THE THERMAL PRESERVATION OF APPLE SLICES IN FLEXIBLE RETORT POUCHES

by

CLARENCE GORDON CHRISTENSON
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C. Gordon Christenson

Department of Food Science
The University of British Columbia
Vancouver, Canada
Date April 21, 1978

ABSTRACT

Newtown Pippin and Winesap apples were taken from terminal storage and prepared as slices to be processed in retortable pouches to determine an optimum process using the relatively new pouch technology. Preprocessing treatments included calcium chloride as a texture modifier, sodium bisulfite as a microbial inhibitor and colour stabilizer, and sodium acid pyrophosphate as a colour stabilizer. These reagents were added to the slices by vacuum infusion, hot blanching or cold dipping to determine their effects on the final product. The slices were packed in 300 gram pouches that were evacuated, then flushed with either nitrogen or carbon dioxide before sealing.

The samples were stored at 22 and 35^{o}C and were examined by physical, chemical and sensory methods, at intervals of two weeks, six weeks and five months after processing to determine the changes occurring within the samples. During storage, quality changes did occur, which affected the acceptance of the samples, particularly at the higher temperatures.

Texture was vastly improved with the addition of calcium ions to old apples. Colour remained significantly lighter in samples with higher SO_2 levels. The addition of pyrophosphate was also shown to increase the lightness of the samples. The levels of reducing sugars and pH were shown to increase with the

length and temperature of storage.

Preparatory methods were also shown to have a great influence on the quality of the final product. Hot blanching of apple slices lead to a lower quality product than either vacuum infusion or cold dipping. Vacuum infusion was by far the most efficient preparatory method but resulted in a product with a translucent appearance and a bland flavour. Cold dipping produced the best final product. The use of carbon dioxide atmospheres within the pouch produces a lower pH and a softer texture in the samples. Nitrogen was found to be the better of the two gases for quality maintenance.

In general, it was determined that apples from terminal storage were more difficult to process into a product of good quality than were apples stored for only a short time after harvest.

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INTRODUCTION

Since the end of the second world war, the development of the petro-chemical industry has led to an increase in the types of materials available for the packaging of food. During this time, a number of flexible wraps became popular in the food industry, but it has only been within the last fifteen years that flexible polymers, capable of withstanding the temperatures required to stabilize low acid foods, have been developed (Mermelstein, 1976). With this has come the rise of a variety of laminated flexible retort pouches which have found widespread acceptance in some parts of the world, notably Japan. In other areas, however, the appearance of the pouch has been particularly slow. This was especially true on the North American continent where the progress of pouch technology has been impeded by the refusal of the Food and Drug Administration to give approval for its use in the food industry of the United States. Recently, however, with the development, by Continental Can Company of a new heat bonded trilaminate which does not require the use of the offending polyurethane adhesives, the last obstacles to acceptance of the pouch have been removed, opening a large market to this concept.

Since the physical aspects of the pouch are somewhat different to those of conventional glass and tinplate containers, there arises the need to establish food formulations, to conduct heat penetration studies, and to assess consumer reactions to such foods before a full scale entry into the field of pouched food can be attempted. It is therefore the purpose of this research to investigate the aspects of processing some fruit products in this manner, to monitor changes which occurred over a preselected storage period and to determine the acceptability of the samples by a small group of panelists. Different varieties of apples were chosen for this project since apples are the most important fruit crop raised in Canada, of which more than ten percent of the total domestic consumption is in the form of canned fruit products. (Canada Year Book, 1975).

Since the history and length of storage of apples can influence their subsequent texture, and since processes involving pouches are less stringent, apples from terminal storage were used to determine if slices of suitable quality could be produced.

REVIEW OF THE LITERATURE

The problems arising from the processing of apple slices in flexible retort pouches for this project were divided into four categories as follows:

1. Establishing a safe process time
2. Assessing a number of preparatory treatments
3. Assessing the value and need for a number of chemical adjuncts used in processing
4. Evaluation of different apple varieties taken from terminal storage for this process

Process Time

The shape of the retort pouch presents a thinner profile for heat processing when compared to other conventional containers and therefore, a shorter heat treatment would be required to achieve microbial stability (Thorpe and Atherton, 1972). For this reason, the degree of quality deterioration which usually accompanies thermal processing in other containers should be less when the pouch is employed.

The establishment of a process time for any product can be carried out by either direct measurement or by mathematical calculation. Heat penetration methods for pouched foods as described by Tung et al., (1976) and Tung and Garland (1976) are an example of a direct measurement and calculation of a reliable process time. The mathematical method involves the use of the

apparatus and method described by Dickerson (1965) along with the equation for a theoretical brick shape (Olson and Jackson, 1942) to provide an f-value which is subsequently used in Ball's straight-line semilog heating curve equation (Stumbo, 1973) to establish a process time.

The mathematical approach provides a relatively reliable process time provided that the process material heats by conduction and it is quickly carried out using relatively simple apparatus. Heat penetration studies also provide reliable process times but require care that the slowest heating point in the container is monitored throughout the process for a number of runs to reduce the effects of natural variation. This method also requires much complicated calculation which is time consuming unless there is access to a computer.

Preparatory Methods

In the canning industry, a great number of preparatory treatments have been used for the preservation of fruits and vegetables. Generally, these procedures are carried out to accomplish specific purposes such as air removal, tissue shrinkage, enzyme inactivation, texture enhancement and the addition of chemical adjuncts (Lee, 1958; Collins and Wiley, 1967; Hoover and Miller, 1975). For the processing of apple slices, it is desirable to retain a fairly firm texture while

removing gases, especially oxygen and inactivating enzymes. Oxygen removal is necessary to prevent browning and oxidative flavour changes (Hope, 1961).

A submerged vacuum infusion method described by Hoover and Miller (1975) was reported to be successful in the elimination of gas and the provision of a fine texture while permitting the addition of chemical preservatives to the tissues. Collins and Wiley (1967) found that this method was the most satisfactory to achieve an even distribution of calcium salts throughout apple tissue. The disadvantage of this method was found to be that enzyme activity was not curtailed unless live steam was used to break the vacuum in which case the slices could not be submerged in a liquid medium, thus eliminating the possibility of chemical addition. Sulfur dioxide, however, is known to be an inhibitor of certain enzyme-catalyzed reactions, notably enzymic browning (Lindsay, 1976) and therefore, if this chemical is present in the tissues, the importance of enzyme activity is greatly reduced. Tissue shrinkage is not as important in this procedure since the addition of fluid to the slices increases the density thereby making it easier to attain a proper fill weight (Gutterson, 1972).

Hot blanching, as described by Lee (1958), provides tissue shrinkage, air removal, enzyme inactivation, and limited chemical addition. The major disadvantage of this method is the loss of firmness which occurs with heating (Gutterson,

1972). The addition of firming agents, such as calcium salts, is known to counteract softening due to processing (Wiley and Lee, 1970). A second and more serious disadvantage to this process is the loss of solubles, particularly nutrients, from heat blanched tissues (Holmquist et al., 1954).

A third method of preparatory treatment used in fruit and vegetable processing is cold dipping. This method is used more in the frozen and refrigerated storage of these products and is employed mainly to apply a surface coating of chemical preservatives. Enzyme inhibition, air removal, and tissue shrinkage are not accomplished by this method and therefore, problems can arise from both oxidative and enzymic browning and difficulty could be encountered when trying to achieve an optimum fill weight in a container. The browning problems can be greatly reduced with the application of sulfur dioxide (Lindsay, 1976). The main advantage to this method is the retention of the fresh texture.

Chemical Adjuncts

In the processing of apple slices, various chemical additives can be used to enhance and maintain their texture, flavour and colour. It is desirable, however, from both an economic and aesthetic perspective, to use as few chemical additives as possible in the processing of all food materials.

Texture in apple slices can be a particularly difficult problem since it is related to apple variety, maturity, type and length of storage and the processing techniques to which they are subjected (Wiley and Thompson, 1960; Wiley and Stembridge, 1962). Calcium salts are proven firming agents but cannot always be relied on to give a product of uniform firmness because of the aforementioned variables. Collins and Wiley (1967) reported that the distribution of calcium salts throughout the fruit tissues had a marked effect on the final texture. The addition of sucrose and the raising of the pH of the addition medium to a range of 5.5 - 6.5, also was shown to have a beneficial effect on the firming action of added calcium in apple slices (Wiley and Lee, 1970; Ponting et al., 1971). This firmness was subsequently maintained when the pH was lowered with the addition of citric acid, a well known chelator of calcium ions.

Colour in apple slices is enhanced and maintained with the use of various chemical additives. Sulfur dioxide is commonly used and is highly effective in maintaining lightness in apple slices and has been successful for this purpose in unprocessed refrigerated apple slices for up to several weeks (Ponting et al., 1971). Ascorbic acid is also effective in maintaining lightness in apple slices (Ponting et al., 1972) but its cost is much higher than the acceptable sulfites which makes its use less attractive to processors. Ponting

et al., (1972) were also able to show that calcium ions were synergistic with both sulfur dioxide and ascorbic acid in maintaining lightness.

It has also been reported by Timberlake (1957) that metallic ions such as copper are responsible for catalyzing the oxidation of phenolic compounds producing a dark colour in the juices of apples and pears. Ortho and polyphosphate ions are known to be chelators of various metallic ions including iron and copper (Ellinger, 1972) and therefore, could be useful in lengthening the shelf life of canned apple products.

Sucrose can be added to processed apple products as a flavour enhancer although this is not always done in industry (Hope, 1961). Added sugar also provides a degree of body to the juices which are released from apple tissues when heated and as stated earlier, are thought to enhance the action of calcium in firming apple tissues.

A number of organic acids, notably citric, malic, and fumaric, may also be added to apple slices to increase their tartness (Gutterson, 1972). In many varieties of apples, however, this is unncecessary since the natural levels of acids, particularly malic acid, are sufficient to provide the required acidity (Eheart and Mason, 1967). Citric acid and to a lesser extent other organic acids are chelators of

calcium ions (Gardner, 1968) and therefore, might have a detrimental effect on the texture of apple tissue.

Varieties

In the British Columbia area there are several varieties of apples produced which are suitable for processing including: Golden Delicious, Red Delicious, Newtown Pippins, Winesaps, Spartans, Rome Beauties and McIntosh. Some of these varieties can provide processing problems when taken from prolonged storage (Kitson, 1976). McIntosh and Spartan varieties tend to have a high level of chlorophyll in the tissue which when processed, give a grey green cast to the product. Both have relatively short storage lives and are usually not available after December of the year of harvest. Red Delicious have very low levels of acid and do not have very good flavour when processed. Rome Beauties and Winesaps have a fairly long storage life but have a tendancy to turn pink when processed. This is possibly due to the presence of leucoanthocyanins present in the tissues. Golden Delicious are excellent processing apples and have a fairly long storage life of approximately six months after harvest. They also have been known to have a green cast when processed. Newtown Pippin apples have a very long storage life of about ten months. They have excellent texture and because of their fairly high acid content, provide

a good processed product. This variety, however, is also very popular on the fresh market.

Storage conditions and harvest maturity also have a profound effect on the final quality of apple products. Wiley and Thompson (1960) found that processed apple slice quality was about the same if apples used from common storage had only been stored for half the time of apples from cold storage. They also concluded that apple maturity at harvest influenced the length of storage for which apples could be held before they were past a processing quality. Long storage times produced processed apple slices lacking both firmness and a bright colour. Apples harvested at a post optimum maturity produced the best canned apple slices especially if processed immediately after harvest. From this study, they also found that no single chemical or physical measurement on raw apples was suitable for predicting the overall quality of processed slices but that shear press measurements on raw slices showed promise as an indicator of processed slice texture.

EXPERIMENTAL METHODS

EXPERIMENTAL DESIGN

For this project it was decided that a large pack of apple slices would be subjected to a number of different treatments and undergo a storage trial in an attempt to determine an approximate shelf life and the effect of the various treatment factors on it. The factors examined included two varieties of apples, the addition of SO_2 which was varied both by method of addition and levels, the addition of calcium ions which was varied both by method of addition and levels, the addition of pyrophosphate ions which was varied by methods of addition and levels, the replacement of air in the pouch by two different gases, and three different methods of preheating treatments before thermal processing.

The experiment was set up so that a total of 29 different experimental sample groups were produced. The sample groups were each divided in half and stored at different temperatures (22 and 37^{o} C) to note the effects on shelf life. Within the different experiments there were several comparisons which could be made on each of the factors while maintaining the other conditions constant.

A simple analysis of variance employing a Duncan's Multiple Range test for differences between ranked samples at a 5% probability level was used. Simple and stepwise multiple regression procedures were also employed to determine the relationships among the different variables and measurements made on the samples. These analyses were submitted to the University's I.B.M. computer for calculation.

PROCESSING

Process Time Determination

For the purposes of this research, a thermal process time was determined. This goal was accomplished by using two procedures.

Thermal Diffusivity Studies

The first method used to establish a thermal process time involved the measurement of the thermal diffusivity of apple tissue in an attempt to arrive at a rate of heat penetration which could then be used to determine a process time depending on shape and dimensions of the container. Because the pouch was somewhat different in geometric shape than the conventional tinplate can and the process technology for the pouch was limited, it was felt that the measurement of thermal

diffusivity of apple tissue might be beneficial in determining a process time for apple slices in a pouch and perhaps a rapid method for calculating a process time for any size of pouch.

The measurement of thermal diffusivity of apple tissue involved the use of an apparatus designed specifically for this purpose (Dickerson, 1965). The apparatus consisted of a stainless steel cylindrical container and two plexiglas end caps. One of the caps was drilled, threaded and fitted with two 1.6 mm diameter thermocouple probes, one positioned at the outer edge of the cap while the other passed through the central axis. This permitted the outer thermocouple to come in contact with the wall of the cylinder at a position midway along the length of the cylinder when the end cap with thermocouples was inserted in the end, while the central thermocouple was positioned in the geometric centre of the container. The cylinder had an inner diameter of 35 mm and a void length of 23 cm.

In order to use raw apple tissue in this apparatus it was necessary to prepare discs of apple which were perfectly round and of a sufficient diameter to fit snugly into the cylinder. Each disc had an even thickness so that adjacent slices in the cylinder would fit snugly together leaving no spaces for the collection of juices. The discs were carefully threaded on to the probes so that the central thermocouple penetrated the

exact center of a disc while the other probe was partially embedded in the edge of the disc. Care was taken to gauge the thickness of each disc so that the last disc to be threaded on (central position in the cylinder) was only penetrated to one-half its thickness. This ensured a more reliable reading than would have been achieved if the ends of the probes had been positioned at the junction between two slices. When the probes had been thus embedded in the discs, the entire assembly was inserted carefully into the cylinder. Additional discs were then inserted in the other end until the cylinder was filled and the remaining end cap was inserted so that the apple discs were compressed snugly together. Both end caps were sealed with waterproof tape and circular hose clamps were applied to prevent a blowout of the cap when the tissue expanded with increasing temperature.

The full cylinder was then immersed to the level of the top clamp on the probe end of the cylinder in an insulated 4.5 l water bath at room temperature. Sufficient time was allowed for the temperature to equilibrate between the cylinder and the water bath before the experiment was started. The water bath was equipped with a submerged heating coil, a propeller-type stirrer to ensure uniform distribution of heat, and a large temperature-sensitive probe. Both the heating element and the temperature-sensitive probe were connected to

a temperature programmer (Valley Forge Instrument Co.) which provided a constant rise in temperature with time in the water bath and was governed by feedback from the temperature-sensitive probe.

The outer ends of the thermocouple probes were fitted with connector plugs for the attachment of copper/constantan leads to a potentiometric data logger (Digitec Model 1268, United Systems Corp.) which could monitor the changes in temperature of the two thermocouple probes by recording the millivolt signal at one minute intervals.

As the temperature of the water bath rose, so did the temperature recorded by the outer probe. Due to the insulating nature of the apple tissue there was a heating lag at the position of the central probe. When the central temperature began to increase, the temperature recorded by the outer probe was already much higher. Initially the rate of temperature change per unit time of the central probe was not as fast as that of the outer probe but eventually the difference between the two rates decreased until the temperature difference between the two probes became essentially constant. This is described as the linear heating rates of both probes. The thermal diffusivity of the apple tissue could then be calculated using the equation:

Equation I

$$\alpha = \frac{A(R^2)}{4(T_r - T_o)}$$ (Dickerson, 1965)

where:

α = thermal diffusivity (in^2/min)

$A = \frac{dT}{dt}$ = the linear rate of heating ($^oF/min$)

R = the inner radius of the cylinder (in)

T_r = temperature registered by the outer thermocouple (^oF)

T_o = temperature registered by the inner thermocouple (^oF)

Since the heating rates at the two positions were not quite equal nor was the temperature difference exactly constant but seemed to fluctuate back and forth, a method to obtain a mean heating rate was devised. A Wang 600 desk top calculator with a linear regression analysis program was used to obtain the straight line parameters for the linear portions of the two heating curves. The time-temperature data for these portions were submitted to the program to receive:

Equation II

$$T = a + bt$$

where:

T = temperature (^{o}F)

t = time (min)

In this equation the slope or b value is equal to the heating rate and because the heating rates for the curves were never quite equal, it was decided to take their mean as a common heating rate for both thermocouple probes. Once having established a separate ordinate intercept for each heating curve along with a time from the abscissa common to both linear portions, the two corresponding temperatures, T_r and T_o, were established.

When all of the parameters and the temperature values for each probe at a given time had been established, the appropriate values were substituted into the thermal diffusivity equation (Equation I) and the thermal diffusivity of apple tissue was calculated. This operation was carried out 21 times and the thermal diffusivity values were totalled and a mean and standard deviation were calculated. In order to reduce the possibility of an error resulting in a process too short to achieve pasteurization, a value of three times the standard deviation was subtracted from the mean value of the thermal diffusivity giving a value known as the modified thermal diffusivity (α^*).

Once the value of α^* had been determined, it could be used in the equation, derived from the works of Ball (1928), Olson and Jackson (1942), and Stumbo (1973) for rectangular food containers to determine the f_h or time (min) required for the linear portion of a semilog heating curve to traverse one log cycle.

Equation III

$$f_h = \frac{.933}{\alpha^* \left[\left(\frac{1}{a^2}\right) + \left(\frac{1}{b^2}\right) + \left(\frac{1}{c^2}\right) \right]}$$

(Olson and Jackson, 1942)

where:

f_h = time required for the linear portion of a semilog heating curve to traverse 1 log cycle (min)

α^* = corrected thermal diffusivity (in^2/min)

a = ½ the width of the pouch (in)

b = ½ the length of the pouch (in)

c = ½ the thickness of the pouch (in)

Using the f_h derived for a pouch of apple tissue and Stumbo's Method (Stumbo, 1973), a process time was calculated as follows:

Equation IV

$$B = f_h \ (\log j_{ch} I_h - \log g_c)$$

where:

B = process time (min)

j_{ch} = lag factor in a heating curve for the centre of a container.

I_h = difference between the retort temperature and the product temperature at the start of heating (^oF)

g_c = difference between the retort temperature and the temperature in the centre of the product at the end of heating (^oF)

For the purpose of this research and since the pouch most closely resembles a brick shape, a j_{ch} value of 2.064 was chosen (Olson and Jackson, 1942). The initial centre temperature of the product, the centre temperature at steam off, and the retort temperature were set at 80, 180 and 220^oF respectively.

The process time P_t or time from when the retort reaches its operating temperature until steam off (min) is calculated using the equation:

Equation V

$$P_t = B - .4\ 1$$

where:

l = the time taken for the retort to reach its operating temperature after the steam is turned on.

Heat Penetration

The second method used to determine a processing time for the apple slices was a heat penetration method (Tung, 1974) which was used to verify the results of the thermal diffusivity study. Because apples are naturally acidic (pH less than 4.0) the heating requirements did not need to be as stringent as for non-acid products to achieve microbial stability in a sealed container (Stumbo, 1973). It was therefore decided that the achievement of a temperature of 180°F (82.2°C) at the point of greatest temperature lag would be sufficient (Ball, 1938). Because of the insulating nature of apple tissue and the geometric shape of the pouch, the point of greatest temperature lag was considered to be the geometric centre of an apple slice located precisely at the geometric centre of a pouch.

To establish the process conditions, retortable pouches were equipped with metal packing glands (O. F. Eckland Ltd.) near the bottom centre of the container. This facilitated the entry of copper/constantan thermocouples to

monitor the temperature in the package. The 15.2 x 23.4 cm flexible packages were constructed of 0.5 mil Mylar/0.35 mil aluminium foil/3.0 mil C-79 polyolefin (Continental Can Co.). The thermocouple junction was inserted into the centre of a fairly large apple slice which was secured in a helical wire coil of 2.5 cm diameter and 6-7 cm in length. The rigid coil maintained the package thickness at 2.5 cm (1 in) and prevented the slice from being dislodged from the thermocouple during subsequent movement of the pouch. Data from packages in which the thermocouple had moved from the central position were later discarded. The thermocouple wire after passing through the packing gland to the exterior of the package was maintained at a length of at least 10 m. This allowed for passage through the retort lid and attachment to a potentiometric data logger (Digitec, United Systems Corp.) consisting of a digital voltmeter coupled to a 20 point scanner and printer.

The special pouches were then filled with 270 g of prepared slices, 30 g sucrose, and immediately sealed using a Multivac vacuum/gas sealer. Headspace in the package was minimized before sealing by manually flattening the pouch above the product near the sealing area. The sealing was accomplished following evacuation and a nitrogen backflush.

Thermal processing was carried out in a 60 cm diameter vertical laboratory retort using a 220°F (108°C) cook with 8 psig air overpressure. The pouches were arranged horizontally on the open work shelves of the retort rack and spaced so as to allow circulation of the heating medium. A wire screen was clipped over each shelf to prevent pouch flotation. Dummy pouches filled with water were used to maintain a full retort load of 30 packages at all times. Thermocouples were attached to the racks near the test pouches to monitor the retort temperatures throughout each process run.

Water in the retort was preheated to 160°F (71°C), the loaded rack was immersed, the retort closed and brought up to the processing temperature of 220°F (108°C) in seven minutes. Retort and product centre temperatures were monitored at one minute intervals and the data were recorded by the data logger for a 15 minute heating time followed by a 15 minute cooling period during which all thermocouples registered a maximum of at least 180°F (82.2°C).

The process determination was then carried out using a series of computer oriented procedures described by Tung and Garland (1976) which utilized the heat penetration data from the data logger to provide estimates of a process time required to achieve a specified lethality at a single point within the product. Data from two separate retort runs were utilized in order to partially account for the effects of run to run variation of the thermal parameters.

The heat penetration data were entered on punch cards and an I.B.M. 370/168 computer was used for its analysis. The analysis occurred in four basic steps. The first step converted the millivolt readings from the data logger to temperatures in ^{o}F. The come up time was also supplied at this stage so that in addition to supplying the process lethality, which is irrelevant for acid foods requiring only pasteurization, it supplied time-temperature data pairs on separate cards which were required for the next step.

The second step made use of a 10 inch Calcomp plotter to display the data in the form of the log of the temperature difference between the retort and the product for the heating curve or the log of the temperature difference between the product and the cooling water for the cooling curve as a function of time. The retort and cooling water temperatures were the means derived from the replicate retort thermocouple data and were supplied to this program along with the time-temperature data pairs which had been separated into their respective heating and cooling curves.

The heating curves (log g versus time, where g represented the difference between the temperatures of the retort and the product at a specified time) generally contained three regions: an initial curved portion representing the lag period for the centre temperature, a linear portion verifying the theoretical semilog decrease of the temperature difference

between retort and product centre temperatures, and a final region showing deviations of the data from the linear model due to widening precision limits of measurement as the product temperature approached the retort temperature. Cooling curves (log m versus time: where m represents the difference between the temperatures of the product and the cooling water at a specific time) demonstrated an initial cooling lag upon the commencement of cooling procedures, followed by a linear portion which represented a steady-state cooling.

This graphical examination of the data was useful for identifying the beginnings and ends of the linear regions of heating and cooling curves as was required for the next step of the computer program. Data points that deviated from the expected trend could at this time be checked for possible keypunching errors.

The third program of the series made use of the data taken from the linear portions of the curves, and applied least-squares linear regression to compute heating and cooling curve parameters. Data selection for this program was facilitated by the conversion of the time-temperature data to individual cards in step one.

The heating rate (f_h) was calculated as the negative reciprocal slope of the straight line portion of the heating curve. The pseudo-initial heating temperature (T_{pih}) was

derived by extrapolating the straight line portion of the semi-log heating curve to -40% of the retort lag period (Stumbo, 1973). With the initial temperature of the product (T_{ih}), T_{pih} was used to calculate the heating lag factor j_{ch}.

Equation VI

$$j_{ch} = \frac{T_r - T_{pih}}{T_r - T_{ih}}$$

The pseudo-initial cooling temperature (T_{pic}) was calculated by extrapolation of the linear portion of the cooling curve to the "steam-off" time in the process. The cooling lag factor (j_{cc}) was then computed as:

Equation VII

$$j_{cc} = \frac{T_w - T_{pic}}{T_w - T_{ic}}$$

where:

T_w = the cooling water temperature (^oF)

T_{ic} = the product temperature at the "steam-off" time (^oF)

The cooling rate (f_c), the time required for the straight line portion of the semilog cooling curve to traverse one log cycle on the cooling record was calculated to use in extrapolating the cooling curve to "steam-off" for evaluation of T_{pic}.

This step provided a tabulation of the pertinent thermal parameters for all experimental data in a series including means and standard deviations.

The fourth step of the calculation of the process time was carried out with a program on a Wang 600 advanced programmable desktop calculator. Thermal parameter means and standard deviations from the previous step were used for this purpose. Since the product in this research was considered to be an acid food (pH < 4.5) the approach taken was to assure that containers with a heating rate three standard deviations above the mean (f_h*) attained a specified internal temperature. The specified temperature in this case was 180°F, a temperature adequate for the destruction of non-spore-bearing organisms (Stumbo, 1973). The equation used to calculate the processing time was:

Equation VIII

$$B = f_h^*(\log \bar{j}_{ch} I_h - \log g_c)$$

where:

B = process time (min)

I_h = retort temperature minus the initial temperature of the product (°F)

g_c = retort temperature minus the product centre temperature at "steam-off" (^oF)

f_h^* = the mean f_h + 3 S.D. f_h

$\bar{j}_{ch}$ = the mean j_{ch}

Since T_c in this research had a fixed value of 180^oF the g_c derived also had a fixed target value.

The operators process time (P_t), the time interval from when the retort first reaches its operating temperature until "steam-off" is derived from the equation:

Equation IX

$$P_t = B - 0.4\ l$$

where:

l = the comeup time (min)

The figure thus derived from this procedure was then used as the process time for the apple slices in the test pack.

SAMPLE PREPARATION AND PROCESSING

Apples of the fancy grade were used for this project. Three varieties were examined as possible subjects for processing of which two were chosen. These were Newton Pippins and Winesaps with Golden Delicious being disqualified because of colour, texture and flavour problems as determined in the preliminary tests.

The apples for the main experiment were refrigerated (4°C) until processing at which time they were peeled and cored by a mechanical peeler. Slicing was accomplished with a radial eight section kitchen slicer which produced slices of relatively uniform size. The apple slices were then immersed in a 1% NaCl solution to prevent browning on the cut surface. From this point the treatment of the slices diverged according to the pretreatments to be examined.

Apple tissue has a highly porous nature and consequently contains a great deal of gas trapped in interstitial spaces. Oxygen present in air is known to have a significant effect on the rate and degree of browning which can occur in processed apple slices (Olliver, 1971). For this reason it was deemed important to remove as much of the gas as possible to determine whether this would significantly retard or prevent darkening during later storage.

Gas removal was accomplished by submerging the slices in a liquid within a vacuumizing container, and then drawing a vacuum of - 10 psig. Under these conditions a large amount of gas was removed if the slices were allowed a 10 min "boiling-off" period. Reentry of air into the tissue was prevented on breaking of the vacuum by the surrounding liquid which was drawn into the tissue. With this method the liquid could be used as a vehicle to achieve the entry of some of the preservatives such as calcium ions, pyrophosphate ions or SO_2 into

the tissue. These were added in the form of calcium chloride, sodium acid pyrophosphate and sodium bisulfite solutions respectively. This was the basis for one of the pretreatment methods.

A second method of pretreatment was less concerned with the removal of air but concentrated more on the application of preservatives to the outer surface of the slices. The advantage of this method was that it was easy, economical and the apples would not suffer textural changes due to physical changes such as gas removal or heating. With this method the apple slices were dipped in containers of room temperature preservative solutions. A 2 min dip was used in the application of SO_2 and pyrophosphate; a 5 min application was required for Ca^{++} ions. Basically three types of solutions were used with this method - calcium chloride solutions, sodium bisulfite solutions and sodium bisulfite with sodium acid pyrophosphate solutions.

The third pretreatment method involved a hot blanch of 1 min at 180°F to remove gases and inactivate enzymes. The solution used for the blanch was also used as a vehicle for the addition of preservatives. Two types of solution were used in this case, sodium bisulfite or the combination of sodium bisulfite and sodium acid pyrophosphate. If Ca^{++} ions were to be added to the tissue during this method, they were added in the form of a cold dip before the hot blanch. In all cases, treatment with Ca^{++} ions preceeded SO_2 treatments.

The preservatives were added to the slices at various levels depending on the method of pretreatment. Calcium ions were added as a firming agent at levels of 0.25% of the solution weight for the vacuum solution and 0.5% of the solution weight for the cold dip. Sodium acid pyrophosphate was added at levels of 1.0% of the solution weight in the cold dip solution and 0.33% of the solution weight in the vacuum solution. This chemical, added for the maintenance of whiteness in apple slices, was always included in the same solutions as the SO_2. Sulfur dioxide was added at levels of 560 parts per million (ppm) of solution in the vacuum solution, 1160 ppm and 1080 ppm of solution for the hot blanches of Newtowns and Winesaps respectively. Three levels of SO_2 were used in the cold dips to obtain a comparison of the effectiveness of this method of addition. These levels included a low, 1730 ppm of solution, a medium of 2160 ppm of solution and a high of 2810 ppm of solution. The addition of SO_2 was made to preserve the lightness of the apple slices. In general the levels used in the evacuation process were always much lower because of the increased efficiency of this method of addition.

Once the apple slices had undergone the pretreatments they were weighed into 270 g lots and placed in numbered flexible retort pouches with 30 g of sucrose which gave a final pouch weight of 300 g. The pouches were then manually

flattened to reduce the headspace and sealed in a Multivac vacuum/gas sealer. Sealing was accomplished with the removal of most of the remaining air in the pouch and replacement with an inert packing gas such as N_2 or CO_2. Following this, sealing was carried out. The pouches were then placed on the rack of a 60 cm diameter vertical laboratory retort with no more than 35 pouches per run. The retort was filled with water and preheated to 160°F (70°C) before the rack was lowered in and the retort closed. Once the retort was sealed the process was started with an operating temperature of 220°F (108°C) and air overpressure of 8 psig to maintain pouch integrity and thickness. The come up time for the retort was 7 min. The process time (P_t) derived from the thermal diffusivity studies was 19.8 min after which time the steam was shut off and cold water cooling and pressure release was begun. The cooling procedure was maintained until the retort reached a temperature of 100°F (38°C) at which time the pressure had diminished to atmospheric and the retort was opened. The pouches were then removed, dried and sorted into different groups according to storage temperature treatment (22° or 35° C).

Calcium chloride was added to the apples because calcium ions bind with pectic substances notably pectinic acids of a low methoxyl count to give a firm texture (Hodge and Osman, 1976). This reagent must be used with caution, however, as too much can impart a woody texture and bitter flavour to fruit tissues.

Sodium bisulfite was added to the apple tissue because it acts as an antioxidant and helps to maintain the white colour expected in apple slices. The use of too much of this reagent creates flavour problems and therefore appropriate levels should be determined.

Sodium acid pyrophosphate (S.A.P.) can also be used to maintain the light colour in some food products. Its action is derived from its ability to chelate metal ions which are capable of catalyzing various degradation reactions responsible for browing (Furia, 1968). It was found from previous experience that apple slices preserved with SO_2 and stored at a warm temperature (35°C) eventually underwent a darkening. It was thought that the addition of S.A.P. might retard this thereby increasing the shelf life of the product. This reagent also caused flavour problems if used in excess.

STORAGE TESTS

The 29 sample groups were divided in half with one half being stored at a controlled temperature of 35°C while the other half was stored at room temperature (22°C). Tests were carried out on one of the samples one week after processing to determine the initial characteristics of the products. A second testing of the samples was carried out six weeks after processing which included all samples from the 22°C storage

and one of the twenty-nine samples from the 35°C storage. Following a period of five months, a third testing was carried out and included all the samples in the 35°C storage plus the remaining pouches of the same sample from the 22°C storage.

PRODUCT PHYSICAL PROPERTIES

Magness-Taylor Pressure Test - Fresh Apple Texture

In some fruits, including apples, maturity can be used as an indication of probable texture. This, however, can vary with differences in variety and in storage conditions. At the beginning of the project three different varieties of apples from different areas and different storage facilities were available for study. Due to the numbers of factors being tested, it was felt that the processing of three varieties would lead to an extremely large pack which would be too cumbersome to handle. For this reason attempts were made to decrease the number of varieties used. One of the tests used to separate them was the Magness-Taylor Pressure Test. This test is ordinarily carried out in the field with a small portable apparatus but for our purposes, the apparatus was modified to yield accurate results on existing laboratory equipment. This equipment consisted of a puncture probe of Magness Taylor dimensions, 7.9 mm tip diameter, connected to the load cell of an Instron

Model 1122 Universal Testing Machine (Bourne, 1965). The load cell which sensed the force required to puncture the surface of the apple was connected to a strip chart recorder which produced a graphic account of the applied force throughout the duration of the puncture test. The Instron is ideally suited to this type of test because both the speed and depth of penetration are controlled electronically and therefore are not subject to the variations present when performing this test manually. The graphic record also gives some insight into the behaviour of the apple tissue during puncture.

It has been found that the speed of penetration of the Magness-Taylor has little influence on the force required for penetration (Bourne, 1965). Thus, a speed of 5 cm/min was arbitrarily chosen. The puncture depth was set at 0.79 cm in all cases.

An equal number of apples was chosen randomly from each of the three varieties in cold storage and were given sufficient time to reach room temperature before proceeding. A maximum of four punctures were made at right angles to each other around the "equator" of the apple. In order to eliminate the high yield pressure required to puncture the tough apple skin a shallow circular section 1 cm diameter was pared (with a sharp knife) at each puncture point on the apple (Bourne, 1965). It was necessary to have a flat surface for puncturing

(Schomer & Olson, 1962) and it was required that the plane of opposing flat surfaces on the apple be in parallel planes. This permitted the presentation of a flat surface perpendicular to the probe when the apple was resting on the opposing flat surface and gave the most consistent results. During the puncture test, the apple was supported on a firm bed of plasticine to prevent mechanical damage to the underside in all cases.

The force-deformation curves produced in this experiment consisted of an essentially linear rise, at the selected chart speed, to a break or yield point, representing penetration, then a flatter "saw-toothed" curve representing a series of smaller yields as the tip penetrated further into the tissue. The major yield pressure was used in all cases as an indication of texture (Mohsenin et al., 1962).

Single Blade Shear - Apple Slice Texture

Texture of the fresh and stored apple slices was measured with an Instron Model 1122 Universal Testing Machine coupled to a single blade shear cell from an Allo Kramer Shear Press. The cell consisted of three main parts. The metal shear blade (12 x 7 x 0.3 cm) was fastened to the load cell of the Instron by an adaptor. The cell body consisted of a base plate with a slit (0.35 x 7.5 cm) and two side plates with guide slots for blade alignment. The support frame functioned to fasten the cell body to the base of the Instron while permitting adjustments

so that the position of the cell body was in alignment with the blade thus minimizing friction between the moving parts which could give erroneous results.

The tests were carried out by placing five randomly chosen slices adjacent to one another across the slit of the base plate with the inner or core edge up. The blade was lowered at a speed of 5.0 cm/min and the shear force sensed by the load cell was recorded on a strip chart recorder. The peak or highest reading was taken as the measure of texture in all cases. Care was taken to insure that the slices in each test were essentially the same dimensions. Tests were carried out in duplicate.

Viscous Behaviour - Puree

The function of added calcium ions in fruit tissues is to combine with pectic substances located in intercellular spaces. This renders the pectins water insoluble and creates a bonding between adjacent cell walls and consequently a firmer texture. It was thought that if increased intercellular bonding occurred, it should be more difficult to achieve mechanical disruption and maintain the disrupted condition after blending the calcium-treated tissues. Such tissues should yield a higher proportion of "clumped" cells than non-treated tissues. One method of observing such a difference would be to examine

the flow behaviour of tissue purees. To do this, a Haake Rotovisko coaxial cylinder viscometer with an MVII spindle (gap width 2.55 mm) was employed.

Purees of all experimental samples were made using 250 g of apple slices with 100 ml distilled water in a Waring blendor for 2 min. The puree was allowed to stand for at least one hour after blending in a closed container at room temperature to permit the escape of air incorporated during blending. Just prior to measurement on the Rotovisko, each sample was stirred with a spoon to insure a uniform sample and an appropriate amount was poured into the sample cup. This container was then externally coated with glycerine to facilitate heat transfer and inserted into the controlled temperature water jacket over the spindle. The sample was then allowed a brief period to equilibrate with the water jacket temperature of 20°C.

During each test the spindle rotation was varied in a stepwise fashion through a series of speeds from maximum to minimum. The transmission was then disengaged and the shear relaxation was recorded until a constant value, reflecting the yield stress (σy), was obtained. Following this the transmission was again engaged and the spindle rotation was varied from minimum to maximum speeds to complete the measurement. Shear rates of 529 to 3.27 sec^{-1} were employed, as calculated using Newtonian flow in the gap. The torque caused by the viscous

drag of the fluid was sensed by an electronic torsion dynamometer and was recorded on a Rikadenki multi-pen strip chart recorder.

Flow behaviour curves were constructed for each of the tests using the data derived from the strip chart recording. The flow parameters m and n were evaluated by a computer program which employed two forms of the power law flow model.

Equation X

$$\sigma = m\dot{\gamma}^n \qquad \text{and}$$

Equation XI

$$\sigma = m\dot{\gamma}^n + \sigma y$$

where:

σ = shear stress (dyne cm^{-2})

σy = yield stress (dyne cm^{-2})

$\dot{\gamma}$ = shear rate (sec^{-1})

m = consistency coefficient (dyne sec^n cm^{-2})

n = flow behaviour index (no units)

Data cards containing three data values (dynamometer setting, gear setting and scale reading) were made for each shear rate of each test. These cards were then combined with a program and submitted to the I.B.M. 370/168 computer which evaluated shear stress and shear rate data for each point and

then the rheogram parameters were computed using the method of least squares and a nonlinear curve fitting technique. The program also calculated statistical parameters to estimate the accuracy of the flow model fit to the data.

Colour - Apple Slices

Maintenance of a light colour in the apple tissue was one of the main concerns of this project and therefore colour was monitored throughout the storage period to determine the effects of the different treatments on browning prevention. Colour measurements were made with a Hunterlab Colour Difference Meter. The machine was standardized using the white ceramic standard. Sufficient sample (drained slices) was placed in the sample container to completely cover the bottom. The samples were placed over the aperture, covered and read for their L, a and b values. Each sample was rotated 180^{o} after reading and reread to give duplicates of all measurements. All readings were made on a representative sample of two pooled pouches.

PRODUCT CHEMICAL ANALYSES

Calcium Analysis

The analysis for calcium ions in the samples of apple tissue provided a second evaluation of the efficiency of the preparatory methods and also provided information on the levels

of calcium later to be related to the texture results. These analyses were carried out with a Perkin Elmer Model 306 atomic absorption spectrophotometer.

Prior to the analysis, samples of the 29 experimental groups were reduced to a liquid form so that the elements present were in an ionic state and could be easily aspirated in the spectrophotometer. This was done using a rapid digestion method that could be used to accurately determine the levels of copper, zinc, tin, iron and calcium in foodstuffs (Simpson and Blay, 1966). The samples were prepared by taking 5 g of puree (250 g slices: 100 ml H_2O) and placing it in a 250 ml flask with 25 ml 6M HCl. The mixture was then boiled for a period of 5 - 10 min to insure complete solubilization of the sample and release of the calcium in the form of ions. The resulting solution was then cooled and transferred to a 50 ml volumetric flask and brought up to volume with distilled water. Lanthanum chloride solution of a concentration of 10,000 ppm was added to the samples in a ratio of 1:1 thereby leaving a La^{+++} level of 5,000 ppm. This tied up the phosphate ions and released Ca which would normally be in the form of calcium phosphate. The solutions were then aspirated in this form. The analysis was carried out in the concentration mode and readings were taken in ppm or µg/g. The samples were read in duplicate.

The concentration of Ca^{++} in the original samples were calculated by:

Equation XII

$$\text{Reading} \times \frac{100}{5} \times \frac{350}{250} = \mu g Ca^{++} / g \text{ of apple slice}$$

SO_2 Determination

In order to compare the efficiency of the pretreatment methods of chemical addition and the effect of SO_2 addition on browning it was decided to measure the residual SO_2 in the sample packs over the storage period. The rapid but simple titration method of Ross and Treadway (1960) was employed. This method involved the homogenization of a representative sample of drained tissue in a Waring blendor for 2 min with a citric acid-disodium phosphate buffer to maintain the pH at 4.4 thus preventing losses of SO_2 through oxidation. Following filtration of the homogenate a small amount of filtrate was combined with starch indicator and titrated with a standardized iodine solution. A reagent blank, prepared from the same filtrate with added hydrochloric acid and formaldehyde solution to tie up free SO_2 was also titrated to determine the reducing power of the apple tissue itself. Timing was critical in this procedure with 5 min after homogenization being optimum for titration.

With the values obtained from the titrations, calculations were made to determine the concentration of SO_2 in ppm for each sample:

Equation XIII

$$SO_2 = \frac{(I_s - I_b) \times NI_2 \times E.W. \times 1 \times 10^6}{S.W. \times 0.1}$$

where:

I_s = Vol. of iodine added to the sample (ml)

I_b = Vol. of iodine added to the blank (ml)

NI_2 = Normalty of the iodine

E.W. = Equivalent weight

S.W. = Sample weight

Sugar Analyses

The sugar analyses were carried out using the method of Ting (1956) which is based on the reduction of alkaline ferricyanide followed by conversion to a blue-green arsenomolybdate complex. The absorbance of this complex at a wavelength of 515 nm is then read with a spectrophotometer.

Five grams of puree were taken for each sample and extracted in 250 ml of boiling 80% ethyl alcohol. The samples were then heated for 30 min in an 85°C water bath then vacuum filtered through Whatman #2 filter paper in a Buchner funnel. The filtrate was then cooled to room temperature and made up to 1,000 ml with distilled water.

To determine the total sugar content a 50 ml aliquot of the dilute extract was placed in a 200 ml beaker with 10 ml of 6M HCl. The beaker was swirled and allowed to stand at room temperature for 18 hours. Following inversion, the mixture was partially neutralized with 5 ml of 10 M NaOH and the pH was adjusted to between 5 and 7 with 1M NaOH. The solution was then transferred to a 200 or 250 ml volumetric flask and made up to volume.

At this point the procedure for the total and reducing sugars became identical. One ml samples of the original diluted filtrates and one ml samples of the diluted inverted solutions were taken for the reducing sugars and total sugar analyses respectively. Each was then transferred by pipette to a 100 ml volumetric flask and 5 ml of ferricyanide reagent was added. The flask was swirled and then heated in a boiling water bath for 10 min. After heating the flask was quickly cooled in a stream of running water. The contents were then partially neutralized with 10 ml of 1M H_2SO_4 and were shaken until gas evolution ceased. Four ml of arsenomolybdate reagent was added and the solution was thoroughly mixed and made up to volume. The flask was allowed to stand at least 15 min before a reading was taken.

Absorbance of the ferricyanide-arsenomolybdate complex was measured at 515 nm and a slit width of 0.016 mm with a Beckman DB spectrophotometer. A reagent blank with distilled water was used to standardize the spectrophotometer and glucose and fructose solutions were used to construct a standard curve. The reducing sugar content of each alcoholic extract was determined in duplicate.

Ascorbic Acid Analysis

The processing of apple slices in retort pouches should require a shorter heating process to achieve pasteurization because of the thin geometric shape of the container. Under these conditions there should be less destruction of heat labile nutrients present in the slices. One of these nutrients most commonly considered is ascorbic acid or vitamin C. It was felt that the monitoring of the vitamin C content of the preserved apple slices would provide some indication of the behaviour of other heat-labile components.

The method chosen to analyze for vitamin C was taken from the Association of Vitamin Chemists Offical Methods. This method consists of the oxidation of an acidic extract of the apple tissue containing vitamin C with 2,6-dichlorophenolindophenol dye, monitored by visual titration.

To prepare the sample, a known weight of apple slices (200 g) was combined with an equal weight of 6% metaphosphoric acid. From this slurry, 30 g were transferred to a 100 ml volumetric flask. Twenty ml of acetone were added to stablize SO_2 present which would be oxidized by the dye and give higher values. The solution was made up to volume with 3% metaphosphoric acid solution. The solutions were then shaken vigorously to ensure total extraction of the ascorbic acid. Part of the solution was then transferred to centrifuge tubes and spun for 10 min. Upon completion, two 10 ml aliquots of clear liquid were pipetted off into small Erlenmeyer flasks to be titrated with a standardized 2,6-dichlorophenolindophenol dye and constant stirring. The end-point was considered to be the first faint pink colour which appeared and persisted for 15 sec.

Calculations were made using the formula:

Equation XIV

$$\frac{V \times T}{W} \times 100 = \text{mg ascorbic acid per 100 g sample}$$

where:

V = volume of dye used (ml)

T = the ascorbic acid equivalent (mg/ml of dye)

W = weight of the sample in the aliquot titrated (g)

to determine the amount of ascorbic acid present in 100 g of sample.

pH Determination

The pH of the apple slices was monitored throughout the storage period as an indicator of any chemical change which might have occurred. Measurements were made using a Fisher Model 420 digital pH meter. Measurements were made on the pureed samples (250 g slices . 100 ml distilled water) only.

SENSORY ANALYSIS

Sensory analyses were carried out on a number of samples to determine if differences resulting from different varieties, levels of additives and preparatory treatments could be detected subjectively. As stated earlier the three preservatives used were calcium chloride, sodium bisulfite and sodium acid pyrophosphate: the varieties included Newtown Pippins and Winesaps and the backflush gases used for packaging were nitrogen and carbon dioxide. All of the samples were subjected to one of the three preparatory treatments which were also suspected to have created differences in the samples. Accordingly a subjective comparison, which included representative samples of each of these variables, was carried out by 10 panelists who were asked to rank them on a continuous hedonic scale and to record their reasons. All panelists had previous experience with sensory analysis and were familiar with the procedure. The

sensory evaluations were carried out at both the 1.5 and 5 month storage trials with a series of 7 samples for each time. A total of 8 samples of the 29 available were panelled. Due to a severe browning problem and a short supply, one of the samples used in the first panel had to be replaced in the second panel. The samples from the first panel time were taken exclusively from the 22°C storage while all samples excepting one for the second panel time were taken from the 35°C storage. The sample taken from both storage temperatures for the second panel was suspected to be the best of our 29 samples.

The paneling was conducted in 5 booths in two sittings per time. The panelists were presented with all samples in plain white containers in random order on a tray. The evaluations were carried out under white fluorescent light so that colour differences could be detected. The panelists were asked to evaluate the samples according to four quality attributes which included appeal (colour and appearance), texture of slices, flavour and overall acceptability. Distilled water and plain soda crackers were supplied to cleanse the palate between samples.

STATISTICAL ANALYSES

All data from the apple project were analyzed using the University I.B.M. computer facilities. The sensory analysis data were subjected to an analysis of variance procedure employing a Duncan's Test for significant differences between

ranked means at a 5% probability level. The remaining data collected from the apple project were punched on a series of cards. These cards were then used in a series of mini analyses using an analysis of variance design again with the Duncan's Multiple Range Test at a 5% probability level.

The data cards were also combined with programs for simple and stepwise multiple regression analyses using both single, and single with two-way interaction factors to determine the relation of the experimental factors with the results of the tests carried out. In this way some insight could be gained as to the probable important factors which were able to influence the quality of the samples.

RESULTS

PROCESSING

Process Determination

Thermal Diffusivity

During the thermal diffusivity studies problems of maintaining a constant heating rate between the two thermocouples were encountered and therefore a method had to be devised to determine a mean heating rate for the linear portions of the heating curves. These means were then used to derive the thermal diffusivities for the different runs (Table 1). In order to calculate the process times, it was assumed that the pouch approximated a brick shape and therefore a j_{ch} value of 2.064 could be used for the calculation (Olson and Jackson, 1942).

Also, to provide a safety factor that the chance of determining a smaller mean than the one calculated was less than 1%, a value of three standard deviations about the mean was subtracted to give a modified mean thermal diffusivity. The modified mean thermal diffusivity of the apple tissue found in this research was 0.01032 in^2/min. From this an f_h value of 26.29 min and a process time (P_t) of 19.8 min were established.

Table 1

Results of the Thermal Diffusivity Measurements

of Raw Apple Samples

Run #	Thermal Diffusivity (in^2/min)
1	0.01462
2	0.01285
3	0.01273
4	0.01230
5	0.01409
6	0.01434
7	0.01461
8	0.01493
9	0.01385
10	0.01267
11	0.01220
12	0.01256
13	0.01382
14	0.01274
15	0.01292
16	0.01257
17	0.01248
18	0.01424
19	0.01121
20	0.01313
21	0.01318

Mean Thermal Diffusivity	$\bar{X} = 0.01324$
Standard Deviation	$S.D. = 0.00097$
Modified Thermal Diffusivity	$\bar{X}-3S.D. = 0.01032$

Heat Penetration

The second method used to determine a process time was carried out as a verification of the first method and these results were used in the final process. This method involved a measurement of heat penetration using pouches fitted with thermocouples as described earlier. The results of all the heat penetration studies were submitted to the UBC computer with a series of programs which calculated the f_h and j_{ch} for each (Table 2).

Again, in order to reduce the probability of requiring a higher f_h than the calculated mean to 0.5%, three times the value of the standard deviation about the mean was added to the f_h to give a modified heating rate, f_h^*, which was 23.91 minutes. The process time (P_t) calculated from these results was 15.6 minutes.

Sample Preparations and Their Effects

In this project, three basic methods of preparation were compared to assess their efficiency in regards to the levels of preservatives used, their convenience and their effects on the quality attributes of the final product.

It was discovered in numerous preliminary tests that the amounts of the preservatives added to the vacuum infusion solutions could be reduced in comparison with the hot blanch and cold dip methods. Also, it was found that

Table 2

Results of the Heat Penetration Studies of

Apple Slices in Retort Pouches

Testpack #	f_h (min)	j_{ch}
1	15.38	2.106
2	23.03	1.076
3	19.93	1.295
4	16.83	1.444
5	14.21	2.322
6	16.73	1.609
7	15.86	1.780
8	15.17	1.832
9	15.31	1.433
10	12.29	2.170
11	9.63	3.483
12	14.30	2.820
13	17.39	1.266
14	16.06	1.319
15	18.10	1.146
16	14.82	1.374
17	15.44	1.228
18	15.54	1.498
19	19.14	0.966
20	14.84	1.785
21	15.60	1.305
22	14.80	1.598
Mean f_h	$\bar{X}$ = 15.93	1.675
Standard Deviation	S.D. = 2.66	0.603
Modified f_h	$\bar{X}$ + 3S.D. = 23.91 = f_h*	-

the hot blanch method seemed to require a lower level of the additives than the cold dip solutions. The levels of chemicals added to the solutions of each method are presented in Table 3 as concentrations of their functional groups.

The results of these treatments in regards to the incorporation of the preservatives into the fruit tissue can be observed in the mini-analyses of variance results comparing the results of the SO_2 and Ca^{++} analyses in the samples undergoing the different preparatory treatments. Figures 1 and 2 demonstrate the differences between some of the mean levels of SO_2 in samples taken from the different preparatory treatments.

Since no analysis was carried out on the phosphate content of the samples the levels incorporated into the tissues by the different methods cannot be presented.

The different preparatory methods and the resulting levels of preservatives incorporated by them can be shown to have influenced some of the other measurements carried out. These, however, will be presented and discussed in the following sections.

Table 3

Levels of Additives Used for the Preparatory Treatments of Apple Slices in Retort Pouches

Variety	Treatment	Ca^{++} (ppm)	SO_2 (ppm)	S.A.P. (ppm)
Newtown	Vac. Infusion	2,500	560	3,330
	Hot Blanch	--	1,160	10,000
	Cold Dip			
	(Low)	5,000	2,150	10,000
	(Med)	--	1,720	10,000
	(High)	--	2,790	--
Winesap	Vac. Infusion	2,500	560	--
	Hot Blanch	--	1,070	--
	Cold Dip			
	(Med)	5,000	2,150	10,000

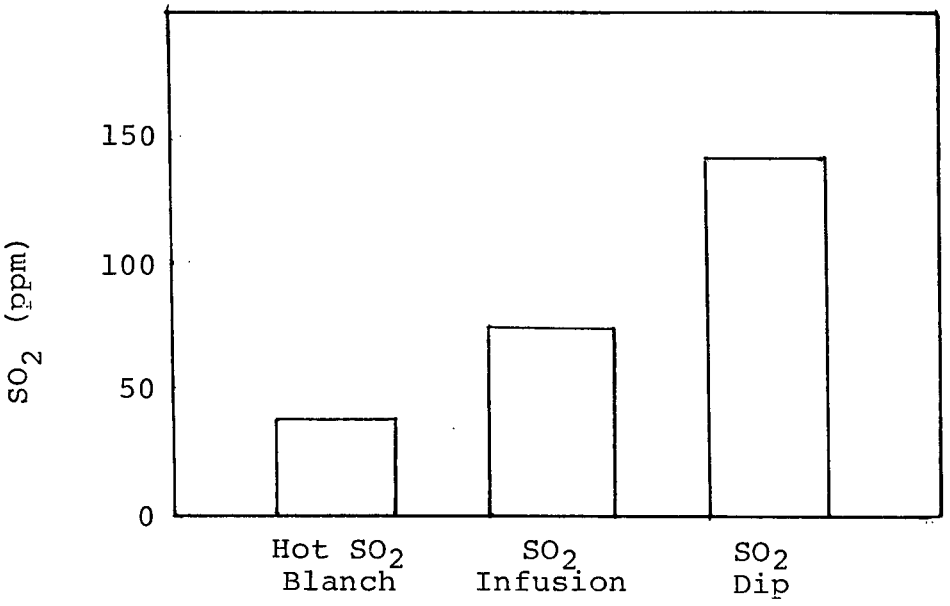

Fig. 1 Mean Levels of SO_2 Incorporated into the Apple Tissues by the Different Preparatory Methods

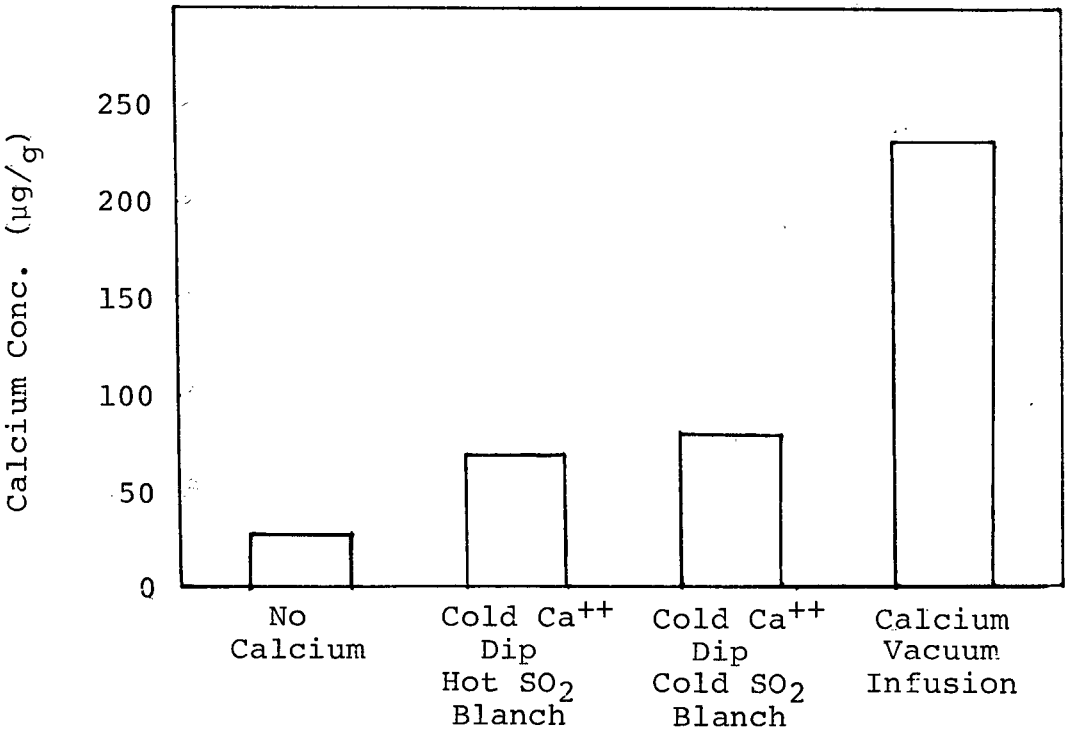

Fig. 2 Mean Levels of Calcium Incorporated into the Apple Tissues by the Different Preparatory Methods

SAMPLE DIFFERENCES

The variability noted between the different samples of this experiment can be split into three categories (i.e. texture, colour and chemical differences) and so will be presented as such.

Texture

Instron Single Blade Shear

Differences in texture between the various samples were determined with the aid of the Instron - Kramer single blade shear combination and the Haake Rotovisko viscometer. The Instron shear force measurements were shown by the step-wise multiple regression using both single and two-way interaction factors and the simple regression analysis to vary significantly with the levels of calcium added and the temperature at which the samples were stored (Table 4).

When both single and two-way interaction factors were included in the multiple regression analysis, it was found that significant single factors of the previous analyses were involved in two-way interactions which gave a better explanation of the variance in the Instron results (Table 5).

The effects of the calcium content of the slices and the preparatory treatments on the shear resistance of the samples is further demonstrated by the results of the analyses of variance (Tables 41, 42).

Table 4

Results of Stepwise Multiple Regression of Instron Shear Force on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	2.780	
Calcium	0.008401	126.1 **
Temperature	- 0.706	98.03 **

Standard Error of Y = 0.586, R^2 = 0.657 **
** P $\leq$ 0.01

Table 5

Results of Stepwise Multiple Regression of Instron Shear Force on Experimental Factors Using Two-way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio
Constant	1.022	
Total Sugar x Calcium	0.002444	53.82 **
Reducing Sugar x Calcium	- 0.00277	18.81 **
Reducing Sugar x Temperature	- 0.001556	10.67 **
Calcium x Time	0.001872	5.090 *

Standard Error of Y = 0.4988, R^2 = 0.7559 **
* P $\leq$ 0.05
** P $\leq$ 0.01

Viscometry

The results from the Haake Rotovisko measurements were used to calculate four parameters describing the flow behaviour of the pureed apple slices. These parameters include the flow behaviour index (n), the consistancy coefficient (m), the yield stress (σ_y), and an apparent viscosity coefficient calculated using the derived n value of each sample as well as an intermediate shear rate value which for the MVII spindle was taken to be 40 sec^{-1}. This parameter was thus labelled η_{40}. These factors combined can provide insight into the possible influence that the different factors can have on the flow behaviour of the puree.

The single factors which were significant in explaining the variability in some or all of the flow parameters were the total ascorbic acid content, the length of storage, the total sugar content of the sample, the backflush gas and the variety of apple (Tables 6, 7, 8, 9).

Table 6

Results of Stepwise Multiple Regression of n on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	0.3872	
Gas	- 0.0246	12.45 **
Total Sugar	- 0.004681	4.019 *
Ascorbic Acid	0.005	17.38 **
Time	0.00791	26.00 **

Standard Error of Y = 0.0284, R^2 = 0.3903 **
* P $\leq$ 0.05
** P $\leq$ 0.01

Table 7

Results of Stepwise Multiple Regression of m on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	61.99	
Variety	- 19.47	7.255 **
Gas	18.10	6.746 *
Total Sugar	7.466	10.19 **
Ascorbic Acid	- 6.821	19.63 **
Time	- 9.920	40.76 **

Standard Error Y = 28.36, R^2 = 0.4805 **
* P $\leq$ 0.05
** P $\leq$ 0.01

Table 8

Results of Stepwise Multiple Regression of σ_y on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	40.12	
Ascorbic Acid	- 4.041	15.49 **

Standard Error of Y = 22.55, R^2 = 0.116 **
** P $\leq$ 0.01

Table 9

Results of Stepwise Multiple Regression of η_{40} on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	5.099	
Variety	- 1.240	7.417 **
Gas	0.9532	4.719 *
Total Sugar	0.6074	17.02 **
Ascorbic Acid	- 0.4332	19.98 **
Time	- 0.6083	38.66 **

Standard Error of Y = 1.786, R^2 = 0.4961 **
* P $\leq$ 0.05
** P $\leq$ 0.01

When two-way interaction factors as well as single factors were considered as independent variables a better explanation for the variance of the four dependent variables was achieved. In the case of the yield stress results the explanation was vastly improved by considering two-way interaction factors as is shown in a comparison of the R^2 values 0.1160 to 0.3080.

For this case, it can again be seen that the single factors which correlated with the dependent variables, are involved in the interactions, giving a better explanation of residual variance than before (Tables 10, 11, 12, and 13). Some of the new factors which combine in the interaction terms are calcium content, reducing sugar content and storage temperature.

Colour

Colour difference between the samples and the changes occurring in each sample throughout the test period were monitored with the aid of a Hunterlab Colour Difference Meter. The three Hunter parameters of colour (L, a and b values) were recorded and subsequently used as dependent variables in the regression analyses to determine which of the experimental factors varied significantly with the colour

Table 10

Results of Stepwise Multiple Regression of n on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio
Constant	0.3904	
Total Sugar	- 0.004920	4.653 *
Gas x Calcium	- 0.0001705	25.38 **
Ascorbic x Temperature	0.0001609	17.36 **
Calcium x Time	0.00006223	22.64 **

Standard Error of Y = 0.0277, R^2 = 0.4175 **
* $P \leq 0.05$
** $P \leq 0.01$

Table 11

Results of Stepwise Multiple Regression of m on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio
Constant	44.96	
Total Sugar	6.766	7.912 **
Variety x Calcium	- 0.1002	4.820 *
Variety x Time	- 2.681	4.911 *
Gas x Calcium	0.1720	15.69 **
Ascorbic x Temperature	- 0.1932	19.57 **
Calcium x Time	- 0.0348	4.093 *

Standard Error of Y = 28.30, R^2 = 0.4876 **
* $P \leq 0.05$
** $P \leq 0.01$

Table 12

Results of Stepwise Multiple Regression of σ_y on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio	
Constant	199.1		
pH	- 71.91	8.557	**
Variety x Total Sugar	1.591	12.31	**
Gas x Calcium	0.0796	8.093	**
Total Sugar x Reducing Sugar	0.3862	17.66	**
Ascorbic x Temperature	- 0.0922	6.380	*
Calcium x Time	- 0.0297	7.938	**

Standard Error of Y = 20.39, R^2 = 0.3080 **
* P $\leq$ 0.05
** P $\leq$ 0.01

Table 13

Results of Stepwise Multiple Regression of η_{40} on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio	
Constant	7.481		
Variety x Calcium	- 0.0121	26.83	**
Gas x Calcium	0.009786	19.49	**
Total Sugar x Reducing Sugar	0.0510	17.98	**
Reducing Sugar x Time	- 0.0938	36.98	**
Ascorbic x Temperature	- 0.0123	22.91	**

Standard Error of Y = 1.674, R^2 = 0.5573 **
** P $\leq$ 0.01

changes. The single factors whose variance coincided significantly with the variance in the three dependent variables of colour were not the same for each (Tables 14, 15, and 16).

When two-way interaction factors as well as single factors were considered in the multiple regression analyses it was found that the single factors of the previous analyses combined in interaction factors to give a better explanation of the variance in the colour parameters (Tables 17, 18, and 19).

Chemical Differences

In order to partially understand the changes occurring in the samples over the storage period and the differences between samples which had been treated differently, a number of chemical analyses were carried out. These included analyses for total calcium, SO_2 content, total and reducing sugar contents, ascorbic acid content and pH.

The results of the analyses for total calcium did not show any differences over the storage time but did indicate differences between samples treated differently (Fig. 2).

The calcium levels were also shown to vary with the backflush gas used in packing. The use of carbon dioxide for this purpose seemed to increase the level of

Table 14

Results of Stepwise Multiple Regression of Hunter "L" Values on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	55.64	
Gas	- 2.874	12.08 **
Total Sugar	1.075	13.79 **
Reducing Sugar	1.308	4.569 *
Time	- 2.038	11.53 **
Temperature	- 0.6463	15.24 **

Standard Error of Y = 3.365, R^2 = 0.7590 **
* $P \leq 0.05$
** $P \leq 0.01$

Table 15

Results of Stepwise Multiple Regression of Hunter "a" Values on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	- 1.994	
Variety	- 1.438	16.83 **
SO_2	- 0.0163	33.80 **
Ascorbic Acid	- 0.3794	16.37 **
Time	1.128	171.8 **

Standard Error of Y = 1.352, R^2 = 0.8001 **
** $P \leq 0.01$

Table 16

Results of Stepwise Multiple Regression of Hunter "b" Values on Experimental Factors Using Single Factors Only

Variable Name	Polynomial Coefficient	F-Ratio
Constant	15.54	
Pyrophosphate	0.9151	11.43 **
SO_2	0.006625	10.15 **
Total Sugars	0.4497	16.30 **

Standard Error of Y = 1.393, R^2 = 0.2765 **
** $P \leq 0.01$

Table 17

Results of Stepwise Multiple Regression of Hunter "L" Values on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio
Constant	54.00	
Pyrophosphate x Variety	0.8846	6.952 **
Gas x SO_2	- 0.0182	9.112 **
Gas x Calcium	- 0.0101	11.68 **
Gas x Time	0.5872	7.198 **
Total Sugar x Reducing Sugar	0.1067	32.67 **
SO_2 x Time	0.0128	45.23 **
Ascorbic Acid x pH	- 0.1297	5.872 *
Time x Temperature	- 0.1565	142.6 **

Standard Error of Y = 2.719, R^2 = 0.8467 **
* $P \leq 0.05$
** $P \leq 0.01$

Table 18

Results of Stepwise Multiple Regression of Hunter "a" Values on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio	
Constant	- 0.2862		
Variety x SO_2	- 0.0134	72.36	**
Gas x Ascorbic Acid	0.3620	7.538	**
Gas x pH	- 0.6784	11.83	**
Ascorbic Acid x pH	- 0.2519	24.01	**
Time x Temperature	0.0272	242.2	**

Standard Error of Y = 1.231, R^2 = 0.8358 **
** P $\leq$ 0.01

Table 19

Results of Stepwise Multiple Regression of Hunter "b" Values on Experimental Factors Using Two-Way Interaction Factors

Variable Name	Polynomial Coefficient	F-Ratio	
Constant	21.29		
Pyrophosphate x SO_2	0.004187	6.466	*
Gas x SO_2	- 0.007170	10.62	**
SO_2 x Reducing Sugar	0.2483	22.32	**
SO_2 x Ascorbic Acid	- 0.1002	22.28	**
Total Sugar x Ascorbic	0.1002	55.65	**
Ascorbic x Temperature	- 0.0282	53.34	**

Standard Error of Y = 1.202, R^2 = 0.4750 **
* P $\leq$ 0.05
** P $\leq$ 0.01

calcium in the samples. Analysis of variance results from a comparison of six of the samples showed that those samples packed with carbon dioxide had signifanctly ($P \leq 0.01$) higher levels of calcium (133.5 ug/g) than those packed with nitrogen (112.3 ug/g). The other factors such as variety, SO_2, pyrophosphate and temperature did not have any significant ($P > 0.05$) influence on the levels of total calcium present in the samples.

The levels of SO_2 found in the samples were also found to vary significantly with the preparatory methods (Fig. 1). The temperature of storage had the effect of decreasing the SO_2 level in the samples with increasing temperature (Fig. 3). The presence of pyrophosphate ions in the apple tissue was also shown to have the effect of increasing the amount of SO_2 detected in comparable samples (Table 20). The variety of apple used in the test was also found to have an effect on the amount of SO_2 found in the samples (Table 21). The presence of calcium and the type of backflush gas used in the sample could not be shown by the Duncan's test to have any significant effect ($P > 0.05$) on the level of SO_2 incorporated into the tissues.

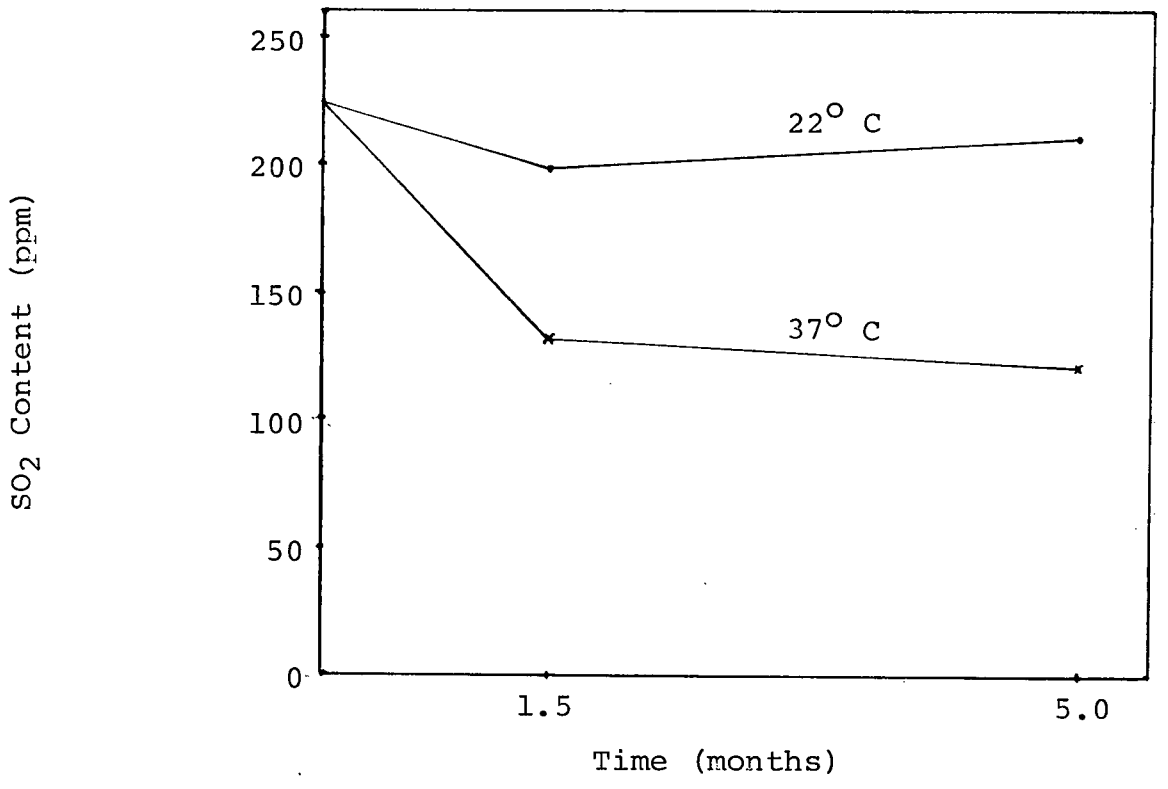

Fig. 3 The Effects of Storage Temperature on the Levels of SO_2 Found in Apple Slices

Table 20

Results of Analysis of Variance for the Effect of Pyrophosphate on the Level of SO_2 in Processed Apple Slices

Test #	Sample Size	Mean SO_2 Levels (ppm) No Pyrophosphate	Pyrophosphate
1	6	149.2 a*	163.6 b
2	4	131.0 a	146.6 b
3	4	119.3 a	147.6 b

* Mean values in a row followed by the same letter do not differ significantly ($P \geq 0.05$) by Duncan's test.

Table 21

Results of Analysis of Variance for the Effect of Apple Variety on the Level of SO_2 in Processed Apple Slices

Test #	Sample Size	Mean SO_2 Levels (ppm) Newtown	Winesap
1	4	144.3 b*	107.4 a
2	4	161.3 b	116.4 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

The levels of total sugars in the samples was shown by the values in the correlation matrix from the computer printout to decrease with increasing time and temperature of storage. Although the effects of these two factors on the total sugar content could not be shown individually, their combined effects can be demonstrated by the results in Table 22. The effects of the individual factors cannot be separated by virtue of the nature of the testing procedures.

The remaining factors which include the presence of SO_2, calcium ions, pyrophosphate ions, apple variety and backflush gas did not show significant influences ($P > 0.05$) on the total sugar content of the slices.

The levels of reducing sugars were also analyzed and it was found that increases in storage time and temperatures have the effect of increasing the reducing sugar levels (Tables 23 and 24).

The combined effects of time and temperature can be seen in Figure 4.

Table 22

Results of Analysis of Variance for the Combined Effects of Storage Time and Temperature on the Total Sugar Content of Processed Apple Slices

Test #	Sample Size	Mean Total Sugar Content (mg/100 mg)	
		22°C for 1.5 Months	35°C for 5 Months
1	8	13.55 b*	12.75 a
2	4	14.24 b	13.20 a
3	6	13.90 b	12.80 a
4	3	14.52 b	12.67 a
5	9	14.00 b	12.93 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 23

Results of Analysis of Variance for the Effect of Storage Time on the Reducing Sugar Content of Processed Apple Slices

Test #	Sample Size	Mean Reducing Sugar Content (mg/100 mg)	
		1.5 Months	5 Months
1	2	8.85 a *	10.80 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

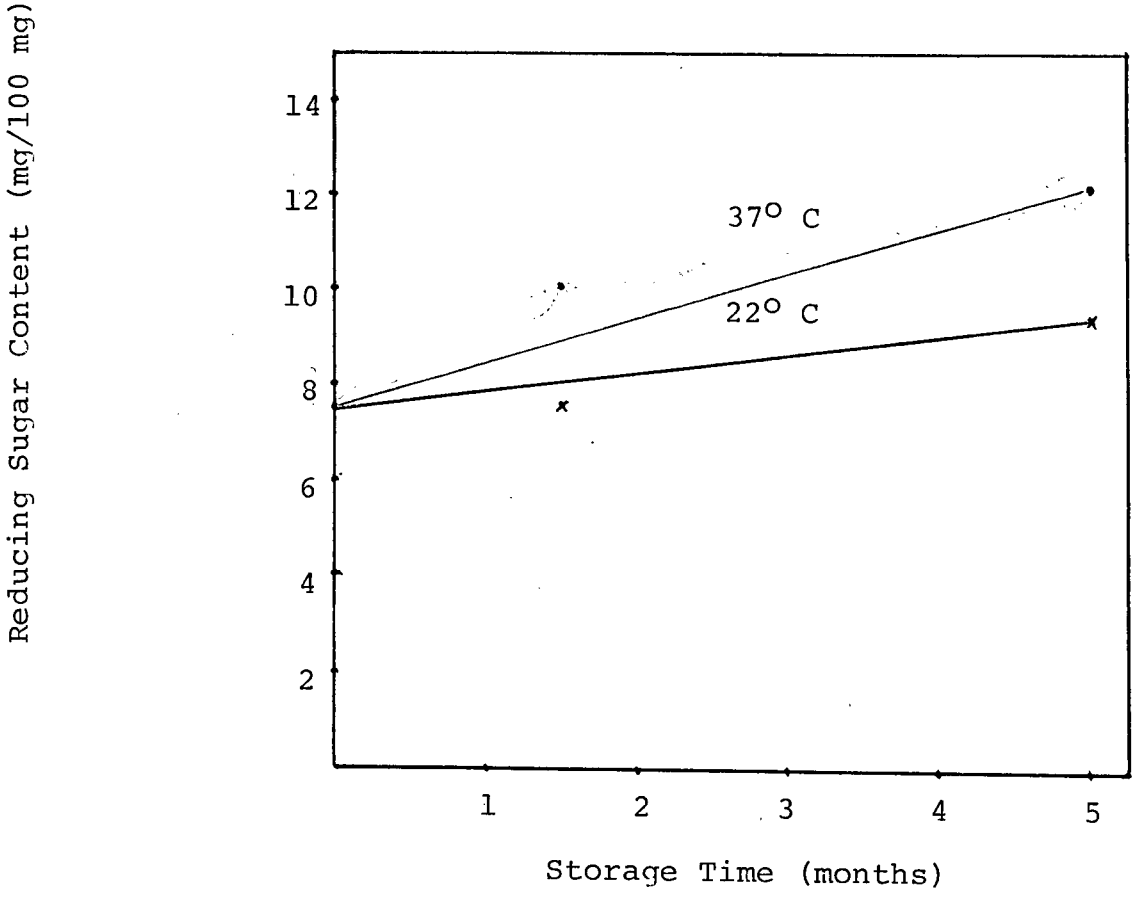

Fig. 4 The Changes in the Reducing Sugar Content with Time in Samples Stored at 22° C and 35° C

The influence on the remaining factors including the presence of calcium and pyrophosphate ions, the presence of SO_2, the variety of apple and the type of backflush gas was not shown to be significant ($P > 0.05$) by Duncan's test. The coefficient for the SO_2-reducing sugar relationship from the correlation matrix indicates that added SO_2 may have some effect on the levels of reducing sugars produced over the storage period. With a closer look at the results, however, it was found that it was not the SO_2 level (Table 25) but the method of incorporation of the SO_2 into the tissues which had an influence on the subsequent levels of reducing sugars in the apple slices (Table 26). These results indicate that the level of reducing sugars was lower in samples subjected to the hot blanch treatment.

The ascorbic acid levels were also determined in each test pack and it was found that these levels were influenced by the preparatory methods (Table 27). The length of storage time was also found to influence the vitamin C levels of the apple slices (Table 28). The presence of calcium was also shown to have an influence on the ascorbic acid content (Table 29). The different levels of calcium incorporated into the apple tissue via the different preparatory methods, however, could not be shown to have any significant effect ($P > 0.05$) on the ascorbic acid content of the slices.

Table 24

Results of Analysis of Variance for the Effects of Storage Temperature on the Reducing Sugar Content of Processed Apple Slices

Test #	Sample Size	Mean Reducing Sugar Content (mg/100 mg)	
		22°C	35°C
1	2	8.43 a *	11.22 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 25

Results of Analysis of Variance for the Effects of SO_2 on the Reducing Sugar Content of Processed Apple Slices

Test #	Sample Size	Mean Reducing Sugar Content (mg/100 mg)		
		1720 ppm SO_2	2150 ppm SO_2	2795 ppm SO_2
1	3	10.42 a*	10.15 a	10.50 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 26

Results of Analysis of Variance for the Effects of Preparatory Treatments on the Reducing Sugar Content of Processed Apple Slices

Test #	Sample Size	Mean Reducing Sugar Content (mg/100 mg) Hot Blanch	Vacuum Infusion	Cold Dip
1	9	9.42 a*	9.87 b	9.98 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 27

Results of Analysis of Variance for the Effects of Preparatory Treatments on the Ascorbic Acid Content of Processed Apple Slices

Test #	Sample Size	Mean Ascorbic Acid Content (mg/100 mg) Hot Blanch	Vacuum Infusion	Cold Dip
1	9	1.56 a*	4.78 b	5.03 c
2	8	1.49 a	4.30 b	4.80 c
3	3	1.47 a	5.28 b	5.80 b
4	3	1.71 a	5.72 b	5.50 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 28

Results of Analysis of Variance for the Effects of Storage Time on the Levels of Vitamin C in Processed Apple Slices

Test #	Sample Size	Mean Ascorbic Acid Content (mg/100 mg)	
		1.5 months	5.0 months
1	2	5.19 a *	6.52 b

* Mean Values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 29

Results of Analysis of Variance for the Effects of Added Calcium on the Ascorbic Acid Content of Processed Apple Slices

Test #	Sample Size	Mean Ascorbic Acid Content (mg/100 mg)	
		No Calcium	Calcium
1	8	3.63 a *	4.84 b
2	4	3.08 a	4.13 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

The variety of apple used for processing was also shown to have influenced the level of ascorbic acid in the samples (Table 30).

The remaining factors such as temperature, SO_2 content, pyrophosphate content and backflush gas could not be demonstrated conclusively to have an effect on the level of ascorbic acid in the apple slices.

The pH of the samples was also monitored throughout the test period. It was thought that changes in the pH would be an indication of chemical changes occurring in the samples. For this reason, it was felt that factors which influenced the pH of the samples could be related to the chemical changes occurring and these were determined with analyses of variance. Time was demonstrated to have a significant influence on the pH of the samples (Table 31). Storage temperature was also shown to have influenced the pH of the samples significantly (Table 32). The SO_2 incorporated into the apple tissue by the different preparatory methods was demonstrated to have influenced the pH of the samples directly with the amount of SO_2 incorporated (Table 33). The level of calcium incorporated into the apple slices also had a significant influence on their pH with greater levels of calcium yielding lower pH values (Table 34).

Table 30

Results of Analysis of Variance for the Effects of Apple Variety on the Ascorbic Acid Content of Processed Apple Slices

Test #	Sample Size	Mean Ascorbic Acid Content (mg/100 mg)	
		Newtown	Winesap
1	4	4.80 b*	2.41 a
2	4	5.65 b	2.43 a

* Mean values in a row followed by the same letter do not differ significantly ($P \geq 0.05$) by Duncan's test.

Table 31

Results of Analysis of Variance for the Effects of Storage Time on the pH of Processed Apple Slices

Test #	Sample Size	Mean pH Values	
		1.5 months	5.0 months
1	2	3.29 a *	3.39 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 32

Results of Analysis of Variance for the Effects of Storage Temperature on the pH of Processed Apple Slices

Test #	Sample Size	Mean pH Values	
		22° C	35° C
1	2	3.30 a *	3.37 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 33

Results of Analysis of Variance for the Effects of Preparatory Method and Level of SO_2 on the pH of Processed Apple Slices

Test for	Sample Size	Mean SO_2 Levels (ppm) and Corresponding Mean pH Values		
		Hot Blanch	Vacuum Infusion	Cold Dip
SO_2	8	42.38 a*	57.88 b	144.3 c
pH	8	3.36 a	3.36 a	3.31 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

The presence of pyrophosphate ions in the apple tissue was also found to be related to a lower pH reading in the samples (Table 35). The variety of apple used also played an important role in the determination of the pH of the samples (Table 36). The choice of the backflush gas also had an effect on the final pH of the processed apple slices (Table 37).

SENSORY ANALYSIS

The results of the sensory evaluation of the different apple slice samples indicate that the product was generally acceptable although some confusion did exist as to what constitutes an acceptable apple slice.

The factors which were found to influence the acceptance of the product were length of storage (Table 38), storage temperature (Table 39), and the presence of calcium ions (Table 40). Other factors such as pyrophosphate ions, SO_2 levels, variety and type of backflush gas did not produce discernible differences ($P > 0.05$) in the sensory evaluations.

Table 34

Results of Analysis of Variance for the Effects of Calcium on the pH of Processed Apple Slices

Test for	Sample Size	Corresponding Mean pH Values: No Calcium	Cold Dip Calcium	Vac. Infusion Calcium
Calcium	6	28.0 a*	74.4 b	230.5 c
pH	6	3.34 a	3.33 b	3.25 c

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 35

Results of Analysis of Variance for the Effect of Pyrophosphate on the pH Value of Processed Apple Slices

Test #	Sample Size	Mean pH Values: No Pyrophosphate	With Pyrophosphate
1	6	3.33 b*	3.28 a
2	4	3.42 b	3.36 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 36

Results of Analysis of Variance for the Effects of Apple Variety on the pH of Processed Apple Slices

Test #	Sample Size	Mean pH Values	
		Newtons	Winesaps
1	4	3.37 a*	3.45 b
2	4	3.33 a	3.44 b

* Mean values in a row followed by the same letter do not differ significantly ($P \geq 0.05$) by Duncan's test.

Table 37

Results of Analysis of Variance for the Effect of Backflush Gas on the pH of Processed Apple Slices

Test #	Sample Size	Mean pH Values	
		Nitrogen	Carbon Dioxide
1	6	3.33 b*	3.26 a

* Mean values in a row followed by the same letter do not differ significantly ($P \geq 0.05$) by Duncan's test.

Table 38

Results of Analysis of Variance for the Effects of Time on the Four Quality Parameters in the Sensory Evaluation of Processed Apple Slices

Quality Parameter	Sample Size	Mean Level of Acceptance (%)	
		1.5 months	5.0 months
Appeal	6	61.10 b*	50.29 a
Texture	6	58.42 b	51.21 a
Flavour	6	63.45 b	55.95 a
Acceptability	6	59.02 b	49.36 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 39

Results of Analysis of Variance for the Effects of Storage Temperature on the Four Quality Parameters in the Sensory Evaluation of Processed Apple Slices

Test Parameter	Sample Size	Mean Level of Acceptance (%)	
		22° C	35° C
Appeal	2	72.56 b*	47.90 a
Texture	2	65.11 b	37.56 a
Flavour	2	72.17 b	56.58 a
Acceptability	2	68.60 b	42.55 a

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 40

Results of Analysis of Variance for the Effect of Calcium on the Four Quality Parameters in the Sensory Evaluation of Processed Apple Slices

Test Parameter	Sample Size	Mean Level of Acceptance (%)	
		No Calcium	Calcium
Appeal	10	41.18 a*	66.28 b
Texture	10	25.38 a	59.28 b
Flavour	10	54.54 a	65.02 b
Acceptability	10	32.96 a	62.00 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 41

Results of Analysis of Variance for the Effects of Calcium on the Shear Resistance of Processed Apple Slices

Test #	Sample Size	Mean Shear Resistance (kg)	
		No Calcium	With Calcium
1	8	0.77 a*	1.85 b
2	6	0.71 a	2.04 b
3	4	0.88 a	1.94 b
4	6	0.76 a	1.95 b
5	9	0.78 a	1.85 b

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

Table 42

Results of Analysis of Variance for the Effects of the Preparatory Treatment on the Shear Resistance Readings of Processed Apple Slices

Test #	Sample Size	Mean Shear Resistance (kg) Hot Blanch	Cold Dip	Vacuum Infusion
1	9	0.77 a*	1.55 b	1.85 c
2	3	0.89 a	1.57 b	2.21 c
3	3	1.48 a	2.52 b	3.26 c

* Mean values in a row followed by the same letter do not differ significantly ($P > 0.05$) by Duncan's test.

DISCUSSION

PROCESSING

Process Time Determination

It was found when comparing the processing times derived by the thermal diffusivity and heat penetration methods described earlier that there was a considerable discrepancy between them. This discrepancy amounted to 4.2 minutes which is a difference of approximately 20% of the time used for our process. Since the slice was processed for the full 19.8 minutes, there is no doubt that the process was sufficient to achieve microbial stability. In fact, it is suspected that this process was more than adequate and that the product could have been slightly over processed.

The reason for the discrepancies in process time result from the fact that in the thermal diffusivity method the apple tissue in a pouch is considered to be a solid brick instead of discrete slices surrounded by a liquid phase. This would result in a product which heats by conduction rather than by both conduction and convection as is the case for apple slices. It is known that a food product usually heats more quickly by combined convection and conduction than by conduction alone (Schultz and Olson, 1938).

It also should be noted that this product probably does not conform strictly to a convection-conduction model either since the drained dry slices were placed in the pouch with granulated sugar and sealed. It is then during the heating process that liquid is withdrawn from the slices by osmosis and cell wall disruption due to the heating process. This could represent a product that initially heats by conduction and gradually includes convection heating as the syrup fraction increases. If this is the case, the time lag between when the sugar is added to the slices and when the actual heat processing commences will have an effect on the processing time as osmosis will occur and some liquid will be withdrawn depending on the time elapsed. Hot blanching of samples could also affect this as some cell walls would be disrupted and would likely release additional liquid. The significance of these factors was not determined in this research, but could possibly be of interest in some future study. It was noted, however, that there were differences in the types of heating curves for heat penetration studies in which the test pouches were allowed to stand for a few hours before processing and those in which the samples were processed immediately. The curves of the former exhibited linearity, whereas those of the latter had a more curvilinear nature.

The f_h value derived from the heat penetration method was adjusted by the addition of three times the standard deviation to insure that the probability of requiring a higher f_h value was less than 0.005. Similarly, the thermal diffusivity was corrected by subtracting three times its standard deviation. By carrying out these procedures, the process time derived was somewhat longer than if no corrections had been made, thus providing a safety factor to reduce the chances of underprocessing.

Sample Preparation and Their Effects

Observation of the samples undergoing the different preparatory treatments, before the final heat process, turned up some differences which influenced their texture, flavour and appearance in subsequent tests.

It was noted that the apple slices that underwent the ten minute vacuum infusion treatment acquired a translucent appearance and a bland, watery flavour. The flavour changes were partially masked in the final product by the addition of sucrose to the pouches. For this reason, these samples were not downgraded by the panelists and, in the analysis of variance of the results, no significant difference was found. There were, however, several individual comments which clearly indicated that a number of the panelists did detect the flavour change. The translucence of the samples

was also carried over into the finished product and resulted in a slightly lower score on appeal than identical samples undergoing different preparatory treatments. Again, the individual comments of some of the panelists specifically mentioned a frozen-thawed look or at least that the colouration was not uniform.

The texture of the samples undergoing the hot blanch treatment was quite soft and this was found to influence the results in the subsequent texture tests. The hot blanch medium contained the sodium bisulfite as an SO_2 source for the product and also the sodium acid pyrophosphate as the pyrophosphate ion source for those samples in which it was included. The hot blanch was also always carried out after a cold dip in a calcium chloride solution if calcium ions were to be introduced to the sample. This may have resulted in the leaching of calcium ions which had not been bonded to pectin molecules. Also, SO_2 is known to have a softening effect on apple texture but the addition of calcium ions to the same tissue in a basic medium does partially or even completely reverse this effect (Ponting et al., 1971). The vitamin C level in the hot blanched samples was also found to be significantly lower than in those samples undergoing the other preparatory treatments (Table 27). This resulted from heating the slices in the presence of an ample supply of oxygen which resulted in oxidation of L- ascorbic acid (Tannenbaum, 1976).

The apple slices that underwent the cold dip retained their natural appearance and much of their fresh texture but it was found that this also created a problem in that the slices tended to be quite bulky and resulted in greater pouch thickness than was produced by slices undergoing the other treatments. This had the potential of requiring an increased thermal process time to insure that microbial stability was achieved. The gases trapped in the tissues also contained oxygen which when included in the pouch would increase the degree of nonenzymic browning.

The analysis for calcium and SO_2 levels in the apple samples after heat processing indicate that the optimum choice of preparatory treatment is important in the incorporation of these preservatives into the tissues. For example, the vacuum infusion treatment was found to be very efficient in transporting calcium ions into the apple slices (Fig. 2) but only slightly more efficient than the hot blanch method for the incorporation of SO_2 (Fig. 1). Comparison of the levels of calcium ions added to the vacuum infusion solution and the cold dip solution and the levels found in the respective samples, indicates that for the incorporation of calcium ions the vacuum infusion method is approximately six times more efficient than the cold dip treatment.

Comparison of the SO_2 levels added to the vacuum infusion solutions and the cold dip solutions with the levels found in the respective samples indicate that for SO_2 incorporation the vacuum infusion method is only two times more efficient than the cold dip method. It is not known if the efficiency of these methods in incorporating these additives is influenced by concentration i.e. as the concentration of additive increases the efficiency increases. This occurrence seems unlikely, but further study would be required for verification.

There is also the possibility that some of the SO_2 in the solution in the form of dissolved gas may have been removed during the evacuation thus effectively lowering the original concentration of SO_2 available for infusion into the tissues when the vacuum was broken.

A level of 100 ppm of SO_2 residing in the apple tissue was the target level since higher levels gave rise to the characteristic unpleasant SO_2 flavour which was discernible by certain people. As it was some of the panelists commented on the chemical taste of the cold dip sample in the sensory analysis.

The hot blanch method consistently incorporated lower levels of the additives than the other methods. This again could have been corrected by increasing the levels of additives in their respective solutions and further work is

required to establish the levels required. The main advantages of the hot blanch method are the removal of gases and enzyme inhibition. Decreases in firmness (Table 42) and vitamin C content (Table 27) and the lower efficiency of this process make it less desirable than the other methods.

The vacuum infusion method has the advantages of removal of gas from the tissues by replacement with liquid and great efficiency as far as incorporation of chemicals is concerned. Disadvantages of this procedure are that it causes a translucent appearance and a loss of flavour, and would tend to be a batch process on a commercial line although Hoover and Miller (1975) have reported the development of a continuous vacuum impregnation process. This process also has no inhibitory effect on enzyme activity unless steam is used to break the vacuum. It was also reported in the same paper that the flavour changes that accompany this method can be economically masked by the addition of 0.1% malic acid along with sucrose to the infusion solution (Hoover and Miller, 1975). Wiley and Lee (1970) found that vacuum infusion with a sugar solution increased the firmness of apple slices which was partially decreased with the final processing.

The cold dip method is not as economical in terms of amounts of additives required, but is somewhat easier and provides good results as far as incorporation of the chemicals is concerned. This method does, however, have several disadvantages. The first of these is that enzymatic activity is

not necessarily curtailed by this method although SO_2 is known to inhibit enzymatic browning (Lindsay, 1976; Creuss, 1948), thus if an SO_2 dip is used, this problem is eliminated. The second problem encountered with this system is that the gas trapped in the intercellular spaces is not removed. Since the oxygen content of this gas can vary from 3 to 15% depending on the respiration rate of the apple (Lazar and Hudson, 1976), it increases the oxygen content of the container after sealing and is conducive to nonenzymic browning. It also retains the bulky shape of the apple slices and makes it more difficult to achieve an economic fill weight and still seal the pouch. This also produces a thicker pouch which then requires a slightly longer heat process to insure microbial stability.

Of the three methods, it is difficult to say that one is superior to another since in a commerical plant much would depend on the space available and the economics of the situation. However, it is safe to say that in view of the loss of texture, sugars and nutrients (Lee, 1958), the hot blanching process is the least desirable of the three methods as far as the processing of apples is concerned. Steam blanching is less detrimental to fruit tissues but it still causes some losses in quality (Guerrant, 1948) and can create flavour changes (Lee, 1958).

SAMPLE DIFFERENCES

Texture

Probably the most useful and reliable method of measuring the texture of the apple slices used in this research was the Instron-Kramer single blade shear test method. It has been reported that the measurement of shear force is the best estimate of sensory evaluation and therefore the most likely to indicate the degree of acceptability of a sample (Bowman et al., 1972).

Measurement of the viscometric properties of a puree of the samples, showed little relationship to the results of texture measurement on whole slices with the Instron. Originally it was thought that the cells of the apple tissues would be separated into discrete units on maceration and that the presence of calcium ions in this puree would cause reassociation of the cells. This would be accomplished by the formation of the calcium bridges between the free carboxyl groups of pectic substances in the walls of the individual cells. It was hoped that the degree of agglomeration could be measured viscometrically and that differences in levels of calcium would be reflected by increased viscosity. When the viscometric measurements were subjected to the multiple regression analyses, calcium was shown to have a significant relationship only when included in two-way interactions but bore no significant relationship when considered as a single factor.

The single factors shown to relate most significantly to the shear force measurements were the calcium level of the sample and the temperature at which the storage was maintained (Table 4). These factors are shown in Table 5 to give a better explanation of the variance in the shear force in a series of two-way interactions with other factors involved.

The effect of calcium ions on processed fruit texture have been known for many years (Loconti and Kertesz, 1941). The use of calcium ions to firm apple slices which are to undergo intensive heat processing has been limited to certain varieties which include the varieties used in this research (Reeve and Leinbach, 1953). The results of the multiple regression analysis indicate that an increased level of calcium ions results in an increase in the force required to shear the slices. This is also supported by the results of the mini analyses of variance (Table 41).

In the multiple regression analysis using two-way interaction factors, calcium is shown to interact with the total sugar content, the reducing sugar content and the length of storage to influence the texture of the sample. Wiley and Lee (1970) demonstrated that the presence of sucrose in the tissues aids in firming apple slices. It is known that the pectinic acids of plant tissues are capable of forming gels with sugar and acid, or if they are of a low methoxyl content, with certain metallic ions, such as calcium (Hodge and Osman, 1976).

Increases in reducing sugar levels indicate the hydrolysis of sucrose to its component reducing sugars glucose and fructose. This event occurs over prolonged storage times and elevated storage temperatures. This is also accompanied by a breakdown of pectic substances (Adams and Blundstone, 1971) resulting in separation of the tissue cells. Turgor within the cells is lost during the initial heating process due to a denaturation of the cell membrane resulting in a loss of the selective permeability. This effect is reversed with the formation of the calcium and sugar bridges between the pectic substances of the cell wall, most of which have become water soluble with the initial heating.

The results of these physical and chemical changes is that pectic materials, when hydrolysed, are lost to the surrounding medium with hydrolyzed sugars and firmness is reduced.

The factors which were shown to correspond significantly with the viscometric results by the multiple regression analyses were the ascorbic acid content, the backflush gas, the total sugars content and the length of storage (Tables 6, 7, 8, and 9). The variety of apple was shown to be a significant factor in relation to the determination of the consistency coefficients. On closer examination (Table 10, 11, 12, and 13) using two-way interaction factors, calcium in two-way interactions with the backflush gas and time emerge as factors with highly significant relationships to the viscometric results. An interaction between the ascorbic

acid content and the storage temperature was also shown to have a highly significant relationship to the viscometric results. Other factors which partially explained the variance in some of the viscometric results were the total sugar content, the variety - calcium content interaction and a total sugar - reducing sugar interaction.

The calcium content - backflush gas interaction effect can be explained in that in those samples packed with carbon dioxide, a certain amount of the CO_2 was dissolved in the syrup. The carbonate ions thus formed would interact with free calcium ions forming insoluble calcium carbonate particles which would increase the viscosity of purees formed from such samples. Nitrogen being less soluble and more inert would have little or no influence on the tissues (Joslyn, 1964). An interesting speculation arising from this is that, given time, the level of gaseous CO_2 remaining in the pouch should diminish and therefore the protection provided by the natural thickness of a backflushed pouch would be lost resulting in a greater chance of mechanical damage due to handling.

The calcium content - storage time interaction effect indicates that as time increases those samples with greater calcium levels have greater decreases in viscosity than those of lower calcium content. The mechanism of this interaction is not clear and therefore cannot be explained with any certainty. It is known that in those samples with higher levels of calcium there are more calcium bridges formed between the

polysaccharides of the cell walls. It is also known that during maceration the bonds are broken and the cells are separated. It is possible that with time the actual wall of the cell is weakened. This weakening may be of large enough magnitude that the force required to rupture the wall is less than the force required to break the higher number of calcium bridges. In this case, then the rupture of the cells would lead to a lower viscosity of the puree which was noted in all cases over the storage period. Reagglomeration of cells would be decreased as the number of ruptured cells increased also resulting in a lower viscosity. Further studies using microscopy are needed to verify this proposition.

The interaction between the ascorbic acid content and the temperature is also difficult to explain. The reason for this is that the experimental results from the ascorbic acid analysis indicates that the ascorbic acid content of the samples increased with increased storage time and temperature. Since it has been well documented that vitamin C is heat labile (Blundstone et al., 1971) it seems unlikely that these results are correct and it is believed that the increased levels are actually a result of a build up of other interfering substances (Tannenbaum, 1976) which gave positive results in the titration for ascorbic acid.

It is known that the polysaccharide materials of cell walls are broken down by prolonged storage at higher temperature. It is possible that the interfering substances are either a result of this breakdown or in some way interact with temperature to bring about hydrolysis of these materials thus reducing the possibilities of reagglomeration following complete maceration.

The total sugar content of the apple slices was also found to influence the flow behaviour index and the consistency coefficient of the apple puree. Increasing total sugar content was shown to coincide with increased viscosity of the puree. Because the sugar content is small when compared with the water added to make the puree, it is doubtful that the viscosity resulted from any changes in the syrupiness of the liquid phase. A more likely result is that sugar behaved as a gelling agent which at the low pH permitted the formation of a sugar-pectinic acid gel between adjacent cells and thereby increased the particle size of the solids content which resulted in an increase in viscosity (Hodge and Osman, 1976).

An interaction between the total sugars content and the reducing sugars content was shown to have a relation to the intermediate shear rate apparent viscosity and the yield stress. This interaction was positive in relation to that of the viscometric parameters which indicates that increasing

reducing sugar levels corresponded to increased viscosity. The explanation of this interaction is similar to that of the total sugar content in that an increase in the total number of sugar molecules results in a greater number of bonds being formed between the pectinic acids and the sugars. This would indicate that if molecules of sucrose were hydrolyzed as was the case in this research, the number of sugar molecules produced would double. This would provide additional molecules capable of forming a gel with the pectic substances. Thus an increase of the total sugar content could lead to a two-fold increase in the total number of sugar molecules depending on the extent of hydrolysis.

In an overall comparison of the two methods of measuring texture, it can be seen by observing the R^2 values for the analyses that the most accurate explanation of the variance given by the independent variables in the multiple regression analyses is derived when considering both single and two-way interaction factors against the Instron results. It is interesting to note that the calcium levels of the samples had no significant influence on the viscometric measurements when only single factors were considered. It only appeared as a significant contributor in two-way interaction factors with some of the single factors which had been found to be significant contributors in the single factor analysis. This leads to the conclusion that this method is not the best method for determining differences in samples due to differences in

calcium levels and that this method also provides a poorer estimate of subjective analyses of apple slice texture than does the measurement of shear force with the Instron and Kramer Shear cell.

Colour

The results of the multiple regression analyses on the data from the three colour parameters of the Hunterlab Colour Difference meter indicate that the factors whose variance coincides significantly with the variance of each colour parameter are not the same. For this reason, the parameters must be separated and discussed independently.

The first parameter of Hunter L value is a measure of the lightness to darkness ratio of the samples. The factors shown to influence this parameter are presented in Tables 14 and 17. The single factors which best explain the variance in the Hunter L value are the backflush gas, the total sugars content, the reducing sugar content, the storage time and storage temperature. A slightly better explanation is achieved when both single and two-way interaction factors are considered. In this comparison a number of interaction factors emerge as significant and give an R^2 value of 0.847 of which 0.803 is derived from the first four of the following factors. The interactions found to provide a significant explanation for the variance in the Hunter L value are interactions between storage time

and storage temperature, the total and reducing sugar contents, the SO_2 level and storage time, the backflush gas and calcium content, the backflush gas and the SO_2 content, the pyrophosphate content and the variety, and finally the ascorbic acid content and the pH.

The time and temperature interaction bears an inverse relationship to the Hunter L value. This is an expected result since it has been well established that colours in canned fruit deteriorate with both increasing storage time and storage temperature (Daoud and Luh, 1971). This results from the slow build up of non-enzymic browning products in the tissues. Because the pH of the samples was less than 4.0, this browning cannot be classified as of the Maillard type but is suspected of being related to the various organic acids and high levels of sugars present (Adams and Blundstone, 1971). Under aerobic conditions, the ascorbic acid levels of samples undergoing this method of browning usually reaches zero before the onset of browning but under conditions approaching anaerobic, as much as 80% of the original ascorbic acid may remain at the onset of browning (Tressler and Joslyn, 1954). It has been found that this type of browning may have close correlation to lower pH's and high titratable acidity (Huggart et al., 1957).

Since one of the actions of SO_2 in a product is to serve as an antioxidant, it inhibits the formation of brown pigments resulting from nonenzymic browning processes. With time, however, the levels of SO_2 decrease due to reactions with the outer atmosphere caused by permeability through pinholes or seals that are impervious to liquids but allow the passage of oxygen. Thus the SO_2 content may be depleted by the production of sulfate leaving the product free to brown (Joslyn and Braverman, 1954). Some of the samples in this research were suspected to have undergone such a process as their SO_2 levels were lower than expected and their colours, as measured by the Hunter colour meter, were somewhat darker. It is interesting to note that there seems to be a certain amount of this browning which can occur even before the total SO_2 content is depleted. The SO_2 levels in all samples were found to decrease significantly with time (Fig. 3).

The backflush gas was also found to have a significant correlation with the variance in the Hunter L value. This variable was found to be involved in several interactions.

The gas - calcium content interaction was found to have a negative correlation with the Hunter L value. It is suspected that CO_2 combined with calcium, via the formation of carbonic acid, to produce insoluble calcium carbonate. This is supported by the loss of the calcium firming action of slices packed with CO_2 as

mentioned earlier. It was reported by Ponting et al., (1972) that calcium ions derived from calcium chloride have a synergistic effect with both SO_2 and ascorbic acid for the maintenance of lightness in apple tissues. The loss of Ca^{++} as insoluble $CaCO_3$ therefore may have led to darkening. It was also reported that as the SO_2 levels became greater in apple tissues the synergistic effect of Ca^{++} became less.

Gardner (1968) reported that some acidulants when added to foods act as synergists to antioxidants in the prevention of nonenzymic browning. This may explain the interaction noted between the backflush gas and the SO_2 content of the samples. It may also help to explain the significant interaction between the backflush gas and the storage time in that those samples packed with CO_2 maintained a lighter colour over a longer period of time. This would lead to the conclusion that carbon dioxide has better properties in the maintenance of colour than does nitrogen.

The interaction between the pyrophosphate content and the apple variety is probably best explained by varietal differences in the apples. Due to growing conditions as well as variety, apples may contain varying levels of metallic ions which would influence the action of pyrophosphate whose main action is to sequester metallic ions capable of initiating browning reactions. (Furia, 1968).

The single factors most closely correlated with the Hunter a value or ratio of redness to greenness in the apple slices were shown by the multiple regression analysis to be the variety, the SO_2 content, the ascorbic acid content and the storage time (Table 15). A slightly better correlation was achieved when two-way interaction factors as well as single factors were compared. The factors whose variance showed significant correlation with the variance of the Hunter a values in this analysis were interactions between the variety and the SO_2 content, the pH and the ascorbic acid content, the storage time and temperature, the backflush gas and the pH, the backflush gas and the ascorbic acid content. Of these, the first three are the most important as they comprise 0.818 of the 0.836 R^2 value of the analysis. The correlation of the time - temperature interaction with the Hunter a value was highly significant just as it had been previously with the Hunter L value and therefore the explanation remains the same. The correlation in this case is positive which corresponds to increasing redness or browning of the samples with increased time and temperature.

The variety - SO_2 content interaction probably results from the fact that one variety, the Newtown Pippins, was subject to very rapid enzymic browning during the peeling and coring operations. Although this was done quickly and the prepared slices were immersed in brine, a certain amount of melanin was produced before processing this variety. The different levels

of SO_2 were in part determined by the preparatory treatments (Fig. 1) and therefore, it is felt that these treatments, especially the hot blanch method, may have had a significant influence on the degree of browning and the Hunter a value. Analysis of variance results demonstrated that the SO_2 levels in the samples which differed very significantly were also correlated to the Hunter a values for the same samples (Table 41). It would appear from the results that the hot blanch may have deleterious effects on the lightness of apple slices over and above the effects of reduced levels of SO_2 incorporated. It is possible that the levels of SO_2 incorporated by the vacuum infusion method represent a bare minimum below which the browning rate is able to proceed at an increased rate. A more probable explanation is that the heat of the blanch combined with the presence of an abundant oxygen supply, gives rise to non-enzymic browning products to such a degree that the low levels of SO_2 are unable to reverse it; thus, higher Hunter a values are produced. Further work using different levels of SO_2 in hot blanching solutions would be required to verify this.

The correlation between the interaction of the ascorbic acid content and the pH with the Hunter a values is shown to be negative which indicates that as the ascorbic acid level increases there would be a decrease in the Hunter a value and a decrease in browning. It can also be seen that with increasing ascorbic acid levels, the pH of the sample would become lower and it is suspected that this is the key to the interaction

which occurs between the two factors and subsequently influences the Hunter a value. The value of ascorbic acid as an antioxidant is well documented (Bauernfeind and Pinkert, 1970) and it is often used in the canning industry as a method of combatting nonenzymic browning. In this research as mentioned earlier, there was some doubt as to the veracity of the results of the ascorbic acid analysis which indicated that there had been an increase in the level of titratable vitamin C over the five month storage period. It is felt, however, that this effect had little influence on the interaction factor above since the increase in ascorbic acid as measured was of roughly the same magnitude for all samples and the values were relative as far as browning between the different samples was concerned.

The remaining interaction factors contributed only about 0.018 of the 0.836 coefficient of determination and therefore, are not considered to be factors of any major influence; consequently, they will not be discussed.

The third parameter of the colour measurement of the Hunterlab colour difference meter measures the ration of yellowness to blueness in the sample and is designated as the b value.

Although the colour of the samples were definitely more yellow than white, it was found that the variance of the different independent variables in the multiple regression analyses provided a relatively poor explanation of the variance in

the Hunter b values. The highest R^2 value achieved was only 0.475. In the stepwise multiple regression using single factors only (Table 16) the independent variables which were shown to have a variance with significant correlation to the Hunter b value were the presence of pyrophosphate ions, the SO_2 content and the total sugar content. When single and two-way interaction factors were both considered as independent variables in the stepwise multiple regression, the factors which were shown to be correlated significantly to the Hunter b values were interactions between the pyrophosphate and SO_2 content, the backflush gas and SO_2 content, the SO_2 and reducing sugars content, the SO_2 and ascorbic acid contents, the total sugar and ascorbic acid contents and the ascorbic acid contents and storage temperature (Table 19). The three interaction factors which make up the greater part of the R^2 value are interactions between the total sugars and ascorbic acid contents, the pyrophosphate and SO_2 contents and the SO_2 and reducing sugar contents. The relationship of these three interaction factors to the Hunter b value was a positive one indicating that an increase in the interaction term corresponded to an increase in the Hunter b reading.

The interaction between the total sugar and ascorbic acid contents in relation to colour is difficult to explain but Tannenbaum (1976) indicates than the degradation of ascorbic acid can follow any of the many complex pathways depending

on the conditions present. Some of these are influenced by sugar content in that higher sugar concentrations have a tendency to "salt-out" any O_2 dissolved in the medium. Although the O_2 content in these samples is low, it is not completely excluded from the pouch and therefore O_2 could influence the degradation of vitamin C. Some sugars, particularly fructose, are capable of forming complexes with metallic ions such as Cu^{2+} and Fe^{3+} which are capable of acting as catalysts in the breakdown of ascorbic acid (Pollard and Timberlake, 1971). Therefore, the sugar concentration also plays another role in the protection of ascorbic acid. The breakdown of the sugars themselves also leads to the build up of breakdown products and a decrease in the total concentration of sugars. The breakdown products of both sugars and ascorbic acid are involved in the production of non-enzymic browning pigments in canned fruit products (Reynolds, 1965). Because of the number of different pathways and the similarity of intermediate products the exact pathway and mechanisms of the breakdown of these components is difficult to pinpoint and requires work which goes beyond the scope of this research.

It is known that the breakdown of ascorbic acid is dependent on the temperature of the media (Tannenbaum, 1976) and that its breakdown results in the production of reductones which can influence assays for vitamin C. It has also been shown that SO_2 acts as an inhibitor and possibly a bleaching

agent in nonenzymic browning thus blocking the browning reaction and bleaching any melanoidin pigments produced (Gehman and Osman, 1954; Lindsay, 1976). It is also known that with increased storage time and temperature, reducing sugars are produced from non-reducing sugars (sucrose) by hydrolysis (Tables 23 and 24). The reducing sugars then undergo further changes which are influenced by heating and acid conditions to produce compounds capable of condensing into brown pigments (Hodge and Osman, 1976). The presence of SO_2 inhibits this activity by forming an addition compound between the carboxyl group of the reducing sugar moiety or one of its intermediate products and the bisulfite ion from the solution (Gehman and Osman, 1954). This blocks the condensation step and severely restricts the rate of browning. With prolonged storage time and elevated storage temperatures, however, browning does eventually proceed causing a darkening of the samples.

The action of added pyrophosphate ions in a sample is to sequester metallic ions such as Fe^{3+} and Cu^{2+} which can catalyze a number of breakdown reactions which in turn initiate browning reaction (Furia, 1968). The exact interaction mechanism of this ion with the SO_2 is unknown but it is assumed that the chelating activity of the pyrophosphate may in some way slow the formation of intermediate products which use up the supply of available SO_2, thereby prolonging its activity.

In general, the colour parameters which provide the best indication of the action of the independent variables in colour changes in the apple slices of this research are the Hunter L and a values with R^2 values in the multiple regression analyses of approximately 0.80 as compared to the Hunter b readings which had R^2 values of less than 0.50 which indicate that either this parameter is less valuable in predicting the factors responsible for colour changes in apple slices or that the factors responsible for the changes in the yellowness to blueness ratio are quite different than those proposed for the other parameters. Since browning is of primary concern and is more accurately measured by the Hunter L and a values it is likely that Hunter b values could be ignored.

Chemical Analyses

For this research, there were a number of chemical analyses which were considered as possible methods of monitoring the changes which occurred in the products over the storage period at the different temperatures. Because the available time to carry out these tests was limited, only six were chosen to be carried out. Two of these were done specifically to show if any differences could be found between the levels of additives which were incorporated by the different preparatory treatments. These were the analyses for the calcium and SO_2 contents. The remaining tests, which include

analyses for total sugars, reducing sugars and ascorbic acid as well as pH measurements, were carried out to elucidate changes in the quality attributes of the samples with time. However, when the time came to assess the results of these various tests, it was found that the results from both categories could be applied interchangeably, so that Ca^{++} and SO_2 analyses could be used to indicate quality changes while ascorbic acid and sugar analyses were indicative of the effectiveness and desirability of the preparatory methods.

Calcium Analysis

Because it was originally planned that the measurement of calcium levels would only serve to indicate the effectiveness of the preparatory treatments, and a limited access to an atomic absorption spectrophotometer, duplicate measurements of the calcium levels were not made for both testing times. Single samples, taken at each time from the slices undergoing the shear force test, were used to obtain calcium levels and the results were combined as duplicates for assessing the effectiveness of the preparatory methods. As a result of this, it was impossible to determine if differences in storage time and temperature really had any effect on the texture of apple slices as a direct result of changes in the calcium content.

It was thought that pyrophosphate, in its role as a sequestering agent, would tie up some of the calcium ions in the apple tissue and might therefore have a significant influence on the results of the calcium analyses. This, however, could not be shown in either the mini analyses of variance or the multiple regression analyses where the level of pyrophosphate had no significant correlation with any of the texture measurements.

The variety of apple seemed to have no influence on the level of calcium which was incorporated into the tissues although variety was involved in the multiple regression independent interaction factors which explained some of the variance in the viscometric results.

The backflush gas was found to have a significant influence on the level of calcium found in the samples. From the results it appears that carbon dioxide in some way increases the retention of calcium in the tissues. The explanation of this effect revolves around the solubility of the CO_2 and its ability in this form to combine with Ca^{++} to form insoluble calcium carbonate. This material was probably deposited within the tissues whereas some of the Ca^{++} in the nitrogen packed samples would be free to diffuse out of the tissues and into the syrup media which was discarded before the calcium analysis.

SO_2 Analysis

The SO_2 content of the samples was found to be influenced by a number of the factors involved in this research. The preparatory methods were found to have a large influence on the level of SO_2 found in the samples (Fig. 1).

The temperature of storage was also found to influence the levels of SO_2 found in the samples. It is known that under ambient conditions, the level of SO_2 in a canned product will decrease with the length of storage and that this decrease is accelerated as the storage temperature is increased (Joslyn and Braverman, 1954). In this research, only one of the samples prepared could be tested for separate time and temperature effects because of its storage procedure. Analysis of these results did not show conclusively a storage time effect on the SO_2 content of the samples. The measurement of SO_2 levels for the 1.5 month storage time of samples stored at the lower temperature gave lower results than expected (Fig. 3). The reason for this is suspected to have been the slight permeability of the pouch which allowed slow entry of O_2 into the product. This diffusion was slow enough that at the 1.5 month period the visual effects were not discernable but some of the results of other chemical analyses lend support to this suspicion. These include a lower ascorbic acid content and Hunter L reading coupled with a slightly higher Hunter a value when compared with other similar samples. The results of this was to give a lower mean SO_2 level in the

samples from the room temperature sample which when combined with the SO_2 readings from the warm temperature storage gave an overall mean lower than the overall mean after 5.0 months storage. This in effect appeared as a significant increase in SO_2 with time which was erroneous.

The effect of the storage temperature on the SO_2 content was more obvious as can be seen in Fig. 3. In this case there seems to have been a profound decrease in the SO_2 content of samples stored at the higher temperature between the day of processing and the 1.5 month storage test time. Following this, the SO_2 content seemed to level off indicating that most of the reactions which were "consuming" the SO_2 were limited and had been depleted and that only reactions with very slow reaction ratios were still occurring between the 1.5 and 5.0 month storage period.

The pouches stored at the lower temperature on the other hand had a much slower loss of SO_2 indicating the possibility that the energy of activation of the reaction(s) which had caused the sudden decrease in the SO_2 content of samples stored at the higher temperature had not been reached at the lower temperature. Further work must be done with tests at closer time intervals and greater sample numbers in order to verify the results and to establish whether there is an energy threshold for these reactions and limiting factors that prevent continuation until all the SO_2 is lost. It is suspected that at higher temperatures the rate of sugar de-

gradation is increased resulting in sugar breakdown products that combine with the SO_2 (Gehman and Osman, 1954).

The results of the analyses of variance also indicate that the presence of pyrophosphate in a sample increased the levels of SO_2 remaining at the testing time (Table 20). The action of pyrophosphate ions is one of sequestering metallic ions. It is suspected that some of these metallic ions may play a role as catalysts in the breakdown of certain components of the sample such as organic acids to reactive carbonyl compounds which in turn would deplete the SO_2 content of the sample (Pollard and Timberlake, 1971). Removal of these ions from this activity would therefore help to conserve the SO_2 content of the sample. An interaction factor between the pyrophosphate content and the SO_2 content was shown by the stepwise multiple regression analysis using both single and two-way interaction factors to vary with significant correlation to the variance of the Hunter b readings of the samples (Table 19).

The analyses of variance on the samples also indicates that the variety of apple used for each sample had a significant influence on the amount of SO_2 remaining in the sample at the time of testing. From the results of Table 21 it can be seen that the Winesap variety seemed to have lower levels of SO_2 than the Newtown Pippin variety. The reason for this cannot be explained except for the possibility of

some varietal differences which affect either the incorporation of SO_2 into the tissue or the depletion rate of SO_2 incorporated. The variance of an interaction term between the variety and the SO_2 content was found to have a significant correlation to the variance of the Hunter a values.

The remaining factors, such as the calcium level and the backflush, could not be shown to have had any significant effect on the levels of SO_2 found in the samples at the two test times.

Total Sugar Analysis

From the analyses of variance to determine the effects of all the other factors on the total sugars content of the samples it was found that only time and temperature of storage had a sigificant influence (Table 23). The other variables including preparatory methods, calcium content, SO_2 content, pyrophosphate content, backflush gas and variety had no effect on the total sugar content. Because of the design of this experiment it was again difficult to separate the effects of time and temperature and therefore the results must be presented in a combined form. It is impossible to tell which of the two factors had the greater effect on the total sugar content, but it is suspected that the higher storage temperatures had the greatest effect. As support for this assumption, it is known that sugars undergo very few reactions

in watery media at approximately pH 4.0 and that the pH must be raised to neutrality or a slightly basic point in order for the cyclic hemiacetal structure of reducing sugars to convert to the acyclic carbonyl form which are then free to begin a number of decomposition reactions. However, with the application of heat and pH less than 4.0 a slow enolization of sugar molecules can occur which is followed by a rapid acid catalyzed dehydration to produce furfurals and browning pigments thus reducing the total sugar content (Hodge and Osman, 1976).

It was thought that the preparatory methods might have influenced the total sugar content of the samples but this could not be supported statistically. The probable reason for this is that after processing with the added sucrose there was a gradual diffusion of sugars back into the tissues. Since the sugar content in the outer media was many times greater than the sugar content of the tissues any differences caused by the preparatory methods would soon be disguised as stabilization occurred. Support for this supposition can be taken from the measurement of the total sugar content of one of the samples the day following processing. In this case a total sugar content of 12.4% was found in comparison to 14.9% in the same sample after 1.5 months in storage.

Reducing Sugar Analysis

The analyses of variance to show the influence of the factors on the reducing sugar content of the samples indicates that only three variables were related significantly with the reducing sugar content. These factors include storage time, storage temperature and the preparatory treatment (Tables 23, 24, 26).

The sucrose content of fresh apple tissue is always less than the reducing sugar levels, and fructose is found in greater quantities than glucose (Eheart and Mason, 1967). Upon the addition of sucrose to the apple slices, the total sugar content rises and the ratio of reducing to total sugars in the processed samples changes in a direction indicating an increase in non-reducing sugar levels. This trend, however, is reversed and the reducing sugar content gradually increases as a result of the hydrolysis of the non-reducing disaccharide sucrose. This hydrolysis reaction is known to be influenced by many factors such as the acidity of the media, the type of linkage between the monosaccharide units, the ring form of the sugar units, the extent of intermolecular hydrogen bonding and the presence of glycosyl hydrolases (Hodge and Osman, 1976).

In the analyses of variance used to determine the influence of storage time and temperature on the levels of reducing sugars in the samples, the effect of hydrolytic enzymes can be discounted because of the heat denaturation which occurs during processing. However, when considering the influence of

the preparatory methods on the reducing sugars (Table 26), one logical explanation which can be presented is based on the activity of these same hydrolytic enzymes which are denatured by the hot blanch method but continue to function in the vacuum infused and cold dipped samples in spite of the presence of SO_2. It is possible that the distribution of the SO_2 throughout the tissues is not uniform therefore allowing some hydrolysis to occur. It is also possible that SO_2 does not inhibit these enzymes as effectively as it does some of the others involved in browning reactions.

In order to assess the effects of the preparatory treatments it was necessary to use samples to which the SO_2 had been added by the three different methods. In order to prove that it was the difference in methods and not the difference in SO_2 levels which were influencing the reducing sugar levels, samples using different levels of SO_2 incorporated by the cold dip method were also compared (Table 25). From this it can be seen that the SO_2 level itself has no effect on the reducing sugar level and therefore the differences must result from differences in treatment.

Hodge and Osman (1976) also reported that the - D - fructo-furanosyl linkage in sucrose, which was the predominant disaccharide in this case, makes it labile even under mildly acidic conditions at low temperatures and at extremely low water contents. The increase in storage temperature would therefore serve to hydrolyze the different bonds (Fig. 4).

From this it would seem that the hydrolysis of sucrose into its component reducing sugars is accomplished easily under a wide range of conditions. It is known that reducing sugars are responsible for, or take part in, a great number of the reactions which are detrimental to the quality of food and therefore the hydrolysis of sucrose and the liberation of these sugars is a limiting factor in the life of a product.

Ascorbic Acid

Although apples contain some ascorbic acid, they are not considered to be an important source of vitamin C in man's diet. Their relatively low content, when compared to other fruits such as citrus, can vary with a number of factors including growing and storage conditions, maturity, variety and whether the skin is consumed as part of the apple. Canned apples contain even less vitamin C because heat processing, especially in the presence of oxygen, has been shown to bring about its decomposition (Tannenbaum, 1976). Fresh unpeeled apples can contain from 6.0 to 15.0 mg of ascorbic acid per 100 grams of apple tissue whereas prepared and heat processed apple products have only approximately 2.0 to 6.0 mg/100 g (Wiley and Thompson, 1960).

The purpose of the ascorbic acid analysis in this research was to determine if the less rigorous thermal treatment required to preserve products in flexible pouches could be beneficial in the preservation of ascorbic acid and thus

perhaps other nutrients.

There are a number of analytical procedures for detecting ascorbic acid but none is entirely satisfactory because of a lack of specificity and the presence of a large number of interfering substances in most food products (Tannenbaum, 1976). The procedure chosen for this research as described earlier was a method based on the oxidation - reduction properties of ascorbic acid alone and does not take into account the presence of dehydroascorbic acid which can also be present and may be converted to ascorbic acid. A number of oxidizing agents can be used in this method but the 2, 6 - dichlorophenolindophenol has been found to be the most successful although it too is subject to interference from a number of sources. Some products which have undergone extensive heat treatments and/or prolonged storage are subject to the build up of a number of substances collectively known as "reductones" which will interfere with an analysis for ascorbic acid (Assoc. of Vit. Chem., 1966).

The factors which were found by the analysis of variance to have an influence on the ascorbic acid content of the samples in this research were storage time, preparatory treatments, variety and the presence of added calcium. The storage temperature was anticipated to have an influence on the ascorbic acid content but could not be shown to have any significant effect.

According to the analysis of variance for the effects of storage time on the ascorbic acid content of the samples, there was an increase in vitamin C with increasing storage time (Table 28). This may have been an erroneous result caused by the build up of the reductone materials mentioned earlier. It also could have resulted from the reduction of dehydroascorbic acid to ascorbic acid although it must be assumed that the ascorbic acid was stable and that oxidation did not cause the conversion of ascorbic to dehydroascorbic.

It would appear that the vitamin C in these samples was stable because of the lack of influence by temperature; however, since vitamin C is noted for being sensitive to increases in temperature this seems unlikely. Possibly, the ascorbic acid decomposition was accompanied by a build up of reductones so that the two reactions were in balance and no difference in the ascorbic acid levels was detected by the analysis. If a greater number of samples from the 37°C storage had been tested at the 1.5 month storage time it is possible that a difference between samples from the two storage temperatures could have been found. From what information we have, however, it is impossible to accurately assess the effects of either storage time or temperature on the ascorbic acid content of the slices.

The effect of the preparatory treatments on the ascorbic acid content of the samples as determined by the analyses of variance turned out as expected (Table 27). Samples undergoing the hot blanch treatment were shown to have the lowest ascorbic acid content. It is interesting to note that although the ascorbic acid readings for the 5 month storage period were somewhat higher than the 1.5 month reading they were still very much lower than those 5 month readings for the vacuum infusion and cold dip methods. This suggests that the initial level of ascorbic acid at the time of processing may have had some effect on the level of "reductones" produced. The hot blanch samples were expected to have a lower ascorbic acid level because of the oxidation which would occur when vitamin C is heated in the presence of oxygen (Pollard and Timberlake, 1971).

It was also shown in two of the analyses that more ascorbic acid was found in samples which had undergone the cold dip treatment rather than the vacuum infusion treatment. This can also be explained in that ascorbic acid is soluble and some may have diffused from the tissue during evacuation of the infusion chamber. When the vacuum was broken, much of the ascorbic acid which was withdrawn from the tissues remained in the infusion media and was lost. The effect of calcium on the level of ascorbic acid in the tissues can also be related to the solubility of vitamin C in water. Table 29

indicates that the presence of added calcium ions in the samples helped to maintain the levels of ascorbic acid. Other analyses comparing the effects of different levels of added calcium indicated that there was no significant difference ($P > 0.05$) in retained ascorbic acid levels. Therefore, it would seem that the presence of calcium ions and not their level influenced the stability of the vitamin C. It is thought that this influence may have been related to the maintenance of the cell wall structures which led to better retention of the liquid fraction of the tissues and consequently the dissolved ascorbic acid. Samples which had no added calcium had very poor texture measurements and their appearance was similar to that of applesauce. This would lead to a greater loss of liquid and soluble solids from the tissues.

The variety of apple used for processing was also shown to influence the level of ascorbic acid as determined by the analysis (Table 30). Processed Newtown Pippin samples were shown to have higher levels of ascorbic acid than processed Winesaps. This result was directly related to the quantity of ascorbic acid present in the original peeled fresh tissues. Analyses of the peeled fresh tissues of Newtown Pippin and Winesap apples carried out earlier had indicated that ascorbic acid levels of 7.84 and 3.13 mg/100 g respectively were present.

The results of the ascorbic acid analysis indicate that the hot blanching of apple slices under normal atmospheric conditions is definitely detrimental to the vitamin C level while the other methods had a relatively small effect on it. By observing the ascorbic acid levels of one sample tested immediately after processing and then again at 1.5 months (Table 45) it can be seen that approximately 25% of the level found in peeled apples was lost during the process after which the rate of ascorbic acid decomposition was reduced.

Adams and Blundstone (1971) have indicated that the retention of vitamin C in acid products with low oxygen partial pressures and an absence of copper ions is quite high. If some oxygen is retained in the product, greater protection is given to the ascorbate in plain tinplate containers as opposed to lacquered and glass containers because tin ions are more susceptible to oxidation at low pH than are ascorbate ions. Their feeling was that more vitamins are lost from canned fruit products because of their solubility. Vitamin C is highly soluble and consequently is lost from the tissues along with the moisture if the syrup from these products is discarded.

In this research, the ascorbic acid analysis was only carried out on drained samples, thus it is likely that a large portion of the 25% reduction in ascorbate content was contained in the syrup. This would indicate that heat processing at low oxygen partial pressures is not as detrimental

to the ascorbate content of acid products, such as apple slices, as is the peeling operation and the anaerobic degradation that occurs regardless of other conditions. Processing using the flexible retort pouch may therefore have little if any additional advantage over conventional containers for the retention of vitamin C in processed apple slices.

pH Changes

Changes in the pH of the apple slices were found to be influenced by a number of factors. Storage time and temperature were shown to reduce the acidity of the products (Tables 31 and 32). This can be explained by the many chemical reactions such as the destruction of ascorbic acid that occur during storage. Increased storage temperatures supply the energy to initiate and carry out these reactions at a faster rate and therefore influence the pH.

The addition of bisulfite, calcium ions and pyrophosphate ions to the samples all served to decrease the pH with increasing levels of preservatives (Tables 33, 34, and 35). These decreases were small in the case of calcium ions but were all highly significant.

The samples packed with carbon dioxide were also found to have a lower pH than comparable samples packed with nitrogen (Table 37). This results from the high solubility of carbon dioxide which produces carbonic acid with water, thus slightly lowering the pH.

The variety of apple used for processing was also found to influence the pH (Table 36). Processed Newtown Pippins had lower pH readings than processed Winesaps. This came as no surprise as fresh samples of the Newtown Pippins and Winesap varieties were found to have pH readings of 3.40 and 3.52 respectively. This aspect of apple physiology is again related to several factors such as growing and storage conditions, maturity and variety.

SENSORY ANALYSIS

The results of the taste panel scoring indicate that the important factors influencing the acceptance of the samples were the time and temperature of storage and the level of calcium ions incorporated into the tissues. It was found that as the storage time and temperatures were increased, the acceptance of the samples decreased (Table 38 and 39). Calcium levels are presumed to be linked with texture since the samples with the highest scores were samples with higher calcium levels and consequently better texture readings.

There was, however, some confusion among the panelists as to what constituted a desirable apple slice. For instance, most panelists preferred the firmer slices but some actually preferred the softer samples which they compared to apple sauce. There was also diversity in the colour preferences among the panelists. Some objected to the yellowness of the slices and

stated they preferred white. Others made no mention of yellowness but criticized the non-uniformity of colour when white slices were present.

Perhaps the most confusing results were obtained from the flavour scores. Several panelists were able to detect an SO_2 taste especially at the 1.5 month testing period. Also, some panelists complained of the blandness or lack of apple flavour in the vacuum infused samples. Generally, however, the flavour scores for a single sample had such wide diversity that little can be derived from them. It was noted that on the whole, the Newtown Pippin samples received more favourable comments than the Winesap samples although no significant differences were detected between the sensory scores for the varieties by analysis of variance.

In the overall acceptance category as in the texture category, the Duncan's Multiple Range test divided the samples into two groups according to the panelists scores. In both cases, the sample which had no added calcium made up the group having the lowest scores while the remaining samples were included in the group receiving the highest scores. This indicates that texture had the greatest influence in determining the overall acceptance of the samples although from panelists comments it was felt that flavour was also a major factor. It was also interesting to note that in the flavour and appeal categories, the sample with no added calcium was always included in the group receiving the lowest scores for sensory evaluation.

The cold dipped sample was shown by the Duncan's Multiple Range test to be the only sample which was consistently included in the groups receiving the highest scores in all four categories and was never "shared" with groupings receiving lower scores as were the other samples. This sample was thought to be the optimum when first processed and was proven to be the best all round sample during the testing.

The remaining variables such as backflush gas, variety, bisulfite level or the inclusion of pyrophosphate could not be shown by statistical analysis to have any significant influence ($P > 0.05$) on the scoring of the panelists.

The overall acceptability category is considered to be an indication of whether a product would be accepted or rejected by a prospective consumer. Observation of the mean acceptance values for all samples presented at the 5 month testing, showed that the cold dipped sample had the highest score of 69%, which is an indication that the sample could be acceptable. Before any definite judgements could be made, however, more extensive consumer acceptance tests would have to be employed.

It was also found that the method of storage for the samples is critical to their quality. For this research we had no rigid paperboard containers to protect each individual pouch from mechanical damage. As a result, in spite of the fact that the samples were carefully stacked in large corrugated paperboard boxes, there was some damage due to the weight of

the stack. Perhaps if a more suitable method of storage had been employed, some of the texture scores would have been improved. This information should be taken into consideration in future projects involving flexible pouches.

CONCLUSIONS

Due to the discrepancy between the results of the thermal diffusivity and heat penetration methods for determination of a process time for apple slices in flexible retort pouches, there arises a question pertaining to the reliability of at least one of the methods. Since the heat penetration study is a measurement of the conditions within the specific product under actual retorting procedures, and since the measurements were derived from a number of "retort runs", there is a tendency to be more confident in those results. It was also found that the heat penetration study was less time consuming and the return of data was greater. For these reasons, it could be considered the more preferable method of deriving a process time. It must be conceded, however, that this method requires the use of data acquisition and computing facilities which may not always be available and therefore, may not be applicable to all situations.

It was found that apples taken from long term controlled atmosphere storage are not as good for processing as those taken from storage shortly after harvest in spite of the fact that a much shorter heat process is required for stabilization in retort pouches. Texture seems to suffer the greatest decline in these apples but it was shown that calcium ions can be added to improve the firmness. Samples without added calcium had very poor texture ratings and by

the end of the 5 month storage period under elevated temperature they were reduced to a sauce-like consistency. Contrary to a previous report, (Archer, 1962) sufficient calcium was added to this product in the form of calcium chloride in quantities low enough to have no noticeable effect on flavour.

The lightness of the apple slices was also found to be maintained by the addition of low levels of sulfur dioxide in the form of sodium bisulfite. It was noted that even at the low levels added in this research, it was still detected by some of the panelists. It is not known if the levels of SO_2 incorporated in the samples was sufficient to maintain lightness for an extended shelf life at room temperature but there were definite indications of darkening after 5 months storage at elevated temperatures.

The addition of pyrophosphate ions in the form of sodium acid pyrophosphate was also shown to have a significant influence in maintaining lightness in the samples although it did not seem to retard the onset of darkening with increased storage time.

Both varieties of apples chosen for this research were good processors and both withstood the prolonged storage quite well. The Newtown Pippins in their fresh state seemed to surpass the Winesaps in most of the measured quality parameters and this was maintained after processing and throughout the storage period. The biggest problem in the use of Newtown

Pippins for processing in the British Columbia area at the present time is their popularity as a fresh eating apple and their relatively short supply to the processing market. Winesaps are a familiar processing apple which were only slightly less desirable in this process and provide a very good product as was shown by this research.

Nitrogen was shown to be a highly effective backflush gas for maintaining a stable atmosphere in the pouch. Carbon dioxide which was also tested was shown to have been soluble in the liquid media. This reduced its effectiveness as a cushion against mechanical damage and tied up calcium ions in the form of calcium carbonate, both of which had an adverse effect on the texture of the slices. It could not be shown by this research that nitrogen had any positive effects on the slices outside of providing an inert atmosphere and a reduction of the oxygen partial pressure within the pouch.

Hot blanching of the apple slices is not a desirable preparatory method as it was shown to have detrimental effects on the texture, colour and ascorbic acid levels of the samples. Vacuum infusion of apple slices provides good texture but was shown to have serious effects on colour and flavour. Samples treated with this method had a translucent appearance and bland flavour due to the loss of flavour volatiles during the evacuation and the infusion of water with breaking of the vacuum. The cold dip method, although allowing the retention of greater oxygen levels within the pouch, provided the best product.

Viscosity measurements of macerated tissue supply some insight into the possible chemical behaviour of the samples; however, this is not a good method of determining the influence of calcium on texture as is shown by the analyses of the different parameters of viscometric behaviour. By far the most accurate method of texture evaluation of apple slices in relation to sensory analysis is the measurement of the forces required to shear the slices.

It is also evident that great care must be taken when using pouches, to avoid the use of pinholed containers. Care should be taken in heat sealing to insure safety and the stored supplies should be provided with some form of protection to prevent mechanical damage to both the pouch and its contents.

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