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I am submitting herewith a thesis written by Robert José Portillo (Quintero) entitled "Chemical, Physical, And Sensory Attributes of Applesauce Processed From Apples Pressure Infiltrated With Calcium Chloride Prior To Storage." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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Date December 1991

CHEMICAL, PHYSICAL, AND SENSORY ATTRIBUTES OF APPLESAUCE PROCESSED FROM APPLES PRESSURE INFILTRATED WITH CALCIUM CHLORIDE PRIOR TO STORAGE

A Thesis
Presented for the
Master of Science
Degree
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Robert José Portillo Quintero

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DEDICATORIA

Yolanda, tù me has dado el cuidado y la proteción propios de mamá. Tù me has inculcado historia y letras. Tù me has dado amor infinito.

Heberto, tù me has dado los consejos y el apoyo propios de papá. Tù me has llenado de poesía y filosofía. Tù me has dado amistad eterna.

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Juntos me han colmado la vida con el obsequio más preciado: mi educación y mi formación.

Este pequeno librito no es más que el símbolo de la culminación de mi educación y de mi formación en lo que respecta a lo académico. Las otras facetas de mi formación no terminarán mientras los tenga a ustedes para que me sigan dando, para que me sigan colmando. Por eso les dedico no sólo este librito sino también todo aquello que he logrado.

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ABSTRACT

The purpose of this research was to determine: (1) the attributes of apples and applesauce processed from 'Golden Delicious' (GD) or 'Red Rome' (RR) apples (Malus domestica Borkh) pressure-infiltrated with $CaCl_2$ prior to storage and (2) the attributes of apples and applesauce processed from a blend of GD and RR apples pressure-infiltrated with $CaCl_2$ prior to storage. Calcium (Ca) content, firmness, and soluble solids content were measured on fresh fruit. Quality of sauce was determined with physical analyses and sensory evaluations.

In the first experiment, firmness of GD and RR increased as the percentage $CaCl_2$ increased at the four storage times. Ca treatment did not affect soluble solids content. Ca content of sauce processed from GD fruit ranged from 330 (0% $CaCl_2$) to 1150 (4% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1}, while Ca content of RR sauce ranged from 230 (0% $CaCl_2$) to 560 (8% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1}. Consistency of GD and RR sauce increased (flowed less) as Ca increased. The amount of free liquid of GD and RR sauce was not affected by Ca but increased as storage increased. Hunter '-a' values of GD sauce decreased (became less green) as Ca increased. Hunter 'b' values increased (became more yellow) as Ca increased up to 800 $\mu g \cdot g$ dry wt^{-1}. Hunter 'L' values of RR sauce increased (became lighter) as Ca increased. Apparent viscosity of GD and RR sauce increased as Ca increased. A sensory panel evaluated color, off-flavor, consistency and

overall acceptability of sauce. GD sauce was judged lighter and RR sauce judged darker as Ca increased. Panelists detected off-flavors in GD sauce when Ca increased above 800 $\mu g \cdot g$ dry wt^{-1}, and for RR off-flavors decreased as Ca increased. GD and RR sauce became thicker as Ca increased. GD and RR showed optimum acceptability when Ca approached 450 $\mu g \cdot g$ dry wt^{-1}.

In the second experiment, Ca of GD fruit ranged from 190 (0%) to 290 (4%) $\mu g \cdot g$ dry wt^{-1}, while Ca of RR fruit ranged from 230 (0%) to 380 $\mu g \cdot g$ dry wt^{-1} (8%). Firmness of GD and RR increased as Ca and storage increased at both times. Soluble solids content was not affected by Ca treatment. Ca content of sauce made from a blend of GD and RR ranged from 165 (0% $CaCl_2$ GD mixed with 0% $CaCl_2$ RR) to 280 $\mu g \cdot g$ dry wt^{-1} (4% $CaCl_2$ GD mixed with 8% $CaCl_2$ RR). Consistency values increased (flowed less) as Ca and storage time increased, while amount of free liquid was not affected by Ca content or storage time. Hunter 'L' values of blended sauce increased (became lighter) as Ca and storage time increased. Apparent viscosity increased as Ca and storage time increased. A sensory panel evaluated color, off-flavor, consistency, and overall acceptability of the sauce. The blended sauce became lighter as Ca increased. Intensity of off-flavors of sauce made from apples stored 2 months decreased as Ca increased. However, sauce from fruit stored 4 to 6 months showed increased intensity of off-flavors as Ca increased. Consistency increased as Ca increased. Overall acceptability increased slightly as Ca increased.

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INTRODUCTION

A primary goal of the apple industry is to offer consumers fresh and processed products of excellent quality. The apple industry faces the task of maintaining satisfactory quality of apples for the general public throughout the apple season and during the off-season.

Usually, apples are stored at 0°C to extend shelf life of fresh apples for processing later during the season (Massey, 1989). Technological advances make possible the use of controlled-atmosphere storage. When apples are held in controlled-atmosphere storage, carbon dioxide and ethylene (the respiratory gases which influence ripening and senescence of the fruit) are monitored and controlled, allowing apples to maintain acceptable quality for longer periods than if they are held in standard cold rooms (Smock, 1979). This technique is expensive, and alternative methods of preserving the quality of stored fruit are needed.

Postharvest calcium (Ca) treatments prevent numerous storage disorders (Shear, 1975; Bangerth, 1979), maintain firmness (Betts and Bramlage, 1977; Poovaiah and Shekhar, 1978), and reduce the process of ripening and senescence of apples (Scott and Wills, 1977). Such postharvest treatments in combination with storage in standard cold rooms permit the fruit to maintain quality for longer periods of time without the cost associated with controlled-atmosphere storage.

The importance of preserving quality of apples is related, not only to the marketability of the fresh fruit, but also to the quality of processed products prepared from the apples. The positive effects of postharvest Ca treatments on fresh fruit are transmitted to the quality of processed products (Drake and Spayd, 1983; Laufmann, 1989). Quality of products prepared from Ca-treated apples can be determined by both laboratory analyses and sensory evaluation. Sensory evaluation studies have included such apple products as pies, sauces and other canned products. These studies demonstrated the effect of cultivar, storage conditions, and harvesting time on quality of the products (Stirton and Hills, 1950; Wiley and Toldby, 1960; Hayakawa et al., 1978; McLellan et al., 1984).

This thesis includes four major sections. The first section is a review of literature pertinent to the research. The second section reports the effect of postharvest Ca treatment on quality of sauce processed from individual cultivars of apple. Both, quantitative physical analyses and sensory evaluations are included. The third section reports the effect of postharvest Ca treatment on physical and sensory attributes of sauce made from a blend of two apple cultivars. The sauce was processed, using techniques comparable to those used by commercial processors. The fourth section is the appendix that includes data collected for the study and a description of procedures used.

I. LITERATURE REVIEW

Role of calcium in plants

(a) Calcium nutrition

The importance of calcium (Ca) in plant nutrition has been documented (Marschner, 1986). Calcium is an integral component of the structure of cell walls and participates actively in many enzymatic processes.

Among the macronutrients necessary for plant survival, Ca has a unique role. Calcium regulates the rate of absorption of other ions such as K^+ and NO_3^- by inhibiting effects of Na^+ on uptake of these ions (Epstein, 1988). Also, Ca regulates soil pH by neutralizing acids present in the soil (McLean, 1975).

Once in the plant system, the function of Ca becomes more involved and complex. Calcium performs a crucial role in cell structure and integrity (Kirkby and Pilbeam, 1984) and is located primarily in the cell wall where it bonds pectic polymers, the major components of middle lamella (Ferguson, 1984). Calcium acts as an ionic bridge between pectic polymers by attracting the negative carboxyl groups of two different chains with its double positive charge. The Ca bridge holds pectic polymers closer together, making the cell wall more rigid (Ferguson, 1984; Kirkby and Pilbeam, 1984; Brady, 1987). Calcium also stabilizes the cell membrane by bridging phospholipids and proteins at the cell membrane surface (Legge et al., 1982). Thus, Ca acts to maintain cell integrity.

Calcium functions as coordinator of a number of metabolic processes. Along with other compounds, Ca regulates activity of enzymes such as amylase, phospholipase, and ATPase (Marschner, 1986). However, Ca inhibits activity of enzymes such as hexodiphosphatase and PEP carboxylase (Christiansen and Foy, 1979; Kirkby and Pilbeam, 1984; Marschner, 1986). Huber (1983) suggested that low levels of bound Ca in the cell wall caused an increase in galacturonase activity. Pectin esterase activity increases with increasing Ca due to pH increases (Bartley and Knee, 1982).

(b) Ripening and senescence

Among the processes involved in ripening and senescence of fruits, softening is one of great importance (Brady, 1987). The role of Ca in decreasing softening and its connection with ripening are documented (Ferguson, 1984). A relatively high Ca content in apples contributes to firmer fruit which, in turn, decreases susceptibility of the fruit to disease and reduces the rate of ripening and senescence.

Other metabolic processes such as respiration and ethylene production are associated with regulation of ripening and senescence events. High Ca concentration (110 ppm or higher) in apple flesh maintains stable rates of fruit respiration, whereas, fruit containing less than 110 ppm Ca have increased rates of CO_2 production (Faust and Shear, 1972). High respiration rates initiate numerous cellular disorganization events such as disintegration of mitochondria, endoplasmatic reticulum, and cytoplasmatic membranes. Therefore, Ca also functions to preserve cellular organization by stabilizing rates of respiration (Faust and Shear, 1972).

The leaking of solutes from apple tissue due to increased permeability of the cell wall is related to ripening and senescence. Calcium inhibits enzymes that hydrolyze cell wall material that induce softening, leakage of solutes, and senescence of the fruit (Brady, 1987).

Calcium participates in various physiological processes in association with calmodulin, the best known Ca binding protein (Poovaiah and Reddy, 1987). As a messenger or controller substance, Ca influences hormonal actions, secretory processes, cellular division, cationic transport, photosynthesis, physiological disorders, and many other processes. As calmodulin binds with Ca it undergoes a series of conformational changes, transforming it from an inactive to an active form. Active calmodulin then interacts with other proteins and enzymes to regulate physiological processes. The Ca-calmodulin complex regulates such enzymes as NAD kinases, ATPases, oxidoreductases, and protein kinases.

Calcium and fresh fruit quality

(a) Extension of storage life

Postharvest treatments of 'Stayman' and 'Delicious' apples with calcium chloride ($CaCl_2$) resulted in higher quality fruit than untreated apples after 5 to 6 months in storage at 0°C (Hardenburg and Anderson, 1981). Scott and Wills (1975) and Mason (1976) studied the effects of Ca treatment on quality of apple cultivars. They found that such treatments reduced the rate of softening, decreased the incidence of storage breakdown, and increased shelf life of the apples.

Occurrence of internal breakdown is a limiting factor in extending storage life of apples. Postharvest application of Ca reduced the incidence of internal breakdown in 'Jonathan', 'Cox's Orange Pippin', and 'Twenty Ounce' apples (Scott and Wills, 1975).

(b) Disorder prevention

Shear (1975) suggested that even though disorders such as bitter pit, cork spot, water core, lenticel breakdown, internal breakdown, senescence breakdown, and others are promoted by environmental conditions and cultural practices, these disorders may also be related to Ca nutrition. These disorders may occur from Ca-rich soils if the Ca distribution within the plant is poor (Bangerth, 1979).

Postharvest Ca treatment in apples proved to be effective in controlling decay due to fungal invasion. Conway and Sams (1983) found that $CaCl_2$-treated apples inoculated with Penicillium expansum were affected less by decay than untreated fruit. Severity of decay was measured by calculating the area of decay at the inoculation sites. These authors also found that fruit treated with the highest $CaCl_2$ concentration used in their experiments had a higher Ca content in the cell wall than fruit treated with lower levels of Ca (Conway and Sams 1987).

Another disorder related to Ca deficiency is storage breakdown. Perring et al. (1985) found that slices of 'Cox's Orange Pipping' apples with storage breakdown had lower Ca concentration than healthy fruit from the same source. The amount of Ca in the core zone was also lower than the amount of Ca in the core of sound fruit. Dipping 'Jonathan' apples in $CaCl_2$ solutions prior to storage reduced the development of internal breakdown significantly (Bangerth et al., 1972). Similar results occurred in 'Cox's Orange Pippin' and 'Twenty Ounce' apples after a postharvest $CaCl_2$ dip (Scott and Wills, 1979).

(c) Parameters used to measure apple quality

Basic parameters useful in measuring apple quality are those which are obvious to consumers such as fruit texture and color. Calcium affects both firmness and color of fresh apples. Mason et al. (1974) increased the firmness of 'Spartan' apples by 3.73 N (0.38 kg) using a $CaCl_2$ dip immediately after harvest. A similar postharvest Ca dip reduced softening of 'McIntosh' apples. Treated fruit were 2.94 N (0.3 kg) firmer than untreated fruit after four months in cold storage (Mason et al., 1975). In a follow-up study, Mason (1976) showed that effects of Ca treatment increased as storage periods increased. Apples treated at harvest were 5.1 N (0.52 kg) firmer than untreated fruit after 4 months storage and 7.16 N (0.73 kg) firmer after 5 months storage (Mason, 1976). 'Golden Delicious' apples infiltrated after harvest with $CaCl_2$ yielded textural profiles that indicated an increase in firmness and compression strength of the fruit which seemed to persist during storage (Abbot et al., 1989).

Using an Agtron colorimeter, Drake and Spayd (1983) showed that Ca-treated apples had a lighter color than untreated apples after 5 months storage.

(d) Methods of extending storage and preserving quality

Many methods exist for extending storage of apples while preserving quality of the fruit. Some of these methods are used in combination with postharvest Ca treatment to enhance its effects. As an example, Ca-dipped 'Anna' and 'Granny Smith' apples were held at 38°C for 4 days before storage at 0°C. The heat treatment yielded firmer apples than the untreated fruit upon removal from storage, but yellowing of skin and loss of acidity due to the heat treatment were not controlled by the Ca treatment (Klein et al., 1990). Use of controlled atmosphere storage (CA) is common in the apple industry because it allows fruit to remain in storage for longer periods of time by decreasing O_2 concentration and increasing CO_2 in the storage atmosphere. Drake et al. (1979) observed the effects that CA had on quality of applesauce made from apples held in CA storage. They reported that the yield of applesauce from apples in CA was less than that of apples in cold storage. However, they found that color of the sauce from CA apples was similar to color of apples held in cold storage (Drake et al., 1979). The effect of CA and Ca treatment on decay was investigated by Sams and Conway (1985). They demonstrated that the effects of the Ca treatment and the CA storage were similar, regarding both the decay caused by Penicillium expansum and the firmness of the fruit immediately after storage. However, after holding the apples for 3 days at

20°C, rate of decay of the Ca-treated fruit was lower than that of either fruit held in CA or the untreated fruit (Sams and Conway, 1985). In a follow-up study, Sams and Conway (1987) determined that untreated fruit held in CA storage was firmer and had less decay than either $CaCl_2$-treated fruit held in 0°C normal-atmosphere or untreated fruit held at 0°C after 3 months. However, the combination of $CaCl_2$ treatments and CA storage yielded firmer apples with less decay than $CaCl_2$ treatment or CA storage alone. Apples held in CA storage showed a sharp decrease in ethylene production when the highest $CaCl_2$ treatment was used (Sams and Conway, 1987).

Increasing calcium content of apples

(a) Field applications

Numerous methods have been explored to increase levels of Ca in trees and fruit tissue. Addition of calcium nitrate ($Ca(NO_2)_3$) directly to the soil controlled bitter pit in apples grown on clayey soils saturated with Mg and K (Mason, 1979). Frequent applications of $CaCl_2$ achieved elevated levels of water soluble Ca in the root zone, reducing Ca deficiency problems (Mason, 1979). Often, Ca deficient soils are fertilized with lime as the level of Ca decreases due to leaching (McLean, 1975). But the effect of liming does not guarantee an increase in Ca uptake by the plant because of the presence of high levels of Mg, Na, and K (Wiersum, 1979). In addition to the uncertainty of Ca uptake by the plant, application of Ca directly to the soil does not guarantee Ca uptake evenly throughout all plant parts. Evidence indicates that Ca moves in plants from the roots to the above ground parts primarily through the xylem by ion exchange and that distribution of Ca to leaves and fruit is dependent on the transpiration stream (Hanger, 1979). Normally, Ca uptake of young developing fruit is adequate, but as the rate of growth increases the phloem becomes the major supplier of nutrients and water. This phenomenon causes the amount of Ca supplied to fruit to diminish and thus the concentration of developing fruit decreases (Hanger, 1979). Consequently, other methods of increasing Ca level of fruit become necessary.

Foliar sprays have been fairly effective for supplying Ca to plants. However, poor translocation limits the movement of Ca into fruit (Hanger, 1979). Diluted $Ca(NO_3)_2$ and concentrated $Ca(NO_3)_2$ and $CaCl_2$ sprays, applied over a period of time, reduce storage breakdown and increase firmness of 'Spartan' apples. Several late season sprays, applied directly to the fruit, proved more efficient than early sprays but less efficient than a single application of a concentrated spray of $CaCl_2$ just before harvest (Mason, 1979). Bramlage et al. (1985) found that $CaCl_2$ spray applications at two-week intervals beginning three weeks after petal-fall increased Ca content and reduced senescent breakdown of 'McIntosh' apples.

Four weekly applications of $CaCl_2$ just before harvest significantly increased Ca concentration of 'Golden Delicious' apples (Neilsen et al., 1985). They also found that injecting $CaCl_2$ directly into the trunks of 'Golden Delicious' apple trees did not increase Ca concentration of the fruit. This finding emphasized the problem of poor translocation of Ca to fruit.

(b) Postharvest applications

Postharvest applications are efficient for introducing Ca into fruit. The most commonly used methods are dipping, temperature differential infiltration, partial vacuum infiltration and pressure infiltration.

Dipping apples in Ca solutions was reported in the early 1970's. Mason et al. (1974) used $CaCl_2$ dips to increase Ca concentration of 'Spartan' apples by 76 ppm. Similar studies showed that 4% $CaCl_2$ dips increased the Ca level of 'Spartan' apples and as storage time increased, the Ca migrated from the fruit surface to the inner tissue (Mason and Drought, 1975). Betts and Bramlage (1977) used Ca dips and increased Ca concentration by 60 to 100 ppm in different cultivars of apples. Calcium dips are most efficient when used in conjunction with surfactants and thickeners. The additives allowed greater amounts of Ca to penetrate the apples and improved penetration and distribution across the fruit surface

(Mason, 1979; Johnson, 1979).

Hydrocooling was used by Lee and Dewey (1981) to infiltrate Ca into 'Jonathan' apples. The process involved lowering temperature of the Ca solution and increasing fruit temperature before the Ca treatment. Penetration of the solution into the fruit was caused by a positive pressure differential between the atmosphere and the intercellular spaces of the fruit tissue. Infiltration of $CaCl_2$ solution was enhanced with surfactants (Lee and Dewey, 1981).

Johnson (1979) submerged apples in $CaCl_2$ solutions under partial vacuum and increased Ca concentration of the fruit by 138 ppm, whereas Ca concentration of apples dipped at atmospheric pressure was increased by only 51 ppm. The partial vacuum-infiltrated fruit were firmer than fruit dipped at atmospheric pressure and exhibited few signs of bitter pit after being held in cold storage. Scott and Wills (1977) used partial vacuum of 650-110 mm Hg to infiltrate $CaCl_2$ into apples. This treatment prevented bitter pit and improved firmness. One benefit this method had over dipping at atmospheric pressures was that the solution could be rinsed off after treatment. Rinsing eliminated risk of injury on the skin from excess Ca without removing the Ca already infiltrated (Mason, 1979).

Pressure infiltration is an effective method of introducing Ca into fruit. Instead of using partial vacuum, pressure is used to force the Ca solution into the apples.

Drake and Spayd (1983) treated 'Golden Delicious' apples with a 3% $CaCl_2$ solution in a sealed chamber at 34.47 kPa (5 psi) for 8 min. They found that storage quality of the fruit was improved and products prepared from the apples exhibited excellent color and texture. The storage quality was improved, in part, because of a decline of ethylene production. Pressure infiltration of $CaCl_2$ solution up to 12% immediately after harvest lowered the rate of ethylene production in 'Golden Delicious' apples during a storage period of seven days at 20°C (Sams and Conway, 1984). Level of maturity at harvest proved to be a limiting factor in effectiveness of infiltrating $CaCl_2$ under pressure into apples. Apples picked after optimum maturity occurred had greater uptake of Ca and developed less decay after being inoculated with <u>Penicillium expansum</u> than fruit harvested before or at optimum maturity (Conway and Sams, 1985). Drake and Fridlund (1986) studied effects that pressure infiltration of a 3% $CaCl_2$ solution had on 'Golden Delicious' and 'Lord Lambourne' apples as compared to a 3% $CaCl_2$ dip. They found that the storage quality of the pressure infiltrated apples was enhanced, whereas, storage quality of the dipped apples was similar to that of untreated fruit. 'Golden Delicious' apples pressure infiltrated with $CaCl_2$ at harvest possessed more desirable textural attributes than untreated fruit after 6 months in cold storage (Abbot et al., 1989).

(c) Different Calcium Sources

Different forms of Ca have been examined in preharvest and postharvest treatments to increase Ca level of apple fruit. Comparison among $CaCl_2$, calcium phosphate ($CaHPO_4 \cdot 2H_2O$), and calcium chelate applied as foliar sprays to 'McIntosh' trees showed that both $CaCl_2$ and calcium chelate increased fruit Ca concentration and reduced senescent breakdown, while $CaHPO_4 \cdot 2H_2O$ only increased P level and reduced superficial scald (Bramlage et al., 1985). Effectiveness of other divalent cations for improving apple quality was investigated. A study in which 'Delicious' apples were pressure-infiltrated with $CaCl_2$, magnesium chloride ($MgCl_2$), and strontium chloride ($SrCl_2$) at harvest showed that the Ca ion was the optimum cation for reducing decay, maintaining firmness, and decreasing ethylene production after the apples had been placed in storage for five months (Conway and Sams, 1987).

Calcium and processing quality of apples

(a) Quality parameters of different apple products

The amount of Ca in apples affects quality of fresh fruit and, therefore, quality of products made from the fruit. Use of Ca salts prior to processing of apple slices increased firmness and resistance to breakdown due to heat of baking

(Collins and Wiley, 1963). Applesauce and apple slices made from apples pressure-infiltrated with $CaCl_2$ displayed superior quality parameters than products made from apples held in cold storage or CA storage (Drake and Spayd, 1983). Applesauce prepared from Ca-treated apples was lighter in color than sauce prepared from apples held in cold storage. Also, the sauce had more acceptable consistency than sauce prepared from untreated fruit after a week in cold storage. Apple slices prepared from Ca-treated fruit were firmer than slices made from untreated fruit (Drake and Spayd, 1983). Laufmann (1989) found that applesauce made from Ca-treated apples had greater consistency and was darker than sauce made from untreated fruit. Juice prepared from Ca-treated fruit was lighter than juice made from untreated fruit (Laufmann, 1989).

(b) Sensory evaluation

Sensory studies for evaluating quality of apples treated with postharvest Ca treatments and their products are limited. Szczesniak et al. (1975) modified the sensory texture profile technique which involved participation of trained panelists, into the consumer profile technique allowing for participation of untrained consumers. This technique provided for quantitative description of products under investigation based on the panelists perception of the product quality by the use of an evaluation scale. This method was adapted to other areas of sensory analysis including evaluation of flavor, color, and aroma. A sensory panel evaluated the flavor of apple pies made from fruit of summer, fall, and winter cultivars treated with diluted Ca salt solutions to preserve texture of the slices during cooking. The results indicated that Ca salts, as applied to softer cultivars for the purpose of preserving firmness during cooking, did not affect flavor (Stirton and Hills, 1950). Sensory evaluation studies on canned apple slices have been conducted to determine quality after one year of storage at different temperatures. The trained panel determined that overall sensory quality of canned products held at 38°C for one year was lower than that of canned products held at -29.0, 2.0, 4.5, or 21.0°C (Hayakawa et al., 1978). Another sensory evaluation study investigated sensory components responsible for differences in perception of products made from different cultivars and their blends (McLellan et al., 1984). Approximately 85% of the variation in perception among applesauce of different cultivars was found related to aroma, sweetness, color, and texture.

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II. QUALITY OF APPLESAUCE PROCESSED FROM 'GOLDEN DELICIOUS' OR 'RED ROME' APPLES PRESSURE INFILTRATED WITH CALCIUM CHLORIDE PRIOR TO STORAGE

Abstract

'Golden Delicious' and 'Red Rome' apples (Malus domestica Borkh) were pressure infiltrated at 69 kPa (10 psi) with 0, 1, 2, 3 or 4% ('Golden Delicious') and 0, 2, 4, 6 or 8% $CaCl_2$ ('Red Rome') solutions (w/v) and placed in 0°C storage. Quality parameters of treated fruit and applesauce made from the fruit were evaluated after 0, 2, 4 and 6 months in storage. Firmness of 'Golden Delicious' and 'Red Rome' fruit increased as the percentage $CaCl_2$ in the treatment solution increased at the four storage times. Soluble solids content was not affected by the Ca treatment. The Ca content of the sauce processed from 'Golden Delicious' ranged from 330 (0% $CaCl_2$) to 1150 (4% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1} while the Ca content of the sauce processed from 'Red Rome' ranged from 230 (0% $CaCl_2$) to 560 (8% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1}. Consistency of applesauce increased as Ca content increased in the sauce that was prepared from both cultivars. Amount of free liquid of the sauce of both cultivars was not affected by Ca content, but increased as time in storage increased. Hunter '-a' values of the 'Golden Delicious' sauce decreased (became less green) as

Ca content increased; Hunter 'b' values of the sauce increased (became more yellow) as the Ca content of the sauce increased to 800 $\mu g \cdot g$ dry wt^{-1}. Hunter 'L' value of 'Red Rome' sauce increased (became lighter) as Ca increased. The viscosity of 'Golden Delicious' and 'Red Rome' sauces increased as Ca increased.

A sensory panel evaluated the sauce for color, flavor, consistency, and overall acceptability. 'Golden Delicious' sauce became lighter and 'Red Rome' sauce became darker as Ca increased. The panelists detected off-flavors in 'Golden Delicious' sauce with greater than 800 $\mu g \cdot g$ dry wt^{-1} Ca. Intensity of off flavors decreased for the 'Red Rome' sauce as Ca increased. 'Golden Delicious' and 'Red Rome' sauces became thicker as Ca increased. Acceptability of 'Golden Delicious' and 'Red Rome' sauces was optimum when the Ca content of the sauce reached approximately 450 $\mu g \cdot g$ dry wt^{-1}.

Introduction

Postharvest Ca treatment of apples prolongs storage life and preserves fruit quality (Betts and Bramlage, 1977; Sams and Conway, 1984). There are different methods for applying Ca in postharvest treatments. These methods include dipping (Bangerth et al., 1972; Mason et al.,1975), partial vacuum infiltration (Mason, 1979; Johnson, 1979), and pressure infiltration (Sams and Conway, 1985). An increase of Ca in the fruit tissue reduced the rate of ripening and senescence (Bangerth et al., 1972; Mason et al., 1975), increased fruit firmness (Mason, 1976; Johnson, 1979; Conway and Sams, 1983), and prevented storage disorders (Shear, 1975; Bangerth, 1979). Also, controlled atmosphere storage (CA) can be used to maintain fruit quality. However, CA storage involves sophisticated technology which is expensive to implement and is not available in some parts of the world (Pantastico, 1975; Massey, 1989).

Quality of products such as applesauce is affected by quality of the fresh fruit used to prepare the products. Attributes such as cultivar, maturity, firmness, and soluble solids affect sauce quality directly (LaBelle et al., 1960; Massey, 1989). Handling and storage methods used prior to processing also influence quality of the final product. Apples held in CA storage yielded lower grade applesauce (Drake et al., 1979). Postharvest Ca infiltration performed prior to cold storage extended storage life of apples. Pressure infiltration of $CaCl_2$ extended storage life and maintained quality of "Golden Delicious" apples and improved quality of products prepared from these apples (Drake and Spayd, 1983).

Quality attributes of apple products processed from Ca-treated fruit can be evaluated by chemical and physical techniques in the laboratory. However, sensory responses of people can also be utilized to evaluate quality. Sensory evaluation of product quality is important because it estimates directly the opinion of consumers. Sensory evaluations of apple products processed from experimental treatments have been reported previously. Apple slices made from postharvest heat treated apples were found to be firmer by a sensory panel (Lidster et al., 1979). Wiley and Toldby (1960) reported that more mature fruit yielded applesauce of higher quality.

The objectives of this study were to determine the effect of postharvest pressure-infiltrated Ca on 1) firmness and soluble solids of fresh apples, and texture, color, and ascorbic acid of applesauce processed from the apples and 2) applesauce sensory parameters including color, intensity of off-flavors, consistency, and overall acceptability.

Materials and Methods

In September, 1988, 30 100-traypack boxes of 'Golden Delicious' apples (Malus domestica Borkh) from Wooden Orchards of Pikeville, TN and 30 100-traypack boxes of 'Red Rome' apples from The University of Tennessee experiment station, Crossville, TN were harvested. Twenty-four hours after harvest, the apples were treated with $CaCl_2$ solutions.

The 'Golden Delicious' apples were submerged in a 30 gallon plastic chamber filled with Ca solution and pressure infiltrated. Calcium solutions of 0%, 1%, 2%, 3%, or 4% (w/v) were prepared with calcium chloride dihydrate ($CaCl_2.2H_2O$) powder and distilled deionized water. The chamber was sealed and pressurized 2 min with air at 69 kPa (10 psi). Each solution treated 200 apples. Due to size of the barrel, only 100 apples were treated at a time. The solution was reused for a second batch of 100 apples. This procedure was repeated for each solution and replicated three times. Treated apples were removed from the plastic chamber, placed on kraft paper and air-dried. The fruit was packed in boxes that were lined with perforated plastic bags to maintain humidity and allow gas exchange during storage. Each box of apples was labeled according to the treatment, replication, and processing time of the fruit before being placed in standard cold storage at 0 ±1°C.

The procedure used to treat 'Red Rome' apples was the same as that used for 'Golden Delicious' apples, except for the concentration of the solutions and the infiltration time used. Since 'Red Rome' fruit were more difficult to infiltrate due to fewer and smaller lenticels, higher Ca concentrations were used. Concentrations used were 0%, 2%, 4%, 6%, or 8% (w/v), and infiltration time was 4 min at the same pressure used for 'Golden Delicious' apples.

At each processing time, the apples were tested for ethylene production, firmness, and soluble solids content. A Shimadzu GC-8APF gas chromatograph equipped with a column (5 mm O.D/2.6 mm I.D/5.4 m long) packed with activated alumina and a flame ionization detector (FID) was used to determine ethylene production rates, which were expressed in $\mu L \cdot Kg^{-1} \cdot hr^{-1}$. To collect the ethylene samples, a group of previously weighed apples was sealed in one-gallon plastic jars with lids specially designed to allow withdrawal of samples with a plastic syringe. The apples were allowed to produce ethylene for one hr before the gas samples were collected. This procedure was repeated for two consecutive days. An Effigy penetrometer equipped with an 11 mm Magness-Taylor tip was used to measure the firmness of the apples, and the results were expressed in newtons (N). The firmness of each apple was measured on opposite peeled sides along the equatorial line. An Atago refractometer was used to determine percent soluble solid contents. Several drops of apple juice were squeezed from the apple tissue onto the prism of the refractometer for reading.

Processing involved making applesauce from individual cultivars. Some apples were processed immediately while the others were processed after holding 2, 4, or 6 months in storage at 0°C. Applesauce was prepared with a home recipe that required 3,000 g of peeled and cored apples (from about 30 whole apples) and 1,500 mL of distilled water. After cooking for 20 min, the apples were passed through a 1.59 mm mesh finishing sieve to obtain uniform applesauce particle size. The product was canned in four 473-mL jars according to the canning procedures suggested in the Ball Canning Book

(Ball Corp., 1982). After canning was completed, the jars were labeled and placed in a dark room at 23°C for 2 months.

Quality attributes of the applesauce were determined with a consumer texture profile technique (Szczesniak et al., 1975). This technique was modified to include appearance and flavor parameters (Swanson and Penfield, 1988). This procedure involved the participation of a group of 30 untrained panelists. The panel consisted of 16 females and 14 males whose ages ranged from 20 to 50 years. All panelists were either students or staff at The University of Tennessee. Sensory evaluation was conducted in the laboratory equipped for product testing in The Department of Food Science and Technology, The University of Tennessee. Beginning two months after each processing time, panelists evaluated the applesauce samples during six one-day sessions. The first 3 days of each session were dedicated to the evaluation of sauce made from 'Golden Delicious' fruit. The remaining 3 days were used for the evaluation of sauce from 'Red Rome' fruit. Each day the panelists tasted samples from a complete replication of treatments for the applesauce prepared from one of the two cultivars. The panelists were provided with scorecards that were used to evaluate the samples according to different parameters. The parameters evaluated for applesauce included appearance (color), flavor (intensity of possible off-flavor), texture (moistness, consistency, uniformity of particles), and overall acceptability. The panelists were given an additional scorecard designed to collect information concerning their perception of ideal applesauce. This scorecard included all the parameters of the sample scorecard except for the overall acceptability. In both the ideal and sample scorecards, each parameter was provided with a scale of nine levels. The scale was designed such that the ends of the scale indicated opposite extremes of characteristics given. For the purpose of statistical analysis, the different levels in the scale were assigned numbers from 1 to 9 after the scorecards were collected.

Immediately following sensory evaluation, samples were brought to the laboratory for determination of texture, moisture, color, ascorbic acid, and Ca content. Texture was determined by measuring consistency and apparent viscosity. A Bostwick consistometer was used to determine consistency expressed in $cm \cdot 10\ min^{-1}$. Sixty grams of sauce were placed in the sample container, and the sauce was allowed to flow for 10 min. The sauce and free liquid front were measured, using the scale provided on the consistometer. A Brookfield Viscometer was used to measured the apparent viscosity which was expressed in $mPa \cdot s$ (see appendix A for procedure). A HunterLab Color/Difference Meter D25-2 was used to measure the color parameters of the sauce. Samples were placed in the same Petri dish for all measurements to ensure that the characteristics of the glass were consistent for every sample. The Petri dish was filled completely with sample, placed on the colorimeter, and covered with a black cloth. Color was expressed as L (luminosity), '-a' (greenness), and 'b' (yellowness).

Samples of applesauce were weighed and placed in a drying oven at 70°C until they reached a constant weight to obtain a measurement of moisture content to be used in ascorbic acid determinations. The method of titration with indo-phenol dye was used to determine the ascorbic acid content of all the samples (AOAC, 1980). This method involved the preparation of sauce samples with extraction solutions, the centrifuging of particulate matter from the samples, and the titration of samples prepared with indo-phenol dye which bound to ascorbic acid in the sample. This dye was previously calibrated with a known ascorbic acid standard within the range of the samples. The amount of dye used in the titration was then used to calculate the amount of ascorbic acid in mg/100 g of edible portion (see appendix A for ascorbic acid determination).

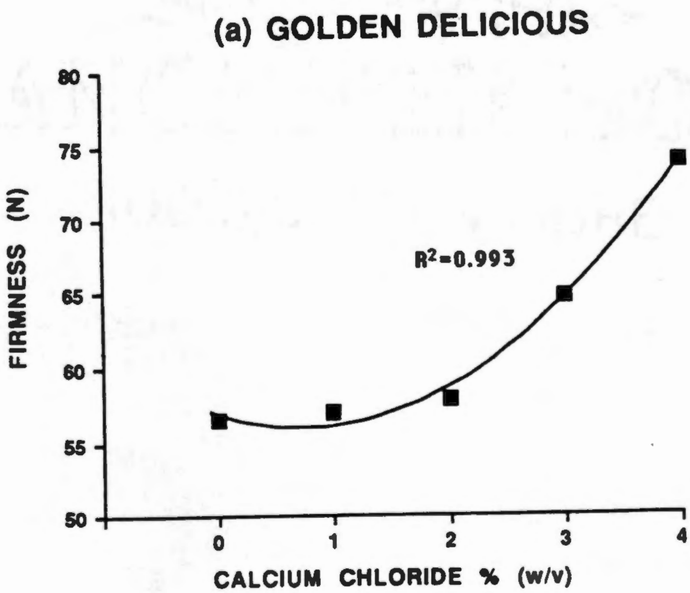
A Perkin Elmer model 5000 atomic absorption spectrophotometer, was used to determine the Ca content of samples. The samples were removed from the sealed jars, bagged in cheesecloth, labeled, dipped in liquid nitrogen, and placed in a Virtis model USM-15 freeze-drier until dried to constant weight (2 to 3 days). The dry samples were removed from the cheesecloth and ground into powder. Then, 0.5 g of this powder was ashed overnight, dissolved with a 2N HCl solution and diluted to the linear range of the spectrophotometer. The amount of Ca in the samples was expressed as $\mu g \cdot g$ dry wt^{-1} (see appendix A for Ca analysis).

A randomized incomplete block design was utilized. Each Ca treatment was replicated three times for each cultivar. Analysis of variance was performed utilizing the general linear model (GLM) procedure (SAS, 1985) and the general linear mixed model (GLMM) procedure (Blouin and Saxton, 1989). Panelists were considered a random effect for analysis of sensory data. For the purpose of discussion, treatments that had an effect at $p \leq 0.01$ were referred to as very significant. Treatments that had an effect at $p \leq 0.05$ were referred to as significant. Treatments that had an effect at $p > 0.05$ were referred to as not significant.

Results and Discussion

(a) Fresh Fruit Quality Parameters

Postharvest application of $CaCl_2$ had a very significant effect on firmness of 'Golden Delicious' apples. Both the processing time and the $CaCl_2$ treatment by processing time interaction had no effect on the firmness of 'Golden Delicious'. 'Golden Delicious' apples treated with the two highest $CaCl_2$ concentrations were firmer than the untreated fruit (Fig. II.1a). Fruit treated with 4% $CaCl_2$ solution was 50% firmer than the untreated fruit. $CaCl_2$ treatment and processing time had a very significant effect on the firmness



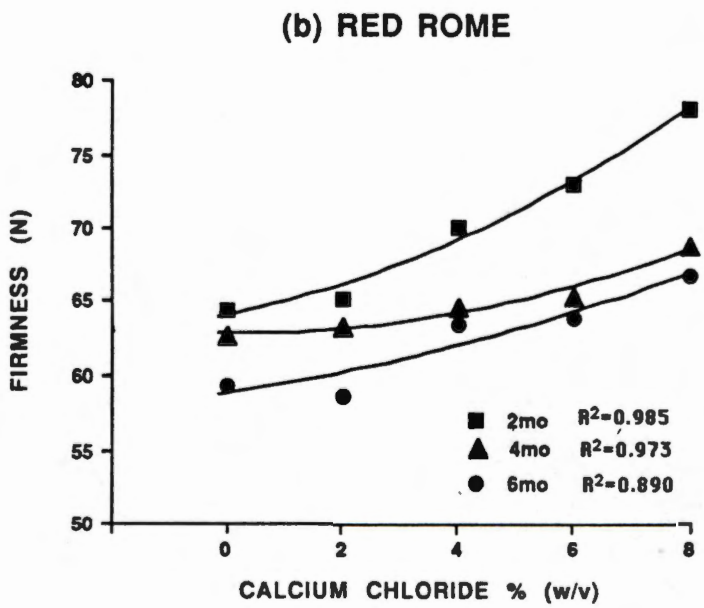


Fig. II.1: The effect of calcium chloride concentration in the treatment solution on firmness of 'Golden Delicious' and 'Red Rome' apples. (a) Average firmness of 'Golden Delicious' fruit across storage times. (b) Firmness of 'Red Rome' fruit after 2, 4, and 6 months in storage . The best fit quadratic equations were: (a) $y=56.818 - 2.4846x + 1.6759x^2$; (b) 2mo: $y=63.993 + 0.80907x + 0.11768x^2$; 4mo: $y=62.695 -2.6571*10^{-2}x + 9.3571*10^{-2}x^2$; 6mo: $y= 58.739 + 0.58293x + 5.2321*10^{-2}x^2$.

of 'Red Rome' apples while the $CaCl_2$ treatment by processing time interaction had no effect on firmness (Fig. II.1b). 'Red Rome' apples treated with 8% $CaCl_2$ solution maintained firmness after four and six months storage at a level similar to firmness (64 N) of untreated fruit after two months storage. Calcium treatment was effective for increasing firmness of 'Red Rome' apples at the three removal times. Increasing and/or maintaining firmness of apples through pressure infiltration with $CaCl_2$ has been documented previously (Conway and Sams, 1983; Sams and Conway, 1987; Abbot et al., 1989). Tissue damage due to Ca injury was minimal as damage was only detected in 'Golden Delicious' apples treated with 4% $CaCl_2$ and 'Red Rome' apples treated with 8% $CaCl_2$. Fruit of both cultivars exhibited no physiological disorders during six month storage.

The $CaCl_2$ treatment and, hence, Ca content of the fruit did not affect the soluble solids content of either 'Golden Delicious' or 'Red Rome' apples. The same was true for the processing time and the $CaCl_2$ treatment by processing time interaction. Similar results were reported by Laufmann (1989).

(b) Applesauce Quality - Physical Parameters

The application of $CaCl_2$ as a postharvest treatment had a very significant effect on the Ca content of the sauce prepared from 'Golden Delicious' and 'Red Rome' apples. The treatment increased the amount of Ca in the fresh fruit, which resulted in an increase in the Ca content of the applesauce prepared from the fruit. Both the processing time and the $CaCl_2$ treatment by processing time interaction had no effect on Ca content of the sauce prepared from 'Golden Delicious' and 'Red Rome' apples. The rate of uptake of Ca by the apples increased sharply as Ca treatment increased which was reflected in the Ca content of the sauce. 'Golden Delicious' apples treated with the 1% $CaCl_2$ solution was higher than the Ca content of the sauce prepared from untreated fruit, but the sauce made with fruit treated with 4% $CaCl_2$ solutions produced applesauce with almost three times the Ca content of the control sauce (Fig. II.2a). 'Red Rome' sauce made from 2% $CaCl_2$ solution exhibited similar Ca content as the sauce prepared from untreated fruit, but apples treated with 8% $CaCl_2$ solution yielded sauce with more than double the Ca content of sauce prepared with untreated fruit (Fig.II.2b).

Treatment with $CaCl_2$ and storage time had a very significant effect on the consistency of sauce prepared from 'Golden Delicious' and 'Red Rome' apples. The $CaCl_2$ treatment by storage time interaction was very significant for the sauce prepared from 'Golden Delicious' apples, but not significant for the sauce prepared from 'Red Rome' apples. The consistency of sauce prepared from both 'Golden Delicious' and 'Red Rome' apples increased (sauce flowed less in the Bostwick Consistometer) as Ca content of sauce and storage time

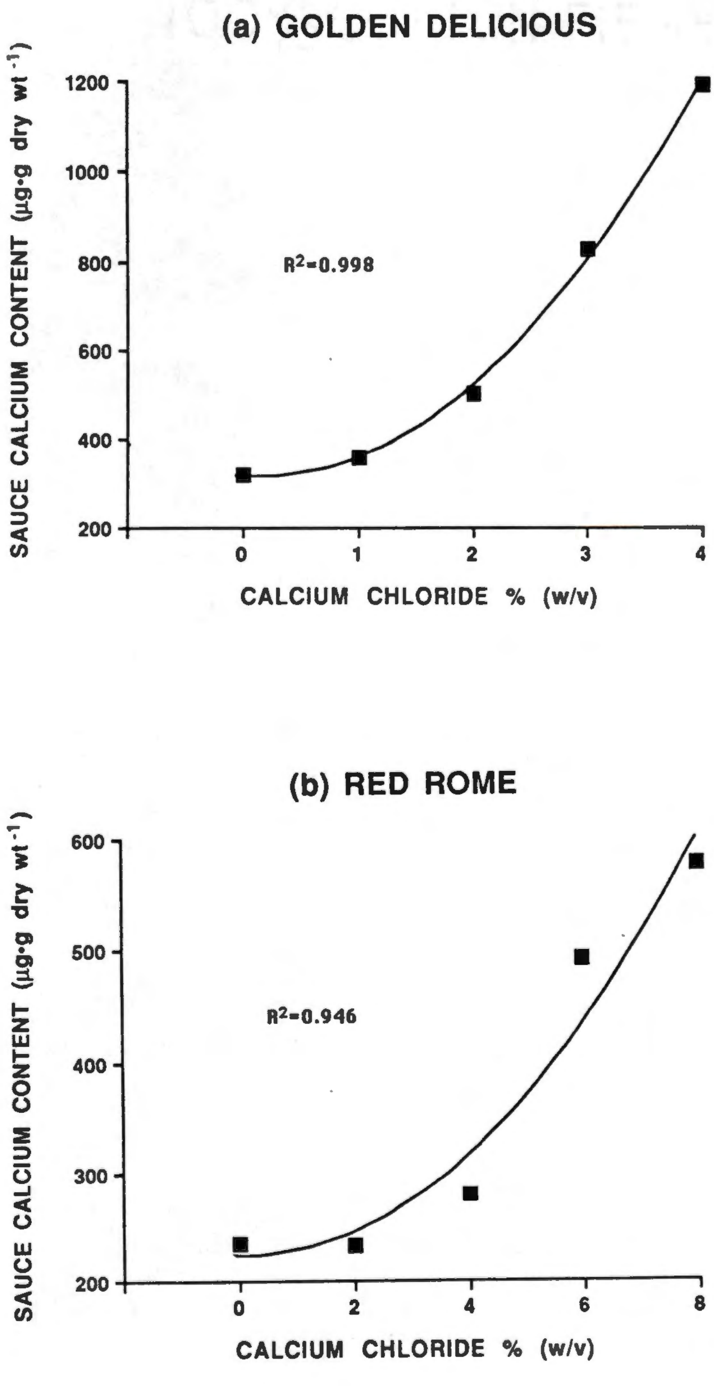


Fig. II.2: Calcium content of applesauce prepared from apples treated with different calcium chloride concentrations. (a) Calcium content of 'Golden Delicious' applesauce. (b) Calcium content of 'Red Rome' applesauce. The best fit quadratic equations were: (a) $y=315.27 - 15.987x + 58.964x^2$; (b) $y=223.69 - 1.8933x + 6.0993x^2$.

increased. 'Golden Delicious' sauce with a Ca content above 800 $\mu g \cdot g$ dry wt^{-1} exhibited similar consistency values for all four removal times (Fig. II.3a). The same was true for 'Red Rome' sauce with Ca content of 580 $\mu g \cdot g$ dry wt^{-1} (Fig. II.3b). The consistency of both the 'Golden Delicious' and the 'Red Rome' applesauce made from all treatments falls into the category of Grade A applesauce. The consistency readings for Grade A applesauce must be less than 6.5 cm (Judge, 1991). Drake and Spayd (1983) found opposite results. They concluded that sauce made from 'Golden Delicious' apples pressure infiltrated with a 3% $CaCl_2$ solution did not posses greater consistency than sauce from untreated apples. However, the authors concluded that sauce prepared from $CaCl_2$-treated apples met the standards for grade A applesauce, while applesauce made from apples held in CA met standards only for grade B sauce. Apples used to process the applesauce were held in 1°C or CA storage for 5 months.

Syneresis, the amount of free liquid that separates from the applesauce, was measured also with the Bostwick Consistometer. The free liquid of the 'Golden Delicious' applesauce was affected very significantly by Ca treatment, storage time, and the Ca treatment by storage time interaction. The free liquid of 'Red Rome' sauce was affected very significantly by the Ca treatment but not affected by storage time and the Ca treatment by storage time interaction. The amount of free liquid in sauce prepared from 'Golden

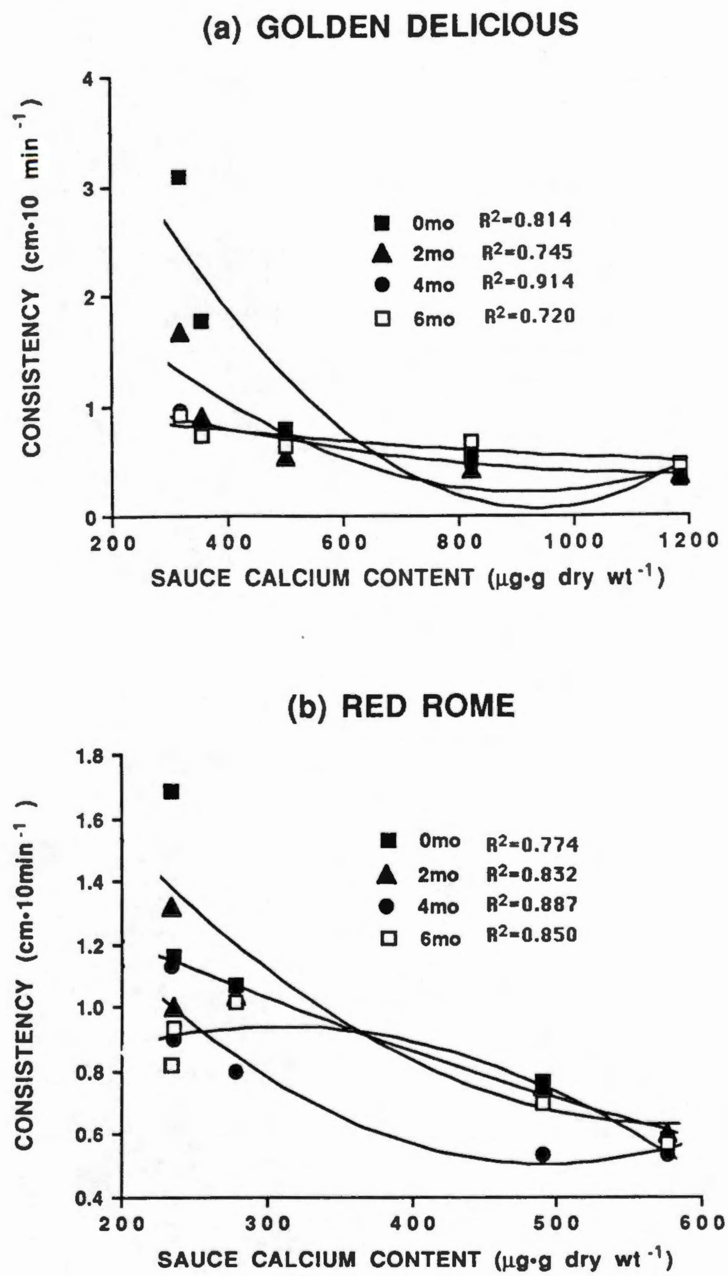


Fig. II.3: Consistency of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. (a) Consistency of 'Golden Delicious' applesauce. (b) Consistency of 'Red Rome' applesauce. The best fit quadratic equations were: (a) 0mo: $y=5.6133 - 1.1824*10^{-2}x + 6.2993*10^{-6}x^2$; 2mo: $y=2.8123 - 5.656*10^{-3}x + 3.0715*10^{-6}x^2$; 4mo: $y=1.3186 - 1.5722*10^{-3}x + 6.5019*10^{-7}x^2$: 6mo: $y= 1.0252 - 6.9766*10^{-4}x + 2.0653*10^{-7}x^2$; (b) 0mo: $y= 2.7313 - 7.2341*10^{-3}x + 6.2238*10^{-6}x^2$: 2mo: $y=1.6414 - 2.3303*10^{-3}x + 9.4447*10^{-7}x^2$: 4mo: $y=2.2966 - 7.2487*10^{-3}x + 7.3199*10^{-6}x^2$; 6mo: $y= 0.40536 + 3.4418*10^{-3}x + 5.5759*10^{-6}x^2$.

Delicious' apples increased slightly as the Ca content of the sauce increased and sharply as the storage time increased (Fig. II.4a). As reported by Laufmann (1989), this phenomenon could be due to the fact that apple tissue tends to become dryer as it reaches the senescence stage, thus lowering its capacity to hold water. The water holding capacity of the tissue could also be affected by Ca content. Calcium content of the sauce prepared from 'Red Rome' apples had different effects on the free liquid at the different storage times (Fig. II.4b). The amount of free liquid of the sauce increased slightly as Ca content of sauce increased at the 0 months storage time. However, after two months of storage sauce prepared with untreated fruit presented a high amount of free liquid which decreased sharply as Ca content reached 500 $\mu g \cdot g$ dry wt^{-1} but increased again as Ca content reached 600 $\mu g \cdot g$ dry wt^{-1}. Sauce prepared after four and six months of storage exhibited a decrease in free liquid as Ca content increased. The reason for the lack of consistency in the syneresis data of the sauce prepared from 'Red Rome' apples could be maturity of the apples at harvest and after two months storage. Based on ethylene production data, these fruit were less mature at harvest than the 'Golden Delicious' (see appendix B).

Regarding color, the Hunter 'a' and 'b' values of the 'Golden Delicious' applesauce were changed very significantly due to the treatment and storage time. The Ca treatment by storage time interaction had no effect on the 'a' and 'b'

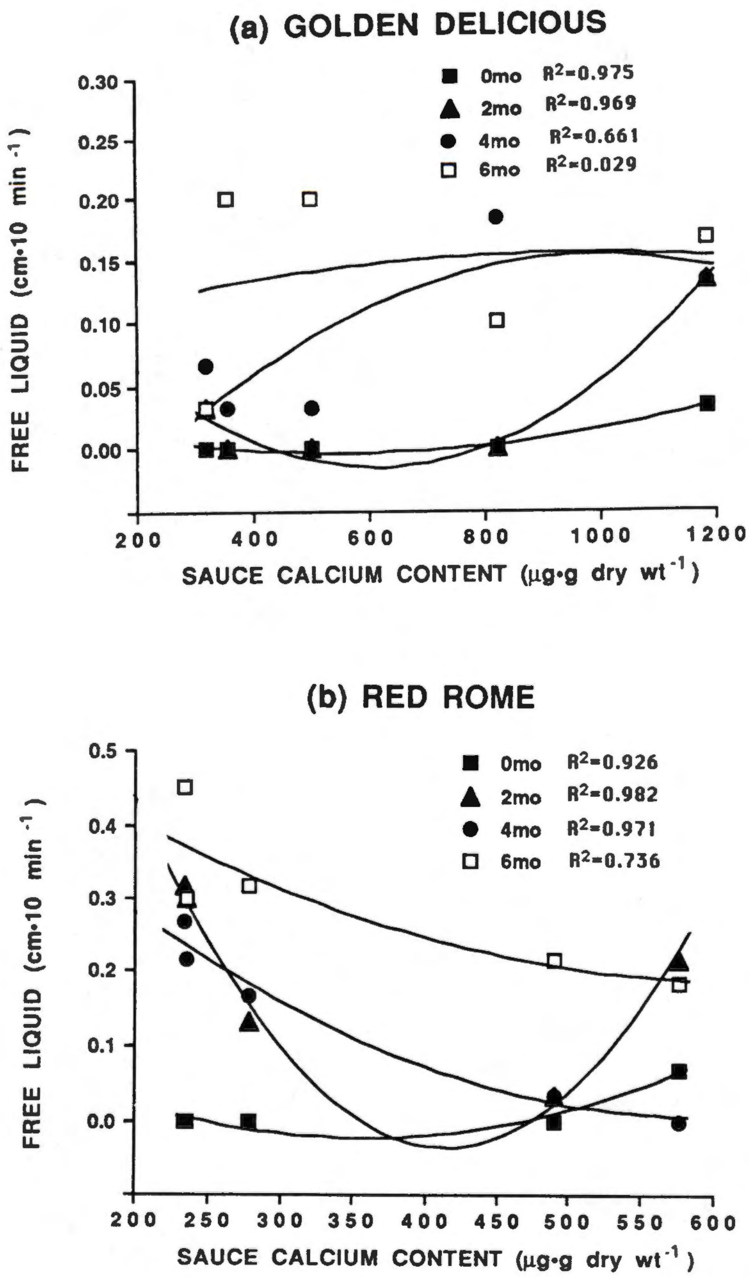


Fig. II.4: Free liquid of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. (a) Consistency of 'Golden Delicious' applesauce. (b) Free liquid of 'Red Rome' applesauce. The best fit quadratic equations were: (a) 0mo: $y=2.6137*10^{-2} - 1.0679*10^{-4}x + 9.4744*10^{-8}x^2$; 2mo: $y=0.15716 - 5.6075*10^{-4}x + 4.5538*10^{-7}x^2$; 4mo: $y=-0.11146 + 5.2906*10^{-4}x - 2.6477*10^{-7}x^2$: 6mo: $y= 9.1827*10^{-2} + 1.2905*10^{-4}x - 6.6465*10^{-8}x^2$; (b) 0mo: $y= 0.21652 - 1.3433*10^{-3}x + 1.8703*10^{-6}x^2$: 2mo: $y=1.7353 - 8.5299*10^{-3}x + 1.0258*10^{-5}x^2$: 4mo: $y=0.64287 - 2.1656*10^{-3}x + 1.8382*10^{-6}x^2$; 6mo: $y= 0.66287 + 1.5395*10^{-3}x + 1.2429*10^{-6}x^2$.

values. Hunter '-a' values represent the amount of green present, and for 'Golden Delicious' sauce intensity of greenness decreased as both the Ca content and the storage time increased (Fig. II.5). Hunter '-a' values of sauce with a Ca content of 380 $\mu g \cdot g$ dry wt^{-1} (lowest Ca content) ranged from -2.9 for the 0 months sauce to -1.5 for the 6 months sauce while the sauce with a Ca content of 1200 $\mu g \cdot g$ dry wt^{-1} (highest Ca content) ranged from -1.2 to -0.8. Hunter 'b' values represent the amount of yellow present, and for 'Golden Delicious' sauce processed at 0 and 2 months, the intensity of yellowness increased from 19.9 and 20.8 respectively to 22.3 as Ca increased up to 800 $\mu g \cdot g$ dry wt^{-1}. At higher Ca levels the yellowness decreased to 20.8 and 21.2 respectively (Fig. II.6). The intensity of yellowness decreased from 22.4 to 22.1 as Ca content of the sauce increased from 380 $\mu g \cdot g$ dry wt^{-1} to 1200 $\mu g \cdot g$ dry wt^{-1} at the 4 month storage time while at the 6 month storage time the data was inconclusive. Drake and Spayd (1983) obtained similar results for the 'b' value, but opposite results for the 'a' values. The 'L' values of the 'Golden Delicious' sauce ranged from 47.8 to 49.7, but were not significantly different among treatments or storage times.

For the 'Red Rome' applesauce only the 'L' value was very significantly changed due to Ca treatment and storage time. Theoretical 'L' values range from 100 (absolute white) to 0 (absolute black). The 'L' values or lightness of the 'Red Rome' for the 0, 2, and 4 months storage times ranged from

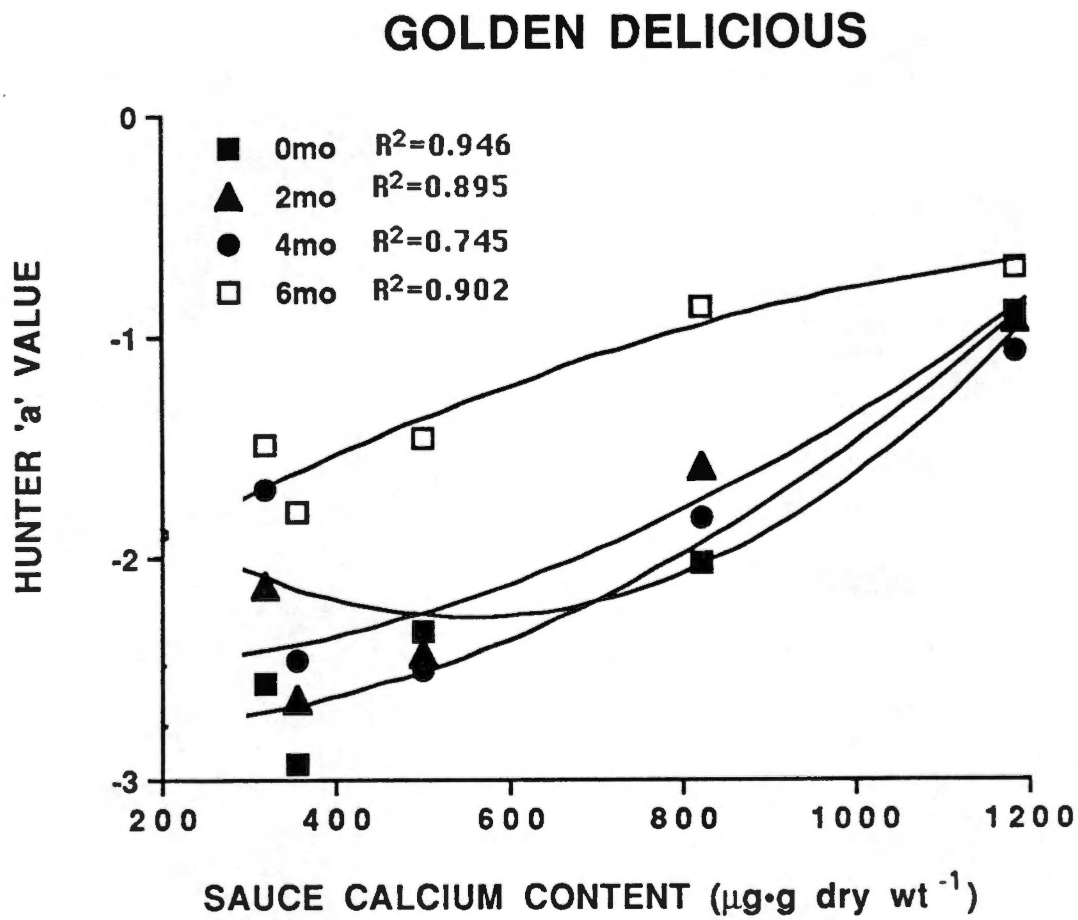


Fig. II.5: Hunter 'a' values of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. Hunter 'a' value of 'Golden Delicious' applesauce. The best fit quadratic equations were: 0mo: $y= -2.7717 - 2.7855*10^{-4}x + 1.5531*10^{-6}x^2$; 2mo: $y=-2.5230 - 9.9287*10^{-5}x + 1.2485*10^{-6}x^2$; 4mo: $y=-1.2913 - 3.5499*10^{-3}x - 3.199*10^{-6}x^2$: 6mo: $y= -2.37622 + 2.3866*10^{-3}x - 8.0206*10^{-7}x^2$.

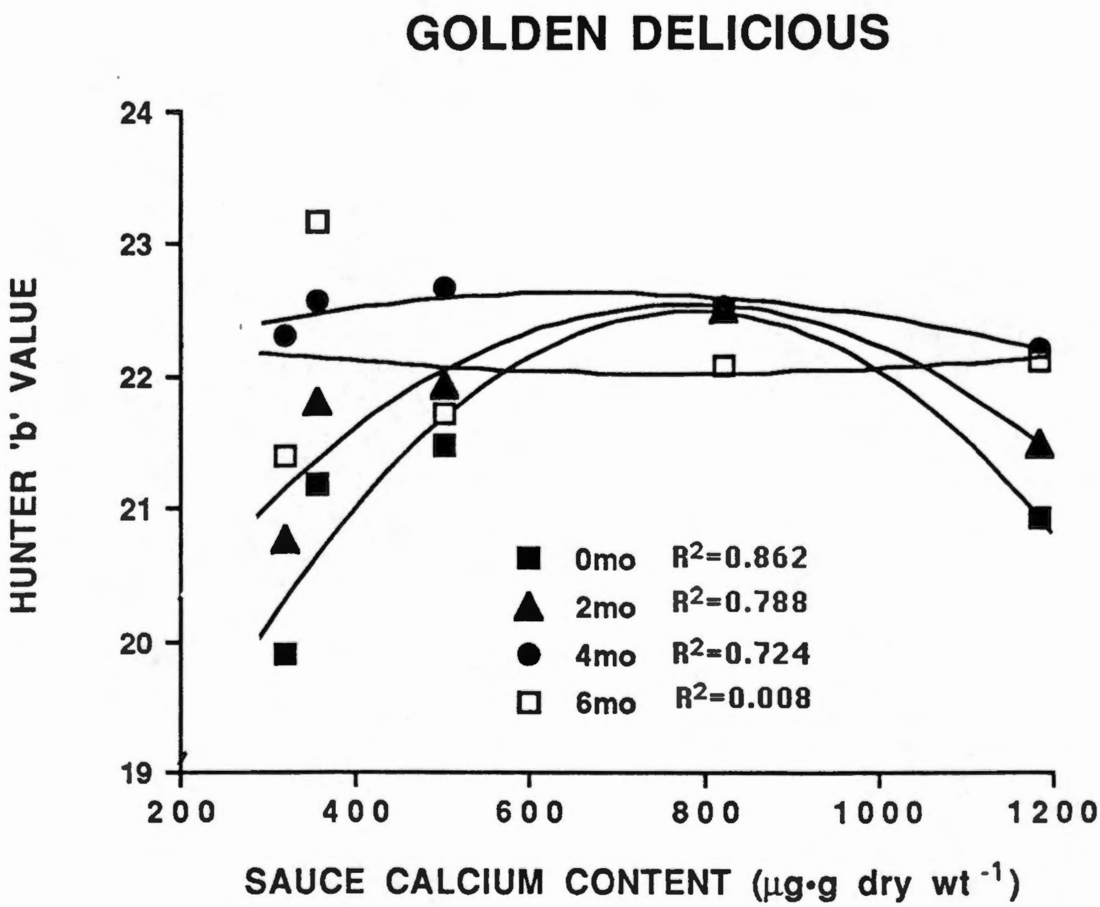


Fig. II.6: Hunter 'b' values of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. Hunter 'b' value of 'Golden Delicious' applesauce. The best fit quadratic equations were: 0mo: $y= 16.3 + 1.5669*10^{-2}x - 9.943*10^{-6}x^2$; 2mo: $y=18.521 + 1.0267*10^{-2}x - 6.5732*10^{-6}x^2$; 4mo: $y=21.916 + 2.1275*10^{-3}x -1.6087*10^{-6}x^2$: 6mo: $y= 22.419 - 1.0689*10^{-3}x + 6.814*10^{-7}x^2$.

40.6 to 43.4 for sauce with a Ca content of 225 $\mu g \cdot g$ dry wt^{-1} and from 43.1 to 43.5 for sauce with Ca content of 580 $\mu g \cdot g$dry wt^{-1} (Fig. II.7). The increase of the 'L' values as the Ca content of the sauce increases suggests that the added Ca contributes with the prevention of non-enzymatic browning. As the storage time increased, the 'L' values also increased, indicating a lighter sauce up to 4 months storage. However, at the 6 months storage time the sauce became lighter as the sauce Ca content increased up to 475 $\mu g \cdot g$ dry wt^{-1}, but at higher concentrations the sauce became darker. The stage of senescence of the 'Red Rome' apples used to prepare the sauce at the 6 months storage time may have caused the Hunter 'L' value data to be erratic. The '-a' and 'b' values ranged from 0.0 to -1.1 and from 15.5 to 16.9 respectively, but neither value had significant differences among treatments or replications.

Calcium content had a very significant effect on the apparent viscosity of sauce prepared from 'Golden Delicious' and 'Red Rome' apples. Storage time had a significant effect on the viscosity of sauce prepared from both cultivars while the Ca content by storage time interaction had no effect on the viscosity of the sauce. Viscosity generally increased as Ca content and storage time increased. Viscosity of the sauce prepared with untreated 'Golden Delicious' fruit (Ca content of 325 $\mu g \cdot g$ dry wt^{-1} was 1.3 million mPa·s for all storage times except for the 0 months time for which viscosity was

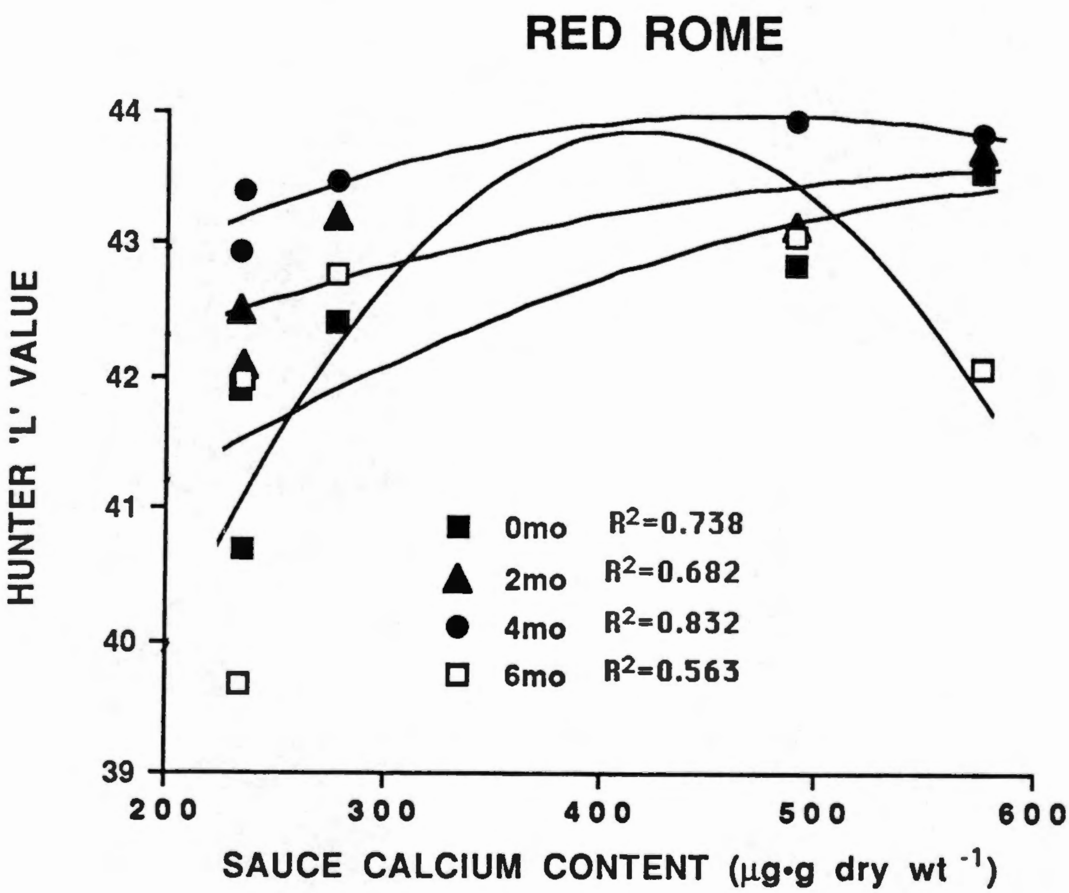
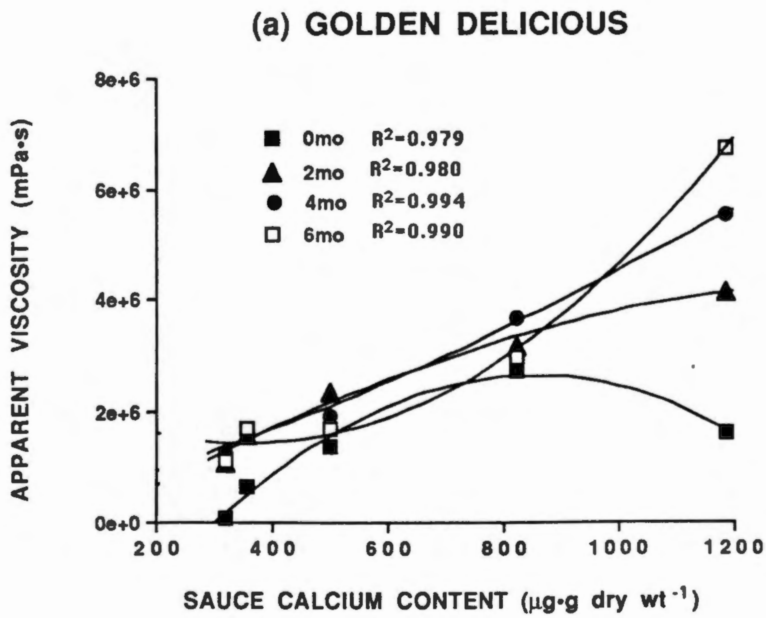


Fig. II.7: Hunter 'L' values of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. Hunter 'L' value of 'Red Rome' applesauce. The best fit quadratic equations were: 0mo: $y= 38.763 + 1.4133*10^{-2}x - 1.0584*10^{-5}x^2$; 2mo: $y=40.852 + 8.5123*10^{-3}x - 6.6603*10^{-6}x^2$; 4mo: $y=40.898 + 1.291*10^{-2}x - 1.3619*10^{-5}x^2$: 6mo: $y= 29.441 - 6.8525*10^{-2}x + 8.1536*10^{-5}x^2$.

200,000 mPa·s. Sauce with the highest Ca content (1,150 $\mu g \cdot g$ dry wt^{-1}) exhibited a viscosity of 1.5 million mPa·s at the 0 months time, 3.9 million mPa·s at the 2 months time, 5.5 million mPa·s at the 4 months time, and 6.8 million mPa·s at the 6 months time. Viscosity of the sauce with the highest Ca content at the 0 months time exhibited a slight decrease (Fig. II.8a). This may be the result of Ca injury to the tissue due to the high treatment (4% $CaCl_2$). The maturity of the fruit may have contributed to a more viscous sauce which is reflected by the increase of the apparent viscosity as the storage time increases.

The viscosity of the sauce prepared with 'Red Rome' fruit also increased as both the Ca content of the sauce and the storage time of the fruit increased except for the viscosity of the sauce with the highest Ca content which decreased slightly. As in the case of the 'Golden Delicious', the decrease in viscosity of the sauce with the highest Ca content could be due to injury to the tissue caused by excess Ca (Fig. II.8b).

The ascorbic acid content of the applesauce of both the 'Golden Delicious' and the 'Red Rome' cultivars was not significantly different among Ca treatments. Extremely low levels of ascorbic acid were found as compared to commercial applesauce (see appendix B). This finding could be attributed to overcooking of the sauce since the cooking time needed to prepare the apples for the finisher was 20 min, whereas, the



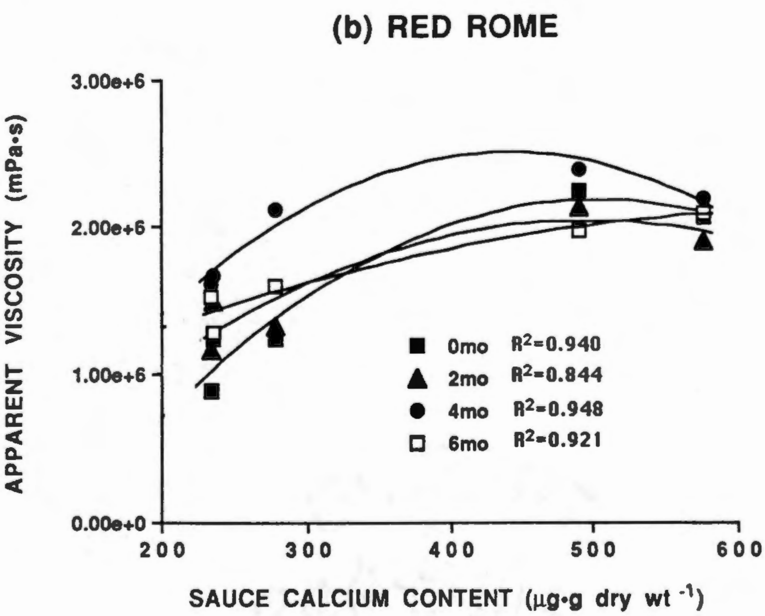


Fig. II.8: Apparent viscosity of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. (a) Viscosity of 'Golden Delicious' applesauce. (b) Viscosity of 'Red Rome' applesauce. The best fit quadratic equations were: (a) 0mo: $y=-3.7573*10^6 + 1.5036*10^4x - 8.8263x^2$; 2mo: $y=-5.8426*10^5 + 6586.5x - 2.2206x^2$; 4mo: $y=2.3228*10^5 + 3163.7x + 1.1047x^2$: 6mo: $y=2.3881*10^6 - 5428.4x + 7.6461x^2$; (b) 0mo: $y=-1.9275*10^6 + 1.6327*10^4x - 16.236x^2$: 2mo: $y=-7.6344*10^5 + 1.1337*10^4x - 11.487x^2$: 4mo: $y=-1.2508*10^6 + 1.7039*10^4x - 19.313*10x^2$; 6mo: $y= 4.6307*10^5 + 4922.6x - 3.6839x^2$.

industry standard for cooking time is 4 to 5 min (Wiley and Binkley, 1989). Ascorbic acid is heat labile in the presence of O_2 (Kurtsky, 1981) and may have been degraded during processing.

(c) Applesauce Quality - Sensory Parameters

The $CaCl_2$ treatment affected the quality of the applesauce prepared with treated apples as perceived by a group of panelists who evaluated the sauce from the sensory standpoint.

Calcium content and Ca content by storage time interaction affected the color of sauce prepared from 'Golden Delicious' apples very significantly (Fig. II.9a). Storage time had no significant effect on color. The sensory evaluation study indicated that the 'Golden Delicious' applesauce became darker as the Ca content of the sauce increased except for the sauce processed at 6 months storage time. The sauce processed at 6 months prepared with untreated fruit was initially darker (4.8) than the sauce made from untreated fruit at the other storage times, but became lighter (4.0) as the Ca content increased to 1150 $\mu g \cdot g$ dry wt^{-1}. The applesauce prepared after 0, 2, and 4 months in storage exhibited color values raging from 3.2 to 3.5 for the sauce made with untreated apples up to a range of 3.9 to 4.1 for the sauce with a Ca content of 1,150 $\mu g \cdot g$ dry wt^{-1}.

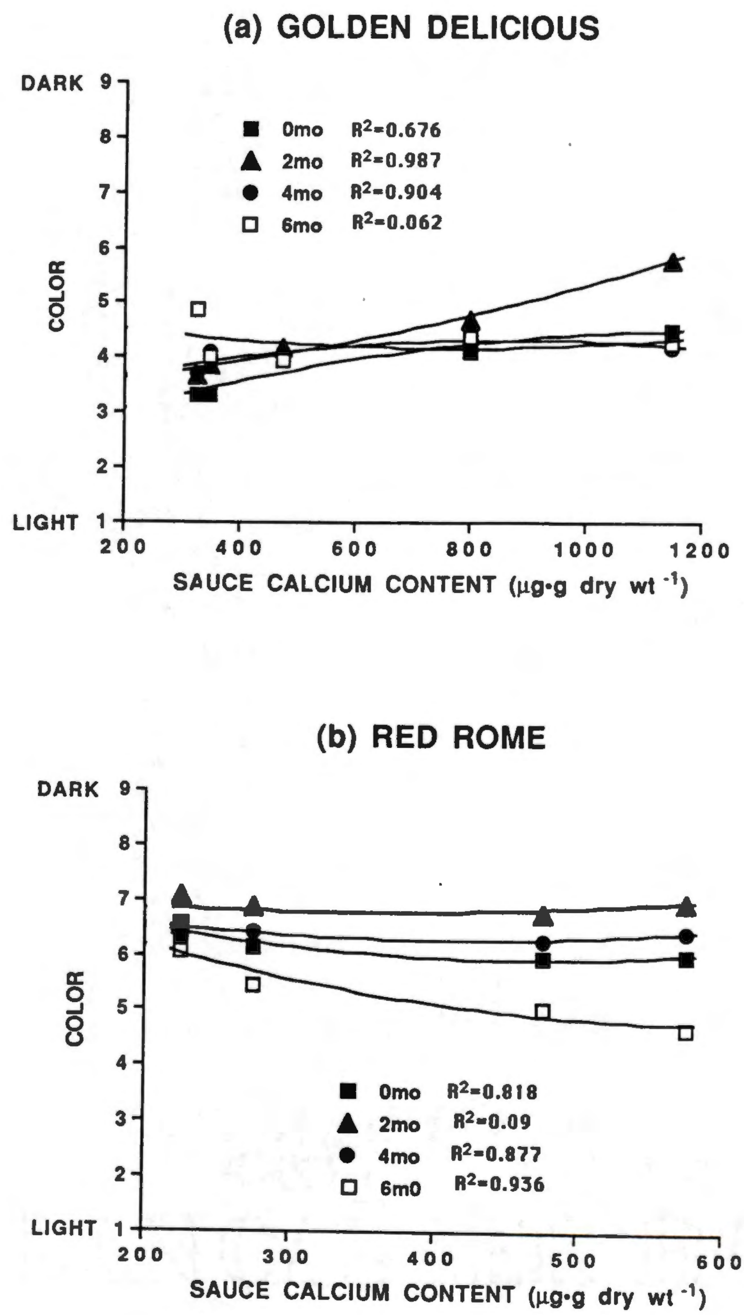


Fig. II.9: Color evaluation by sensory panel of applesauce with different calcium concentrations after 0, 2, 4, and 6 months in storage. (a) Color evaluation of 'Golden Delicious' applesauce. (b) Color evaluation of 'Red Rome' applesauce. The best fit quadratic equations were: (a) 0mo: $y=2.44 + 3.3*10^{-3}x -1.3448*10^{-6}x^2$; 2mo: $y=3.4114 + 8.0234*10^{-4}x + 1.0669*10^{-6}x^2$; 4mo: $y=3.2 + 2.5284*10^{-3}x - 1.4622*10^{-6}x^2$: 6mo: $y= 4.8123 - 1.7843*10^{-3}x + 1.1336*10^{-6}x^2$; (b) 0mo: $y= 7.6899 - 7.5934*10^{-3}x + 8.0628*10^{-6}x^2$: 2mo: $y=7.240 - 2.6943*10^{-3}x + 3.7933*10^{-6}x^2$: 4mo: $y=7.3022 - 5.0571*10^{-3}x + 5.9909*10^{-6}x^2$; 6mo: $y= 8.0269 - 1.1032*10^{-2}x - 6x^2$.

Color of sauce prepared from 'Red Rome' apples was affected very significantly by storage time and significantly by Ca content (Fig. II.9b). The Ca content by storage time interaction had no effect on the color of the sauce. Sauce prepared from fruit stored 0, 2, and 4 months became lighter as the Ca content of the sauce increased. Fruit stored for 6 months yielded sauce that became lighter as Ca content increased. These results are similar to the Hunter color values except for the 6 month storage time values. The 6 month storage time presented a sharper drop in the color scores which translates into much lighter sauce than the other storage times. Calcium content had more effect on the luminosity of sauce prepared from both 'Golden Delicious' and 'Red Rome' apples after 6 months storage than in sauce processed at the previous storage times. The age of the fruit at the time of processing may have contributed to the effectiveness of the calcium in making the sauce lighter.

Intensity of the off-flavors present in 'Golden Delicious' applesauce was significantly affected by Ca content. For 'Golden Delicious' sauce intensity of off-flavors decreased slightly as Ca content of sauce reached 475 $\mu g \cdot g$ dry wt^{-1} (Fig. II.10). As Ca content increased to the maximum level (1,150 $\mu g \cdot g$ dry wt^{-1} a slight increase of off flavors was detected. The off-flavor may be caused by an excess of Ca in the tissue of the apples from which the applesauce was made. Intensity of the off-flavors detected in the 'Red Rome'

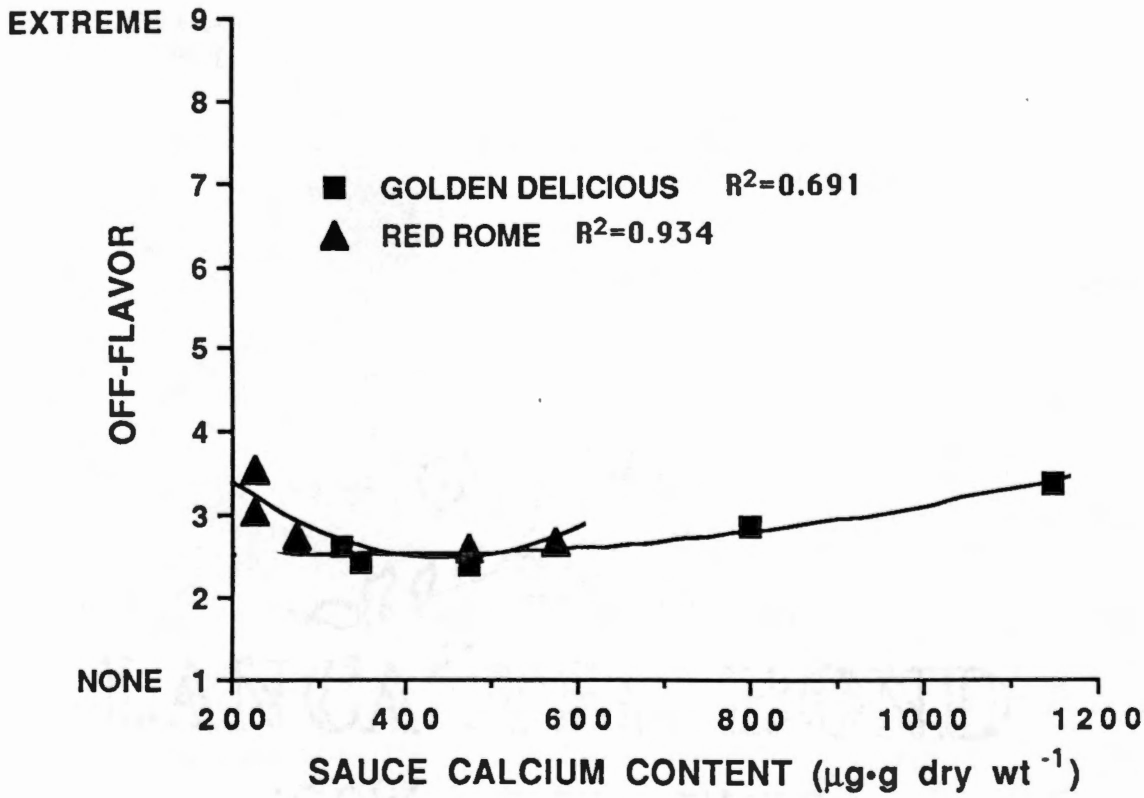


Fig. II.10: Off-flavor evaluation by sensory panel of applesauce with different calcium concentrations. Off-flavor evaluation of 'Golden Delicious' and 'Red Rome' applesauce. The best fit quadratic equations were: For 'Golden Delicious' sauce: $y=2.6602 - 9.7788*10^{-4}x + 1.3944*10^{-6}x^2$; For 'Red Rome' sauce: $y= 5.5545 - 1.3811*10^{-2}x + 1.5433*10^{-5}x^2$.

applesauce was significantly affected by Ca content. For 'Red Rome' sauce the intensity of off-flavors decreased as the Ca content of the sauce increased (Fig. II.10). The reason panelists were not able to detect any off-flavors at the highest Ca content may be that the Ca content of the 'Red Rome' apples used to prepare the sauce was not high enough to impart a detectable flavor caused by the $CaCl_2$ salt. The highest Ca content of the 'Red Rome' sauce was 580 $\mu g \cdot g$ dry wt^{-1} which is considerably lower than the highest Ca content of the 'Golden Delicious' sauce (1,150 $\mu g \cdot g$ dry wt^{-1}).

Panelists evaluated the consistency of the applesauce based on the mouth feel of the sauce. Calcium content of 'Golden Delicious' sauce had a very significant effect on the consistency (Fig. II.11). Consistency of the sauce increased as the Ca content of the sauce increased. However, the storage time had no effect on consistency. Similarly, Ca content had a very significant effect on the consistency of 'Red Rome' applesauce which became thicker as the Ca content of the sauce increased, while the storage time had no effect on consistency of the sauce (Fig. II.11). These results agreed with the textural analysis in which consistency and apparent viscosity readings indicated that applesauce of both cultivars thickened as Ca content increased.

Final evaluation was based on overall acceptability of the sauce. Calcium content had a very significant effect on overall acceptability of applesauce prepared from 'Golden

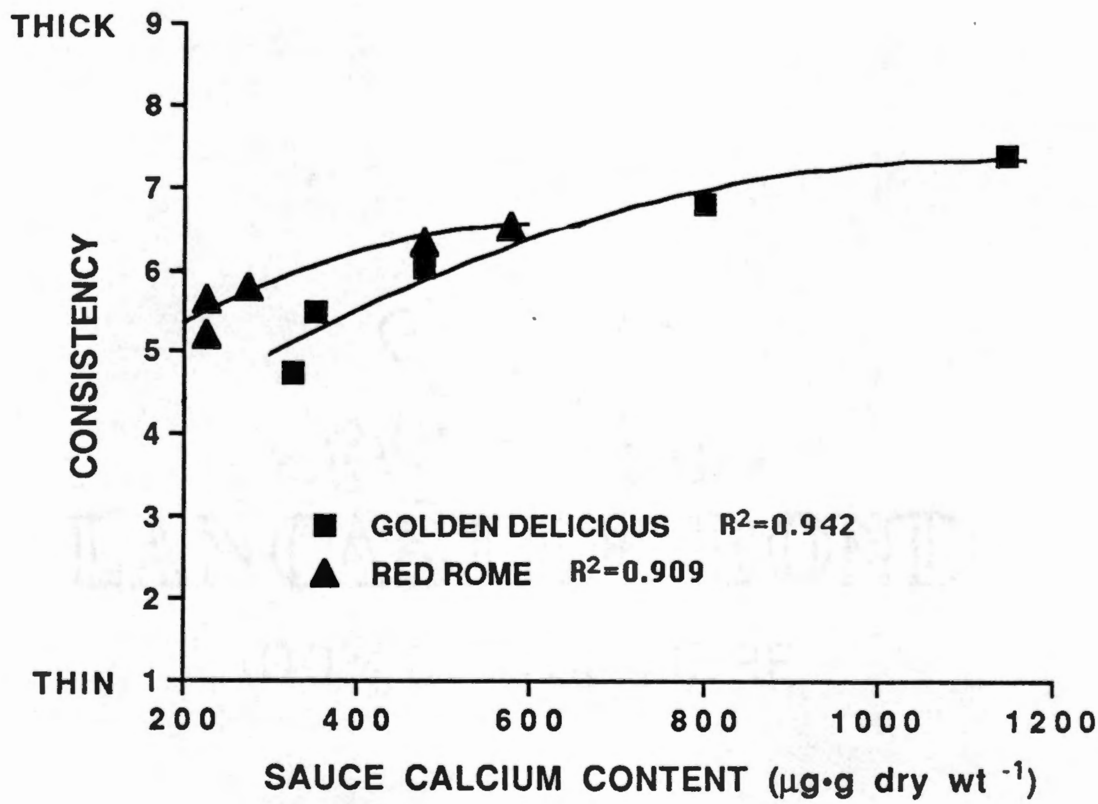


Fig. II.11: Consistency evaluation by sensory panel of applesauce with different calcium concentrations. Consistency evaluation of 'Golden Delicious' and 'Red Rome' applesauce. The best fit quadratic equations were: For 'Golden Delicious' sauce: $y=2.9555 + 7.6834*10^{-3}x - 3.3821*10^{-6}x^2$; For 'Red Rome' sauce: $y= 3.8348 + 8.84*10^{-3}x - 7.2769*10^{-6}x^2$.

Delicious' apples (Fig.II.12). 'Golden Delicious' sauce reached an optimum level of acceptability at a Ca content of 350 $\mu g \cdot g$ dry wt^{-1} and after that point, the sauce became significantly less desirable than the optimum sauce and sauce prepared from untreated fruit. Calcium had a very significant effect on the overall acceptability of 'Red Rome' sauce. 'Red Rome' sauce became more desirable as Ca increased and the maximum level of acceptability (4.3) was reached when the applesauce Ca was 450 $\mu g \cdot g$ dry wt^{-1} (Fig. II.12). Acceptability of the sauce decreased slightly (4.1) when the sauce Ca content was the highest, but it was more desirable than the acceptability of sauce prepared with untreated fruit (3.2). It is also evident that the overall acceptability of the 'Golden Delicious' sauce is higher than that of the 'Red Rome' sauce except for the 'Golden Delicious' sauce prepared from the fruit treated 4% $CaCl_2$. However, regardless of the cultivar, there was a similar threshold (between 350 and 450 $\mu g \cdot g$ dry wt^{-1}) after which the panelists established that the Ca had a detrimental effect on the overall quality of the sauce.

In conclusion, postharvest application of $CaCl_2$ to apples not only improved and prolonged storage quality of the fruit, but enhanced the quality of products made from these apples. Optimum Ca treatments yield high quality products, but if the optimum level in the fruit (about 600 $\mu g \cdot g$ dry wt^{-1} for 'Golden Delicious' apples) is exceeded, Ca may be detrimental to the

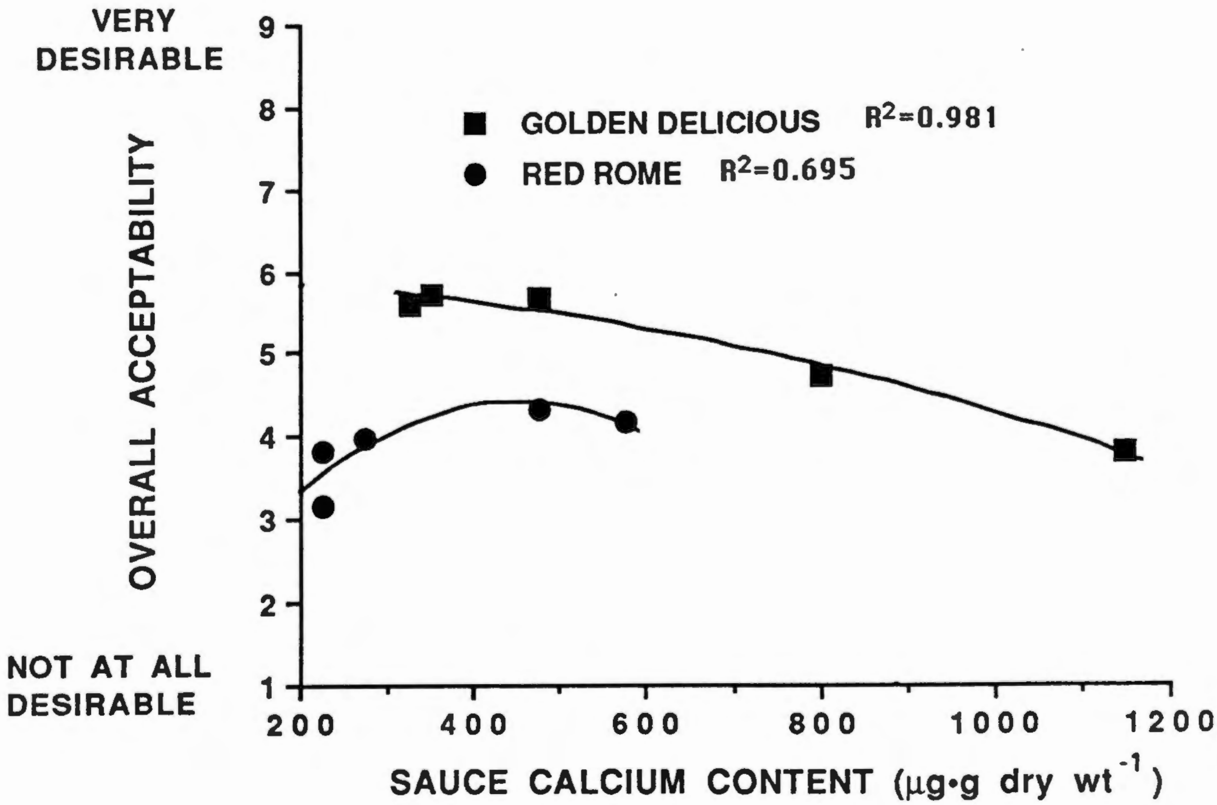


Fig. II.12: Overall acceptability evaluation by sensory panel of applesauce with different calcium concentrations. Overall acceptability of 'Golden Delicious' and 'Red Rome' applesauce. The best fit quadratic equations were: For 'Golden Delicious' sauce: $y=5.9279 - 1.5293*10^{-4}x - 1.518*10^{-6}x^2$; For 'Red Rome' sauce: $y= 0.87677 + 1.5703*10^{-2}x - 1.7463*10^{-5}x^2$.

quality of applesauce and may affect adversely quality of other products. Further research is needed to investigate the optimum level of Ca in the fruit and determine how it relates to cultivar and maturity of the fruit. The next step in this study should be to simulate industry processing procedures and evaluate the products for analytical and sensory quality.

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III. QUALITY OF APPLESAUCE PROCESSED FROM A BLEND OF 'GOLDEN DELICIOUS' AND 'RED ROME' APPLES PRESSURE INFILTRATED WITH CALCIUM CHLORIDE PRIOR TO STORAGE

Abstract

'Golden Delicious' and 'Red Rome' apples (Malus domestica Borkh) were pressure infiltrated at 73 kPa (12 psi) with 0, 1, 2 or 4% ('Golden Delicious') and 0, 2, 4 or 8% calcium chloride ($CaCl_2$) ('Red Rome') solutions (w/v) and placed in 0°C storage. Attributes of treated fruit and applesauce made from a blend of the fruit were evaluated after 2, 4 and 6 months storage. Calcium (Ca) content of 'Golden Delicious' fruit ranged from 190 (0% $CaCl_2$) to 290 (4% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1} while Ca of 'Red Rome' fruit ranged from 230 (0% $CaCl_2$) to 380 (8% $CaCl_2$) $\mu g \cdot g$ dry wt^{-1}. Firmness of 'Golden Delicious' and 'Red Rome' fruit increased as Ca increased at all storage times. Soluble solids content was not affected by Ca treatments. Calcium content of sauce processed from a blend of both cultivars ranged from 165 (0% $CaCl_2$ 'Golden Delicious' blended with 0% $CaCl_2$ 'Red Rome') to 280 (4% $CaCl_2$ 'Golden Delicious' blended with 8% 'Red Rome') $\mu g \cdot g$ dry wt^{-1}. Consistency of applesauce decreased (sauce became thicker) as Ca and storage time increased. Amount of free liquid was not

affected by Ca or time of storage. Hunter 'L' value of the sauce increased (became lighter) and apparent viscosity increased as Ca and time in storage increased.

A sensory panel evaluated the sauce for color, off-flavor, consistency, and overall acceptability. The sauce became lighter as Ca increased. Intensity of off-flavors in sauce processed at 2 months decreased as Ca increased, but at 4 and 6 months intensity of off-flavor increased as Ca increased. Consistency of the sauce increased as Ca content increased. Acceptability of the sauce increased slightly as Ca increased.

Introduction

Calcium content of apples in storage had a direct effect on quality of the fruit (Bramlage et al., 1979; Ferguson, 1984; Brady, 1987). Adequate levels of Ca maintained firmness of apples (Bramlage et al., 1974; Sams and Conway, 1984), increased resistance to diseases (Conway, 1982; Sams and Conway, 1985), and reduced the rate of ripening and senescence (Scott and Wills, 1975; Lee and Dewey, 1981). Addition of Ca by postharvest treatment either had no detrimental effect or enhanced the physical attributes of applesauce prepared with treated apples (Drake and Spayd, 1983). However, these quality assessments of products prepared from treated apples were made by objective tests without considering subjective evaluation of a sensory panel. Nevertheless, there have been studies on sensory evaluation of apples and apple products. These studies include the evaluation of sensory characteristics on 'McIntosh' apples treated with succinic acid-2,2-dimethylhydrazide (SADH) (Murphy et al., 1971) and sensory evaluation of the effect of overripeness on texture, flavor, and appearance of several cultivars of apples (Blanpied and Blak, 1977). Among sensory studies on apple products are the evaluation of canned apple slices by a sensory panel that concluded that overall quality deteriorated more rapidly when stored at 38°C than when stored at 21°C or less (Hayakawa et al.,1978), and determination of sensory components of applesauce to compare applesauce made from different cultivars (McLellan et al., 1984). Sensory evaluation is an essential tool to determine consumer acceptance of products prepared from apples treated with Ca.

The purpose of this study was to evaluate chemical, physical, and sensory attributes of blended applesauce prepared with Ca-treated apples using processing procedures similar to those used commercially.

Materials and Methods

In September, 1989, 30 100-traypack boxes of 'Golden Delicious' apples (Malus domestica Borkh) from Biglerville, PA and 30 100-traypack boxes of 'Red Rome' apples from Wooden Orchards in Pikeville, TN were harvested. Twenty-four hours after harvest, the apples were treated with different $CaCl_2$ solutions.

'Golden Delicious' apples were treated at the pilot plant of Knouse Foods, Biglerville, PA where 200 fruit were treated at a time. In order to facilitate handling, apples were put in nylon laundry bags . Four, 50 gallon-plastic tanks were used. The first tank contained 1% chlorine solution, the second contained water for rinsing, the third contained calcium chloride ($CaCl_2$) solution, and the fourth contained water for a final rinse. Calcium chloride dihydrate ($CaCl_2.2H_2O$) powder was disolved in deionized water to prepare the Ca solutions. Concentrations were 0%, 1%, 2%, or 4% (w/v) and an untreated control. The fruit was held in the chlorine solution for one min, rinsed in water and placed in the treatment tank with $CaCl_2$ solution which was sealed and pressurized with air to 73 kPa (12 psi). In order to allow adequate infiltration, the fruit remained under pressure 6 min. After treatment, the fruit was rinsed again to remove excess Ca from the surface of the fruit. The apples were dried with paper towels. Calcium solutions were changed after every treatment, while chlorine solution and water rinses were changed between replications. This procedure was repeated for each of the solutions and replicated three times. The fruit was placed in boxes lined with perforated plastic to maintain humidity and to allow gas exchange during storage. Before being placed in standard storage at 0 ±1°C, each box of apples was labeled according to the treatment, replication, and processing time of the fruit.

'Red Rome' apples were treated at The University of Tennessee Plant Science Farm. Except for concentration of the solutions, the procedure used for 'Red Rome' apples was similar to that used for 'Golden Delicious' fruit. Because of fewer lenticels of smaller size, 'Red Rome' fruit should absorb less solution and require greater concentrations of Ca to infiltrate the fruit with similar amounts of Ca as in 'Golden Delicious' fruit. Concentrations used were 0%, 2%, 4%, or 8% (w/v) and an untreated control.

At each processing time the apples were tested for ethylene and carbon dioxide production, firmness, and soluble solids content. A GC-8APF Shimadzu gas chromatograph, equipped with a column (5 mm O.D/2.6 mm I.D/5.4 x 2) packed with activated alumina and a flame ionization detector (FID), was used to determine ethylene production rates which were expressed in $\mu g \cdot g$ dry wt^{-1}. To collect samples for ethylene analysis, a group of previously weighed apples was placed in one-gallon plastic jars equipped with lids specially designed to allow withdrawal of samples with a plastic syringe. The apples produced ethylene for one hour before the gas samples were collected. This procedure was repeated for two consecutive days. Gas samples for CO_2 analysis were taken from the jars also. The gas was analyzed in a GC-8AIT Shimadzu gas chromatograph equipped with a column packed with molecular sieve 5A and Porapak Q and a thermal conductance detector

(TCD). CO_2 readings were expressed as mg $CO_2 \cdot Kg^{-1} \cdot hr^{-1}$.

An Effigy penetrometer, equipped with a Magness-Taylor probe, was used to measure the firmness of the apples, and the results were expressed as Newtons (N). Firmness of each apple was measured on opposite peeled sides along the equatorial line.

An Atago refractometer was used to determined percentage soluble solids content. Several drops of juice were squeezed from the apple tissue onto the refractometer for reading.

A Perkin Elmer model 5000 atomic absorption spectrophotometer was used to determine Ca content of the fruit. The samples were placed in a cheesecloth bag, labeled, dipped in liquid nitrogen for 30 seconds, and placed in a Virtis model USM-15 freeze-drier for 2 to 3 days. When samples were dry, they were placed in plastic bags and held until ground into powder. Later, 0.5 gram of this powder were ashed overnight and dissolved with a 2N HCl solution and diluted to the linear range of the spectrophotometer. The amount of Ca was expressed as $\mu g \cdot g$ dry wt^{-1} (see appendix A for Ca analysis procedure).

The processing procedure involved making applesauce from a blend of both cultivars. Apples were processed after two, four, or six months storage at 0°C. Applesauce was prepared with a recipe that required 6 Kg (about 60 whole apples) of peeled and cored apples (approximately the same amount of each cultivar), 6 L of distilled water, and three cups of sugar.

After cooking 20 min, the apples were passed through a 1.59 mm mesh finishing sieve to obtain uniform applesauce texture. The product was canned in eight 473-mL jars according to the canning procedures suggested in the Ball Blue Book (Ball Corp., 1982). After canning was completed, the jars were labeled and placed in a dark room at 23°C for 1.5 months.

Quality attributes of the applesauce were determined using a consumer profile technique that involved the participation of a group of 27 untrained panelists. The panel consisted of 15 females and 12 males whose ages ranged from 20 to 50 years. All panelists were either students or staff at The University of Tennessee. Evaluation was conducted in the sensory laboratory of The Department of Food Technology and Science at The University of Tennessee. Beginning 1.5 months after each processing time, panelists evaluated applesauce samples during three sessions of three days each. During each session, the panelists evaluated applesauce for each storage time. Each day the panelists evaluated a complete replication of samples. The panelists were provided with scorecards for evaluating samples for different parameters. The parameters evaluated included appearance (color), flavor (intensity of possible off-flavor), texture (moistness, consistency, and uniformity of particles), and overall acceptability. The panelists were given an additional scorecard designed to collect information concerning the panelists' perception of ideal applesauce. Except for the overall acceptability, this scorecard included all the parameters of the sample scorecard. In both the ideal and sample scorecards, each parameter was provided with a scale of nine levels. The scale was designed such that its ends indicated opposite extremes of the characteristics evaluated. For the purpose of statistical analysis, the different levels in the scale were assigned numbers from 1 to 9 after the data were collected.

Immediately after sensory evaluation, samples of sauce were brought to the laboratory for texture, moisture, color, ascorbic acid, and Ca determinations. Consistency and apparent viscosity measurements were used to determine the texture. A Bostwick Consistometer was used to measure consistency expressed as $cm \cdot 10\ min^{-1}$. Sixty grams of sauce were placed in the consistometer, and the sauce was allowed to flow for 10 min. The distance flowed by the sauce and free liquid fronts were measured. A Brookfield Viscometer was used to measured apparent viscosity expressed as $mPa \cdot s$ (see appendix A for apparent viscosity procedure). A HunterLab color/Difference Meter D25-2 was used to evaluate the color parameters of the applesauce. Samples were read in the same petri dish to ensure uniform characteristics of the glass with each sample. The dish was filled completely with the sample, placed on the colorimeter and covered with a black cloth. Color was read as 'L' (luminosity), '-a' (greenness), and 'b' (yellowness).

Samples of sauce were weighed and placed in a drying oven until they reached a constant weight to determine moisture content for ascorbic acid determinations. The method of titration with indo-phenol dye was used to determine the ascorbic acid content (AOAC, 1980). This method involved preparation of sauce samples with extraction solutions, the centrifuging of particulate matter from the samples and the titration of prepared samples with indo-phenol dye. This dye was previously calibrated with a known ascorbic acid standard within the range of the samples. The amount of dye used in the titration was used to calculated the amount of ascorbic acid as mg/100 grams of edible portion (see appendix A for ascorbic acid determination).

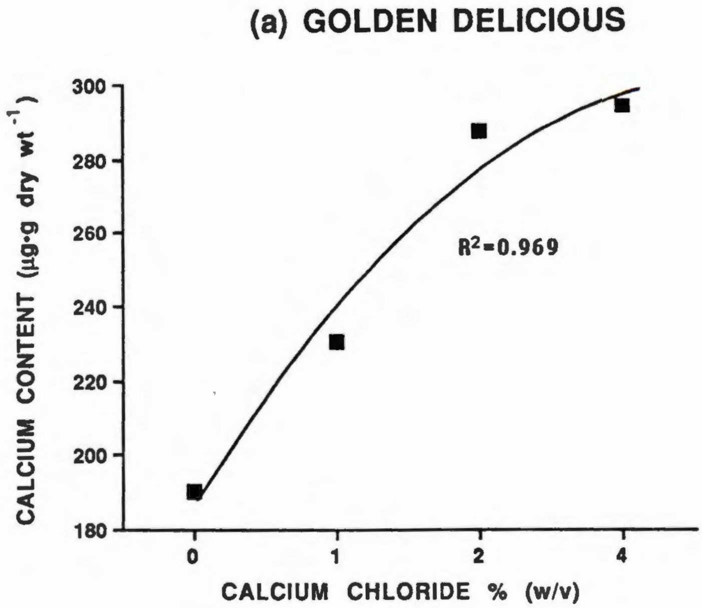
A Perkin Elmer model 5000 atomic absorption spectrophotometer was used to determine Ca. The samples were removed from the sealed jars, placed in a cheesecloth bag, labeled, dipped in liquid nitrogen for 30 seconds, and placed in a Virtis model USM-15 freeze-drier for 2 to 3 days. When samples were dry, they were placed in plastic bags and held until ground into powder. Later, 0.5 gram of the powder was ashed overnight and dissolved with a 2N HCl solution and diluted to the linear range of the spectrophotometer. The amount of Ca was expressed as $\mu g \cdot g$ dry wt^{-1} (see appendix A for Ca analysis procedure).

A randomized incomplete block was utilized for the statistical analysis of the data. Each Ca treatment was replicated three times. Analysis of variance was performed utilizing the general linear model (GLM) procedure (SAS, 1985) and the general linear mixed models (GLMM) procedure (Blouin and Saxton, 1989). Panelists were considered a random effect for analysis of sensory data. For the purpose of discussion, treatments that had an effect at $p \leq 0.01$ were referred to as very significant. Treatments that had an effect at $p \leq 0.05$ were referred to as significant. Treatments that had an effect at $p > 0.05$ were referred to as not significant.

Results and Discussion

(a) Fresh Fruit Quality Parameters

The pressure infiltration of $CaCl_2$ solutions had a very significant effect on Ca content of 'Golden Delicious' and 'Red Rome' fruit. The $CaCl_2$ treatment increased Ca content of fruit tissue for both cultivars. This increase in Ca content was limited by maturity of the apples. As indicated by CO_2 and ethylene production, the fruit were preclimacteric which limited the capability of the fruit to absorb the solution (see appendix B). Calcium of 'Golden Delicious' fruit at harvest was 187 $\mu g \cdot g$ dry wt^{-1} and after a maximum treatment with a 4% $CaCl_2$ solution Ca content increased to 290 $\mu g \cdot g$ dry wt^{-1} (Fig. III.1a). Ca content of 'Red Rome' apples was 230 $\mu g \cdot g$ dry wt^{-1} at harvest which after a maximum treatment with an 8% $CaCl_2$ solution, increased to 380 $\mu g \cdot g$ dry wt^{-1} (Fig. III.1b).



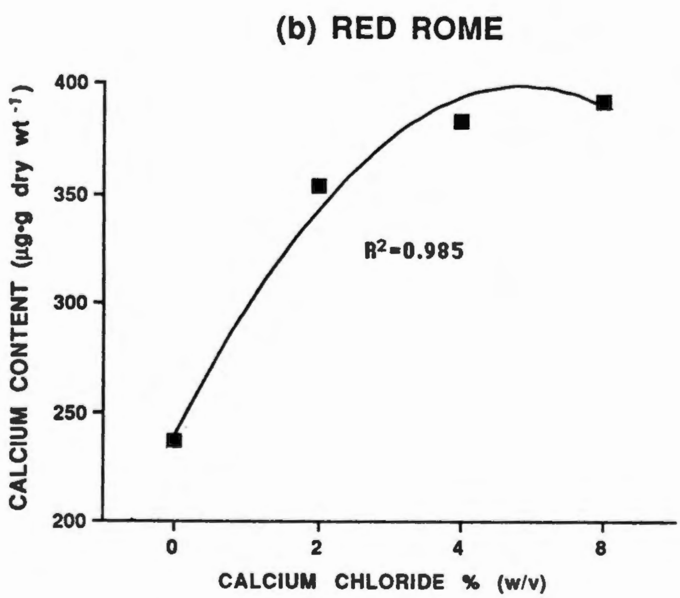
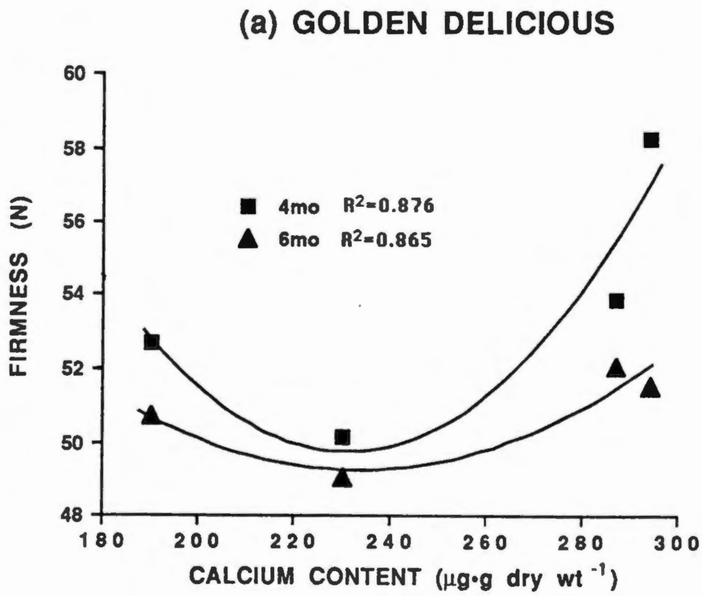


Fig. III.1: Calcium content of fresh apples treated with different calcium chloride concentrations. (a) Calcium content of 'Golden Delicious' fruit. (b) Calcium content of 'Red Rome' fruit. The best fit quadratic equations were: (a) $y = 116.55 + 78.558x - 8.33x^2$; (b) $y = 81.33 + 185.52x - 27.195x^2$.

Postharvest application of $CaCl_2$ had a significant effect on firmness of 'Golden Delicious' and 'Red Rome' apples. Storage time had a significant effect on firmness of 'Golden Delicious' apples and very significant effect on firmness of 'Red Rome' apples. The Ca treatment by storage time interaction had no effect on firmness. Firmness of both cultivars was either maintained or increased as Ca of the fruit increased. These findings are consistent with those of previous studies (Conway and Sams, 1987; Sams and Conway, 1987; Abbot et al., 1989). Firmness measurements taken at 4 months and 6 months storage indicated that 'Golden Delicious' apples with Ca of 280 $\mu g \cdot g$ dry wt^{-1} and above were firmer than untreated fruit (52.5 N after 4 months in storage and 50.5 N after 6 months in storage) (Fig. III.2a). Apples removed from storage after 4 months were significantly firmer than those removed after 6 months. 'Red Rome' apples followed a similar pattern, and at 4 months storage the fruit containing 375 $\mu g \cdot g$ dry wt^{-1} or more Ca were considerably firmer than untreated fruit (65.5 N) (Fig. III.2b). Apples removed at 6 months became firmer as Ca increased. Neither 'Golden Delicious' nor 'Red Rome' apples showed signs of rotting, shriveling, physiological disorders, or Ca injury after 6 month storage.

Calcium content of the fruit did not affect the soluble solids content of 'Golden Delicious' and 'Red Rome' apples. Similar results have been reported by Laufmann (1989).



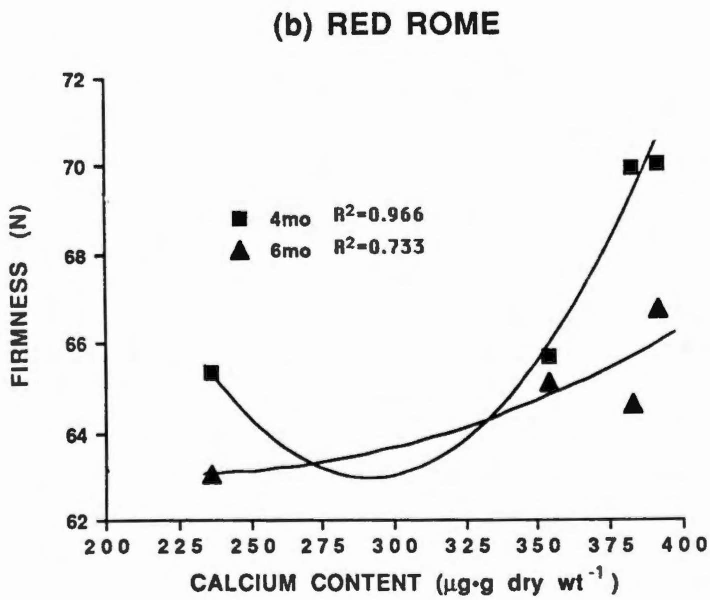


Fig. III.2: Firmness of fresh apples treated with different calcium chloride concentrations. (a) Firmness of 'Golden Delicious' fruit. (b) Firmness of 'Red Rome' fruit. The best fit quadratic equations were: (a) 4mo: $y= 147.35 - 0.84384x + 1.8232*10^{-3}x^2$; 6mo: $y= 91.203 - 0.35942x +7.6913*10^{-4}x^2$: (b) 4mo: $y= 127.58 - 0.44279x + 7.5851*10^{-4}x^2$; 6mo: $y= 68.628 - 4.8865*10^{-2}x + 1.07339.3571*10^{-4}x^2$.

(b) Applesauce Quality - Physical Parameters

The application of $CaCl_2$ had a very significant effect on the Ca content of the blended sauce prepared from both 'Golden Delicious' and 'Red Rome' apples. Storage time and the Ca treatment by storage time interaction had no effect on the Ca treatment of the sauce. Postharvest infiltration of $CaCl_2$ solutions increased Ca of the fresh fruit and, consequently, the Ca of the applesauce made from the treated fruit. Calcium content of blended applesauce of 'Golden Delicious' apples treated with 4% $CaCl_2$ and 'Red Rome' apples treated with 8% $CaCl_2$ was 280 $\mu g \cdot g$ dry wt^{-1}, 120 $\mu g \cdot g$ dry wt^{-1} greater than that of the control sauce made from the untreated 'Golden Delicious' and 'Red Rome' apples (Fig. III.3).

Calcium content had a very significant effect on consistency. The Ca content by storage time interaction had no effect on consistency. Consistency values of the blended applesauce decreased significantly as Ca increased (lower consistency readings indicate a thicker applesauce). These results were comparable to those obtained by Drake and Spayd (1983). Storage time had a very significant effect on consistency. Sauce prepared from apples stored for 2 months exhibited a mean consistency readings of 4.75 $cm \cdot 10\ min^{-1}$, dropping to 3.93 $cm \cdot 10\ min^{-1}$ for sauce prepared after 4 months in storage, and 2.67 $cm \cdot 10\ min^{-1}$ for sauce prepared after 6 months in storage (Fig. III.4a). Consistency of the sauce made

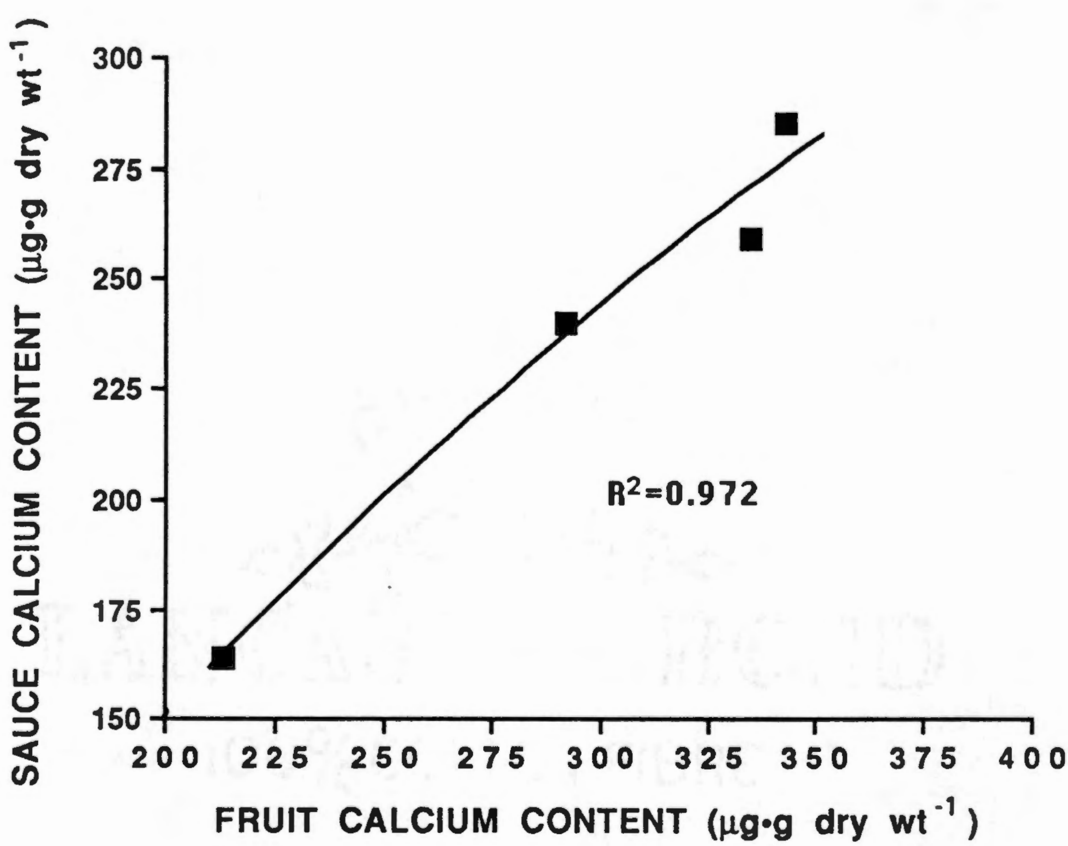


Fig. III.3: Calcium content of applesauce made from a blend of 'Golden Delicious' and 'Red Rome' apples with different calcium content. The best fit quadratic equation was: $y = -112.76 + 1.571x - 1.2781 * 10^{-3}x^2$.

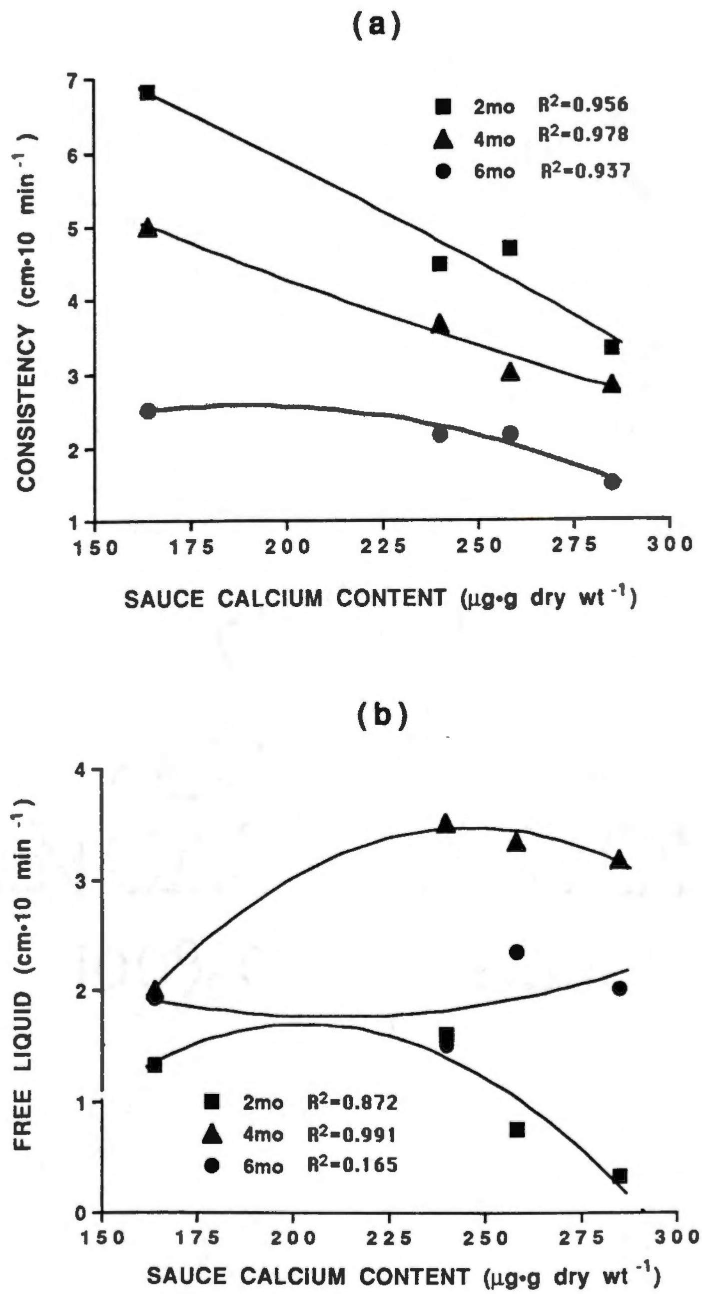


Fig. III.4: Consistency and free liquid of applesauce made from a blend of 'Golden Delicious' and 'Red Rome' apples with different calcium concentrations after 2, 4, and 6 months in storage. (a) Consistency of blended applesauce. (b) Free liquid of blended applesauce. The best fit quadratic equations were: (a) 2mo: $y = 10.322 - 1.7938*10^{-2}x - 2.3707*10^{-4}x^2$; 4mo: $y = 9.1505 - 2.9201*10^{-2}x + 2.3887*10^{-5}x^2$; 6mo: $y = -1.2821 + 4.0786*10^{-2}x - 1.083*10^{-4}x^2$: (b) 2mo: $y = 7.2819 + 8.8208*10^{-2}x - 2.1688*10^{-4}x^2$: 4mo: $y = -9.3020 + 0.10338x - 2.0959*10^{-4}x^2$: 6mo: $y = 4.9162 - 2.9980*10^{-2}x + 7.0966*10^{-5}x^2$.

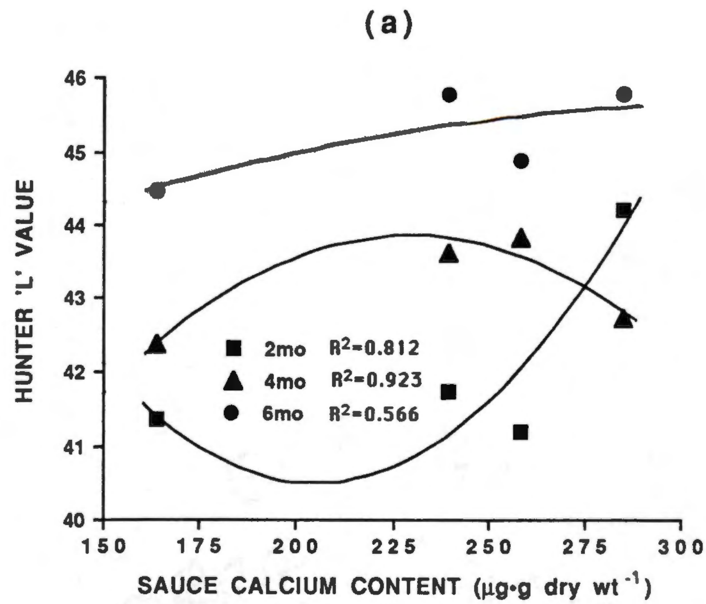
from all treatments fell into the Grade A category except for the sauce prepared with control fruit at 2 month storage which was Grade B. Grade A applesauce has consistency readings less than 6.5 cm, and Grade B applesauce should not exceed 8.5 cm (Judge, 1991).

Free liquid of the blended sauce was very significantly affected by Ca content and storage time. The Ca content by storage time interaction had no effect on free liquid. Free liquid of sauce prepared with fruit held in storage for 2 months increased from 1.3 $cm \cdot 10\ min^{-1}$ when Ca was 160 $\mu g \cdot g$ dry wt^{-1} to 1.6 $cm \cdot 10\ min^{-1}$ when Ca was 240 $\mu g \cdot g$ dry wt^{-1} but after that free liquid decreased to 0.25 $cm \cdot 10\ min^{-1}$ when Ca was 285 $\mu g \cdot g$ dry wt^{-1} (Fig. III.4b). Free liquid of sauce prepared from apples held in storage for 4 month increased (up to 3.2 $cm \cdot 10\ min^{-1}$) as Ca increased except for the sauce with the highest Ca content (285 $\mu g \cdot g$ dry wt^{-1}) which dropped to 3.1 $cm \cdot 10\ min^{-1}$. Data at the 6 months storage time was erratic and definite conclusions could not be drawn. The fact that the amount of free liquid increased as the storage time increased may be due to a decrease in the water holding capacity of the tissue as it aged.

Calcium content and storage time had a very significant effect on the Hunter 'L' values of the blended applesauce. The Ca content by storage time interaction had a significant effect on the Hunter 'L' values. Generally, as Ca content of the fruit increased, the 'L' values of the sauce increased (the sauce became lighter) except for sauce containing the highest level of Ca at 4 month storage. The 'L' values of sauce with 250 $\mu g \cdot g$ dry wt^{-1} Ca decreased sharply as Ca increased. As storage increased to 6 months, 'L' values increased (Fig. III.5a). Drake and Spayd (1983) and Laufmann (1989) obtained different results when they measured the 'L' value of sauce made from 'Golden Delicious' fruit. The differing results could be attributed to the maturity of the fruit used to prepare the applesauce. Also, blending the cultivars for processing applesauce could have affected the color of the sauce.

Apparent viscosity was affected very significantly by Ca content and storage time. The Ca content by storage time interaction had no effect on apparent viscosity of the sauce. Apparent viscosity measurements of sauce with 280 $\mu g \cdot g$ dry wt^{-1} Ca and processed after 2 months and 4 months storage were similar but considerably higher at 6 months storage (Fig. III.5b). Also, apparent viscosity of sauce prepared from untreated fruit at 6 months storage was similar or higher than the viscosity of all the samples at the 2 months and 4 months storage times.

Ascorbic acid data (see appendix B) indicated that the experimental sauce prepared with 'Golden Delicious' and 'Red Rome' apples had significantly less ascorbic acid than commercial sauce (1.7 $mg \cdot 100\ g^{-1}$ edible portion) (USDA, 1982). The reason for this extremely low ascorbic acid values could



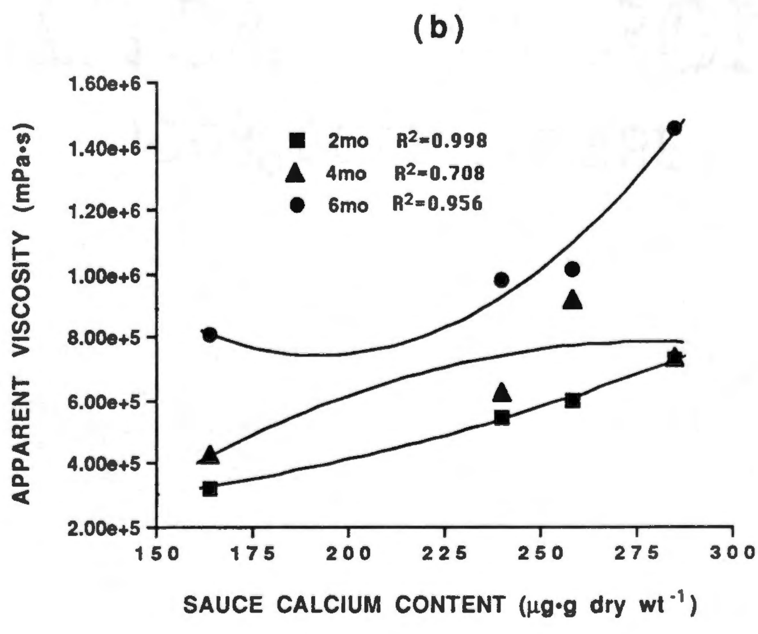


Fig. III.5: Color and apparent viscosity of applesauce made from a blend of 'Golden Delicious' and 'Red Rome' apples with different calcium content after 2, 4, and 6 months in storage. (a) Hunter 'L' value of blended applesauce. (b) Apparent viscosity of blended applesauce. The best fit quadratic equations were: (a) 2mo: $y= 63.296 - 0.22219x + 5.4158*10^{-4}x^2$; 4mo: $y= 25.754 + 0.15746x - 3.4243*10^{-4}x^2$; 6mo: $y= 40.868 + 2.9814x - 4.6649*10^{-5}x^2$: (b) 2mo: $y= 2.9712*10^5 - 1609.4x + 10.871x^2$: 4mo: $y= -1.3219*10^6 + 1.5049*10^4x - 26.934x^2$: 6mo: $y= 3.7721*10^6 - 3.1426*10^4x + 81.425x^2$.

be the prolonged time use for cooking the apples and extended exposure to oxygen, which may have degraded most of the vitamin C present. This experiment used 20 min cooking compared to 4 to 5 min used by industry (Wiley and Binkley, 1989).

(c) Applesauce Quality - Sensory Parameters

The applesauce was evaluated by panelists for attributes such as color, off-flavor, consistency, and overall acceptability.

Calcium content had a very significant effect on the color of the applesauce. Storage time and the Ca content by storage time interaction had no effect on color. The panelists detected a slight darkening of the sauce as Ca increased. The color readings ranged from 3.9 when Ca was 150 $\mu g \cdot g$ dry wt^{-1} to 4.5 when Ca was 260 $\mu g \cdot g$ dry wt^{-1}. When the sauce reached the maximum level of Ca (280 $\mu g \cdot g$ dry wt^{-1}) the color reading dropped to 4.2. These results agreed with those obtained through the readings taken with the Hunter colorimeter (Fig. III.6a).

Calcium content and the Ca content by storage time interaction had very significant effects on intensity of off-flavors. Storage time had no effect on intensity of off-flavors. Intensity of off-flavors was considerably higher in sauce prepared with untreated apples removed after 2 months

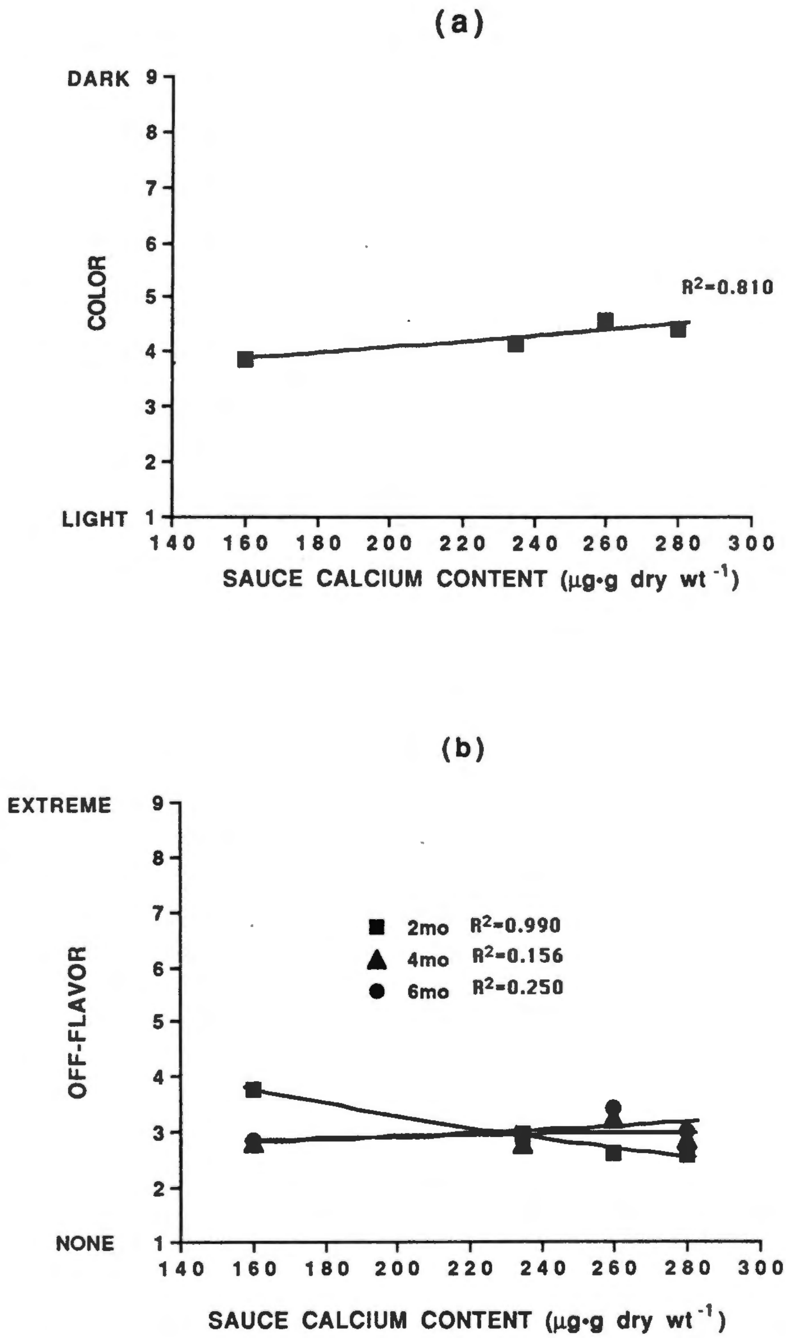


Fig. III.6: Color and off-flavor evaluation by sensory panel of applesauce made from a blend of 'Golden Delicious' and 'Red Rome' apples with different calcium content. (a) Average color of blended applesauce across storage times. (b) Off flavor of blended applesauce after 2, 4, and 6 months in storage. The best fit quadratic equations were: (a) $y= 3.1825 + 3.7202*10^{-3}x + 8.3260*10^{-6}x^2$; (b) 2mo: $y= 6.4798 - 2.0788*10^{-2}x + 2.4*10^{-5}x^2$: 4mo: $y= 2.2032 + 5.0814*10^{-3}x - 8.155*10^{-6}x^2$: 6mo: $y= 2.9763 - 2.7375*10^{-3}x + 1.2249*10^{-5}x^2$.

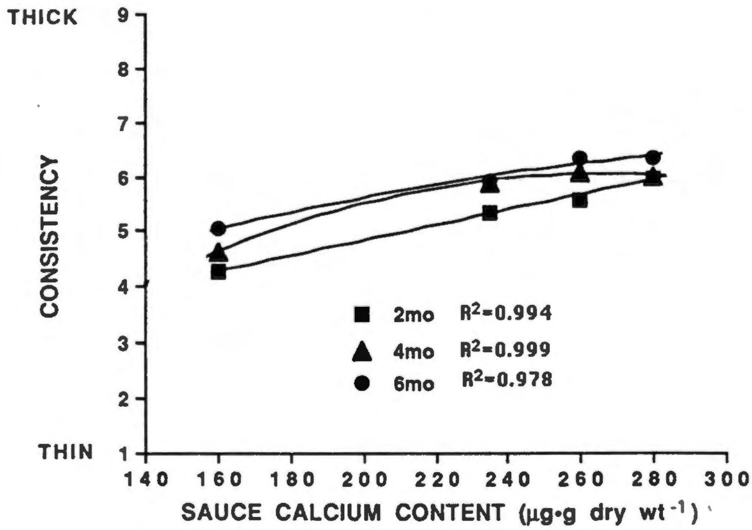
storage (3.9) than in sauce prepared with untreated apples removed after 4 and 6 month storage (2.8). For the 2 months storage time the intensity of the off flavors decreased as the Ca content of the sauce increased (Fig. III.6b).

Calcium content and the Ca content by storage time interaction had a very significant effect on consistency. Storage time had no effect on consistency of the sauce. The sensory panel found that the consistency values of the applesauce increased (the sauce became thicker) as Ca increased. Mean consistency values ranged from 5.1 for sauce with 160 $\mu g \cdot g$ dry wt^{-1} Ca to 6.1 for sauce with 280 $\mu g \cdot g$ dry wt^{-1} Ca These results agree with those obtained with the Bostwick Consistometer (Fig. III.7a).

Overall acceptability scores of sauce prepared from the two cultivars were not affected by Ca treatment or storage time. The scores ranged from 5.1 when Ca was 160 $\mu g \cdot g$ dry wt^{-1} to 5.5 when Ca was 280 $\mu g \cdot g$ dry wt^{-1} (Fig. III.7b).

The $CaCl_2$ treatments were effective in prolonging storage life of the apples and retaining attributes. In general, postharvest $CaCl_2$ treatments of the apples had either no effect or an enhancing effect on the quality of the applesauce. Contrary to the first experiment presented in this thesis, Ca content of apples treated in the second experiment did not reach the optimum level. Additional research is needed to determine how cultivar differences and maturity affect uptake of Ca applied by postharvest treatment. The next

(a)



(b)

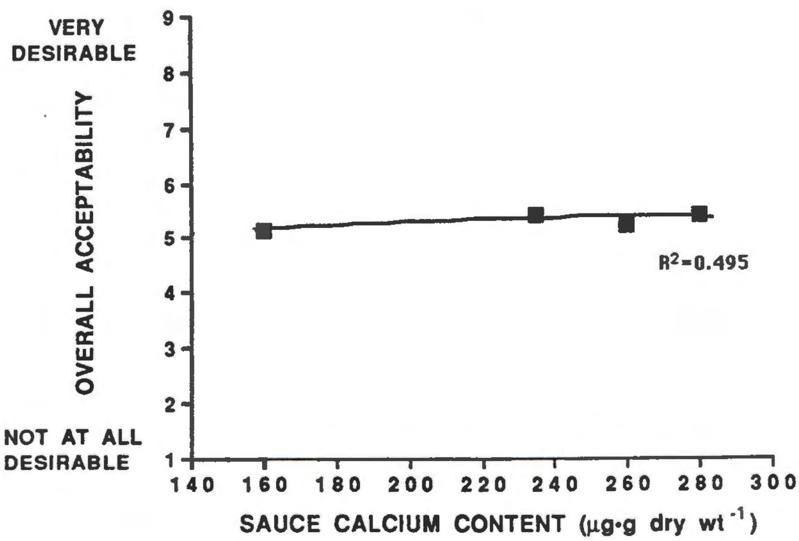


Fig. III.7: Consistency and overall acceptability evaluation by sensory panel of applesauce made from a blend of 'Golden Delicious' and 'Red Rome' apples with different calcium content. (a) Consistency of blended applesauce after 2, 4, and 6 months in storage. (b) Average overall acceptability of blended applesauce across storage time. The best fit quadratic equations were: (a) 2mo: $y= 2.2234 + 1.2266*10^{-2}x + 3.4217*10^{-6}x^2$; 4mo: $y= -2.7813 + 6.6013*10^{-2}x - 1.2397*10^{-4}x^2$: 6mo: $y= 1.7379 + 2.6037*10^{-2}x - 3.3857*10^{-5}x^2$: (b) $y= 4.0824 - 9.6529*10^{-3}x -1.8302*10^{-5}x^2$.

logical step for such research would be development of a model to determine the appropriate level of Ca to apply to apples of different cultivars and maturities.

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IV. SUMMARY AND CONCLUSIONS

The objective of this study was to evaluate chemical, physical, and sensory attributes of applesauce prepared from apples pressure-infiltrated with $CaCl_2$ prior to storage.

The $CaCl_2$ treatment was effective in increasing Ca content of fresh fruit and, in turn, Ca content of sauce prepared with treated fruit. However, the amount of Ca uptaken by the fruit varied with cultivar, maturity of fruit, and the concentration of the $CaCl_2$ solution in the treatment. Firmness of fresh fruit increased as Ca content increased, but soluble solids content was unaffected by Ca treatment.

Consistency of applesauce made from treated apples increased (became thicker) as Ca content increased, but syneresis (free liquid) remained unaffected by Ca content of the sauce. Sauce prepared from treated 'Golden Delicious' apples became less green and more yellow as Ca content increased while sauce prepared from 'Red Rome' became lighter as Ca content increased. Sauce prepared from a blend of the two cultivars became lighter as Ca content increased. Viscosity of the sauce increased as Ca content increased.

A sensory panel determined that color of sauce prepared from 'Golden Delicious' apples became lighter as Ca content increased and sauce prepared from 'Red Rome' apples became darker. Panelists determined that off-flavors in the sauce are detectable after Ca content surpasses a threshold of 450 $\mu g \cdot g$

dry wt^{-1}. According to the score of the panelists, intensity of off-flavors of the sauce increased as the storage time of the apple used to prepare the sauce increased. Panelists also established that consistency of the sauce increased as Ca content increased. Finally, panelists concluded that overall acceptability of sauce increased as Ca content increased up to a threshold level.

Previous studies have proven that postharvest calcium treatments extend the storage life of treated apples and preserve the quality of the fresh fruit throughout the season. The results of this study indicate that pressure infiltrating $CaCl_2$ into apples prior to storage also has an impact on the quality of applesauce prepared from treated apples as indicated by both physical analysis and sensory evaluation. Applesauce prepared from apples treated with the optimum $CaCl_2$ solution was superior in overall quality than applesauce prepared from untreated fruit.

The next step in this research should be to establish the appropriate calcium treatments for different apple cultivars at different maturities to obtain optimum quality of fresh apples and apple products.

APPENDICES

APPENDIX A

PROCEDURES

ANALYSIS PROCEDURE FOR CALCIUM MEASUREMENT

Procedure

1. Weigh 0.5 g dried ground sample into test tube.
2. Ash sample at least 4 hours at 500°C.
3. Add up to 4 mL 2N HCl (add enough to dissolve sample).
4. Stir sample in a vortex.
5. Dilute with distilled deionized water to exactly 10 mL (depending on amount of 2N HCl required to dissolve).
6. Using the auto-diluter, withdraw 1 mL and dispense in a clean tube.
7. Add 1 mL 5% lanthium chloride (or 0.1 mL 50% lanthium chloride) to obtain a 0.5% lanthium chloride solution.
8. Additional dilutions may be necessary to meet specifications posted for the atomic absorption spectrophotometer. Keep track of dilutions, and adjust for lanthium chloride in solution.

ASCORBIC ACID DETERMINATION

Reagents

-Extraction Solution: Metaphosphoric acid/acetic acid solution. In a 500 mL volumetric: 200 mL H_2O + 40 mL acetic acid. Add 15 g HPO_3 pellets and dissolve with shaking or stirring. Bring to 500 mL. volume with H_2O and filter rapidly with fluted paper (#2) into 500 mL Erlenmeyer flask. (Store in refrigerator, renew weekly).

-Indophenol standard dye: Use Sigma dye
In 500 mL volumetric: 125 mL H_2O + 105 mg sodium bicarbonate. Add 125 mg dye and dissolve by shaking vigorously. When dye has dissolved bring to 500 mL volume with H_2O and filter through fluted paper (#4) into a dark glass bottle. Keep closed, out of light, and stored in refrigerator. (To check activity, add 5 mL extraction solution containing excess ascorbic acid to 15 mL dye. If not practically colorless, prepare fresh dye).

-Ascorbic acid standard: prepare fresh daily
Place 50 mg USP ascorbic acid reference standard in 50 mL volumetric flask. Bring to volume with extraction solution immediately before use.

Standardization of Dye (daily)

In 100 mL beaker: place 5 mL extraction solution + 2 mL ascorbic acid standard solution, (2 or 3 replications). Titrate rapidly with dye until light but distinct rose pink persists for 25 seconds. Amount of dye may exceed 15 mL but should not vary widely from day to day. Dye required should agree closely among replications.
Blank: 7 mL extraction solution + vol of H_2O similar to volume of dye used in above titrations. Subtract blank from standard solution and calculate dye value: 2 mg ascorbic/1 mL dye=2mg/__ mL dye above, used as dye value in later calculations.

Sample Extraction

1. Bring all solutions to room temperature.

2. Place 20 mL extraction solution in a beaker. Add 10 g applesauce. Add another 10 mL extraction solution. Blend for 2 min. Centrifuge 5 min at 2500 rpm.

3. Pipette 10 mL clear solution into 25 mL beakers.

4. Titrate with standardized dye to light rose pink. Record mL dye required.

Ascorbic acid calculation

$$\text{Ascorbic acid: } D \times S \times \frac{(V_1 + V_2)}{V_3} \times \frac{100}{W}$$

D = mL dye required to titrate sample
S = dye value calculated before (mg ascorbic acid/ml dye)
V_1= mL extraction solution
V_2= mL H_2O in sample (determined by drying)
V_3= mL of aliquot titrated
W = weight of sample

Reference: A.O.A.C. 1980. Official Methods of Analysis Association of Official Analytical Chemists. 13th Edition. Determination of ascorbic acid #43. 057 p. 746. AOAC Washington, DC.

APPARENT VISCOSITY PROCEDURE FOR APPLESAUCE

1. Mount Brookfield Viscometer and helipath attachment on the upright rod and level using the leveling screws provided.

2. Set velocity of the viscometer and select T-spindle size to accommodate for the viscosity range of the sample.

3. Place samples in 150 mL beakers filled to the rim.

4. With the viscometer and the helipath attachment turned off, put the spindle in the sample.

5. Turn on both the viscometer and the helipath attachment.

6. After 1 min take first reading; 30 sec after first reading take second reading; 30 sec after second reading take third reading.

7. Average the readings and multiply by Brookfield factor (it depends on the speed-spindle combination) to obtain viscosity readings in centipoise (mPa·s).

Reference: Brookfield. 1986. Brookfield dial reading viscometers. Operating instructions. Stoughton, MA.

APPENDIX B
DATA
(Least Square Mean Estimates
Based On Three Replications)

Table B.1: Carbon dioxide (CO_2) and ethylene (C_2H_4) production rates of 'Golden Delicious' (GD) and 'Red Rome' (RR) apples as measured by gas chromatography.

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	CO_2 (mL/kg*hr) Day 1	CO_2 (mL/kg*hr) Day 2	C_2H_4 (μL/kg*hr) Day 1	C_2H_4 (μL/kg*hr) Day 2
GD	88	0	0	-----	-----	0.06	0.09
GD	88	2	0	-----	-----	115.78	172.15
GD	88	2	1	-----	-----	96.53	143.40
GD	88	2	2	-----	-----	83.88	120.04
GD	88	2	3	-----	-----	62.20	87.07
GD	88	2	4	-----	-----	34.15	44.72
GD	88	4	0	-----	-----	244.01	340.55
GD	88	4	1	-----	-----	313.86	344.28
GD	88	4	2	-----	-----	267.07	353.89
GD	88	4	3	-----	-----	225.24	264.89
GD	88	4	4	-----	-----	217.73	231.31
GD	88	6	0	-----	-----	290.59	396.29
GD	88	6	1	-----	-----	310.67	353.40
GD	88	6	2	-----	-----	260.08	297.54
GD	88	6	3	-----	-----	224.36	221.52
GD	88	6	4	-----	-----	208.60	209.26
RR	88	0	0	-----	-----	0.48	0.39
RR	88	2	0	-----	-----	56.85	81.03
RR	88	2	2	-----	-----	54.57	91.31
RR	88	2	4	-----	-----	45.04	67.08
RR	88	2	6	-----	-----	33.61	59.99
RR	88	2	8	-----	-----	24.17	43.16
RR	88	4	0	-----	-----	102.11	150.63
RR	88	4	2	-----	-----	81.53	169.21
RR	88	4	4	-----	-----	105.80	206.49
RR	88	4	6	-----	-----	79.20	182.69
RR	88	4	8	-----	-----	57.07	120.42
RR	88	6	0	-----	-----	118.63	63.29
RR	88	6	2	-----	-----	107.33	63.14
RR	88	6	4	-----	-----	125.68	62.74
RR	88	6	6	-----	-----	99.74	50.79
RR	88	6	8	-----	-----	77.12	48.15
GD	89	0	X	31.96	28.66	143.37	59.50

Table B.1 cont:

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	CO_2 (mL/kg*hr) Day 1	Day 2	C_2H_4 (μL/kg*hr) Day 1	Day 2
GD	89	2	X	15.63	16.51	108.68	104.58
GD	89	2	0	13.60	15.50	136.90	127.50
GD	89	2	1	14.21	15.56	103.61	85.55
GD	89	2	2	12.51	14.81	97.99	85.27
GD	89	2	4	12.64	14.84	89.66	84.76
GD	89	4	X	90.95	151.14	57.93	228.95
GD	89	4	0	56.38	147.11	26.12	255.64
GD	89	4	1	85.19	123.83	52.10	178.21
GD	89	4	2	79.95	131.02	53.16	187.05
GD	89	4	4	50.96	139.20	47.21	184.66
GD	89	6	X	17.39	17.74	46.23	26.78
GD	89	6	0	21.00	21.06	26.94	27.51
GD	89	6	1	20.26	20.21	22.90	19.63
GD	89	6	2	17.78	19.68	14.63	19.13
GD	89	6	4	27.06	27.46	20.06	19.10
RR	89	0	X	33.39	31.49	4.97	5.58
RR	89	2	X	13.58	14.30	36.55	47.48
RR	89	2	0	12.85	14.11	30.03	45.25
RR	89	2	2	11.31	14.10	28.14	35.60
RR	89	2	4	11.09	13.56	24.18	33.31
RR	89	2	8	10.65	12.84	25.70	37.44
RR	89	4	X	87.62	112.83	36.06	106.07
RR	89	4	0	72.39	128.71	29.36	99.23
RR	89	4	2	62.51	134.07	29.05	102.70
RR	89	4	4	60.55	128.13	31.34	92.32
RR	89	4	8	68.58	126.39	29.38	100.62
RR	89	6	X	26.18	26.55	64.74	10.16
RR	89	6	0	21.94	26.43	43.56	7.40
RR	89	6	2	25.73	27.34	43.94	10.75
RR	89	6	4	11.79	14.71	12.36	9.05
RR	89	6	8	21.25	25.47	47.09	12.23

Table B.2: Calcium content, firmness, and soluble solids (SS) of 'Golden Delicious' (GD) and 'Red Rome' (RR) apples.

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	Calcium ($\mu g \cdot g$ dry wt^{-1})	Firmness (N)	SS (%)
GD	88	0	0	------	-----	-----
GD	88	2	0	334.56	53.75	14.36
GD	88	2	1	574.94	55.78	13.97
GD	88	2	2	909.16	56.64	14.59
GD	88	2	3	1999.54	65.76	14.54
GD	88	2	4	2816.90	76.22	14.03
GD	88	4	0	264.52	59.27	14.53
GD	88	4	1	314.84	57.50	14.13
GD	88	4	2	493.34	58.05	13.93
GD	88	4	3	547.40	62.98	13.85
GD	88	4	4	1616.36	72.92	14.07
GD	88	6	0	128.86	56.47	13.28
GD	88	6	1	282.20	57.47	14.19
GD	88	6	2	425.68	58.58	13.79
GD	88	6	3	771.46	65.07	14.12
GD	88	6	4	994.84	72.12	13.47
RR	88	0	0	------	-----	-----
RR	88	2	0	------	64.33	09.74
RR	88	2	2	------	65.11	10.83
RR	88	2	4	------	70.01	10.48
RR	88	2	6	------	72.86	11.29
RR	88	2	8	------	77.96	10.28
RR	88	4	0	------	62.57	09.56
RR	88	4	2	------	63.14	09.99
RR	88	4	4	------	64.46	10.71
RR	88	4	6	------	65.28	11.09
RR	88	4	8	------	68.72	11.41
RR	88	6	0	------	59.29	09.08
RR	88	6	2	------	58.53	10.24
RR	88	6	4	------	63.34	09.66
RR	88	6	6	------	63.78	10.42
RR	88	6	8	------	66.68	09.49
GD	89	0	X	190.12	-----	-----

Table B.2 cont:

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	Calcium ($\mu g \cdot g$ dry wt^{-1})	Firmness (N)	SS (%)
GD	89	2	X	190.12	-----	-----
GD	89	2	0	185.32	-----	-----
GD	89	2	1	230.62	-----	-----
GD	89	2	2	287.28	-----	-----
GD	89	2	4	294.16	-----	-----
GD	89	4	X	190.12	52.67	13.07
GD	89	4	0	185.32	51.16	12.85
GD	89	4	1	230.62	50.19	13.55
GD	89	4	2	287.28	53.86	13.03
GD	89	4	4	294.16	58.18	13.44
GD	89	6	X	190.12	50 73	12.73
GD	89	6	0	185.32	50.03	13.14
GD	89	6	1	230.62	49.06	13.35
GD	89	6	2	287.28	52.05	12.87
GD	89	6	4	294.16	51.51	13.49
RR	89	0	X	236.26	-----	-----
RR	89	2	X	236.26	-----	-----
RR	89	2	0	263.89	-----	-----
RR	89	2	2	353.75	-----	-----
RR	89	2	4	382.95	-----	-----
RR	89	2	8	391.66	-----	-----
RR	89	4	X	236.26	65.32	11.47
RR	89	4	0	263.89	70.75	11.40
RR	89	4	2	353.75	65.48	11.20
RR	89	4	4	382.95	69.91	11.47
RR	89	4	8	391.66	70.04	11.09
RR	89	6	X	236.26	63.06	10.93
RR	89	6	0	263.89	64.21	10.47
RR	89	6	2	353.75	65.08	11.11
RR	89	6	4	382.95	64.59	10.75
RR	89	6	8	391.66	69.73	11.07

Table B.3: Calcium content, consistency (Consis), and syneresis (Syner) of 'Golden Delicious' (GD) and 'Red Rome' (RR) applesauce in 1988 and of a blend of the two cultivars (GD/RR) in 1989.

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	Sauce Calcium ($\mu g \cdot g$ dry wt^{-1})	Consis ($cm \cdot 10\ min^{-1}$)	Syner
GD	88	0	0	209.31	3.10	0.00
GD	88	0	1	304.15	1.77	0.00
GD	88	0	2	475.71	0.78	0.00
GD	88	0	3	808.94	0.55	0.00
GD	88	0	4	1274.04	0.33	0.03
GD	88	2	0	635.20	1.68	0.03
GD	88	2	1	293.81	0.90	0.00
GD	88	2	2	462.06	0.53	0.00
GD	88	2	3	822.92	0.43	0.00
GD	88	2	4	913.41	0.37	0.13
GD	88	4	0	221.81	0.97	0.07
GD	88	4	1	416.19	0.73	0.03
GD	88	4	2	523.80	0.72	0.03
GD	88	4	3	547.40	0.47	0.18
GD	88	4	4	828.97	0.37	0.13
GD	88	6	0	220.59	0.93	0.03
GD	88	6	1	410.54	0.73	0.20
GD	88	6	2	545.21	0.63	0.20
GD	88	6	3	832.47	0.67	0.10
GD	88	6	4	344.55	0.47	0.17
RR	88	0	0	223.91	1.17	0.00
RR	88	0	2	212.94	1.68	0.00
RR	88	0	4	245.97	1.07	0.00
RR	88	0	6	413.49	0.77	0.00
RR	88	0	8	461.03	0.58	0.07
RR	88	2	0	260.46	1.00	0.30
RR	88	2	2	255.29	1.32	0.32
RR	88	2	4	304.65	1.03	0.13
RR	88	2	6	509.08	0.75	0.03
RR	88	2	8	605.12	0.60	0.03
RR	88	4	0	219.10	0.90	0.22
RR	88	4	2	228.86	1.13	0.27
RR	88	4	4	271.00	0.80	0.17
RR	88	4	6	495.28	0.53	0.03
RR	88	4	8	573.09	0.53	0.00

Table B.3 cont:

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	Sauce Calcium ($\mu g \cdot g$ dry wt^{-1})	Consis ($cm \cdot 10$ min^{-1})	Syner
RR	88	6	0	233.05	0.93	0.30
RR	88	6	2	229.69	0.82	0.45
RR	88	6	4	280.34	1.02	0.32
RR	88	6	6	517.05	0.70	0.22
RR	88	6	8	625.27	0.57	0.18
GD/RR	89	0	X/X	------	-----	-----
GD/RR	89	2	X/X	148.01	6.83	1.33
GD/RR	89	2	0/0	172.84	6.17	1.50
GD/RR	89	2	1/2	231.97	4.48	1.60
GD/RR	89	2	2/4	247.80	4.67	0.75
GD/RR	89	2	4/8	271.77	3.33	0.33
GD/RR	89	4	X/X	164.18	5.00	2.00
GD/RR	89	4	0/0	160.65	4.50	3.00
GD/RR	89	4	1/2	227.27	3.67	3.50
GD/RR	89	4	2/4	246.53	3.00	3.33
GD/RR	89	4	4/8	274.47	2.83	3.17
GD/RR	89	6	X/X	178.89	2.50	1.93
GD/RR	89	6	0/0	181.18	2.83	1.83
GD/RR	89	6	1/2	260.15	2.17	1.50
GD/RR	89	6	2/4	281.06	2.17	2.33
GD/RR	89	6	4/8	308.72	1.50	2.00

Table B.4: Hunter values of 'Golden Delicious' (GD) and 'Red Rome' (RR) applesauce in 1988 and of a blend of the two cultivars (GD/RR) in 1989.

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	Hunter values 'a'	'b'	'L'
GD	88	0	0	-2.57	19.90	48.27
GD	88	0	1	-2.93	21.16	49.20
GD	88	0	2	-2.33	21.47	50.43
GD	88	0	3	-2.03	22.50	51.00
GD	88	0	4	-0.90	20.90	48.77
GD	88	2	0	-2.13	20.77	48.17
GD	88	2	1	-2.63	21.80	42.53
GD	88	2	2	-2.43	21.93	49.80
GD	88	2	3	-1.60	22.50	49.70
GD	88	2	4	-0.93	21.47	48.53
GD	88	4	0	-1.70	22.30	48.90
GD	88	4	1	-2.47	22.57	49.13
GD	88	4	2	-2.50	22.67	49.13
GD	88	4	3	-1.83	22.50	48.17
GD	88	4	4	-1.07	22.20	47.67
GD	88	6	0	-1.50	21.40	47.70
GD	88	6	1	-1.80	23.17	50.37
GD	88	6	2	-1.47	21.70	48.63
GD	88	6	3	-0.87	22.07	47.67
GD	88	6	4	-0.70	22.10	48.37
RR	88	0	0	0.10	14.65	40.70
RR	88	0	2	-1.55	15.25	41.90
RR	88	0	4	-0.75	15.45	42.40
RR	88	0	6	-1.10	16.05	42.85
RR	88	0	8	-1.45	16.30	43.55
RR	88	2	0	-0.23	15.50	42.10
RR	88	2	2	-1.33	15.53	42.50
RR	88	2	4	-1.23	15.90	43.20
RR	88	2	6	-1.33	16.40	43.13
RR	88	2	8	-1.27	16.90	43.70
RR	88	4	0	-0.80	16.27	43.40
RR	88	4	2	-1.00	16.47	42.93
RR	88	4	4	-1.17	16.43	43.47
RR	88	4	6	-1.23	17.27	43.93
RR	88	4	8	-0.90	17.60	43.83

Table B.4 cont:

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	Hunter values 'a'	'b'	'L'
RR	88	6	0	-0.10	15.30	41.97
RR	88	6	2	1.40	14.77	39.67
RR	88	6	4	-0.30	16.33	42.77
RR	88	6	6	-0.73	17.43	43.07
RR	88	6	8	-0.07	16.40	42.07
GD/RR	89	0	X/X	------	-----	-----
GD/RR	89	2	X/X	-3.17	13.97	41.37
GD/RR	89	2	0/0	-2.30	14.40	42.13
GD/RR	89	2	1/2	-2.60	14.03	41.73
GD/RR	89	2	2/4	-2.43	13.67	41.20
GD/RR	89	2	4/8	-2.97	15.73	44.20
GD/RR	89	4	X/X	-3.20	14.53	42.37
GD/RR	89	4	0/0	-2.30	14.37	42.07
GD/RR	89	4	1/2	-2.67	15.50	43.63
GD/RR	89	4	2/4	-2.13	15.50	43.83
GD/RR	89	4	4/8	-1.77	14.80	42.73
GD/RR	89	6	X/X	-2.27	15.97	44.47
GD/RR	89	6	0/0	-1.97	16.47	44.33
GD/RR	89	6	1/2	-2.13	17.20	45.77
GD/RR	89	6	2/4	-1.70	16.27	44.87
GD/RR	89	6	4/8	-2.17	17.30	45.77

Table B.5: Apparent viscosity and vitamin C content of 'Golden Delicious' (GD) and 'Red Rome' (RR) applesauce in 1988 and of a blend of the two cultivars (GD/RR) in 1989.

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	Viscosity (mPa·s)	Vitamin C (mg·100g^{-1})
GD	88	0	0	662222.22	0.31
GD	88	0	1	670000.00	0.26
GD	88	0	2	1380000.00	0.27
GD	88	0	3	2733333.33	0.26
GD	88	0	4	1642222.22	0.21
GD	88	2	0	1091111.11	0.18
GD	88	2	1	1591111.11	0.19
GD	88	2	2	2364444.45	0.22
GD	88	2	3	3175555.55	0.22
GD	88	2	4	4146666.66	0.25
GD	88	4	0	1282222.22	0.29
GD	88	4	1	1675555.55	0.20
GD	88	4	2	1931111.11	0.29
GD	88	4	3	3670000.00	0.22
GD	88	4	4	5511111.11	0.22
GD	88	6	0	1133333.33	0.17
GD	88	6	1	1691111.11	0.16
GD	88	6	2	1717777.78	0.19
GD	88	6	3	2968888.89	0.19
GD	88	6	4	6731110.78	0.18
RR	88	0	0	1226666.66	0.22
RR	88	0	2	882222.22	0.19
RR	88	0	4	1226666.67	0.17
RR	88	0	6	2248888.89	0.14
RR	88	0	8	2051555.55	0.20
RR	88	2	0	1448888.89	0.21
RR	88	2	2	1164444.44	0.22
RR	88	2	4	1324444.45	0.20
RR	88	2	6	2135555.56	0.22
RR	88	2	8	1902222.22	0.28
RR	88	4	0	1666666.67	0.17
RR	88	4	2	1611111.11	0.17
RR	88	4	4	2111111.11	0.19
RR	88	4	6	2391111.11	0.20
RR	88	4	8	2195555.56	0.18
RR	88	6	0	1273333.33	0.15

Table B.5 cont:

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	Viscosity (mPa·s)	Vitamin C ($mg \cdot 100g^{-1}$)
RR	88	6	2	1520000.00	0.14
RR	88	6	4	1593333.33	0.16
RR	88	6	6	1966666.67	0.14
RR	88	6	8	2088888.89	0.16
GD/RR	89	0	X/X	----------	-----
GD/RR	89	2	X/X	324444.44	0.22
GD/RR	89	2	0/0	392222.22	0.21
GD/RR	89	2	1/2	543333.33	0.24
GD/RR	89	2	2/4	597777.78	0.25
GD/RR	89	2	4/8	724444.44	0.24
GD/RR	89	4	X/X	427777.78	0.21
GD/RR	89	4	0/0	631111.11	0.21
GD/RR	89	4	1/2	628888.89	0.24
GD/RR	89	4	2/4	917777.78	0.27
GD/RR	89	4	4/8	731111.11	0.28
GD/RR	89	6	X/X	805555.56	0.23
GD/RR	89	6	0/0	834444.44	0.20
GD/RR	89	6	1/2	975555.56	0.22
GD/RR	89	6	2/4	1011111.11	0.21
GD/RR	89	6	4/8	1454444.44	0.21

Table B.6: Sensory evaluation of 'Golden Delicious' (GD) and 'Red Rome' (RR) applesauce in 1988 and of a blend of the two cultivars (GD/RR) in 1989.

Cultivar	Year	Storage (mo)	Tmt (%$CaCl_2$)	Color	Off-Flavor	Consis-tency	Overall Accept.
GD	88	0	0	3.32	3.58	5.06	5.05
GD	88	0	1	3.33	3.15	5.23	5.08
GD	88	0	2	3.96	3.08	6.30	5.04
GD	88	0	3	4.08	3.65	7.26	3.62
GD	88	0	4	4.50	3.37	7.17	4.02
GD	88	2	0	3.68	2.49	4.34	5.79
GD	88	2	1	3.89	2.41	5.79	5.96
GD	88	2	2	4.16	2.58	6.46	5.47
GD	88	2	3	4.65	3.08	6.85	4.92
GD	88	2	4	5.77	3.49	7.54	3.75
GD	88	4	0	3.70	2.24	4.98	5.77
GD	88	4	1	4.08	2.14	5.68	5.54
GD	88	4	2	4.10	1.85	6.15	6.16
GD	88	4	3	4.25	2.50	6.70	5.13
GD	88	4	4	4.19	3.62	7.49	3.60
GD	88	6	0	4.85	2.14	4.62	5.77
GD	88	6	1	4.00	2.04	5.27	6.23
GD	88	6	2	3.94	2.01	5.22	6.04
GD	88	6	3	4.36	2.19	6.36	5.24
GD	88	6	4	4.24	2.94	7.23	3.72
RR	88	0	0	6.55	3.60	5.68	3.31
RR	88	0	2	6.28	3.23	5.20	4.25
RR	88	0	4	6.14	2.66	6.04	3.93
RR	88	0	6	5.94	3.02	6.56	4.41
RR	88	0	8	5.97	2.87	6.47	4.25
RR	88	2	0	7.06	3.06	5.97	3.54
RR	88	2	2	6.53	2.52	5.32	4.53
RR	88	2	4	6.86	2.40	6.12	4.61
RR	88	2	6	6.77	2.12	6.30	4.78
RR	88	2	8	6.97	2.45	6.75	4.28
RR	88	4	0	6.50	3.41	5.52	3.03
RR	88	4	2	6.44	3.00	5.25	3.62
RR	88	4	4	6.42	3.23	5.66	3.53
RR	88	4	6	6.24	2.93	6.21	4.07
RR	88	4	8	6.41	2.98	6.81	3.85

Table B.6 cont:

Cultivar	Year	Storage (mo)	Tmt ($\%CaCl_2$)	Color	Off-Flavor	Consis-tency	Overall Accept.
RR	88	6	0	6.12	4.13	5.37	2.70
RR	88	6	2	6.08	3.40	5.07	2.92
RR	88	6	4	5.45	2.63	5.40	3.86
RR	88	6	6	5.03	2.30	6.27	4.07
RR	88	6	8	4.68	2.33	6.13	4.27
GD/RR	89	0	X/X	----	----	----	----
GD/RR	89	2	X/X	3.34	3.76	4.27	4.56
GD/RR	89	2	0/0	4.13	2.87	4.90	5.53
GD/RR	89	2	1/2	3.94	2.97	5.34	5.47
GD/RR	89	2	2/4	4.23	2.62	5.57	5.50
GD/RR	89	2	4/8	4.32	2.58	5.96	5.79
GD/RR	89	4	X/X	4.12	2.82	4.63	5.51
GD/RR	89	4	0/0	4.46	2.89	5.19	5.05
GD/RR	89	4	1/2	4.18	2.79	5.88	5.44
GD/RR	89	4	2/4	4.63	3.24	6.06	5.22
GD/RR	89	4	4/8	4.50	2.86	5.99	5.59
GD/RR	89	6	X/X	4.16	2.87	5.04	5.38
GD/RR	89	6	0/0	4.41	2.97	5.31	5.46
GD/RR	89	6	1/2	4.29	2.82	5.91	5.35
GD/RR	89	6	2/4	4.81	3.42	6.34	4.95
GD/RR	89	6	4/8	4.39	3.02	6.32	4.85

VITA

Robert José Portillo Quintero was born September 11, 1964 in Caracas, Venezuela. He is the son of Yolanda Del Carmen Quintero Semidey and Heberto José Portillo Castro. In October of 1982, he obtained a High School diploma from Unidad Escolar "Gran Colombia" in Caracas, Venezuela. In 1983, he attended Ohio Wesleyan University in Delaware, Ohio, where he completed an English program for foreign students and his freshman year. He entered The University of Tennessee, Knoxville in September of 1984 and completed a Bachelor of Science degree in Agricultural Engineering in August of 1987. He became a graduate student in the Plant and Soil Science department at The University of Tennessee, Knoxville in August of 1988 and received a Master of Science degree in December of 1991.

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