EVALUATION AND CHEMICAL CHARACTERIZATION OF POSTHARVEST DEGREENED BELL PEPPERS (*CAPSICUM ANNUUM*)

by

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Under the Direction of Robert Shewfelt

ABSTRACT

Bell peppers are used as foods or flavorings and are consumed as green or colored fruits. During pepper season many green bells are sold at or below cost or rot in the field rather than being sold. Colored bells command a higher market price and provide an alternate channel for the pepper crop. We investigated the potential of an on-farm degreening process for bell peppers. Ethylene treatments did not assist the degreening process. Holding sufficiently mature peppers at 20°C/90% relative humidity (RH) provided significant degreening. The storage life of the degreened peppers was 7 to 14 days. With precautions against decay, this should allow sufficient time for distribution. Pepper maturation results in flavor and nutritional quality differences. These characteristics of degreened peppers were studied, the expected changes occurred. Ascorbic acid, dry matter, and total soluble solids increased with maturation; titratable acidity and pH decreased. Volatile levels also decreased with maturation.

INDEX WORDS: Bell peppers, Capsicum annuum, maturation, degreening, Postharvest

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DEDICATION

For my family

In loving memory of my grandparents Edith Pease and Raymond Reagan

This work is lovingly dedicated to my husband

You are the love of my life

Thank you

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

History

Peppers belong to the nightshade plant family, Solanaceae, along with tomatoes, potatoes, tobacco, and eggplant. Peppers are members of the genus *Capsicum*, from the Greek *kapto* meaning “to bite”. Currently the genus contains twenty-seven species, including the mild bell and the blazingly hot Serrano (DeWitt and Bosland 1993). Those twenty-seven species contain approximately 1600 varieties or cultivars. Most are not commonly grown or used, with only around two hundred under commercial cultivation. The majority of these varieties, including the Bell pepper, belong to a single species, *Capsicum annuum* (Naj 1992). Black pepper, *Piper* nigrum, is unrelated to the capsicums.

Over one hundred varieties of bell peppers exist, of which many have been bred for specific traits, such as color, pungency, disease resistance, and availability (DeWitt and Bosland 1993). Among these varieties there exists a large amount of diversity. For example, North American bell peppers are blocky and around 10 cm long and wide, normally with a flat bottom. On the other hand, European growers cultivate an elongated bell pepper, La Muyo, which has a non-flat end. Additionally, North American peppers tend to be four-celled while the La Muyo peppers tend to be two or three celled. Another source of variation is color ranging from immature colors of green, purple, yellow, or white and mature colors of red, orange, yellow, green, or brown. And, although bell peppers are often described as sweet or non-pungent, breeding has developed pungent cultivars, such as ‘Mexibell’ (Bosland and Votava 2000). Although these pungent bell varieties are only slightly so ranging from 100 to 600 Scoville Heat Units (DeWitt and Bosland 1993).

Pepper plants, native to South America, are perennial subshrubs that in more temperate climates are grown as annuals. Bell pepper plants are subcompact or almost prostrate, ranging from one to two and a half feet tall. Pollination generally occurs via wind or insects, peppers can self-pollinate or cross-pollinate. White flowers develop into pods that are pendant, three- or four-lobed, and blocky. Bell pepper pods are technically berries, but horticulturists call them fruits, and consumers consider them vegetables (DeWitt and Bosland 1993). For cultivation, bell peppers require similar conditions to those of tomatoes and eggplants, preferably a long frost-free growing season in a sandy loam soil with good drainage (DeWitt and Bosland 1993; Bosland and Votava 2000). Whether the peppers will be harvested as immature or mature peppers determines the growing period, which generally ranges from eighty to one hundred days. A single bell pepper plant can produce between ten and twenty pods in that time (DeWitt and Bosland 1993).

The wild *chiltepin* (*Capsicum annuum* var. *aviculare*) is believed to be the ancestor of the *Capsicum annuum* varieties of today. *Chiltepin* is currently found from southern Arizona to South America, but the original cultivation of *annuums* was concentrated in Mexico and Central America. The domestication date of peppers is somewhat of a controversy. Peppers may have been domesticated as early as 7500 B.C. or as late as 2500 B.C., but most likely they were under cultivation by at least 3300 B.C., according to experts. Due to the ease of cross-pollination between peppers, hundreds possibly thousands of varieties of peppers have been developed since that early date of domestication (DeWitt and Bosland 1993).

Economic Importance and Uses

Capsicum annuum is the world's most extensively cultivated species in both commercial and home growing situations (DeWitt and Bosland 1993). In 1992, the average world total production of *Capsicums* was 9,638,000 Mt (Andrews 1995). Mexico grows the most diverse crop of peppers, but of the 53,000 tons of peppers annually produced there only about 5% are Bells, most of which are exported to the United States (Naj 1992; Andrews 1995). On the other hand, of the 687,000 tons of peppers produced annually in the United States 60% are Bells (Naj 1992). Canada also produces mostly Bells with 82% of its pepper crop being of that type (Andrews 1995).

Worldwide, peppers are gaining in economic importance. For example, although the United States produces approximately 686,570 tons of peppers every year, demand results in the importation of an additional 5 to 6 tons, primarily from Mexico, Spain, Portugal, North Africa, and Asia (Andrews 1995). The most extensively cultivated species in the world is *Capsicum annuum* in all its various forms. It is the most commonly grown species in Hungary, India, Mexico, China, Korea, and the East Indies (DeWitt and Bosland 1993). The most economically important type is probably the Bell type, in part because it has the most cultivars (Bosland and Votava 2000). The Bells are the most commonly grown peppers in the United States, they make up approximately 64.7% of the peppers grown there (DeWitt and Bosland 1993; Bosland and Votava 2000).

Bell peppers fall into a special category of approximately 30 fruits that are commonly used as vegetables. Such fruits are generally used in either their immature or ripened states, however peppers are consumed in both states (Whitfield and Last 1991). As a fresh vegetable bell peppers are valued for their deep red or green color, crisp texture, delicate aroma, and lack of pungency (Govindarajan 1986; Govindarajan and Sathyanarayana 1991). According to Yuen and Hoffman 50% of Australian consumers purchase fresh peppers for use in salads; 49% purchased peppers for cooking, the remaining 1% purchased them for other purposes, such as canning or pickling (Yuen and Hoffman 1993). Ripe peppers are consumed fresh as vegetables, or dried and ground (paprika), or in the form of oleoresin, or a food additive. They can also be canned, brined and pickled, frozen, or fermented (Govindarajan 1986; Bosland and Votava 2000; Yamauchi, Aizawa et al. 2001). When sweet red bell peppers are dried and ground, the powder is known as paprika and is often used as a spice or to impart color to other foods (Nagle, Villalon et al. 1979; Matsui, Shibata et al. 1997).

Nutritional Quality

Many previously undervalued nutrients are now becoming the object of much scrutiny due to their antioxidant properties, which may be linked to the prevention of certain cancers, heart disease, and atherosclerosis. Vitamin C (ascorbic acid), carotenoids, and vitamin E are among those chemicals (Simonne, Simonne et al. 1997). Bell peppers are considered an extremely nutritious food and the US Food and Drug Administration (USFDA) describes them as free of fat, saturated fat, and cholesterol as well as being low in sodium and calories and high in vitamins A and C. They are also an excellent source of many vitamins, minerals, flavonoids, and phytochemicals; including vitamin C, provitamin A, vitamin E, vitamin P (citrin), thiamine (B1), riboflavin (B2), and niacin (B3) (Simonne, Simonne et al. 1997; Bosland and Votava 2000). These nutritional components have been shown to appear in a wide range of concentrations in peppers, such variation is believed to be due to differences in cultivation practices, cultivars, maturity levels, climate, postharvest handling, and analytical methods used (Bosland and Votava 2000). Although these variations have been shown repeatedly, the USDA Handbook currently lists nutritional information obtained from only seven samples (Simonne, Simonne et al. 1997).

Bell peppers contain a moderate amount of provitamin A, which generally increases during pepper ripening, except in the case of certain yellow varieties. However, as with other nutritional components, provitamin A content appears to be cultivar dependant; black, purple, and white pepper cultivars have a lower provitamin A content than that of green, red, orange, and brown cultivars (Simonne, Simonne et al. 1997).

Vitamin C (ascorbic acid) is a required component of the human diet and is primarily fulfilled through the consumption of fruits and vegetables (Kays 1997). Bell peppers are one of the richest vegetable sources of vitamin C (Yuen and Hoffman 1993; Bosland and Votava 2000). They provide 100 – 200% RDA for vitamin C per 100 g of edible portion (Simonne, Simonne et al. 1997). Generally, vitamin C content increases as the peppers ripen, however this is cultivar dependent and in some cultivars the vitamin C content stays the same or decreases. Overall vitamin C content is also affected by cultivar, with black, purple, and white peppers having lower ascorbic acid levels than green, yellow, red, brown, and orange peppers (Simonne, Simonne et al. 1997; Bosland and Votava 2000). Cultivation differences have also been shown to affect the vitamin C content of bell peppers (Simonne, Simonne et al. 1997). Differences in vitamin C content among cultivars is due to variations in the moisture content of the fruits, since vitamin C is a water-soluble compound (Bosland and Votava 2000).

Vitamin E (alpha-tocopherol) is one of the vitamins at the forefront of the current surge of antioxidant studies. Bell peppers are a very good source of this vitamin. Based on dry weight composition, 100 g of red bell pepper fruit would contain more than 100% of the USRDA (8-10 mg) of alpha-tocopherol for an average adult. Vitamin E levels are also subject to wide variations, and the concentrations can range from 3.7 to 236 mg per 100 g dry weight. It is believed that alpha-tocopherol levels are dependent on the lipid content of the fruit (Bosland and Votava 2000).

Color

The color of bell peppers, particularly of ripe bell peppers, was an obvious attractant to early man while gathering food (Govindarajan 1986). Even today color plays a major role in attracting consumers. Fruit color is due to the presence of various plant color pigments. Some of these pigments, including anthocyanins and carotenoids, are believed to have important health benefits (Knee 2002). In bell peppers, these pigments are contained in either chloroplasts or chromoplasts in the outer pericarp tissues of the fruits (Kirk and Juniper 1966; Govindarajan 1985). The pigment content of different pepper cultivars has been shown to be quite varied (Nagle, Villalon et al. 1979).

The numerous shades of peppers are due to the variations in carotenoid pigments produced by bell peppers as they ripen. More than 30 different pigments, including the green pigments chlorophylls a and b; the yellow-orange pigments lutein, zeaxanthin, violaxanthin, antheraxanthin, beta-cryptoxanthin and beta-carotene; and the red pigments capsanthin, capsorubin and cryptocapsin have been identified in bell pepper fruits (Bosland and Votava 2000). The amount of pigments produced also varies based on cultivar, maturity stage and growing conditions (Camara and Moneger 1978; Bosland and Votava 2000).

The various chlorophylls contained in the chloroplasts are responsible for the color of green bell peppers (Govindarajan 1986). The color change that occurs with the ripening of bell pepper fruits is due to a change in pigment content. This change is due mainly to the conversion of chloroplasts to chromoplasts during the ripening process and the subsequent changes in pigment synthesis (Kirk and Juniper 1966; Camara and Moneger 1978; Govindarajan 1986; Matsui, Shibata et al. 1997). During the conversion process chlorophyll begins to disappear and the synthesis of carotenoids increases (Camara and Moneger 1978). The resulting carotenoid content of the chromoplasts is responsible for the color of ripe bell peppers (Kirk and Juniper 1966; Govindarajan 1986).

Green bell peppers contain many pigments including lutein, beta-carotene, violaxanthin, neoxanthin, phytonene, phytofluene, alpha-carotene, and zeta-carotene. The major pigments are lutein, making up 40% of the composition; beta-carotene, which constitutes 13-20% of the pigment composition; violaxanthin; and neoxanthin. The other pigments are considered minor pigments. Green bell peppers do not contain capsanthin, capsorubin, and capsolutein (Curl 1964; Govindarajan 1985).

The various shades of red seen in ripe bell peppers are derived from between 37 and 54 different components, mainly carotenoids and xanthophylls such as capsanthin, capsorubin, cryptoxanthin, violaxanthin, cryptocapsin, and zeaxanthin (Nagle, Villalon et al. 1979; Govindarajan 1985). Capsanthin makes up between 30 and 60% of the total pigments present in ripe red bell peppers, beta-carotene makes up approximately 10%, cryptoxanthin accounts for about 6%, capsorubin makes up between 6 and 18%, cryptocapsin makes up about 4%, and the rest is filled by various other carotenoids present in amounts of 2% or less (Curl 1962; Nagle, Villalon et al. 1979; Govindarajan 1985; Yamauchi, Aizawa et al. 2001). During the maturation and ripening process of red bell peppers, chlorophylls a and b disappear followed by the increased synthesis of various carotenoids (Curl 1964; Camara and Moneger 1978; Govindarajan 1985). During the early stages of ripening the concentration of lutein decreases rapidly and eventually completely disappears and is replaced by capsolutein (Curl 1964; Davies, Matthews et al. 1970; Camara and Moneger 1978; Govindarajan 1985). In addition to changing the carotenoid content, ripening also increases the total carotenoid content by a factor of 100 (Curl 1964; Davies, Matthews et al. 1970; Govindarajan 1985). Differences in the amounts of pigments in the tissues is dependant on such factors as cultivar, maturity level and growing conditions (Nagle, Villalon et al. 1979).

Ripe yellow bell pepper fruits contain lutein, violaxanthin, and neoxanthin. However, none of the ketocarotenoids present in the red-ripe bell pepper fruits, such as capsanthin and capsorubin, are present in the yellow cultivars. During the maturation process of yellow-ripe cultivars, chlorophylls a and b disappear as rapidly as they do in red cultivars. Additionally, the increase in carotenoids seen in yellow-ripe cultivars is only a 5-fold increase (Govindarajan 1985).

Flavor

The flavor characteristics of foods, particularly fruits, are a primary consideration in determining which foods consumers will select for consumption (Kays 1997; Knee 2002). Flavor perception is generally accepted to be a complex mix of both taste and odor sensations stimulated by the varied arrays of chemicals present in each product (Kays 1997; Bosland and Votava 2000; Knee 2002). These unique combinations of chemically stimulated oral and nasal sensations create a flavor profile unique to each product.

The taste portion of flavor is perceived by the taste buds in the mouth and is believed to be limited to the sensations of sweetness, sourness, saltiness, bitterness, and perhaps umami (Kays 1997). The sugars and organic acids that produce the sweet and sour sensations respectively are the primary compounds detected by taste in fruits. The overall taste sensation associated with the flavor of the fruit is dependent upon the composition of individual sugars and acids and the balance between them (Knee 2002). This composition and balance can be affected by numerous factors, including cultivar, pod type, and maturity level (Bosland and Votava 2000). Other compounds contribute other aspects of taste to the overall flavor sensation, including bitter and salty flavors (Knee 2002). However, the heat present in some capsicum species is not actually an aspect of the flavor or even the taste sensation of these fruits. The heat sensation is actually the stimulation of trigeminal cells, the pain receptors of the mouth, nose, and stomach (Bosland and Votava 2000).

The aroma portion of the complex flavor sensation is perceived by the olfactory receptors of the nose. These receptors in the olfactory epithelium have the potential to perceive up to 10,000 distinct odors, which provides for an almost unlimited potential for flavor diversity. Therefore, volatile compounds are often very significant in determining the overall flavor of a product, providing the subtle aspects of flavor (Kays 1997; Knee 2002). This is particularly true of bell peppers, which are mostly used for their complex flavors (Bosland and Votava 2000). Aroma is particularly important to the quality and overall flavor of green and colored bell peppers (Govindarajan 1986).

Volatile compounds play an important role in the aroma portion of the flavor of fruits. Uncooked bell peppers have been shown to contain 23 volatile compounds, while cooked bell peppers have been shown to contain 39 volatile compounds (Whitfield and Last 1991). The major volatile compounds found in bell peppers include 2-methoxy-3-isobutylpyrazine, trans-beta-ocimene, limonene, linalool, nona-trans,cis-2,6-dienal, deca-trans,trans-2,4-dienal, and hex-cis-3-enol (Buttery, Seifert et al. 1969). 2-Methoxy-3-isobutylpyrazine is generally believed to be the character impact compound of green bell peppers; Buttery et al. (1969) determined that 70 to 80% of untrained panelists would indicate that this compound had an odor similar to that of fresh green bell peppers. This compound also has an extremely low odor detection threshold of 2 parts per trillion. Other important odor compounds with low odor detection thresholds present in bell peppers are nona-trans,cis-2,6-dienal with a threshold of 0.01 ppb and deca-trans,trans-2,4-dienal with a threshold of 0.07 ppb (Buttery, Seifert et al. 1969; Luning, de Rijk et al. 1994; Bosland and Votava 2000).

Most of the volatile compounds, particularly those with green-related odor notes, decrease or disappear during the maturation and ripening of bell peppers. The levels of (E)-2-hexenal and (E)-2-hexenol are the only volatile compounds known to increase during the ripening process, these compounds have almond, fruity, sweet odors (Luning, de Rijk et al. 1994).

Respiration and Gas Exchange

The respiration rate of a product is often a very good indicator of the perishability of a fruit product, it has been demonstrated that fruits with higher respiration rates have shorter postharvest lives (Knee 2002). Therefore understanding what affects respiration rates and rates of gas exchange in fruits can lead to new ways to extend the postharvest lives of fruits. Studies of respiration and gas exchange focus most closely on three gases; these are carbon dioxide (CO2), oxygen (O2), and ethylene. Research in this area will benefit both consumers and the industry by helping producers and transporters to understand how they can increase the postharvest life of fresh fruits by reducing respiration rates without adversely affecting the quality of the fruit. Recently food companies and researchers have become interested in coatings, both edible and inedible, that would enhance the storage life of fresh fruits. It is important to understand the permeability factors of these respiratory gases in order to understand the effects of such coatings.

The cuticle of the pepper fruit has been shown to have different permeabilities to oxygen and carbon dioxide. Removal of the cuticle from the fruit eliminates this difference. This upholds the theory that peppers, and some other solanaceous fruits, conduct the majority of their gas exchange through the calyx (Banks and Nicholson 2000). Because of the significance of the fruit cuticle to the exchange of respiratory gases, wounding of the fruit can have a dramatic impact on respiration rate and thus the overall postharvest life of the fruit. Wounded areas show a permeability to both oxygen and carbon dioxide that is approximately 260 times the original value of the intact surface for oxygen and 26 times higher for carbon dioxide (Banks and Nicholson 2000).

Ethylene Response and Non-Climacteric Ripening

While the examination of carbon dioxide and oxygen as respiratory gases is readily understandable, the reasons for examining ethylene are not as clear cut. Ethylene, an unsaturated hydrocarbon gas and a natural product of ripening fruits, is known to stimulate respiration in many types of plant tissues, and is believed to trigger ripening in climacteric fruits (Kays 1997).

Fruits are often classified as either climacteric or nonclimacteric; however this classification is often misused or misunderstood. It is often stated that climacteric fruits will ripen off the plant, while nonclimacteric fruits will not (Knee 2002). However, as this research and others like it have shown some nonclimacteric fruits, such as bell peppers, will in fact ripen off the plant, or postharvest. Therefore it is best to use the botanical or horticultural definition of climacteric. According to this definition, climacteric fruits are those that exhibit a dramatic increase in respiration at the end of the maturation stage of fruit development, known as the respiratory climacteric. This upsurge indicates the transition between maturation and senescence of the fruit. In climacteric fruits the internal concentration and synthesis of ethylene increases concurrently with the respiration increase. Current theory is that ethylene is the triggering mechanism for inducing the respiratory climacteric, whether produced internally or introduced externally. When climacteric fruits are exposed to an external source of ethylene it results in an increase in the internal synthesis of ethylene within the fruit tissues and a decrease in the length of the preclimacteric period without an effect on the rate of respiration at the respiratory climacteric. Removal of the external ethylene after ripening is initiated does not affect the following respiratory rate or pattern. Therefore introduction of external ethylene can be used to trigger the respiratory climacteric and the ripening response, allowing for earlier ripening of the fruit. Nonclimacteric fruits do not exhibit a respiratory climacteric; rather they exhibit a slow decline of respiration during the end of maturation and throughout senescence. Introduced ethylene also stimulates respiration in nonclimacteric fruits, but when the external ethylene is removed the respiratory rate and pattern returns to normal (Kays 1997).

Ethylene is a natural product of plants and fruits in particular. Bell peppers exhibit a nonclimacteric pattern of ethylene production during ripening and color development, although other members (tomato) of the Solanaceae family are climacteric (Saltveit 1977; Cantwell 2000). Bell peppers produce very small levels of ethylene, in the amounts of 0.1 - 1.2 µl/kg hr at 10C-20C (50-68F) (Cantwell 2000). These production levels remain low throughout the development and maturation of bell pepper fruits (Meir, Rosenberger et al. 1995). Although the concentration of ethylene in bell pepper fruits nearly doubles during color development, it is still a small increase compared to the dramatic increase in ethylene concentration seen in climacteric fruits (Saltveit 1977). Additionally, propylene treatment (Meir, Rosenberger et al. 1995) and exposure to ethylene do not accelerate the ripening process or the subsequent color change that normally occurs in bell peppers (Saltveit 1977; Hoyer 1996; Cantwell 2000).

Storage Conditions and Quality

Temperature reduction is a generally accepted practice for the extension of the shelf life of fruits and vegetables. It is one of the most effective tools for this purpose, not only does it extend the quality life of the produce, but it also provides a strong defense against postharvest pathogens and diseases (Bosland and Votava 2000). Low temperatures extend the postharvest life of fruits and vegetables by slowing the metabolic rate of the various products (Lurie 2002). Respiration rates generally decrease with temperature decreases (Ryall and Lipton 1979). Refrigeration also extends shelf life by decreasing water loss (Bosland and Votava 2000).

Bell pepper fruits have a relatively low storage quality due to their sensitivity to low temperatures, rot development, and water loss (Meir, Rosenberger et al. 1995). However at temperatures between 7°C and 13°C, the storage life of bell peppers is relatively long (Ryall and Lipton 1979; Yuen and Hoffman 1993; Meir, Rosenberger et al. 1995; Bosland and Votava 2000; Cantwell 2000). The optimum temperature within this range is between 8°C and 9°C (Ryall and Lipton 1979). However, the best conditions for storage can vary with cultivars and cultivation practices (Govindarajan 1985). It is important to maintain the appropriate range of temperature continuously after harvest, throughout both storage and transportation, in order to maintain high quality fruit (Yuen and Hoffman 1993). Refrigeration does not completely prevent the development of decay, mostly due to *Botrytis cinerea* and *Alternaria alternate* infection and growth, but it does slow it down (Meir, Rosenberger et al. 1995). Temperatures above this range promote the spread of postharvest diseases, such a bacterial soft rot, as well as increasing the rate water loss and incidence of shriveling (Hardenburg, Watada et al. 1986; Cantwell 2000). Temperatures below this range will cause chilling injury in mature green bell peppers; ripe colored bell peppers are not susceptible to this type of disorder (Ryall and Lipton 1979; Meir, Rosenberger et al. 1995; Cantwell 2000).

Chilling and Freezing Injury

Peppers are susceptible to chilling injury, the injury which occurs to tropical or subtropical species in the temperature range of 0-20°C (Ryall and Lipton 1979; Kays 1997; Bosland and Votava 2000). In peppers, this injury takes place when they are stored in temperatures ranging from 0-12°C, although mostly when stored at temperatures under 7°C (Hardenburg, Watada et al. 1986; Paull 1990). Chilling injury reduces the storage life and quality of bell peppers (Paull 1990). It can be difficult to determine to what degree postharvest losses are due to chill injury, because this injury predisposes the fruits to pathogenic attacks and other decay causing organisms, particularly *Alternaria* rot and *Botrytis* decay (Hardenburg, Watada et al. 1986; Paull 1990). The exposure temperature, duration of exposure, and cultivar sensitivity to chilling injury all determine the severity of the chilling injury (Kays 1997). Ripe bell peppers are less sensitive to chilling injury than green bell peppers (Paull 1990; Cantwell 2000). Symptoms of chill injury generally do not develop until after the fruit is removed from the chilling temperature to non-chilling temperatures (Paull 1990). Symptoms can begin appearing within a few days depending upon the severity of the chill injury (Hardenburg, Watada et al. 1986; Paull 1990), and include water-soaked sheet pitting, decay, discoloration of seeds near the calyx, softening without water loss, surface lesions, the appearance of large sunken areas, and a predisposition to decay particularly *Alternaria* rot, which causes mold and decay growth on the pepper calyx (Paull 1990; Cantwell 2000).

Bell peppers are also very sensitive to freezing injury, which occurs at temperatures at or below 0°C (Bosland and Votava 2000). The freezing point of bell peppers is -0.7°C (Kays 1997). The symptoms of freeze injury include water-soaked tissue, extreme softening of tissue, surface pitting, shriveling, and darkened stem and calyx which then become water-soaked. Symptoms of freeze injury, like those of chill injury, do not show up until after being returned to non-freezing temperatures. Unlike chill injury freezing injury only increases incidences of decay if the injured peppers are held above 5°C for at least a week (Ryall and Lipton 1979).

Storage Life

At 7-8°C most fresh bell peppers have a storage life of 2-3 weeks (Bosland and Votava 2000). While the storage life can range from 9 to 20 days at 8.5°C (Yuen and Hoffman 1993). USDA storage guidelines state that even under the best of conditions bell peppers should not be stored for more than 2-3 weeks (Hardenburg, Watada et al. 1986). Green bell peppers can be stored under optimum conditions for 2 weeks if ripening is not acceptable, or 3 weeks if some ripening is tolerable (Ryall and Lipton 1979). Decay and shriveling to moisture loss are the primary causes of loss among bell peppers postharvest, the susceptibility of the bell pepper to these problems makes them one of the more perishable products during storage (Miller, Risse et al. 1986). Maturity level, cultivar, postharvest handling, and storage conditions all affect the storage life of bell peppers (Govindarajan 1985; Lownds, Banaras et al. 1994; Meir, Rosenberger et al. 1995). On an odd note, bell peppers with an oblong shape tend to have a longer shelf-life than other pepper shapes, possibly due to a smaller incidence of shrivel (Yuen and Hoffman 1993).

Maintaining an appropriate temperature of 7 – 10°C during transportation along with a high relative humidity is vital to the maintenance of quality peppers (Yuen and Hoffman 1993). In developed countries, peppers are harvested, the field heat is removed and the peppers are transported by trucks in waxed corrugated boxes to centers where they are washed, sorted, and packed again in waxed corrugated boxes for distribution to consumers (Govindarajan 1985; Bosland and Votava 2000).

The rapid rate of postharvest water loss is the primary factor limiting the shelf life of bell peppers, additionally it can affect other factors influencing shelf life (Lownds, Banaras et al. 1994). The maximum acceptable loss of water from bell peppers is only 7% of the original fresh weight (Kays 1997). Thus, to extend the shelf life of bell peppers, ways to slow the rate of water loss must be considered. Although the reduced temperatures of refrigerated storage help to reduce the rates of water loss, it is still important to reduce those rates even more to maintain high quality bell pepper fruits. Maintenance of a high relative humidity is essential to this task, it helps to maintain the appropriate turgor of the fruit (Yuen and Hoffman 1993; Knee 2002). The optimum range of relative humidity for maintaining high quality bell pepper fruits is between 85 and 95% (Ryall and Lipton 1979; Bosland and Votava 2000; Cantwell 2000). Another method for reducing the rate of moisture loss from peppers is to apply a thin coat of wax to the fruit, this method is currently commercially practiced (Ryall and Lipton 1979; Hardenburg, Watada et al. 1986). There is a theory that peppers conduct the majority of their gas exchange, and thus their water loss, through the calyx (Banks and Nicholson 2000). Therefore any attempt to prevent moisture loss from pepper fruits needs to consider the calyx area of the fruit.

Alternative Storage Conditions to Extend Storage Life

Although it is not currently common commercial practice, many studies have shown that prepackaging in plastic films could increase the storage life of fresh bell peppers by reducing the rate of water loss from the fruits. Researchers in several countries have now shown that by individually wrapping bell peppers in polyethylene film extended the shelf-life of the fruits by reducing moisture loss and slowing senescence (Miller, Risse et al. 1986). Studies have shown that prepackaging bell peppers in 150-guage polyethylene could increase the shelf life from 8-10 days to 18-20 days when stored at 10°C and 80-90% relative humidity (RH). Prepackaging in 150-guage polyethylene could even increase the storage life of bell peppers to 12-14 days when stored at room temperature in temperate (25°C, 65-75% RH) and tropical (37°C, 90% RH) climates. Peppers stored in fiber trays covered in polyethylene at 13C had the highest consumer acceptance rate (Govindarajan 1985). Meir and Rosenberger et al. (1995) found that water loss could be reduced by 40-50% in peppers stored for 2 weeks at 7.5°C and then for 3 days at 17°C by packaging in polyethylene bags, thus dramatically increasing the final fruit quality (Meir, Rosenberger et al. 1995). Another study found that bell peppers packaged perforated polyethylene resulted in extending the shelf life of the fruits up to a week when stored at 7°C-10°C (Hardenburg, Watada et al. 1986). The packaging of bell peppers has great potential for increasing the storage life of bell peppers by reducing the rate of moisture loss from the fruits. Decay and disease are the primary factors limiting the shelf life of prepackaged bell pepper fruits, this may be due to the high moisture content of the air within the packaging (Miller, Risse et al. 1986; Lownds, Banaras et al. 1994). Therefore, it is important that any packaging be equipped with adequate ventilation to prevent the accumulation of condensation inside the packaging (Ryall and Lipton 1979). It is also important to note that although water loss is reduced by the use of moisture-retentive packaging, this technology needs to be used in conjunction with refrigerated storage to provide the best results.

Although controlled atmosphere (CA) storage has shown dramatic results in extending the storage lives of other fruits and vegetables, bell peppers do not generally respond well to CA storage (Cantwell 2000). In fact peppers may even respond negatively to CA storage. Low oxygen CA storage, atmospheres with 2-5% O_2, has been shown to have no apparent affect upon the quality of bell pepper fruits (Mercado, Quesada et al. 1995; Cantwell 2000), although it can slow ripening and respiration (Hardenburg, Watada et al. 1986). It can even cause damage if combined with high CO_2 levels and higher than recommended temperatures (Ryall and Lipton 1979). High carbon dioxide CA storage can be beneficial to some products, but others are susceptible to CO_2 injury (Kays 1997). Bell peppers fall into the second category, atmospheres containing more than 5% CO_2 can cause pitting, discoloration of the fruit and calyx, internal browning, and softening in particularly if the fruits are stored below 10°C (Hardenburg, Watada et al. 1986; Kays 1997; Cantwell 2000). Maturity level of the pepper fruit does appear to affect the response to CA storage (Mercado, Quesada et al. 1995; Cantwell 2000), and perhaps future research needs to consider these differences more closely.

Quality

The quality of bell peppers is affected by many different variables including cultivar selection, seed quality, growing conditions, cultivation practices, disease management of fields, genetic factors, harvest maturity, harvest method, processing methods, harvest conditions, and postharvest handling (Bosland and Votava 2000; Knee 2002).

Whether consumed green or colored high quality bell peppers are those fruits which are firm with a fresh crisp texture have a rich, bright color; thick-flesh; fresh, green calyx and stem (if present); are free of excessive softening, shriveling, bruises, abrasions, and diseases (Ryall and Lipton 1979; Luning, de Rijk et al. 1994; Sethu, Prabha et al. 1996; Bosland and Votava 2000). The degree of dehydration of pepper fruits is an important quality parameter of fresh bell peppers, and is relatively easily measured by the consumer as pod firmness (Bosland and Votava 2000). Shape is not necessarily a quality characteristic, as irregular shapes do not detract from the edible quality of the fruits. However consumers may see odd shaped fruits as negative or difficult to use (Ryall and Lipton 1979).

Regardless of other considerations, the major indicator of pepper quality is the absence of defects. Defects can include those caused pre-harvest due to insect, disease, pest, climate, or chemical damage; or postharvest due to various physical, physiological, or pathological causes (Knee 2002). Common defects seen in bell peppers include darkening, shriveling, sunscald, heat damage, stem rot, and mechanical damage which often causes an increase in weight loss and decay (Bosland and Votava 2000; Cantwell 2000). Excess water loss is another common defect of bell peppers and is one of the major causes of postharvest losses.

Consumer Expectations

Yuen and Hoffman (1993) performed a thorough survey of Australian consumers in order to determine their preferences about bell peppers. Although this study was undertaken in Australia, its results should easily transfer to the population of other countries, at least until such research is completed in those areas. For now it provides the best available information on consumer preferences about bell peppers. When asked about shape preference, the majority of consumers (52%) preferred flat round peppers, while 25% of those surveyed had no preference for shapes (Yuen and Hoffman 1993). Consumers preferred small (49%) or medium (42%) sized peppers, while a small segment preferred large (8%) and very few had no preference (1%) (Yuen and Hoffman 1993). The majority of consumers considered crispness (54%) to be the most important sensory quality, the second most popular was sweetness (30%) (Yuen and Hoffman 1993). When selecting peppers for purchase and consumption, consumers looked for a lack of blemishes (40%), color (22%), taste (17%), shape (11%), and size (10%) (Yuen and Hoffman 1993). Of the consumers who expressed dissatisfaction with the bell peppers currently on the market, 78% chose shriveling or softening as the major quality defect, unsightly marks and rotting were only cited by 13% and 9% of the dissatisfied respectively (Yuen and Hoffman 1993). Overall, it appears that consumers prefer a flat round, small to medium sized, smooth glossy pepper that is crisp and free of blemishes and defects (Yuen and Hoffman 1993). The study above also determined that a substantial portion of the consuming population would be willing to pay more for higher quality bell peppers. Thus it is easy to see that the industry could benefit financially by implementing practices that would reduce blemishes, decay, and shriveling (Yuen and Hoffman 1993). These results indicate that the pepper industry would be best served by attempting to improve the areas paid the most attention by consumers. Consumers are often easily influenced by preconceived ideas about the qualities a particular fruit should have, marketers can often influence consumers through these preconceived ideas (McGuire 1992).

The appearance of bell pepper fruits is the primary means of evaluation when consumers make purchasing and consuming decisions, this quality of appearance is affected by factors such as shape, size, gloss, color, and lack of defects and decay (Knee 2002; Shewfelt 2003). Australian consumers preferred red (41%) and green (34%) bell peppers to other color varieties, although they did indicate that these preferences were due to a lack of familiarity with the other color varieties (Yuen and Hoffman 1993). This indicates that it might be possible to increase the sales of other color varieties by education consumers about their flavors and uses.

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CHAPTER 2

EVALUATION OF POSTHARVEST DEGREENING POTENTIAL OF BELL PEPPERS (*CAPSICUM ANNUUM*)[1]

[1] Wright, JM., D.M. Granberry, B. Tucker, and R.L. Shewfelt. To be submitted to *HortTechnology*.

Abstract

Bell peppers are used both as a food and as a food flavoring, and are consumed fresh as immature green or mature colored fruits. During the pepper season, green bells are sold at or below cost or are allowed to rot in the field. Colored bells command a higher wholesale market price and provide and alternate channel for the pepper crop. Most colored bells sold in the U.S. are greenhouse grown and imported from Europe and Canada. We investigated the potential for the development of an on-farm degreening process for bell peppers to add value to the pepper crop. Ethylene treatments were unsuccessful in assisting the postharvest degreening process. Holding sufficiently mature peppers at 20°C/90% relative humidity provided significant degreening, and maintained relatively high quality levels. The storage life of the degreened peppers was between 7 and 14 days. This should allow sufficient time for distribution, especially if precautions against decay are taken.

Introduction

Georgia is an important producer of fresh vegetables, but much of the crop consists of traditional products marketed through traditional markets. Opportunities exist for adding value to fresh Georgia produce through innovative techniques. Georgia growers produce large amounts of green bell peppers and sell them at low prices, while yellow and red bell peppers are bought and sold at much higher prices. At the peak of pepper season, many green peppers are sold at or below the cost of production or are dumped rather than being sold. Red and yellow peppers command a higher price on the wholesale market and could provide an alternate channel for the pepper crop. Processed peppers of different colors are in demand in processed foods as ingredients and food service as components in salad bars. However, the majority of colored peppers are grown in greenhouses and imported from Europe and Canada.

Past and current research on degreening of bell peppers is limited. Molinari, Castro et al. (1999) studied the postharvest ripening of greenhouse grown red- and yellow-ripe cultivars when picked with 10 - 30% coloration. They found that peppers of both cultivar types would ripen to high quality colored peppers, when stored at 20°C and 90% relative humidity (RH). Simple "gassing" with ethylene of the green pepper as done for the ripening of green tomatoes or bananas will not provide the quality of pepper needed to meet the demands of the marketplace. This was confirmed by Molinari, Castro et al. (1999), when they showed that continuous exposure to ethylene gas (100 ppm) did not affect the ripening of the fruits. So far, ethylene treatments have proven to be ineffective with the varieties tested. Postharvest color development is primarily a function of time, temperature, and relative humidity. Maturity at harvest is a critical factor in postharvest color development with maturity assessed on the basis of % coloration.

Appearance is one of the main factors in determining the quality of fruit products, and in the case of bell peppers an adequate description of color is essential to this endeavor. Additionally, as the description of color is central to this research it is vitally important to use an appropriate method of reporting color. In order to communicate a perception of color, the color must be evaluated and described and then visualized by someone else. In the past this has often been done through visual evaluation and the use of color charts, however these methods can be flawed (McGuire 1992). Therefore an objective method of color measurement is vital to the understanding and reporting of color. Thus scientists use colorimetry, an instrumental technique that uses mathematics to describe color in terms of human perception.

Obtaining colorimetry measurements is also usually less expensive and less time intensive than the use of color charts (Nagle, Villalon et al. 1979). The most commonly used scale is the CIE (L*a*b*) method based on the CIE color solid. In this method, the a-axis represents the amount of red-green color character and the b-axis represents the amount of blue-yellow character of the color. As peppers change from green to red the a* measurement changes form negative to positive. A lower positive b* measurement indicates a smaller yellow character in the pepper color. The L* portion of the measurement relates to the lightness of the color, wherein 0 corresponds to black and 100 corresponds to white (McGuire 1992; Shewfelt 2003).

However, these readings do not directly relate to the human perception of color, as humans are not capable of screening out the different color aspects. Therefore, another representation of the data is needed. This is achieved by transforming these color functions into the measurements of hue and chroma. Hue, which is also the color name (red, orange, yellow, green, blue, purple, etc.), is the angular distance from the + a*-axis. Chroma, the brightness of the color, is the distance from the origin (0,0) (Shewfelt 2003).

Because bell pepper fruits remain living and continue to respire postharvest, the metabolic processes involved in ripening can continue. Therefore, our research investigated the potential for development of on-farm degreening of bell peppers to add value to the pepper crop.

Methodology

Peppers were produced under normal commercial cultivation in Adel, GA (Cook County). During the Fall 2001 harvests, except for the last harvest, the peppers were commercially harvested. The last harvest, Fall 2001, was hand picked by the researchers. During the Summer 2002 harvests, all of the harvests were handpicked by the researchers, with the sole exception of the cultivar Camelot from the last harvest of Summer 2002. This is notable because when the peppers were commercially harvested, while the actual harvesting is still done by hand, the peppers are submerged in cool water to remove field heat. When the researchers hand picked the peppers the field heat was not removed.

Harvested peppers were immediately driven to Athens, GA (Clarke County) and placed into their respective treatments within six hours. Peppers harvested in the first two harvests of Fall 2001 were placed into one of 4 treatments: 15°C, 20°C/90% RH, 25°C, or (control) 4.4°C (40°F). During the final harvest of Fall 2001 and all of the Summer 2002 harvests, the peppers were placed into 1 of three treatments: 20°C/90% RH, ethylene treatment at RT, or control conditions of 4.4°C (40°F). Ethylene treatments were performed at a room temperature of approximately (**22**°C) in glass desiccator chambers to keep the humidity at a high enough level to prevent moisture loss of the peppers. After the ethylene treatments were completed the peppers were moved to the environmental chamber and kept at 20°C/90% RH.

Measurements of mass, color, and % coloration of surface were performed on all peppers in all treatments. Mass was taken using a Sartorius 1219MP electronic balance. Color was measured using a Minolta CR-300 colorimeter using the CIE L* a* b* and CIE LCH methods. The percentage of surface area showing coloration was estimated by the researcher by visually dividing the pepper into quarters. Peppers were also nominally evaluated for quality in that peppers showing serious quality defects were removed from the study – especially those with advanced deterioration.

Once a pepper achieved 100% coloration and a hue angle of about 30, the pepper was subjectively evaluated by the researcher. If the researcher found the pepper to be a well colored red bell pepper likely to be acceptable to a consumer, the pepper was either frozen or placed into a shelf life study. The shelf life study was only done for the Summer 2002 harvests. A small number of acceptable peppers from the Fall 2001 harvests were frozen. Peppers from the Summer 2002 harvests that met the color requirements, but did not meet the quality requirements for continuing the shelf life study on day 0 were frozen.

Peppers that received the ethylene treatment were placed into glass desiccator chambers at room temperature (RT). They were then subjected to 100 ppm of ethylene gas twice at 24 hour intervals. The chambers were aired out before each treatment so that the peppers were never subjected to low oxygen conditions.

The shelf life study was performed under refrigerated conditions of 4.4°C (40°F). These peppers were evaluated at days 0, 7, 14, and 21. During the study the peppers were measured for mass and color as well as being evaluated on a 9 point scale for three quality characteristics: shriveling, decay, and appearance. At the point that any of the three quality characteristics dropped to a 6 on the 9 point scale the pepper was considered to no longer be salable and was removed from the study.

All data was compared using analysis of variance (ANOVA) to determine the differences in means between treatments ($p<0.05$) (Ott and Longnecker 2001).

Data, Results, and Conclusions

Peppers from the initial trials (early October, 2001) were harvested at the "suntan" stage denoting the first appearance of color in which the red pigment begins to develop without the loss of green chlorophyll. The resultant color resembles a darkening and browning. It became apparent that harvest at this stage of development was too early to permit adequate degreening. Peppers in all subsequent trials were harvested at color break, in which there was an obvious tinge of red showing in the peppers. Excellent degreening was achieved in peppers harvested at this stage.

Of the three temperatures studied in Fall (2001) tests, 20ºC provided the best color development without loss of quality of the degreened pepper. Maintenance of high relative humidity (90% RH) was critical in prevention of shriveling. Loss of 90% RH in the 15°C and 25°C incubators doomed the comparative portion of the experiment. All Summer, 2002, studies focused on the effects of 20ºC/90% RH conditions on pepper degreening.

As shown by tables 2.1 and 2.2, the mass lost by the peppers during treatment at 20°C/90% RH and throughout the various treatments was generally much less than the maximum acceptable loss of 7% even through 17 days of treatment. The fall harvest on October 30th had a high percentage of mass lost, close the 7% limit. However, the loss of mass in the control peppers for this harvest was also very high, so this was probably due to conditions affecting that particular harvest and is probably not relevant to the treatment conditions. Table 2.3 shows the mass lost by the ethylene treated and ethylene control peppers. These peppers also generally lost less mass than the acceptable limit, with the exception of the June 7th 2002 harvest. The excessive loss seen in this harvest is most likely due to the lack of true humidity control for this treatment. After the excessive loss seen in this harvest, ethylene treated peppers were placed in an environmental chamber at 20°C/90% RH after their respective treatments. Overall these three tables show that the treatments themselves do not cause an excessive amount of moisture loss and should provide an acceptable quality pepper.

Table 2.1: Effect of storage at 20ºC/90% RH on mass loss, measured as a percentage of initial weight, in peppers harvested after color-break stage.

20 deg C	Har + 2-3	har + 5 days	Har + 7 days	Har + 9-10	Har +12 days	har + 14 days	har + 17 days
10-30-2001 - Colored Only							
Sentry	1.14% ± 0.20%			5.32% ± 0.62%	6.95% ± 0.94%		
830	1.46% ± 1.71%			4.96% ± 2.45%	6.61% ± 2.93%		
ALL	1.37% ± 1.46%			5.04% ± 2.19%	6.69% ± 2.57%		
11-13-2001							
830	0.84% ± 0.32%		2.75% ± 0.55%				
Lexington	0.74% ± 0.24%		2.74% ± 0.63%				
ALL	0.79% ± 0.29%		2.74% ± 0.59%				
6-7-2002							
Wizard	0.85% ± 0.83%	1.24% ± 0.18%	1.64% ± 0.25%	2.26% ± 0.35%	2.51% ± 0.24%	2.95% ± 0.21%	3.41% ± 0.32%
Lexington	0.67% ± 0.13%	1.17% ± 0.22%	1.54% ± 0.29%	2.13% ± 0.40%	2.65% ± 0.52%	3.19% ± 0.68%	3.66% ± 0.70%
209	0.66%± 0.14%	1.14% ± 0.25%	1.42% ± 0.24%	1.98% ± 0.33%	2.21% ± 0.26%	2.58% ± 0.31%	3.09% ± 0.29%
ALL	0.74% ± 0.53%	1.17% ± 2.40%	1.89% ± 0.27%	2.42% ± 0.38%	6.16% ± 0.39%	2.94% ± 0.49%	3.44% ± 0.51%
6-13-2002							
Wizard	0.76% ± 0.21%	1.21% ± 0.32%	2.36% ± 0.73%	3.05% ± 0.86%	3.83% ± 0.87%	4.49% ± 0.61%	4.73% ± 0.91%
Lexington	0.68%± 0.12%	1.11% ± 0.20%	1.89% ± 0.42%	2.51% ± 0.50%	2.92% ± 0.43%	3.26% ± 0.58%	3.70% ± 0.66%
226	0.69% ± 0.17%	1.11% ± 0.29%	2.12% ± 0.60%	2.72% ± 0.74%	3.12%± 0.78%	3.12% ± 0.77%	3.57% ± 0.79%
ALL	0.70% ± 0.17%	1.14% ± 0.26%	2.09% ± 0.60%	2.72% ± 0.71%	3.22% ± 0.77%	3.51% ± 0.86%	3.82% ± 0.83%
6-20-2002							
Camelot	0.78% ± 0.11%	1.23% ± 0.16%	1.63% ± 0.20%	2.38% ± 0.28%	2.74% ± 0.27%	3.17% ± 0.31%	4.02% ± 0.17%
226	0.85% ± 0.11%	1.30% ± 0.15%	1.71% ± 0.22%	2.45% ± 0.63%	2.69% ± 0.37%	3.19% ± 0.36%	3.94% ± 0.51%
Wizard	0.69% ± 0.11%	1.04% ± 0.14%	1.36% ± 0.17%	1.83% ± 0.26%	2.22% ± 0.32%	2.75% ± 0.48%	3.38% ± 0.42%
ALL	0.77% ± 0.13%	1.18% ± 0.19%	1.55% ± 0.25%	2.19% ± 0.53%	2.47% ± 0.41%	2.99% ± 0.46%	3.69% ± 0.50%

Table 2.2: Effect of storage at 4.4°C on mass loss, measured as a percentage of initial weight, in peppers harvested after color-break stage.

Controls							
4.4°C	Har + 2-3	har + 5 days	Har + 7 days	Har + 9-10	Har +12 days	har + 14 days	har + 17 days
10-30-2001 - Colored Only							
Sentry	5.09% ± 0.03%			6.67% ± 0.17%			
830	5.06% ± 0.07%			6.47% ± 0.25%			
ALL	5.08% ± 0.05%			6.57% ± 0.22%			
11-13-2001							
830	0.13% ± 0.10%		0.73% ± 0.19%				
Lexington	0.41% ± 0.10%		1.06% ± 0.34%				
ALL	0.27% ± 0.18%		0.89% ± 0.31%				
6-7-2002							
Wizard	0.36% ± 0.06%	0.66% ± 0.08%	0.87% ± 0.10%	1.22% ± 0.13%	1.45% ± 0.18%	1.68% ± 0.24%	1.87% ± 0.29%
Lexington	0.39% ± 0.12%	0.71% ± 0.22%	0.91% ± 0.30%	1.30% ± 0.44%	1.54% ± 0.52%	1.73% ± 0.61%	2.03% ± 0.72%
209	0.44% ± 0.17%	0.79% ± 0.23%	1.04% ± 0.32%	1.48% ± 0.44%	1.76% ± 0.52%	2.03% ± 0.62%	2.33% ± 0.73%
ALL	0.40% ± 0.12%	0.72% ± 0.18%	0.94% ± 0.24%	1.33% ± 0.35%	1.58% ± 0.42%	1.81% ± 0.50%	2.08% ± 0.59%
6-13-2002							
Wizard	0.09% ± 0.02%	0.24% ± 0.07%	0.54% ± 0.16%	0.47% ± 0.31%	0.73% ± 0.36%	0.89% ± 0.42%	1.06% ± 0.54%
Lexington	0.37% ± 0.07%	0.64% ± 0.15%	0.97% ± 0.21%	1.22%	1.62%	1.86%	2.24%
226	0.32% ± 0.17%	0.63% ± 0.28%	1.09%± 0.34%	1.43% ± 0.46%	1.88% ± 0.52%	2.19% ± 0.63%	2.71% ± 0.77%
ALL	0.30% ± 0.15%	0.56% ± 0.25%	0.93% ± 0.32%	1.23% ± 0.45%	1.64% ± 0.53%	1.90% ± 0.62%	2.32% ± 0.78%
6-20-2002							
Camelot	0.41% ± 0.08%	0.55% ± 0.04%	0.73% ± 0.01%	1.05% ± 0.03%	1.17%	1.31%	1.70%
226	0.54% ± 0.11%	0.73% ± 0.19%	1.02% ± 0.28%	1.48% ± 0.42%	1.75% ± 0.51%	1.96% ± 0.61%	2.48% ± 0.72%
Wizard	0.41% ± 0.09%	0.62% ± 0.15%	0.82% ± 0.23%	1.24% ± 0.37%	1.41% ± 0.40%	1.57% ± 0.45%	2.02% ± 0.57%
ALL	0.45% ± 0.10%	0.63% ± 0.15%	0.87% ± 0.23%	1.28% ± 0.35%	1.52% ± 0.44%	1.70% ± 0.51%	2.17% ± 0.61%

Table 2.3: Effect of ethylene treatment on mass loss, measured as a percentage of initial weight, in peppers harvested after color-break stage. Experimental peppers were treated with 100 ppm of ethylene gas twice at 24-hour intervals. Control and experimental peppers were stored at 20ºC/90% RH. Hue angle decreases as the peppers turn to red.

Ethylene Treated	har + 3 days	har + 5 days	Har + 7 days	har + 10 days	Har +12 days	har + 14 days	har + 17 days
6-7-2002							
Wizard	0.27% ± 0.00%	0.44% ± 0.01%	6.43% ± 0.03%	7.21% ± 0.13%			
Lexington	0.27% ± 0.06%	0.43% ± 0.09%	6.38% ± 0.09%	7.06% ± 0.06%	7.36% ± 0.00%		
209	0.28% ± 0.02%	0.45% ± 0.04%	6.43% ± 0.05%	7.19% ± 0.04%			
ALL	0.27% ± 0.03%	0.44% ± 0.05%	6.41% ± 0.06%	7.15% ± 0.10%	7.36% ± 0.00%		
6-13-2002							
Wizard	0.80% ± 0.10%	1.42% ± 0.13%	1.76%	2.40%	2.87%		
Lexington	0.75% ± 0.05%	1.29% ± 0.11%	1.76% ± 0.23%	2.44% ± 0.40%	4.71% ± 2.51%		
226	0.75% ± 0.01%	1.24% ± 0.12%	1.69% ± 0.08%	2.35% ± 0.15%	2.76% ± 0.19%		
ALL	0.77% ± 0.06%	1.32% ± 0.13%	1.73% ± 0.15%	2.39% ± 0.25%	3.75% ± 1.90%		
6-20-2002							
Camelot	0.68%	1.21%	1.59%	2.15%	2.64%	3.35%	4.09%
226	0.61% ± 0.06%	1.33% ± 0.28%	1.72% ± 0.33%	2.31% ± 0.34%	2.84% ± 0.39%		
Wizard	0.67% ± 0.07%	1.29% ± 0.16%	1.67% ± 0.21%	2.02%	2.43%		
ALL	0.64% ± 0.06%	1.29% ± 0.19%	1.68% ± 0.23%	2.22% ± 0.27%	2.72% ± 0.33%	3.35%	4.09%
Ethylene Controls	har + 3 days	har + 5 days	Har + 7 days	har + 10 days	Har +12 days	har + 14 days	har + 17 days
6-7-2002							
Wizard		0.13% ± 0.02%	5.96% ± 0.04%	6.65% ± 0.11%			
Lexington		0.17% ± 0.02%	6.01% ± 0.02%	6.86% ± 0.07%			
209		0.16% ± 0.02%	6.01% ± 0.08%	6.74% ± 0.28%			
ALL		0.15% ± 0.02%	5.99% ± 0.05%	6.75% ± 0.17%			
6-13-2002							
Wizard	0.52% ± 0.25%	1.12% ± 0.11%	1.55% ± 0.18%	2.19% ± 0.30%	2.47%	3.65%	
Lexington	0.78% ± 0.06%	1.39% ± 0.16%	1.87% ± 0.26%	2.59% ± 0.40%	3.27% ± 0.68%	3.20%	
226	0.75% ± 0.05%	1.36% ± 0.12%	1.92% ± 0.19%	2.71% ± 0.20%	3.62% ± 0.06%	4.24%	
ALL	0.69% ± 0.17%	1.29% ± 0.17%	1.78% ± 0.24%	2.50% ± 0.34%	3.25% ± 0.58%	3.70% ± 0.52%	
6-20-2002							
Camelot	0.81%	1.70%	2.23%	3.00%	3.62%	4.53%	5.44%
226	0.69% ± 0.02%	1.26% ± 0.06%	1.64% ± 0.12%	2.18% ± 0.20%	2.80%	3.46%	4.27%
Wizard	0.62% ± 0.08%	1.25% ± 0.01%	1.62% ± 0.02%	2.12% ± 0.13%	2.65%	3.22%	
ALL	0.69% ± 0.09%	1.34% ± 0.20%	1.75% ± 0.28%	2.32% ± 0.40%	3.02% ± 0.52%	3.74% ± 0.70%	4.86% ± 0.83%

Overall in every harvest, except for the October 30th 2001 harvest, there was at least one cultivar of which at least half of the peppers obtained 100% coloration of the surface area from the 20°C/90% RH treatment group (Table 2.4). Additionally, no control (4.4°C) peppers in any harvest achieved 100% surface area coloration (Table 2.5).

The total change in percent coloration for 20°C/90% RH treated harvests (Table 2.4) was found to be significantly different, with the exception of the June 7th and June 20th harvests of 2002. With the exception of the October 30th 2001 harvest, peppers held at degreening temperatures were found to be significantly different from their controls (Table 2.5). All of the cultivars were also found to be significantly different from their controls. These results show that the treatment of 20°C/90% RH is effective for degreening of bell peppers. Among the ethylene treated peppers (Table 2.6), the total change in percent coloration of the peppers was shown not to be significantly different from that seen in the ethylene control peppers with no significant differences among cultivars.

Peppers from the Fall harvests, with the exceptions of the November 13th 2001 harvest controls, showed less development of red color in both the treatment and the control peppers than in the Summer, even though the initial color tended to be less green (lower hue angle) in Fall than in Summer (see Tables 2.7 and 2.8). These differences were attributed to lower field heat in the Fall crop, due to lower temperatures in the Fall and cooling in the Fall by dipping in cold water. The differences seen in the November 13th harvest are most likely due to the fact that the field heat was not removed from these peppers. Note that color development continued through 17 days of storage in the treated

Table 2.4: Effect of storage at 20ºC/90% RH on change percent color change in peppers harvested after color-break stage.

20°C	har	har + 2-3	har + 5	har + 7	har + 9-10	har + 11-12	har + 14	har + 17	total change	% ending at 100%
10-30-2001 - Colored Only										
Sentry	39.20 ± 38.87	46.20 ± 38.17	63.60 ± 40.55	73.80 ± 31.89	83.33 ± 28.87	83.33 ± 28.87			38.80 ± 23.97	40.00%
830	22.29 ± 29.28	31.79 ± 36.46	42.46 ± 44.83	43.23 ± 45.14	48.00 ± 47.17	48.15 ± 46.08			25.64 ± 32.11	35.71%
ALL	26.74 ± 31.84	35.58 ± 36.42	48.33 ± 43.59	51.72 ± 43.32	55.07± 45.62	54.75 ± 44.84			29.11 ± 30.13	36.84%
11-13-2001										
830	10.38 ± 10.20	45.77 ± 28.33		99.38 ± 3.08		99.98 ± 0.16			84.80 ± 22.83	92.73%
Lexington	17.77 ± 16.97	48.00 ± 27.86		95.37 ± 15.89		97.05 ± 14.98			77.83 ± 23.82	93.33%
ALL	14.23 ± 14.56	46.95 ± 27.98		97.25 ± 11.90		98.27 ± 11.49			81.17 ± 23.51	93.04%
6-7-2002										
Wizard	16.83 ± 12.49	22.56 ± 18.06	46.79 ± 22.55	69.26 ± 21.22	84.85 ± 12.58	88.33 ± 10.97	90.50 ± 10.39	92.78 ± 7.95	63.78 ± 23.55	24.39%
Lexington	16.67± 14.68	28.97 ± 25.19	51.07 ± 28.78	70.77 ± 23.95	89.60 ± 11.98	95.00 ± 8.94	96.25± 8.76	98.57 ± 3.78	68.83 ± 25.09	53.33%
209	19.12 ± 13.68	36.52 ± 23.69	64.25 ± 28.19	78.52 ± 26.93	88.65 ± 23.74	92.14 ± 21.23	99.67 ± 23.81	100.00 ± 26.19	67.24 ± 22.63	57.58%
ALL	17.51 ± 13.44	28.96 ± 24.46	53.65 ± 27.91	72.72 ± 23.35	87.41 ± 13.49	91.36 ± 10.70	94.71 ± 8.98	96.25 ± 6.46	66.34 ± 22.32	43.27%
6-13-2002										
Wizard	40.29 ± 23.88	57.35 ± 22.72	73.75 ± 23.84	81.93 ± 24.72	89.67 ± 20.91	90.71 ± 16.44	89.00 ± 15.17	87.50 ± 17.68	53.53 ± 18.77	82.35%
Lexington	36.73 ± 22.09	57.71 ± 25.32	76.48 ± 21.08	87.05 ± 17.97	96.77± 11.80	93.90 ± 17.25	92.00 ± 20.73	99.67 ± 0.58	52.65 ± 27.16	76.92%
226	31.04 ± 22.31	50.00 ± 21.69	66.14 ± 20.93	75.75 ± 18.01	89.84 ± 15.71	88.85 ± 14.31	88.75 ± 15.29	94.17 ± 9.70	57.92 ± 24.13	58.33%
ALL	35.60 ± 22.59	54.84 ± 23.30	72.03 ± 21.90	81.74 ± 20.20	92.52 ± 16.04	90.97 ± 15.43	89.95 ± 16.51	94.45 ± 9.81	54.76 ± 23.95	71.64%
6-20-2002										
Camelot	20.89 ± 19.54	68.95 ± 25.20	80.78 ± 22.65	87.72 ± 19.23	89.67 ± 15.75	94.89 ± 11.68	92.00 ± 15.25	93.33 ± 7.64	67.65 ± 19.70	44.44%
226	16.60 ± 17.92	32.29 ± 30.13	48.21 ± 29.32	62.15 ± 27.88	77.08 ± 21.96	83.95 ± 12.31	87.14 ± 11.43	95.33 ± 6.31	61.80 ± 25.94	25.71%
Wizard	14.00 ± 11.20	37.29 ± 15.73	60.33 ± 13.45	75.34 ± 13.82	94.22 ± 7.90	99.38 ± 1.63	99.44 ± 1.41	99.25 ± 1.75	73.56 ± 28.07	60.00%
ALL	16.72 ± 16.20	42.85 ± 27.84	60.71 ± 25.51	73.70 ± 23.02	86.95 ± 17.57	93.20 ± 11.10	93.46 ± 10.57	96.82 ± 5.21	68.08 ± 25.84	43.14%

Table 2.5: Effect of storage at 4.4ºC on change percent color change in peppers harvested after color-break stage.

Controls **4.4°C**	har	har + 2-3	har + 5	har + 7	har + 9-10	har + 11-12	har + 14	har + 17	total change	% ending at 100%
10-30-2001 – Colored Only										
Sentry	3.67 ± 2.31	5.33 ± 4.51	5.33 ± 4.51	5.33 ± 4.51	5.33 ± 4.51				1.67 ± 2.89	0.00%
830	7.00 ± 11.27	8.67 ± 10.02	8.67 ± 10.02	8.67 ± 10.02	12.00 ± 15.72				5.00 ± 4.58	0.00%
ALL	5.33 ± 7.50	7.00 ± 7.18	7.00 ± 7.18	7.00 ± 7.18	8.67 ± 10.97				3.33 ± 3.88	0.00%
11-13-2001										
830	6.67 ± 2.89	10.00 ± 0.00		38.33 ± 22.55		40.00 ± 26.46			33.33 ± 24.66	0.00%
Lexington	6.33 ± 7.57	26.67 ± 16.07		31.67 ± 16.07		35.00 ± 8.66			28.67 ± 13.50	0.00%
ALL	6.50 ± 5.13	18.33 ± 13.66		35.00 ± 17.89		37.50 ± 17.82			31.00 ± 17.97	0.00%
6-7-2002										
Wizard	16.25 ± 6.29	20.00 ± 4.08	27.50 ± 8.66	31.25 ± 9.46	31.25 ± 9.46	32.50 ± 8.66	32.50 ± 8.66	32.50 ± 8.66	16.25 ± 4.79	0.00%
Lexington	22.75 ± 15.06	23.75 ± 13.15	32.50 ± 21.02	40.00 ± 21.60	42.50 ± 22.55	42.50 ± 22.55	42.50 ± 22.55	43.75 ± 23.94	21.00 ± 8.98	0.00%
209	13.75 ± 11.09	17.50 ± 18.48	26.25 ± 13.15	30.00 ± 14.72	33.75 ± 17.97	35.00 ± 17.80	35.00 ± 17.80	35.00 ± 17.80	21.25 ± 7.50	0.00%
ALL	17.58 ± 11.04	20.42 ± 12.33	28.75 ± 14.00	33.75 ± 15.24	35.83 ± 16.63	36.67 ± 16.28	36.67 ± 16.28	37.08 ± 16.98	19.50 ± 7.03	0.00%
6-13-2002										
Wizard	32.50 ± 27.23	55.00 ± 28.28	55.00 ± 28.28	55.00 ± 28.28	75.00	75.00	75.00	75.00	7.50 ± 3.54	0.00%
Lexington	48.75 ± 16.01	48.75 ± 16.01	50.00 ± 13.54	51.25 ± 11.09	51.25 ± 11.09	51.25 ± 11.09	51.25 ± 11.09	51.25 ± 11.09	2.50 ± 5.00	0.00%
226	27.50 ± 15.55	31.25 ± 17.02	33.75 ± 16.52	35.00 ± 16.83	37.50 ± 18.48	43.75 ± 26.58	45.00 ± 28.58	45.00 ± 28.58	17.50 ± 28.43	0.00%
ALL	36.25 ± 20.68	43.00 ± 19.47	44.50 ± 18.17	45.50 ± 17.55	47.78 ± 18.05	50.56 ± 20.22	51.11 ± 21.03	51.11 ± 21.03	9.50 ± 18.17	0.00%
6-20-2002										
Camelot	9.00 ± 7.12	11.50 ± 10.75	15.33 ± 14.50	15.50 ± 20.51	20.50 ± 27.58	45.00	45.00	45.00	7.50 ± 15.00	0.00%
226	13.75 ± 17.50	16.67 ± 20.21	16.67 ± 20.21	16.67 ± 20.21	16.67 ± 20.21	18.33 ± 23.09	18.33 ± 23.09	18.33 ± 23.09	1.67 ± 2.89	0.00%
Wizard	17.50 ± 2.89	18.75 ± 4.79	20.00 ± 5.00	18.33 ± 7.64	21.67 ± 7.64	21.67 ± 7.64	23.33 ± 7.64	23.33 ± 7.64	3.75 ± 4.79	0.00%
ALL	13.42 ± 10.62	15.55 ± 11.59	17.33 ± 12.85	17.00 ± 13.96	19.50 ± 15.74	23.57 ± 17.01	24.29 ± 16.94	24.29 ± 16.94	4.55 ± 9.07	0.00%

Table 2.6: Effect of ethylene treatment on change in percent coloration separated by cultivar. Experimental peppers were treated with 100 ppm of ethylene gas twice at 24-hour intervals. Control and experimental peppers were stored at 20ºC/90% RH. *Percent ending at 100% coloration.

Ethylene	har	har + 3	har + 5	har + 7	har + 10	har + 12	har + 14	har + 17	total change	% at 100%*
6-7-2002										
Wizard		31.67 ± 17.56	65.00 ± 25.98	80.00 ± 21.79	93.33 ± 11.55				61.67 ± 10.41	66.67%
Lexington		30.00 ± 8.66	71.67 ± 15.28	90.00 ± 10.00	91.67 ± 10.41	95.00 ± 7.07	95.00	100.00	68.33 ± 5.77	66.67%
209		26.67 ± 12.58	63.33 ± 10.41	76.67 ± 2.89	98.33 ± 2.89				71.67± 10.41	66.67%
ALL		29.44 ± 11.84	66.67 ± 16.39	82.22 ± 13.49	94.44 ± 8.46	95.00 ± 7.07	95.00	100.00	67.22 ± 9.05	66.67%
6-13-2002										
Wizard	13.33 ± 10.41	41.67 ± 7.64	65.00 ± 13.23	60.00	75.00	90.00			65.00 ± 20.00	0.00%
Lexington	36.67 ± 5.77	46.67 ± 15.28	75.00 ± 18.03	93.33 ± 11.55	98.33 ± 2.89	100.00 ± 0.00			63.33 ± 5.77	100.00%
226	40.00 ± 13.23	58.33 ± 12.58	66.67 ± 11.55	88.33 ± 11.55	99.67 ± 0.58	100.00 ± 0.00	100.00		60.00 ± 13.23	100.00%
ALL	30.00 ± 15.41	48.89 ± 12.94	68.89 ± 13.41	86.43 ± 15.20	95.57 ± 9.25	98.33 ± 4.08	100.00		62.78 ± 12.53	66.67%
6-20-2002										
Camelot	6.67 ± 2.89	20.00	60.00	90.00	100.00	100.00	100.00	100.00	95.00	33.33%
226	10.33 ± 9.50	18.33 ± 11.55	38.33 ± 22.55	55.00 ± 30.41	85.00 ± 13.23	98.33 ± 2.89			88.00 ± 7.21	66.67%
Wizard	10.00 ± 5.00	25.00 ± 8.66	68.33 ± 7.64	92.67 ± 10.97	100.00	100.00			89.33 ± 5.51	33.33%
ALL	9.00 ± 5.83	21.43 ± 9.00	54.29 ± 20.50	76.14 ± 27.21	91.00 ± 12.45	99.00 ± 2.24	100.00	100.00	89.57 ± 5.80	44.44%
Controls										
6-7-2002										
Wizard	15.50 ± 20.51	40.00 ± 49.50	55.00 ± 56.57	77.50 ± 24.75	92.50 ± 10.61				77.00 ± 9.90	50.00%
Lexington	5.50 ± 6.36	7.50 ± 3.54	25.00 ± 7.07	60.00± 14.14	92.50 ± 3.54				87.00 ± 2.83	0.00%
209	32.50 ± 38.89	47.50 ± 53.03	62.50 ± 53.03	77.50 ± 31.82	90.00 ± 14.14				57.50 ± 24.75	50.00%
ALL	17.83 ± 23.32	31.67 ± 37.64	47.50 ± 39.08	71.67 ± 21.13	91.67 ± 8.16				73.83 ± 17.99	33.33%
6-13-2002										
Wizard	25.00 ± 14.14	40.00 ± 7.07	50.00 ± 7.07	55.00 ± 0.00	82.50 ± 10.61	92.50 ± 3.54	95.00		67.50 ± 17.68	0.00%
Lexington	17.50 ± 17.68	27.50 ± 24.75	37.50 ± 31.82	62.50 ± 31.82	72.50 ± 38.89	77.50 ± 31.82	55.00		60.00 ± 14.14	50.00%
226	37.50 ± 17.68	40.00 ± 7.07	67.50 ± 17.68	62.50 ± 3.54	97.50 ± 3.54	99.50 ± 0.71	99.00		62.00 ± 18.38	50.00%
ALL	26.67 ± 15.71	35.83 ± 13.57	51.67 ± 21.37	60.00 ± 14.83	84.17 ± 21.31	89.83 ± 17.50	83.00 ± 24.33		63.17 ± 13.50	33.33%
6-20-2002										
Camelot	5.00	5.00	55.00	70.00	90.00	90.00	95.00	95.00	90.00	0.00%
226	7.50 ± 3.54	27.50 ± 3.54	40.00 ± 14.14	67.50 ± 3.54	90.00 ± 14.14	100.00	100.00	100.00	82.50 ± 17.68	50.00%
Wizard	15.00 ± 7.07	35.00 ± 35.36	65.00 ± 42.43	85.00 ± 21.21	97.50 ± 3.54	100.00	100.00		85.00 ± 7.07	100.00%
ALL	10.00 ± 6.12	26.00 ± 21.62	53.00 ± 25.64	75.00 ± 14.14	93.00 ± 8.37	96.67 ± 5.77	98.33 ± 2.89	97.50 ± 3.54	85.00 ± 10.00	60.00%

Table 2.7: Effect of storage at 20ºC/90% RH on change in hue angle ($\tan^{-1} b^*/a^*$) in peppers harvested after color-break stage. Hue angle decreases as the peppers turn from green to red.

20 deg C	Har	har + 2-3	har + 5 days	har + 7 days	har + 9-10	har + 11-12	har + 14	har + 17	Total Change
10-30-2001 - Colored Only									
Sentry	66.8 ± 22.4	63.2 ± 23.1	49.4 ± 3.0	46.0 ± 3.5	43.4 ± 2.4	40.4 ± 3.9			-23.9 ± 21.4
830	48.5 ± 30.6	45.6 ± 33.1	44.7 ± 33.7	45.9 ± 32.3	43.2 ± 33.1	41.9 ± 23.9			-6.6 ± 21.8
ALL	73.4 ± 28.2	70.2 ± 30.3	60.6 ± 28.9	54.5 ± 27.1	54.3 ± 29.6	45.6 ± 21.0			-19.0 ± 21.3
11-13-2001									
830	62.8 ± 18.4	41.4 ± 12.0		29.2 ± 2.9		27.8 ± 1.9			-34.8 ± 16.9
Lexington	63.2 ± 22.6	44.1 ± 16.6		32.6 ± 6.5		30.5 ± 5.8			-32.2 ± 21.4
ALL	63.0 ± 20.6	42.8 ± 14.7		31.0 ± 5.4		29.3 ± 4.8			-33.4 ± 19.4
6-7-2002									
Wizard	84.0 ± 12.3	61.5 ± 14.9	49.7 ± 9.8	42.9 ± 7.8	35.2 ± 5.3	32.9 ± 3.7	32.9 ± 3.0	30.8 ± 2.0	-50.1 ± 10.7
Lexington	84.2 ± 20.0	68.5 ± 22.9	54.9 ± 16.5	44.6 ± 10.3	34.7 ± 5.2	32.2 ± 4.1	31.3 ± 2.3	30.4 ± 2.9	-50.7 ± 18.2
209	88.4 ± 16.2	65.1 ± 20.8	49.2 ± 14.0	41.3 ± 8.8	32.2 ± 5.3	33.1 ± 3.8	32.3 ± 2.8	29.6 ± 3.4	-54.5 ± 14.5
ALL	85.4 ± 16.1	64.7 ± 19.5	51.0 ± 13.4	42.9 ± 8.9	34.1 ± 5.4	32.7 ± 3.8	32.2 ± 2.7	30.4 ± 2.5	-51.7 ± 14.4
6-13-2002									
Wizard	74.8 ± 26.1	46.8 ± 19.8	38.1 ± 15.8	35.0 ± 12.6	30.7± 4.0	31.6 ± 2.8	30.7 ± 2.3	27.8 ± 2.8	-43.8 ± 24.4
Lexington	70.5 ± 18.7	41.7 ± 8.8	36.2 ± 6.4	33.4 ± 4.9	30.0 ± 3.3	30.6 ± 2.5	29.3 ± 3.4	29.5 ± 4.0	-39.7 ± 17.7
226	82.3 ± 17.6	48.2 ± 12.9	40.9 ± 8.9	35.9 ± 5.9	31.2 ± 3.7	32.0 ± 4.0	30.6 ± 3.1	28.9 ± 2.0	-53.4 ± 15.6
ALL	75.8 ± 20.8	45.4 ± 14.0	38.4 ± 10.4	34.7 ± 7.8	30.6 ± 3.6	31.4 ± 3.2	30.2 ± 2.9	28.9 ± 2.5	-45.7 ± 19.7
6-20-2002									
Camelot	81.6 ± 19.5	44.2 ± 10.3	38.3 ± 7.5	34.1 ± 6.6	31.5 ± 4.4	29.7 ± 3.3	28.6 ± 2.4	27.5 ± 3.2	-45.5 ± 16.2
226	89.1 ± 16.8	63.1 ± 18.5	49.3 ± 14.6	44.7 ± 12.7	35.8 ± 8.5	33.1 ± 5.8	32.1 ± 6.2	27.7 ± 2.3	-53.2 ± 17.7
Wizard	93.7 ± 10.5	57.3 ± 9.6	45.7 ± 6.7	40.8 ± 6.0	33.6 ± 3.7	30.7 ± 2.6	29.2 ± 1.3	27.5 ± 1.1	-59.2 ± 16.3
ALL	88.9 ± 16.1	56.4 ± 15.3	45.3 ± 11.2	40.5 ± 9.8	34.0 ± 6.2	31.4 ± 4.2	30.3 ± 4.3	27.6 ± 1.9	-53.7 ± 17.4

Table 2.8: Effect of storage at 4.4ºC on change in hue angle ($\tan^{-1} b^*/a^*$) in peppers harvested after color-break stage. Hue angle decreases as the peppers turn from green to red.

Controls 4.4°C	har	har + 2-3	har + 5 days	har + 7 days	har + 9-10	har + 11-12	har + 14	har + 17	Total change
10-30-2001 - Colored Only									
Sentry	80.0 ± 12.7	77.7 ± 11.2	75.6 ± 12.5	78.8 ± 11.4	78.1 ± 11.7				-1.9 ± 2.1
830	80.7 ± 21.3	79.3 ± 21.3	77.1 ± 25.2	79.7 ± 26.5	75.4 ± 35.0				-0.7 ± 6.9
ALL	109.9 ± 19.0	109.3 ± 19.6	109.3 ± 21.2	110.1 ± 20.2	110.6 ± 20.0				-0.1 ± 2.4
11-13-2001									
830	52.6 ± 14.0	48.9 ± 13.4		50.2 ± 14.0		49.4 ± 14.8			-3.2± 4.5
Lexington	61.7 ± 10.2	54.2 ± 3.4		56.3 ± 6.6		49.9 ± 1.4			-11.8 ± 11.4
ALL	57.1 ± 12.1	51.6 ± 9.2		53.2 ± 10.3		49.6 ± 9.4			-7.5 ± 9.0
6-7-2002									
Wizard	86.6 ± 6.0	88.6 ± 5.3	86.7 ± 4.9	86.4 ± 9.1	83.9 ± 6.4	82.2 ± 7.6	86.0 ± 6.6	84.8 ± 7.4	-1.9 ± 3.1
Lexington	83.7 ± 18.0	84.6 ± 16.7	83.4 ± 19.1	89.2 ± 16.1	81.6 ± 21.0	82.7 ± 19.1	80.1 ± 18.9	82.1 ± 18.4	-1.5 ± 2.0
209	91.9 ± 9.7	91.7 ± 11.1	91.7 ± 12.0	94.7 ± 13.9	91.9 ± 13.2	93.2 ± 12.1	91.6 ± 12.7	91.8 ± 13.0	-0.1 ± 7.2
ALL	87.4 ± 11.7	88.3 ± 11.2	87.3 ± 12.6	90.1 ± 12.6	85.8 ± 14.1	86.0 ± 13.5	85.9 ± 13.3	86.2 ± 13.1	-1.2 ± 4.3
6-13-2002									
Wizard	71.1 ± 27.0	50.9 ± 1.5	47.9 ± 4.9	46.6 ± 4.9	44.7	44.4	42.4	42.8	2.4
Lexington	81.0 ± 11.3	76.3 ± 15.2	77.7 ± 13.7	77.2 ± 12.4	77.2 ± 14.2	76.4 ± 11.8	76.5 ± 15.5	75.0 ± 15.1	-6.0 ± 7.9
226	82.0 ± 18.9	79.7 ± 20.2	79.9 ± 21.8	79.8 ± 20.4	79.4 ± 20.9	77.9 ± 22.0	72.1 ± 22.0	77.1 ± 23.1	-4.4 ± 5.3
ALL	78.0 ± 18.9	72.6 ± 18.6	72.6 ± 19.9	72.1 ± 19.4	74.6 ± 19.1	73.5 ± 7.8	70.6 ± 19.4	72.3 ± 20.2	-4.4 ± 6.4
6-20-2002									
Camelot	88.6 ± 23.8	87.6 ± 24.6	80.8 ± 30.2	83.6 ± 40.0	82.6 ± 41.1	53.2	62.7	52.0	-3.2 ± 4.4
226	84.0 ± 10.0	81.2 ± 10.5	81.9 ± 10.4	81.3± 10.0	81.7 ± 10.2	80.2 ± 10.6	80.2 ± 10.6	81.3 ± 9.8	-0.4 ± 1.1
Wizard	78.4 ± 10.4	78.5 ± 10.7	72.9 ± 6.4	72.7 ± 4.9	72.5 ± 5.7	71.6 ± 7.8	70.2 ± 4.9	69.9 ± 5.9	-3.0 ± 2.2
ALL	83.6 ± 15.2	82.5 ± 16.0	78.5 ± 16.8	78.6± 41.1	78.4 ± 17.4	72.6 ± 12.2	73.4 ± 9.6	72.2 ± 12.5	-2.3 ± 3.0

peppers and showed remarkable stability in control peppers. In general, a hue angle of 30 or below has a full-red color.

Interesting differences were observed in color development of different lines or cultivars as shown in Table 2.9. Little difference was noted in color development in the

Table 2.9: Means of total change in hue angle (tan^{-1} b*/a*) in peppers harvested after color-break stage separated by cultivar. Hue angle decreases as the peppers turn from green to red.

Cultivar	**Mean - 20°C/90% RH***	**Mean – Control (4.4°C)**
Sentry	-23.9ab	-1.9
830	-31.28a	-1.9
Lexington	-38.6bd	-6.0
Wizard	-52.4ce	-2.7
209	-54.5c	-0.1
226	-53.3cf	-2.7
Camelot	-45.5def	-3.2

* Small letters show significant differences determined by ANOVA analysis.

experimental peppers, but marked differences were noted in the control. The cultivar 'Lexington' was the most difficult to maintain under control conditions with the peppers evidencing undesirable color quickly. This cultivar must be harvested well before color break if they are to be maintained as green peppers during typical postharvest handling. It also shows potential for more controlled degreening if the distributor was interested in "timing the market."

Despite indications from a Florida study (Molinari, Castro et al. 1999), and the relative literature, that ethylene treatment would not speed the color change, comments from many associated with the study indicated that it was not widely believed. To verify the previous work, we conducted a small side study to determine the effect. The results shown in Table 2.10 are almost identical for each treatment verifying that ethylene does not speed up the degreening process. It is clear that degreening of peppers is not climacteric (ethylene-stimulated) ripening as observed in tomatoes. Rather it is a non-climacteric response.

The shelf-life study shows reasonable stability of the degreened peppers during the first seven days but a general decline in stability during the second and third week of storage (Table 2.11). The primary cause for loss of quality was decay, while the secondary cause was due to moisture loss affecting either visual appearance or showing

Table 2.11: Percentage of acceptable peppers remaining at days 0,7,14, and 21 after degreening and storage at 4.4ºC

Days in Storage	0	7	14	21
Wizard	100	81	62	14
226	100	80	80	0
Lexington	100	83	33	25
209	100	67	40	13
Camelot	100	75	38	12

evidence of shriveling (Table 2.12). No fungicides were used during the shelf-life study; this in addition to the lack of any rinsing or washing stage increased the possibility of the presence of decay microorganisms on the experimental peppers. The two cultivars 'Wizard' and '226' appeared to be most stable while '209' was the least stable. Since a week is required for distribution in wholesale and retail markets, performance in the shelf-life study suggests that some type of postharvest intervention would be required for Georgia degreened peppers to be competitive in the marketplace. Careful control of RH

Table 2.10: Effect of ethylene treatment on change in hue angle ($\tan^{-1} b^*/a^*$) in peppers harvested after color-break stage separated by cultivar. Experimental peppers were treated with 100 ppm of ethylene gas twice at 24-hour intervals. Control and experimental peppers were stored at 20ºC/90% RH. Hue angle decreases as the peppers turn to red.

Ethylene Treated	Har	har+ 3	har + 5 days	har + 7 days	har + 10	har + 12	har + 14	har + 17	Total change
6-7-2002									
Wizard	84.5 ± 13.6	52.6 ± 7.4	43.6 ± 6.1	40.1 ± 8.1	33.9 ± 7.2				-50.6 ± 7.0
Lexington	89.9 ± 14.8	56.6 ± 4.1	51.2 ± 2.1	44.8 ± 2.6	37.3 ± 0.8	33.9 ± 1.4	31.4	28.9	-56.0 ± 13.1
209	96.0 ± 5.0	52.1 ± 1.5	46.5 ± 3.5	38.6 ± 2.5	33.3 ± 2.2				-62.7 ± 5.1
ALL	90.1 ± 11.5	53.8 ± 4.8	47.1 ± 4.9	41.1 ± 5.2	34.8 ± 4.2	33.9 ± 1.4	31.4	28.9	-56.4 ± 9.5
6-13-2002									
Wizard	85.4 ± 19.7	49.4 ± 18.4	39.2 ± 5.4	33.3	28.4	28.6			-51.8 ± 24.0
Lexington	72.1 ± 8.5	41.2 ± 9.2	38.0 ± 8.3	32.3 ± 2.9	29.8 ± 2.0	28.0 ± 1.7			-44.2 ± 8.6
226	83.1 ± 12.1	45.8 ± 13.7	39.5 ± 11.0	35.5 ± 7.4	31.8 ± 4.7	32.9 ± 5.2	32.7		-53.4 ± 9.9
ALL	80.2 ± 13.8	45.4 ± 12.9	38.9 ± 7.4	33.8 ± 4.9	30.4 ± 3.2	29.7 ± 3.6	32.7		-49.8 ± 14.3
6-20-2002									
Camelot	94.2 ± 12.0	58.7	46.0	42.7	33.4	32.6	29.9	29.8	-52.9
226	98.8 ± 3.4	74.4 ± 11.7	55.2 ± 2.1	45.9 ± 4.6	34.2 ± 0.3	30.7 ± 0.8			-68.1 ± 3.2
Wizard	88.3 ± 11.0	48.0 ± 7.7	40.5 ± 3.4	36.4 ± 3.2	31.0	29.5			-53.6 ± 22.3
ALL	93.8 ± 9.5	60.8 ± 15.5	47.6 ± 7.7	41.4 ± 5.8	33.4 ± 1.4	30.8 ± 1.2	29.9	29.8	-59.7 ± 11.3
Controls	Har	har+ 3	har + 5 days	har + 7 days	har + 10	har + 12	har + 14	har + 17	Total change
6-7-2002									
Wizard	87.2 ± 23.8	65.1 ± 35.1	52.3 ± 22.9	43.1 ± 12.7	33.0 ± 2.9				-54.2 ± 20.9
Lexington	99.3 ± 20.9	72.6 ± 38.7	58.9 ± 24.9	44.9 ± 13.6	34.2 ± 6.8				-65.1 ± 14.1
226	84.7 ± 32.0	58.0 ± 28.9	40.8 ± 22.6	19.5 ± 34.4	27.3 ± 12.3				-43.1 ± 34.6
ALL	90.4 ± 21.3	64.8 ± 28.3	49.8 ± 18.3	40.6 ± 10.3	32.6 ± 4.3				-57.8 ± 17.4
6-13-2002									
Wizard	95.2 ± 16.0	51.7 ± 5.7	40.2 ± 1.1	37.1 ± 1.3	34.3 ± 0.3	32.6 ± 0.2	31.1		-63.5 ± 16.9
Lexington	83.7 ± 29.9	64.5 ± 39.7	47. ± 19.9	40.8 ± 14.2	34.7 ± 9.5	31.0 ± 6.8	34.2		-53.5 ± 24.3
226	88.8 ± 5.9	57.5 ± 11.5	46.0 ± 1.3	40.9 ± 0.7	32.4 ± 2.1	29.1 ± 3.5	28.5		-61.3 ± 7.3
ALL	89.2 ± 16.2	57.9 ± 19.5	44.4 ± 9.5	39.6 ± 6.7	33.8 ± 2.5	30.9 ± 3.8	31.3 ± 2.9		-59.4 ± 14.4
6-20-2002									
Camelot	90.1	57.0	46.3	37.3	32.6	31.0	29.2	28.3	-61.8
226	97.7 ± 3.3	70.2 ± 3.5	50.7 ± 5.0	42.1 ± 1.6	34.4 ± 0.9	30.3	29.1	27.3	-66.6 ± 2.2
Wizard	90.5 ± 9.2	51.5 ± 12.5	42.3 ± 11.0	36.3 ± 8.3	31.6± 4.1	32.1	31.0		-60.7 ± 10.8
ALL	93.3 ± 6.3	60.0 ± 11.5	46.4 ± 7.3	38.8 ± 5.2	32.9 ± 2.5	31.1 ± 0.9	29.8 ± 1.1	27.8 ± 0.7	-63.2 ± 6.3

Table 2.12: Percentage of peppers removed from shelf life study by cause for removal. *Note: percentages may add up to more than 100% due to the removal of peppers for more than one disorder.

Cultivar	Shrivel	Decay	Visual Appearance
Wizard	6%	72%	67%
Lexington	50%	36%	14%
209	25%	75%	25%
226	9%	48%	30%
Camelot	17%	67%	42%

at low-temperature storage after degreening coupled with a use of fungicides, either on the peppers or in the storage-room environment, could improve shelf stability. An alternative handling regime would be continuation of degreening conditions (20ºC/90% RH) during handling and distribution. During the study, we observed that the greatest cause for loss of quality of fresh red and yellow peppers in the supermarket was due to shriveling, this indicates that methods are already in practice to reduce the incidence of decay seen in our experiment therefore the expected shelf life of the degreened peppers would most likely be longer than indicated by our results. The excellent quality of the red peppers upon completion of degreening suggests that they would be excellent candidates for the processed market. They could be sliced, diced and preserved (e.g. frozen) until needed for further use.

Representative examples of before and after degreening of individual peppers from each Summer 2002 harvest are shown in Figure 2.1. Note the emerging color in the green pepper and the excellent quality of the degreened peppers. The absence of the stem in red pepper in the pictures was due to the development of mold growth on the stem but

Figure 2.1: Examples of before and after degreening of individual peppers from each Summer 2002 harvest (20°C/90% RH).

Harvest 6-7-2002, cultivar Lexington

Harvest 6-13-2002, cultivar 226

Harvest 6-20-2002, cultivar 226

not on the fruit itself. The key to results shown here is harvesting at color break and storage at 90% RH.

Overall, the most important factor during degreening is the maturity level of the bell pepper at harvest. Immature peppers or those just beginning to change color will not degreen properly. Peppers that are picked after color break are the best candidates for degreening. At 20ºC and 90% RH degreening of peppers was observed without loss of quality. As shown above, good quality green bell peppers led to good quality red peppers through controlled degreening.

The second most important factor in the maintaining quality of degreened peppers is the maintenance of the humidity level. Without proper humidity levels peppers rapidly desiccate and decay. The degreening process outlined here will provide red-ripe peppers of acceptable quality for fresh sale or further processing. The shelf life obtained in the study would probably not be sufficient for the demands of wholesale/ retail distribution. However, as stated earlier the typical cleaning operations of the peppers during commercial harvests would probably decrease the presence of mold growth observed in the shelf-life study. More careful control of relative humidity during refrigerated storage would probably reduce the incidence of shriveling, which appears to be the primary cause of postharvest loss of fresh yellow and red pepper. With proper postharvest intervention, acceptable shelf life should be obtained in the fresh market. Although only red cultivars were investigated in this study, we would expect similar results from yellow cultivars.

No hastening of the color development process could be achieved by increasing the temperature or treatment with ethylene. The conditions for degreening (20ºC/90% RH) are readily achievable in a farm environment. While this study clearly establishes that high-quality peppers could be produced from an on-farm degreening operation, it is not clear that such operations could effectively compete in today's marketplace. Quality of the degreened pepper is as good as or superior to fresh red pepper currently available in local supermarket, although observed shelf life was lower than expected. We feel confident that appropriate postharvest interventions could provide an acceptable shelf life for degreened peppers, but a marketing study must be performed to determine the true potential of domestic degreened bell peppers.

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CHAPTER 3

CHEMICAL CONSTITUENTS OF POSTHARVEST DEGREENED BELL PEPPERS (*CAPSICUM ANNUUM*)[1]

[1] Wright, JM., P. Koehler, S.J. Kays, and R.L. Shewfelt. To be submitted to *Journal of Food Quality*

Abstract

Bell peppers are widely used both as a food and as a flavoring for other foods. Bell peppers are consumed both as immature green and mature colored fruits. Differences in maturity result in differences in flavor and nutritional quality. The chemical and nutritional quality characteristics of postharvest degreened bell peppers were studied to show that the expected changes occurred. As expected, ascorbic acid, dry matter, and total soluble solids contents increased with maturation, while titratable acidity and pH decreased. Also as expected, the levels of volatiles detected decreased with maturation. Overall, the degreened bell peppers showed the expected changes in flavor and nutritional chemical characteristics, providing a high quality product.

Introduction

Bell peppers are widely used both as a food and as a flavoring for other foods. Bell peppers are frequently consumed as either immature green or mature colored fruits. Differences in maturity levels result in clear differences in flavor, however the main quality characteristics of Capsicum annuum varieties have long been color and pungency (Luning, Rijk et al. 1994). Recently, however, flavor has become a much more important quality parameter for all fresh fruits and vegetables as consumers become more knowledgeable and demand higher quality produce (Luning, Rijk et al. 1994; Ibanez, Lopez-Sebastian et al. 1998).

The most appreciated flavor related characteristic in fruits is aroma, and the volatile compounds that form fruit flavors are metabolically produced in the fruit during ripening, harvest, post-harvest and storage treatments. The flavor forming volatiles are also affected by factors such as species, variety, and processing (Ibanez, Lopez-Sebastian et al. 1998).

New technologies for extraction of volatiles from complex matrices, such as fruits, may provide a cleared understanding of what volatiles are present in bell peppers to be sensed by humans before, during, and after consumption. Solid phase microextraction (SPME) is a relatively new technique for extraction of volatile compounds for analysis by gas chromatography (GC) (Song, Fan et al. 1998). SPME methods provide a simple, rapid method for volatile extraction from the headspace (HS-SPNE) above a complex food matrix. Other advantages of SPME are solvent elimination, high sensitivity (fiber dependent), small sample volumes, lower costs, and it can easily be used in conjunction with GC or GC/MS (Kataoka, Lord et al. 2000). The limitations of SPME methods include sensitivity, precision, fiber life, and identical fiber replacement (Reineccius 1998).

Studies involving fresh and processed *Capsicum* fruits have yielded more than 125 identified volatile compounds. However, odor evaluation studies on bell pepper volatile compounds have been very limited, thus the impact of these compounds on the aroma is not yet well understood (Luning, Rijk et al. 1994). The objective of the volatile extraction and analysis method used in this research was to show that there are definitive differences between the volatile compounds present in green and red ripe bell peppers. To obtain a cleared understanding of the differences in flavor between green and red-ripe bell peppers, we evaluated the effects of degreening on volatile and nonvolatile contributors to flavor of bell peppers. In addition, since bell peppers are known as an excellent source of vitamin C, we determined the differences in ascorbic acid concentration between green and red bell peppers.

Methodology

Percentage dry matter was determined by the amount of mass lost by 10 g samples after 24 hours at 80°C (Roura, Moreira et al. 2001).

One hundred gram samples were extracted using a home juicer, centrifuged at 2,000 rpm for 5 minutes and then diluted (1:1) with distilled water. The pH of the diluted juice was then measured using a Fisher Scientific Accumet Basic benchtop pH meter (Pittsburgh, PA). The total soluble solids (TTS) content of the sample was determined on the undiluted juice using a Fisher Scientific refractometer (Pittsburgy, PA) and presented as °Brix. Titratable acidity (TTA) was then determined by titrating the dilute sample to pH 8.1 with 0.1N NaOH. The titratable acidity was reported as mg citric acid/100 g sample of pepper (Roura, Moreira et al. 2001).

Ascorbic acid concentration was determined using the titration method described by Pelletier (1985) and the AOAC Official Method 967.21. Fifty gram samples of pepper were ground using a blender and then extracted with 50mL 6% metaphosphoric acid for 3 minutes in a blender. The samples were then made up to 250 mL using 3% metaphosphoric acid and filtered through Whatman 42 filter paper. Five mL aliquots of the filtrate were then titrated using 2, 6 dichloroindophenol (Roura, Moreira et al. 2001).

The volatile compounds from bell pepper samples were extracted using a headspace solid-phase microextraction (HS-SPME) method optimized by Kazmierski et al. (2002). Ten-gram samples were taken from the peppers, diced into ¼ inch pieces, placed into a 40 mL amber vial, and capped with a rubber/plastic screw top. Samples were allowed to equilibrate in a 25°C water bath for 30 minutes prior to volatile extraction. Immediately following this equilibration, the SPME fiber, a fused silica coated with 65 µm Polydimethylsiloxane/Divinylbenzene (PDMS/DVB) on a stable flex fiber (Supelco, Inc., Bellefonte, PA), was used to extract the volatiles from the headspace of the vial. The fiber was cleaned for 20 minutes at 260°C then allowed to cool for 5 minutes before the volatiles were absorbed onto the fiber for 15 minutes. The volatiles were desorbed off of the fiber in the GC injector septum for 20 minutes.

Analysis was conducted on a Hewlett-Packard 5890 Series II gas chromatograph coupled to a FID detector. Volatile compounds were desorbed at the GC injection port equipped with a SPME inlet liner 0.75ID for the entire run time. Compounds were separated using a SUPELCOWAX^{TM} 10 column, 0.25 mm internal diameter, 0.25 μm film thickness column (Supelco, Inc., Bellefonte, PA). The oven temperature was programmed at 50°C for 3 minutes with a subsequent increase to 250°C at 5°C min^{-1}, following the procedure of Ibanez et al. (1997). The nitrogen carried gas at 1 mL/min. The injector and detector temperatures were 270°C and 300°C respectively. Data were acquired and analyzed using interface HP3365 Series II ChemStation (Kazmierski, Logan et al. 2002).

All data was compared using analysis of variance (ANOVA) to determine the differences in means between treatments ($p<0.05$) (Ott and Longnecker 2001).

Data, Results, and Conclusions

Although the mean vitamin C concentrations of the bell pepper samples appear to vary widely. Red bell peppers were higher in ascorbic acid concentration than their green counterparts (Table 3.1). From these results we can see that both green and red peppers are good sources of vitamin C, but that red bell peppers are significantly better sources than their green counter parts. The mean dry matter as a percentage of total weight of the bell pepper samples are displayed on Table 3.2. Red bell peppers had a higher percent dry matter than the green bell peppers.

Table 3.1: Mean vitamin C concentrations (mg ascorbic acid/100g of bell pepper) of bell peppers separated by green stage, red stage, and cultivar

	Mean (mg/100g)
All Green Peppers	152
All Red Peppers	229
Red 209	216
Red 226	187
Red 830	272
Red Camelot	96
Red Crusader	224
Red Lexington	226
Red Sentry	298
Red Sirgalhead	216
Red Stiletto	290
Red Wizard	209
Green 830	169
Green Crusader	145
Green Sentry	153
Green Sirgalhead	200
Green Stiletto	85

Note: The mean ascorbic acid concentration for all green peppers is significantly different from the mean ascorbic acid concentration for all red peppers. There was no significant difference between the varieties within the red and green groups.

Although the mean total soluble solids (TTS) are similar, the mean TTS (°Brix) between red and green bell peppers is significantly different (Table 3.3). The higher TTS of the red bell peppers is probably due to the increase in glucose and fructose seen as the peppers ripen. Red bell peppers exhibited a lower pH than green bell peppers (Table 3.4).

The citric acid concentration increased as the bell pepper is degreened (Table 3.5), explaining the accompanying decline in pH. Thus red peppers have a higher concentration of citric acid than green bell peppers.

Figure 3.1 shows the chromatographic peak heights for green and red samples of bell pepper samples, cultivar Lexington. The most obvious result is that the

Table 3.2: Mean percent dry matter of bell peppers separated by green stage, red stage, and cultivar.

	Mean
All Green Peppers	5.57%
All Red Peppers	6.37%
Red 209	6.10%
Red 226	6.13%
Red 830	6.91%
Red Camelot	5.89%
Red Crusader	6.58%
Red Lexington	6.36%
Red Sentry	5.68%
Red Sirgalhead	6.39%
Red Stiletto	6.48%
Red Wizard	6.18%
Green 830	6.53%
Green Crusader	5.29%
Green Sentry	4.86%
Green Sirgalhead	6.14%
Green Stiletto	4.32%

Note: The mean percent dry matter all green peppers is significantly different from the mean percent dry matter for all red peppers. There was no significant difference between the varieties within the red and green groups.

Table 3.3: Mean °Brix for bell peppers separated by green stage, red stage, and cultivar

	Mean
All Green Peppers	1.341
All Red Peppers	1.342
Red 209	1.341
Red 226	1.341
Red 830	1.342
Red Camelot	1.341
Red Crusader	1.342
Red Lexington	1.342
Red Sentry	1.341
Red Sirgalhead	1.342
Red Stiletto	1.343
Red Wizard	1.342
Green 830	1.342
Green Crusader	1.341
Green Sentry	1.340
Green Sirgalhead	1.342
Green Stiletto	1.338

Note: The Mean °Brix for all green peppers is significantly different from the mean °Brix for all red peppers. There was no significant difference between the varieties within the red and green groups.

Table 3.4: Mean pH for bell peppers separated by green stage, red stage, and cultivar

	Mean
All Green Peppers	5.81
All Red Peppers	5.20
Red 209	5.17
Red 226	5.21
Red 830	5.20
Red Camelot	5.09
Red Crusader	5.23
Red Lexington	5.16
Red Sentry	5.43
Red Sirgalhead	5.28
Red Stiletto	5.16
Red Wizard	5.23
Green 830	5.32
Green Crusader	5.80
Green Sentry	5.97
Green Sirgalhead	5.45
Green Stiletto	6.98

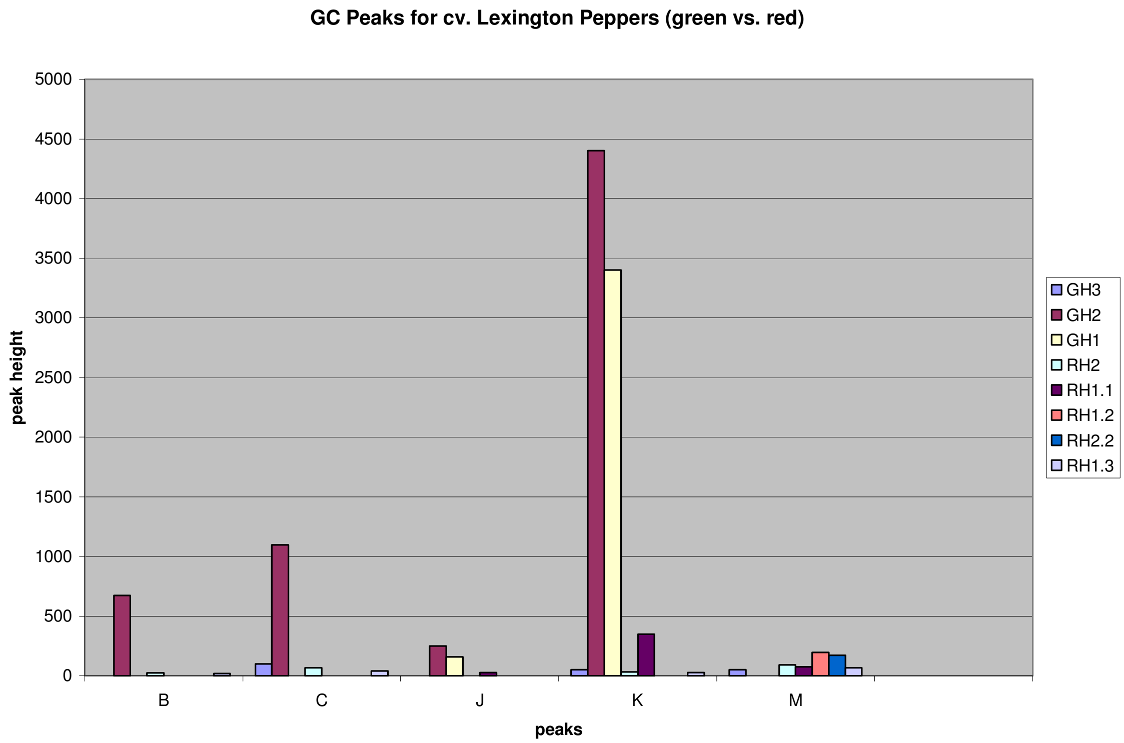
Note: The mean pH for all green peppers is significantly different from the mean pH for all red peppers. There was no significant difference between the varieties within the red and green groups.

Table 3.5: Mean concentration of citric acid (g citric acid/100 g of bell pepper) for bell peppers separated by green stage, red stage, and varieties.

	Mean
All Green Peppers	32
All Red Peppers	77
Red 209	88
Red 226	68
Red 830	79
Red Camelot	85
Red Crusader	69
Red Lexington	72
Red Sentry	83
Red Sirgalhead	87
Red Stiletto	143
Red Wizard	68
Green 830	50
Green Crusader	19
Green Sentry	29
Green Sirgalhead	36
Green Stiletto	9

Note: The mean citric acid concentration for all green peppers is significantly different from the mean citric acid concentration for all red peppers. There was no significant difference between the varieties within the red and green groups.

Figure 3.1: GC peak heights for green and red samples of C. annuum cv. Lexington



*Peaks are equivalent to the following retention times (minutes): Peak B, 2.75-2.76; Peak C, 2.81-2.83; Peak J, 13.47-13.50; Peak K, 13.82-13.85; and Peak M, 17.30-17.33.

concentration of volatiles decreases as the bell peppers ripen. This is as expected, particularly since most of the obvious aromatic characteristics of green bell peppers disappear or are at least noticeably decreased in the ripe red bell peppers. These results also show significant differences in the volatile profiles of red and green bell peppers.

Overall, these results show that the chemical constituents of flavor change during ripening. More importantly, these results show that the expected changes in flavor constituents are seen in the peppers degreened in our project.

These results show that the bell peppers could be produced, harvested early and degreened postharvest and provide a high quality product with the appropriate flavor and nutritional qualities. Currently, field production of bell peppers in the United States is very low, with a small amount being grown in Florida and California. The majority of the colored bell peppers sold in the U.S. are hothouse grown in Holland and Canada (and more recently Israel). Our degreening method would allow growers to produce this relatively high value crop without the extreme losses that currently prevent growers (particularly in Georgia) from producing colored bell peppers in their fields. Retailers could possibly offer these degreened peppers at a lower price than the current imported color crops. Consumers could expect flavorful and nutritious degreened bell peppers of the same quality as they now have in the imported peppers, possibly at a lower cost.

However, this research did not include an economic assessment of the feasibility of on-farm degreening, nor did it include any sensory or consumer testing. Both of these types of assessments would need to be completed before initiating this process commercially.

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CHAPTER 4

OVERALL SUMMARY

The bell pepper is becoming increasingly economically important in the crop production of the United States. Colored bell peppers are also increasing in economic importance, mainly because they make up a large portion of the peppers imported to the U.S. Colored bell peppers command a higher price on the wholesale market and it would be economically beneficial if the proceeds went to U.S. growers. In particular, colored peppers are in demand as ingredients in processed foods as well as in food service.

Our procedure results in high quality colored bell peppers which could be sold on the fresh market or processed. We determined that the most critical factor determining the potential for degreening is maturity at harvest, which we determined based on percent coloration. In order to maintain high quality fruits throughout the degreening process, the relative humidity levels must be maintained. Our degreeening procedure could easily be done in an on-farm environment.

The most important factor in degreening is the maturity level of the bell pepper at harvest. Immature peppers or those just beginning to change color will not degreen properly. Peppers that are picked after color break are the best candidates for degreening. At 20ºC and 90% RH degreening of peppers was observed without loss of quality. Acceptable quality was maintained throughout the degreening process.

The second most important factor in the maintaining quality of degreened peppers is the maintenance of the humidity level. Without proper humidity levels peppers rapidly desiccate and decay. The degreening process outlined here will provide red-ripe peppers of acceptable quality for fresh sale or further processing. The shelf life obtained in the study would probably not be sufficient for the demands of wholesale/ retail distribution. However, as stated earlier the typical cleaning operations of the peppers during commercial harvests would probably decrease the presence of mold growth observed in the shelf-life study. More careful control of relative humidity during refrigerated storage would probably reduce the incidence of shriveling, which appears to be the primary cause of postharvest loss of fresh yellow and red pepper. With proper postharvest intervention, acceptable shelf life should be obtained in the fresh market. Although only red cultivars were investigated in this study, we would expect similar results from other colored cultivars.

Ethylene treatments did not affect the degreening process. While this study clearly establishes that high-quality peppers could be produced from an on-farm degreening operation, it is not clear that such operations could effectively compete in today's marketplace. Quality of the degreened pepper appeared to be as good as or superior to fresh red pepper currently available in local supermarket, although observed shelf life was lower than expected. We feel confident that appropriate postharvest interventions could provide an acceptable shelf life for degreened peppers

Overall, our results showed that the chemical constituents of flavor changed during the degreening process. More importantly, these results show that the expected changes in flavor constituents are seen in the peppers degreened in our project.

These results show that the bell peppers could be produced, harvested early and degreened postharvest and provide a high quality product with the appropriate flavor and nutritional qualities. Currently, field production of bell peppers in the United States is very low, with a small amount being grown in Florida and California. The majority of the colored bell peppers sold in the U.S. are hothouse grown in Holland and Canada (and more recently Isreal). Our degreening method would allow growers to produce this relatively high value crop without the extreme losses that currently prevent growers (particularly in Georgia) from producing colored bell peppers in their fields. Retailers could possibly offer these degreened peppers at a lower price than the current imported color crops. Consumers could expect flavorful and nutritious degreened bell peppers of the same quality as they now have in the imported peppers, possibly at a lower cost.

However, our research did not include an economic assessment of the feasibility of on-farm degreening, nor did it include any sensory or consumer testing. All of these types of assessments would need to be completed before initiating this process commercially.