than air) at both temperatures after 14 days storage.

CHAPTER 5

THE EFFECT OF FILM TYPES AND STORAGE TEMPERATURE ON QUALITY OF CAULIFLOWER

Index words: *Brassica oleracea* L. var *Botrytis*, modified atmosphere packaging, storage life, respiration, anaerobic metabolism, weight loss, off-odors, O_2, CO_2

5.1. ABSTRACT

The objective of this experiment was to evaluate the effectiveness of different film types and temperature on storage life and quality of ' Snowball Y-Improved' cauliflower. Three CRYOVAC polyolefin films (PD941, PD955 and PD961) and vented bags were used as packaging materials for cauliflower and then stored at 0° and 5°C. Change in CO_2 and O_2 inside packages were measured throughout the storage period. Quality evaluation was determined initially and at one-week intervals. Cauliflower retained better quality, as judged by subjective evaluation, for a longer time in PD941 package at 0°C than in other treatments. In addition, no off-odor was noted in cauliflower packed in PD941 after 21 days storage at 0°C whereas off-odor was detected in packages of other MAP treatments. Cauliflower packed in PD955, PD961 and control (vented bags) had slight off-odor starting after 7 days storage at 5 °C. Cauliflower packed in PD941 film gave equilibrium 4 – 5% CO_2 and 4% O_2 concentration which corresponded to the recommended rate for beneficial level of cauliflower as proposed by Brecht (1980) and Saltviet (1997). Packaging cauliflower in three CRYOVAC films significantly reduced weight loss compared to control. Subtle changes in color

were not readily detectable by instrumental (Minolta CR-300 Chroma Meter) measurement, and did not correspond with subjective visual evaluation.

5.2. INTRODUCTION

Cauliflower (*Brassica oleracea* L. var *Botrytis)* is an important vegetable in which controlled atmosphere storage (CA) is gaining practical importance as a technique for maintaining quality and extending shelf life (Stoll, 1974). The technique can slow cauliflower deterioration compared to storage in refrigeration alone (Adamicki and Kepka, 1977; Amariutei et al, 1977). Stoll (1974) recommended an atmosphere of 0 - 3% CO_2 and 2 - 3 % O_2 at 0°C and 95 % RH. Under this atmosphere, most cultivars of cauliflower had good quality after 40 days in controlled atmosphere storage. Isenberg (1979) reported storing cauliflower curds up to 56 days in CA with CO_2 and O_2 between 2 and 5 %. Saltviet (1997) also recommended 2 – 3% O_2 and 3 –4 % CO_2 as beneficial CA levels for cauliflower controlled atmosphere storage.

Modified atmosphere packaging (MAP) is a more economical alternative to controlled atmosphere storage using special types of polyethylene films to create particular atmospheres , which can help in maintaining freshness and quality of fresh vegetables. The principle is that MAP creates a lower O_2 concentration and a higher concentration of CO_2 than would normally occur in storage. As a result, the respiration rate of vegetables may be slowed down, pathogen activity reduced and storage life prolonged. Some commodities which can tolerate high CO_2 may also benefit from less storage rots initiated by high CO_2. Reports on MAP of cauliflower are somewhat conflicting. Adamicki and

Kepka (1977) concluded that the quality of cauliflower in polyethylene bags or film wraps was better than those stored in air. However, Jing (1989) reported that atmospheric modification by film wrapping cauliflower did not retard senescence but high humidity effects of reducing water loss retained curd freshness. Recent research from Australia by Tan et al., (1993) indicated MAP using MPCP 54C and MPCP 72C films extended the postharvest life of cauliflower compared to the traditional paper wrapping method. Polyolefin films, particularly PD941 from CRYOVAC Company, have shown some promise for MAP of other vegetables such as broccoli florets (Cabezas and Richardson, 1997), and green beans (Mekwatanakarn and Richardson, 1997). Suitability of these films for MAP of cauliflower in conjunction with refrigerated storage needs to be investigated. The objective of this experiment was to evaluate the effect of different film types and temperatures on storage life and quality of one variety of cauliflower.

5.3. MATERIALS AND METHODS

Fresh cauliflowers (cv. 'Snowball Y-Improved') was harvested with their wrapper leaves from a local farm in Salem and transported to the laboratory and held overnight at 0°C. The heads were selected for uniformity (1,000 – 1,300 g) and for lack of defects. Next, the outer leaves were trimmed off and short jacket leaves cut at 3 / 4 of the curd top according to commercial practice (Romoparada et al., 1989). Cauliflowers were the surface sterilized by dipping in 100 ppm NaOCl ('Chlorox') for about 2 minutes and drained on paper towels. Cauliflowers were then placed into 10" X 9.5" polymeric film bags. Three polymeric films manufactured by CRYOVAC Company were used as packaging materials.

These films were PD941, PD955 and PD961. Vented bags (eight 6-mm holes per bags) were also used as a control. Packages were sealed with heat impulse sealer (Model CD 500, DEA LUN CO LTD) and immediately kept at 0° and 5°C storage temperature. We have included in the design, storage temperature trials 5°C higher than the optimum to represent likely temperature abuse conditions. The experiment was a 4 x 2 factorial (4 packages, 2 temperatures) in a completely randomized design with 8 replications. Each package represented a replicate.

5.3.1. Headspace CO_2 and O_2 Analysis

Eight packages were used for headspace analysis for CO_2 and O_2 using gas chromatography as described in Chapter 3.

5.3.2. Subjective Quality Evaluation

Two replicates per treatment were evaluated initially and at one-week intervals for overall quality. This subjective evaluation consisted of visual inspection and observation of off-odor. Scores from 1 – 5 were used to describe the overall market quality regarding general appearance and the severity of rots, black/brown/yellow spots (Adapted from Tan et al., 1993). Market quality assessment scores were: 5 = Excellent, 4 = Good, 3 = Moderately acceptable, 2 = Poor, 1 = Very poor

5.3.3. Weight Loss

Eight packages were weighed initially and at one week intervals to determine weight loss over time. Weight loss was calculated from the difference between initial and final weight at each time interval and presented as cumulative weight loss percentage.

5.3.4. Objective Color Analysis

The color of cauliflowers was monitored initially and at one week intervals by using a Minolta Chroma Meter CR -300 as described in Chapter III, measuring L*, a*, b* value. Each treatment had 20 observations.

5.3.5. Data Analysis

Data were statistically analyzed using the generalized linear models in STATGRAPHICS Plus statistical software version 3.0. The model consisted of two class independent effects (packaging and storage temperature) arranged as a factorial completely randomized design measured repeatedly over time. Analysis of variance was used to evaluate the effects of independent variables on color measurement. Fisher protected LSD test was used for mean separation when appropriate. A p value ≤ 0.05 was used to establish significance.

5.4. RESULTS AND DISCUSSION

5.4.1. CO_2 and O_2 Concentration within the Package

A similar pattern was found for CO_2 and O_2 concentration at 0° and 5°C storage temperature. CO_2 and O_2 concentration in PD941 MAP were moderate compared to PD955 and PD961 (Fig. 5.1). In PD941, CO_2 concentration equilibrated to about 4% at 0°C and 5% at 5°C. O_2 concentration equilibrated to about 4% at both temperatures. CO_2 and O_2 concentration in PD941 package

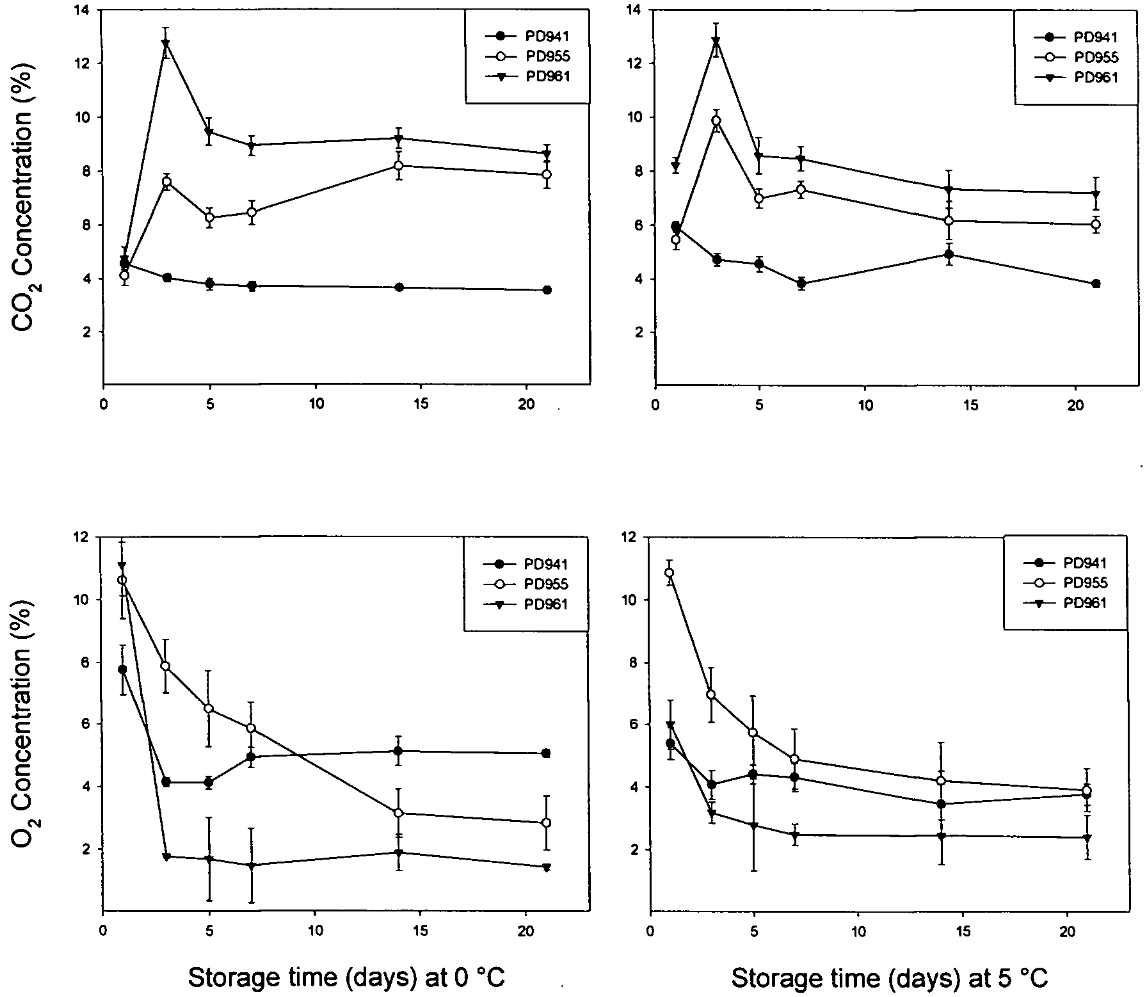


Figure 5.1. Concentrations of CO_2 and O_2 over time in sealed bags of three film types of cauliflower (cv. 'Snowball Y-Improved') stored at 0° and 5°C. Vertical bars represent standard error of the mean (n=8).

corresponded to the recommended rate for beneficial level of cauliflower as proposed by Brecht (1980) and Saltviet (1997). However, CO_2 concentration in PD961 package reached about 12 to 13% at 7 days of storage and equilibrated to 8 – 9%. This high concentration of CO_2 may cause off odor in this package film even at 0°C after 14 days storage.

5.4.2 Subjective Quality Evaluation

Cauliflower retained higher quality, as judged by subjective evaluation, for a longer time in PD941 packages than in other treatments at 0°C (Fig. 5.2). In addition, no off odor was detected in cauliflower packed in PD941 after 21 days storage. At 5 °C, after 21 days, visual appearance of cauliflower packed in PD941 and PD955 were rated more acceptable (3.5 and 3.0) compared to those in PD961 (2.5) and control (vented bags) (1.5). However, cauliflower packed in PD955, PD961 and control had slight off-odor after 7 days storage at 5°C (Table 5.1). These off-odors became stronger after 14 and 21 days storage, particularly in PD961 film, and the off-odor was associated with high CO_2 concentration inside PD961 packages.

5.4.3. Weight Loss

Packaging cauliflower in three types of films significantly reduced weight loss compared to control (vented bags). Only slight differences in weight loss were found in terms of film type and storage temperature (Fig. 5.3). Weight loss of controls at 5 °C (10 %) was three times that at 0 °C (3 %) after 21 days storage.

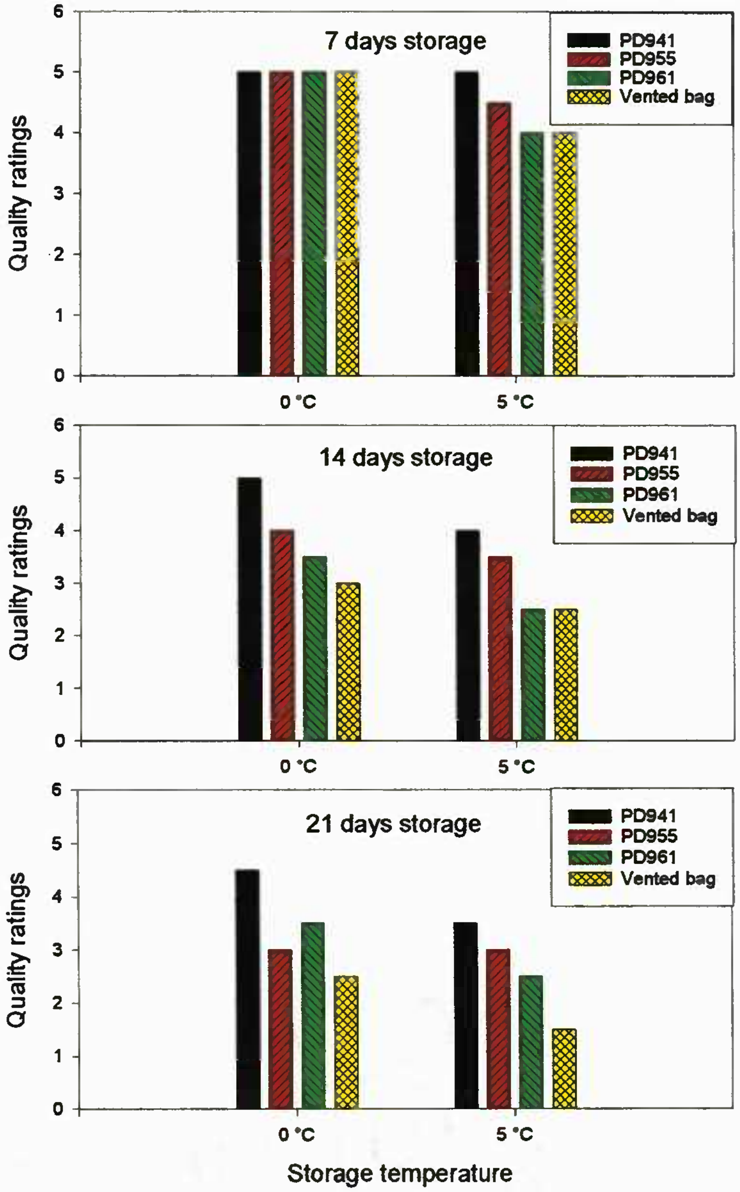
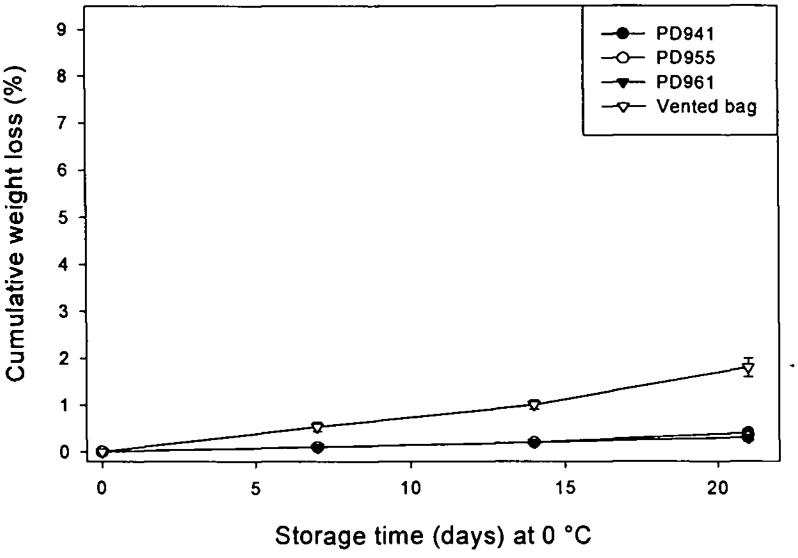


Figure 5.2. Mean quality rating of cauliflower (cv. 'Snowball' Y-Improved) in different film types stored at 0 and 5 ° C. A 1 to 5 scale (1 = poor; 5 = excellent) was used. Samples were evaluated after 7, 14 and 21 days. Each value is the mean of 2 replications.

Table 5.1 Development of undesirable odor during storage of cauliflower at 0 °C and 5 °C in three types of polyolefin films for MAP.

Temperature (°C)	Film	Storage time (days)		
		7	14	21
0	PD941	-	-	-
	PD955	-	-	+
	PD961	-	+	++
	Control (Vented bag)	-	-	+
5	PD941	-	-	+
	PD955	+	+	++
	PD961	+	++	++
	Control (Vented bag)	+	+	++

- = no undesirable odors
+ = light and dissipating readily after aeration
++ = medium and persisting
+++ = strong and persisting



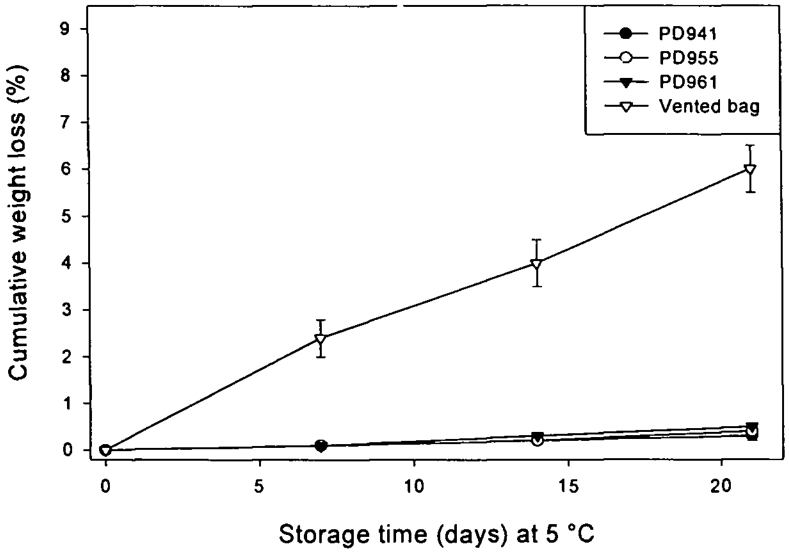


Figure 5.3. Cumulative weight loss percentage of 'Snowball Y Improved' cauliflower affected by film types and storage temperature at 0° or 5°C. Vertical bars represent standard error of the mean (n=8).

5.4.4. Color Analysis

Attempts to measure subtle color changes on an essentially white vegetable have turned out to be an exercise in futility. Table A.1. shows L * a * b * values of cauliflower MAP storage treatments measured by Minolta CR-300 Chroma Meter. While attempts were also made to calculate chroma and hue angle from the L * a * b * data, these transformations were not particularly useful. The human eye can discern visual differences perhaps better than instruments in the case of cauliflower. Of all the measures, changes in L* scale indicated some trend toward darker cauliflower, but there is considerable sample variance which limits its usefulness.

For any measurement of vegetable quality to be useful and practical, results have to ultimately compare to the sensory analysis of consumers. However, in this experiment only subjective evaluation by author was performed. Therefore, conclusive results could not be made unless panel tests are conducted.

5.5. CONCLUSIONS

1. Cauliflower retained higher quality for a longer time in PD941 package at 0°C than in other treatments. No off odor was detected after 21 days storage.
2. Cauliflower packed in PD955, PD961 and vented bags had slight off odor starting 7 days after storage at 5°C.

3. Packaging cauliflower in three CRYOVAC films considerably reduced weight loss compared to control.
4. Cauliflower packed in vented bags started to show some decay of curds 14 days after storage at both 0° and 5°C.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Green Beans

1. Vented bags (control) and unpackaged (control) ‘Strike’ snap beans were only marginally acceptable for 7 days at either 5° or 10°C.
2. Green beans packed in PD941 CRYOVAC MAP at 5°C retained the best overall quality three times longer compared to control. However, a high off-odor score was detected by panelists in PD941 packages at 10°C storage temperature after 21 days storage.
3. Green beans packed in PD941 and PD961 had acceptable appearance quality during 21 days storage at 5°C in terms of mean quality rating, minimum weight loss and color change. However, off-odors developed in PD961 packages after 14 days storage at 5°C and very strong off-odor occurred especially at 10°C after 14 days storage.
4. Green beans packed in PD955 and PD940 were satisfactory for 7 and 14 days at 5°C and they were not acceptable even for 7 days at 10°C.
5. Green beans packed in XTEND120 showed an acceptable general appearance after 21 days in storage. But the highest off-odors score was rated after only 14 days storage which was associated with very high CO_2 concentration (about 25 – 30 %) inside packages. XTEND120 film had less permeability to CO_2 and did not provide beneficial atmospheres for either of the tested cultivars.

6. Weight loss in green beans packed in XTEND120 and vented bags (control) were similar and were three to eight times higher than beans in both CRYOVAC films PD941 and PD961 (less than 1 % moisture loss).
7. Green beans packed in PD941 gave the highest hue angle color compared to other films in both 5° and 10°C which indicated greener bean pods. In addition, no significant change in hue angle over time was found throughout the entire 21 days storage period for PD941 MAP beans at 5°C.
8. The tristimulus a* value and hue angle corresponded more closely to visual observations and were better indicators of green bean color than chroma, L* or b* value.
9. 'Hialeah' and 'Prosperity' were superior followed by 'Bronco', 'Derby' and '91G'.

Sweet Corn

1. PD941 appeared to be the most effective film in retaining quality (sweetness), better general appearance, and least weight loss in both sweet corn cultivars tested at 0 °C.
2. Sugar concentration decreased over storage time but values were still high after 14 days storage in both cultivars tested. Packages and temperature (0 and 5 °C) had no significant effect on sugar concentration in sweet corn (cv. 'Sugar Bun'). However, a significant difference ($p \leq 0.05$) in sugar concentration was found in sweet corn (cv. 'Supersweet Jubilee').
3. 'Supersweet Jubilee' has about twice sugar concentration of 'Sugar Buns'.

4. After 14 days storage, weight loss of sweet corn packed in PD941 and PD961 was low (about 1 – 1.5 %) at both temperatures whereas that of XTEND120 and vented bags was two fold (about 2.5 – 3 %).
5. Water condensation was found in all packages of CRYOVAC film (PD941 and PD961) but no decay was observed after 14 days storage. This lack of decay was likely prevented by high CO_2 in PD941 and PD961 packages. However, very little condensation was noticed in XTEND120 packages.
6. Strong off odors were detected in XTEND120 packages stored at 0° or 5°C from 'Sugar Buns' sweet corn but scarcely any off odors were detected in 'Supersweet Jubilee'.
7. Very strong off odors were also noticed in vented bags at both temperatures but especially at 5°C and in PD941 packages at 10°C. This was associated with high mold incidence.

Cauliflower

1. Cauliflower retained higher quality for a longer time in PD941 package at 0°C than in other treatments. No off odor was detected after 21 days storage.
2. Cauliflower packed in PD955, PD961 and vented bags had slight off odor starting 7 days after storage at 5°C.
3. Packaging cauliflower in three CRYOVAC films significantly reduced weight loss compared to control.
4. Cauliflower packed in vented bags started to show some decay of curds at 14 days storage at both temperatures.

These experiments have shown that MAP using appropriate films can extend fresh market shelf life by at least 50%. Since experiments are often terminated when the controls are exhibiting poor quality, it may be important in future experiments to use enough replicates to find the maximum storage time that saleable quality can be conserved.

Off-odors are a very important determinant of quality of MAP produce even though appearance may be very good. When off-odors occur and what compounds cause off-odors merit further study before the full benefits of MAP can be realized.

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APPENDICES

Figure A.1.

Name.................................

Date.................................

MODIFIED ATMOSPHERE PACKAGING OF GREEN BEANS

QUALITY PANEL:

Please evaluate quality by comparing the coded samples placed before you. For example, suppose one quality factor is general appearance.

```
                D                C               A, B
Poor...............I.................I.................I...............Excellent
```

The general appearance of C is better than D. The general appearance of A and B are the same and better than C and D.

Please make a mark of the quality scale line and sample number

1. GENERAL APPEARANCE

Poor...............................I................................Excellent

2. CRISPNESS

Soft.................................I..................................Crisp

3. OFF-ODOR

None...............................I................................Strong

Figure A.2.

Name.................................

Date..................................

MODIFIED ATMOSPHERE PACKAGING OF SWEET CORN

QUALITY PANEL:

Please evaluate quality by comparing the coded samples placed before you. For example, suppose one quality factor is general appearance.

```
                 A                B            C, D
Poor...............I..................I..................I.................Excellent
```

The general appearance of B is better than A. The general appearance of C and D are the same and better than A and B.

Please make a mark of the quality scale line and sample number

1. GENERAL APPEARANCE

Poor..................................I...................................Excellent

2. MOLD

None..................................I...................................Severe

3. AROMA (NORMAL CORN)

Poor..................................I...................................Very Strong

4. OFF-AROMA

None..................................I...................................Strong

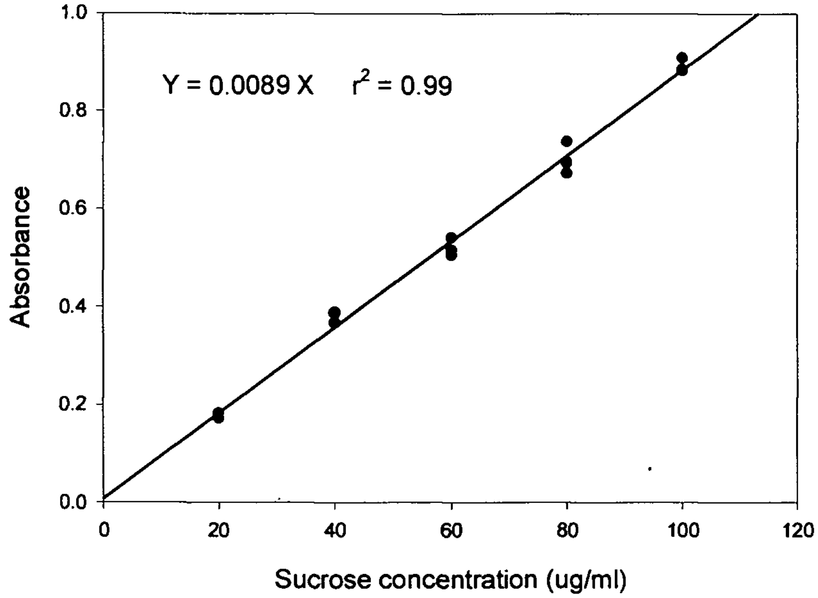

Figure A.3. A standard curve (Phenol-sulfuric method) used for sugar determinations.

Table A.1. Minolta Chromameter L*a*b* values for 'Snowball Y-Improved' cauliflower in film types after 7, 14 and 21 days at 0°C or 5°C storage.

Films/Temp	L*value			a*value			b*value		
	Days			Days			Days		
	7	14	21	7	14	21	7	14	21
0 °C									
PD941	84.5	80.7	80.7	-2.0	-1.8	-1.3	20.6	21.0	19.3
PD955	79.5	82.0	78.3	-1.5	-1.1	-2.3	18.8	18.4	22.1
PD961	83.7	81.2	79.3	-1.1	-1.5	-2.5	17.3	19.4	25.1
Control	83.5	78.3	77.4	-1.5	-1.3	-1.0	20.8	23.5	24.7
5 °C									
PD941	80.1	78.5	78.2	-1.2	-1.5	-2.1	19.2	21.3	23.0
PD955	85.3	81.7	78.4	-2.1	-0.9	-2.4	21.4	19.3	23.9
PD961	81.0	82.6	79.5	-1.7	-1.8	-1.5	20.4	18.9	19.7
Control	83.3	81.5	77.0	-1.6	-0.8	-1.1	20.9	19.4	20.2

- Initial L*, a*, b* values were 82.2, -1.1, and 20.0 respectively

Table A.2. Address of the CRYOVAC COMPANY

CRYOVAC COMPANY
W.R. Grace & CO Cryovac Division
Duncan, SC 29334
USA

Table A.3. ANOVA of sensory evaluation of general appearance of green beans (cv. 'Jade') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	10.4307	7.19	0.0002
Temperature	1	27.4032	18.89	0.0000
Package * Temperature	3	2.71107	1.87	0.1405
Replication	14	9.21055	6.35	0.0000
Error	98	1.451		
Total	119			

Significant at $P \leq 0.05$

Table A.4. ANOVA of sensory evaluation of crispness of green beans (cv. 'Jade') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	16.6418	14.03	0.0000
Temperature	1	64.9651	54.77	0.0000
Package * Temperature	3	1.50938	1.27	0.2886
Replication	14	5.32657	4.49	0.0000
Error	98	1.18621		
Total	119			

Significant at $P \leq 0.05$

Table A.5. ANOVA of sensory evaluation of off – odors of green beans (cv. 'Jade') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	75.1982	28.07	0.0000
Temperature	1	169.297	63.19	0.0000
Package * Temperature	3	38.8546	14.50	0.0000
Replication	14	4.59869	1.72	0.0705
Error	98	2.67935		
Total	119			

Significant at $P \leq 0.05$

Table A.6. ANOVA of sensory evaluation of general appearance of green beans (cv. 'Jade') after 21 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	10.746	7.62	0.0001
Temperature	1	0.0200893	0.01	0.9053
Package * Temperature	3	4.4039	3.12	0.0298
Replication	14	5.97561	4.24	0.0000
Error	98	1.41073		
Total	119			

Significant at $P \leq 0.05$

Table A.7. ANOVA of sensory evaluation of crispness of green beans (cv. 'Jade') after 21 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	10.5339	5.62	0.0014
Temperature	1	11.9604	6.38	0.0132
Package * Temperature	3	5.1325	2.74	0.0479
Replication	14	7.56393	4.04	0.0000
Error	98	1.87363		
Total	119			

Significant at $P \leq 0.05$

Table A.8. ANOVA of sensory evaluation of off – odors of green beans (cv. 'Jade') after 21 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	60.5101	27.51	0.0000
Temperature	1	116.647	53.03	0.0000
Package * Temperature	3	96.5379	43.89	0.0000
Replication	14	3.32792	1.51	0.1278
Error	98	2.19972		
Total	119			

Significant at $P \leq 0.05$

Table A.9. ANOVA of sensory evaluation of general appearance of sweet corn (cv. 'Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	101.421	29.20	0.0000
Temperature	1	102.01	29.37	0.0000
Package * Temperature	3	24.8755	7.16	0.0002
Replication	14	2.53112	0.73	0.7196
Error	98	3.47334		
Total	119			

Significant at $P \leq 0.05$

Table A.10. ANOVA of sensory evaluation of mold incidence of sweet corn (cv. "Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	132.589	67.13	0.0000
Temperature	1	98.6117	49.93	0.0000
Package * Temperature	3	28.1451	14.25	0.0000
Replication	14	5.58068	2.83	0.0027
Error	98	1.97516		
Total	119			

Significant at $P \leq 0.05$

Table A.11. ANOVA of sensory evaluation of corn aroma of sweet corn (cv. 'Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	58.2595	12.31	0.0000
Temperature	1	0.0188462	0.00	0.9498
Package * Temperature	3	9.945	2.10	0.1063
Replication	14	21.9822	4.64	0.0000
Error	98	4.73462		
Total	119			

Significant at $P \leq 0.05$

Table A.12. ANOVA of sensory evaluation of off - flavors of sweet corn (cv. 'Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	30.1327	8.17	0.001
Temperature	1	34.0409	9.23	0.0032
Package * Temperature	3	14.5329	3.94	0.0111
Replication	14	12.9127	3.50	0.0003
Error	98	3.68927		
Total	119			

Significant at P ≤ 0.05

Table A.13. ANOVA of soluble carbohydrate of sweet corn (cv. 'Sugar Buns') after 7 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	42.1781	3.52	0.0303
Temperature	1	246.184	20.55	0.0001
Package * Temperature	3	84.8828	7.09	0.0014
Error	24	11.9783		
Total	31			

Significant at P ≤ 0.05

Table A.14. ANOVA of soluble carbohydrate of sweet corn (cv. 'Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	5.61547	0.45	0.7163
Temperature	1	1.54821	0.13	0.7264
Package * Temperature	3	5.68232	0.46	0.7127
Error	24	12.3477		
Total	31			

Significant at P ≤ 0.05

Table A.15. ANOVA of soluble solids of sweet corn (cv. 'Sugar Buns') after 7 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	1.0	0.61	0.6165
Temperature	1	1.125	0.68	0.4165
Package * Temperature	3	5.45833	3.32	0.0369
Error	24	1.64583		
Total	31			

Significant at $P \leq 0.05$

Table A.16. ANOVA of soluble solids of sweet corn (cv. 'Sugar Buns') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	1.78125	1.05	0.3890
Temperature	1	0.03125	0.02	0.8932
Package * Temperature	3	68.6146	40.41	0.0000
Error	24	1.69792		
Total	31			

Significant at $P \leq 0.05$

Table A.17. ANOVA of sensory evaluation of general appearance of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	104.896	34.89	0.000
Temperature	1	57.4456	19.11	0.000
Package * Temperature	3	14.0677	4.68	0.0049
Replication	14	11.365	3.78	0.0004
Error	98	3.0067		
Total	119			

Significant at $P \leq 0.05$

Table A.18. ANOVA of sensory evaluation of mold incidence of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	152.51	53.07	0.0000
Temperature	1	10.78	3.75	0.0568
Package * Temperature	3	8.25515	2.87	0.0423
Replication	14	11.4453	3.98	0.0002
Error	98	2.87359		
Total	119			

Significant at $P \leq 0.05$

Table A.19. ANOVA of sensory evaluation of corn aroma of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	96.2473	19.42	0.0000
Temperature	1	17.766	3.58	0.0625
Package * Temperature	3	4.34319	0.88	0.4577
Replication	14	20.3108	4.10	0.0002
Error	98	4.95657		
Total	119			

Significant at $P \leq 0.05$

Table A.20. ANOVA of sensory evaluation of off - flavors of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	10.6556	1.77	0.1615
Temperature	1	26.7301	4.43	0.0389
Package * Temperature	3	2.54799	0.42	0.7375
Replication	14	19.8573	3.29	0.0015
Error	98	6.03261		
Total	119			

Significant at $P \leq 0.05$

Table A.21. ANOVA of soluble carbohydrate of sweet corn (cv. 'Supersweet Jubilee') after 7 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	29.7796	3.63	0.0272
Temperature	1	41.8572	5.10	0.0332
Package * Temperature	3	12.0093	1.46	0.2492
Error	24	8.20052		
Total	31			

Significant at $P \leq 0.05$

Table A.22. ANOVA of soluble carbohydrate of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	530.015	38.96	0.0000
Temperature	1	1435.1	105.50	0.0000
Package * Temperature	3	1.30654	0.10	0.9615
Error	24	13.6026		
Total	31			

Significant at $P \leq 0.05$

Table A.23. ANOVA of soluble solids of sweet corn (cv. 'Supersweet Jubilee') after 7 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	0.135417	0.25	0.7098
Temperature	1	2.18125	4.07	0.0612
Package * Temperature	3	0.510417	0.95	0.239
Error	24	0.535417		
Total	31			

Significant at $P \leq 0.05$

Table A.24. ANOVA of soluble solids of sweet corn (cv. 'Supersweet Jubilee') after 14 days storage.

Source	df	Mean Square	F-Ratio	P-Value
Package	3	0.447917	1.43	0.2271
Temperature	1	1.125	3.58	0.0708
Package * Temperature	3	0.125	0.40	0.6504
Error	24	0.313542		
Total	31			

Significant at $P \leq 0.05$