MATHEMATICAL ANALYSIS
OF
PEELING OF CARROTS

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

MATHEMATICAL ANALYSIS
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In this study, carrots of Beypazarı variety, cultivated during 2004 season were chemically and steam peeled. Effects of temperature, concentration of NaOH solutions and immersion time on lye peeling of carrots were studied; optimum time-temperature-concentration relations were analyzed mathematically. Then suitable combinations of concentration, temperature and time were determined just by considering degree of peeling. Increases in both temperature and concentration of lye solution led to a decrease in peeling time. However it was observed that the temperature of the lye solution was the main effect on the quality of carrots. Treatment with 0.75 % NaOH at 77°C for 10.5 minutes was found to be optimum to peel the carrots, mathematically. In steam peeling, the peeled surface area-time relations were analyzed mathematically. Complete peeling was achieved at 8.5 minutes. Under complete peeling conditions, the effect of chemical and steam peeling on quality of carrots were determined. Then the mathematical optimum value for chemical peeling was evaluated for quality parameters. The optimum chemical

peeling value was fitted to the peeling yield-pectin relations. The peeling yield of steam peeled carrot was higher than the chemically peeled carrot. The color of the chemically peeled carrot had the highest consumer acceptance compared to conventional peeling. Finally, the two conditions were suitable for considering the need of the plant design.

Keywords: carrot, chemical peeling, mathematical analysis, pectin, steam peeling,

ÖZ

HAVUÇLARIN SOYULMASININ
MATEMATİKSEL ANALİZİ

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Bu çalışmada Beypazarı havuçları kimyasal ve buhar yöntemleriyle soyulmuştur. Havuçların kimyasal yöntemle soyulmasında sıcaklık, NaOH çözeltileri konsantrasyonu ile daldırma sürelerinin etkileri çalışılmış ve optimum zaman-sıcaklık-konsantrasyon ilgileri matematiksel olarak analiz edilmiştir. Uygun konsantrasyon-sıcaklık-zaman bileşimi sadece soyulma derecesi göz önünde bulundurularak seçilmiştir.Sıcaklık ve çözelti konsantrasyonun artışı soyulma süresinin kısalmasını sağlar. Fakat, çözelti sıcaklığının havuç kalitesi için daha önemli bir faktör olduğu anlaşılmıştır. Matematiksek olarak, %0,75 NaOH çözeltisi , 77°C'de 10,5 dakika uygulanmasının optimum olduğu belirlenmiştir. Buharla soymada soyulmuş alan-zaman ilgileri matematiksel olarak analiz edilmiştir. Tam soyulmaya 8,5 dakikada ulaşılmıştır. Tam soyulma koşullarında kimyasal ve buharla kabuk soyma yöntemlerinin havuçların kalitesine olan etkileri araştırılmıştır. Daha sonra, kimyasal soyulmadaki matematiksel optimum değer kalite parametreleri için değerlendirilmiştir. Kimyasal soyulma optimum değeri sadece soyulma verimi-pektin ilgisine denk düşmektedir. Buharla kabuk soymada soyulma verimi kimyasal

yöntemle soymadakinden yüksektir. Geleneksel yöntemle soyulmayla kıyaslayınca kimyasal yöntemdeki renk değeri tüketici beğenisine daha uygundur. Sonuç olarak, gelecek prosesin ihtiyacına göre iki yöntem de uygundur.

Anahtar sözcükler: buharla soyma, havuç, kimyasal soyma,matematiksel analiz, pektin

To My Parents

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NOMENCLATURE

a* : Hunter a* value

b* : Hunter b* value

L* : Hunter L* value (Lightness)

C : Concentration of caustic solution (%, w/v))

T : Temperature of caustic solution (°C)

t : Peeling time (min)

ΔE : Color

P : Peeled surface area

PE : Pectin

PY : Peeling yield

TSS : Total soluble solids

γ : Constant

σ : Constant

λ : Constant

β : Constant

a : Constant

b : Constant

r^2 :Correlation coefficient

C1 : Control carrot 1(raw)

C2 : Control carrot 2(mechanically peeled)

CHAPTER 1

INTRODUCTION

1.1. Carrot (*Daucus carota*)

Health professionals have consistently advocated the daily consumption of five portions of fruit and vegetables as a means of protecting against the pathogenesis of degenerative diseases including coronary heart disease, cancers and other free radical-mediated conditions. Fruit and vegetables contain a wide range of compounds including antioxidant vitamins C and E, minerals, phenolics and carotenoids.

Carotenoids possess a range of important and well-documented biological activities. They are potent antioxidants and free radical scavengers and can modulate the pathogenesis of cancers and coronary heart disease. A number of carotenoids including β-carotene and α-carotene have pro-vitamin A activity, since they are converted to retinol by mammals. Dietary deficiency of vitamin A can lead to blindness and premature childhood mortality (Surles et al., 2004; Burns et al., 2003).

There is no officially recommended dietary intake for carotenoids. The recommended dietary intake for vitamin A is about 1mg/d retinol equivalent for the German speaking countries (Anonymous, 2000) and the dietary reference intake for vitamin A in North America is up to 3mg/d (Food and Nutrition Board, 2001). It is generally considered that processing of vegetables improves the bioavailability of carotenoids because it breaks down the cellulose structure of the plant cell (Murkovic et al., 2002). Analysis of cooked vegetables has problems somewhat different from those of raw samples. Cooking softens the cell walls and makes the extraction of carotenoids easier (C.deSá and Rodriguez-Amaya, 2004). Cooked vegetables would have variations in their carotenoid composition brought about by varying cooking conditions (e.g. time and temperature), but also by compositional differences of the raw material, due to such factors as stage of maturity, cultivar, part of the plant utilized, climatic or seasonal effects, agricultural and post-harvest handling (C.deSá and Rodriguez-Amaya, 2003).

The carrot belongs to the family Apiaceae (Umbelliferae) which is a member of the parsley family. It includes about 2,500 species such as dill, caraway, cumin, chervil, coriander, fennel, anise, parsley, parsnip, and celery. It also includes poisonous species such a poison hemlock, water hemlock and fools parsley. The cultivated carrot belongs to the genus Daucus L. which contains many wild forms. The cultivated carrot hybridized from the wild carrot can be either an annual (mainly in tropical areas) or a biennial (mainly in temperate areas). There are two main types of cultivated carrots: 1. Eastern/Asiatic carrots - These are often called anthocyanin carrots because of their purple roots, although some have yellow roots. 2. Western or Carotene Carrots - These have orange, red or white roots. These carrots may have originated in Turkey. In Turkey, Beypazarı variety is the most popular. Beypazarı provides 60 % of carrot production of Turkey (www.carrotmuseum.com).

Table 1.1.The main analysis of key ingredients for an average carrot. For the full USDA nutritional analysis see Appendix A1.

Edible part	95%	**Sodium**	95mg
Water	91.6g	**Potassium**	220mg
Proteins	1.1g	**Iron**	0.7mg
Lipids	0g	**Calcium**	44mg
Glucides	7.6g	**Phosphorus**	37mg
Carbohydrates	10	**Niacin**	0.7mg
Fibre	3.1g	**Vitamin C**	4mg
Energy	33kcal	**Vitamin E**	(mg) 0.5
Vitamin A	(mcg) 2813	**Zinc**	(mg) 0.2

Carrots are popular in variety of foods because of their pleasant flavor. The increase in carrot consumption rates may be due to the introduction of prepackaged and precut carrots, as well as the nutritional benefits that carrots provide. Recently

consumers have become interested in purchasing fruits and vegetables in edible form. For carrots there is a minimum processing procedure which are peeling, rinsing and sometimes cutting into sticks. The mature storage organ of carrot consists mainly of vascular tissue with an outer epidermal skin for protection. Peeling is the most important step in processing of carrots. Removing this skin increases respiration and initiates production of a new protective layer. This is especially seen in abrasion (mechanical) peeled carrots. These carrots quickly lose their bright orange color from development of a white material on the surface. That limits consumer acceptability of the product (Bolin and Huxsoll, 1991).

1.2.Peeling of Fruits and Vegetables

Peeling is one of the major operations in the processing of most fruits and vegetables, meant for canning, freezing and dehydration. It is also a high-cost operation in terms of labor, and when coupled with coring, it accounts for approximately 60% of the total labor in processing (Gould, 1983). The selection of the proper peeling method is of importance, as the quality of the finished product depends, to a large extent, upon the method used. The amount of peel removed is important to the processor not only because it is a total loss and reduces product quantity, but also for the cost-intensive nature of peel disposal which, otherwise, causes environmental pollution. Reduction in peel weight also leads to increased product recovery and higher profits. The fruit and vegetable processing up to peeling stage also involves considerable operating cost as the raw material along with the peel gets cleaned, washed and processed for peeling. Hence a need exists for judicious selection of the peeling method (Setty et. al., 1993).

In the beginning of the fruit processing industry, only hand peeling was practised. Several methods, machinery and equipments have been developed, since then. Effects of these methods on the raw material, in addition to peel removal, have also been studied to some extent. It is worth mentioning that the peeling requirements for different products vary. Hence, goals of good peeling operation are; minimizing product losses, peeling to the extent dictated by the products (e.g. potato products), minimizing heat ring formation (e.g. apple, potato), minimizing energy and chemical usage and minimizing the pollution load (Setty et. al., 1993).

In food processing, there are several peeling methods used for different fruits and vegetables. These methods are:

1. Chemical peeling (mostly lye peeling)
2. Steam peeling
3. Mechanical peeling(mainly abrasion peeling)
4. Freeze peeling(cryogenic peeling)
5. Enzymatic peeling
6. Other peeling methods(flame, vacuum, acid peeling, etc.)

Chemical peeling and steam peeling are more widespread methods than others.

1.2.1. Chemical Peeling

It is, by far, the method of choice for removing peel of many fruits and vegetables because of the ease of mechanization; continuous operation; and uniformity, quality as well as high yield of the product. Among the different methods applied by the processing industry, chemical peeling using NaOH (widely known as lye peeling) is one of the most common and the oldest methods. The first commercial use of lye for peeling was in the production of hominy, followed by that of peaches (Cruess, 1958). The rubber disc peeler was used successfully to peel tomatoes in 1973 (Hart et al., 1974), producing peelings with a solids content similar to that of the original tomato. Tomato pulp with acceptable flavor, color, and minimal defects was recovered from caustic peelings of a commercial operation in 1974. Powers et al (1977) reported that hand labor and peeling losses could be reduced by use of warm caustic followed by steaming and washing. Today the use of lye for peeling fruits and vegetables is widespread due to its economy, simplicity and labor-saving advantages, but it continues to face many problems due to processing loss of edible part.

In practice, chemical peeling of fruits and vegetables is a simple process. A simple method of lye peeling is to dip the fruits into heated lye for a definite period

followed by through water washing of peeled fruit. Lye (sodium hydroxide solution) dissolves the fruit and vegetable peels and the rate of dissolution depends on lye concentration, temperature and period of immersion. The surface tissues of most fruits consist of three layers, namely, epidermis, middle lamella and parenchyma. The middle lamella is composed of pectinous substances that are highly soluble in the lye. The parenchyma cells are large and more resistant to the lye. Hence, epidermis layer is removed along with the middle lamella without affecting the parenchyma cells in the normal lye peeling process (Setty et al., 1993).

Theoretically, however, it is a complex process involving diffusion and chemical reactions. Once the caustic solution of NaOH comes in contact with the surface of the fruit, it dissolves the epicuticular waxes, penetrates the epidermis, and diffuses through the skin into the fruit (Floros et al., 1987). Inside the fruit, the NaOH reacts with macromolecules and organic acids in the cytoplasm, middle lamella and cell wall, and as a result, separation of skin takes place.

In chemical peeling, inside the tomato skin, as mentioned before, the NaOH reacts with a variety of substances and macromolecules (polygalacturonic acid, other organic acids, hemicellulosic polysaccharides, proteins, etc.). These reactions slowed down the inward diffusion of NaOH and therefore at low NaOH concentration (1 M NaOH), lower diffusivity values were observed. When the NaOH concentration was sufficiently higher than a baseline needed for chemical reactions, however (2, 3 and 5M NaOH), a fast reaction rate was achieved. This is an instantaneous reaction and the diffusivity is independent of concentration. For temperature dependence studies of diffusivity (2M NaOH was used), diffusion of NaOH didn't occur at 30°C. This can be explained by the presence of epicuticular waxes on the surface of fruits and vegetables, which have a phase transition temperature higher than 45°C. As long as the waxes are in the solid state, they do not allow NaOH enter the fruit. At higher temperatures (>50°C), the wax liquefies and NaOH readily diffuses inside the tissue (Floros et al, 1987 and Floros and Chinnan, 1990).

The cell wall is primarily responsible for the structure, rigidity and the texture of the plant tissue. Cell walls are composed of polysaccharides (primarily cellulose and hemicelluloses) and glycoproteins. The substance which functions as a glue to hold the cells together, the middle lamella, is located between cell walls and it consists of pectic substances mainly polygalacturonic acid. A correlation between

pectic composition in cell walls and softening of cooked vegetables has been reported. Vegetables easily softened by thermal maceration contained high methoxyl pectin than low methoxyl pectin (Fuchigami et al., 1995 (a), (b)). Another structural component of plants, the 'cuticle', which exists as a thin continuous extracellular membrane, has a fundamental protective role as a barrier between the plant and its environment. To simplify, epicuticular wax makes up the exterior part of the cuticle and is composed of soluble waxes deposited on the surface. The cuticle proper lies beneath the epicuticular wax, and is a region formed of cutin and cuticular waxes. Below, the cuticle proper is the cuticular layer(s) which is(are) composed of cutins, cuticular wax and incrustations of cellulosic wall material (Floros et al., 1987).

During processing, the action of lye probably involves dissolution of the epicuticular and cuticular waxes leaving most of the cutin matrix and the cellulose network unaltered. Cutins, which form the main structural component of plant cuticles, are high molecular weight polyesters readily depolimerized by common reagents used to cleave ester bonds. Epicuticular waxes and portions of the cuticle proper (composed of cutin and waxes) may likely have been dissolved by the alkali treatment (Floros et al., 1987)

As the lye penetrated the cuticle and moved further into the interior of the fruit, disruption of epidermal and hypodermal cells took place. The penetration effect of lye was uniform and a distinct boundary of disrupted cells was observed. The boundary of disrupted cells moved deeper as the severity of lye treatment increased. Movement of lye was due to diffusion. Other chemicals and ions have also transferred from surface to the interior of the fruit via diffusion (Floros et al., 1987).

The degree of degradation and the loss of integrity of cell walls are proportional to the severity of the applied lye treatment. Floros et al (1987) studied that when fruits were treated with 1% lye for 1 min, the cell walls of the epidermal and hypodermal cells of the exocarp were partly disrupted but their structure, shape and overall appearance weren't greatly affected. If time was 2 min, a total disruption of cell walls observed. Application of higher concentrations of lye resulted in loss of integrity of cell walls. The basic lye solution solubilizes the pectic and hemicellulosic polysaccharides leaving the cellulose microfibrils with weak structure which in turn results in cell collapsing. Finally, the weakening and dissolution of cell wall

constituents, as well as the solubilization of the middle lamella, eventually caused the separation of the exocarp (skin) from the mesocarp (Floros et al., 1987)

Floros et al (1987) first suggested that NaOH penetrated the skin and moved further into the fruit via diffusion. Based on this assumption, a double-stage peeling process which reduced peeling losses and improved the overall efficiency of the peeling operation was developed and optimized for pimiento peppers. Floros et al (1988 (a)) were indicated that for pimiento peppers high processing temperature of 100°C caused pigment extraction during the peeling operation and resulted in color loss and lower quality final product. It was possible to use low temperatures of about 80°C during processing. Such an application would probably improve the quality of the final product in terms of color. The most widely used method of peeling pimientos involves dipping the peppers into near boiling aqueous solution of NaOH (lye) for a certain period of time and then washing away the loosened skin by pressurized spray water. This 'single-stage' lye-peeling process was studied by Floros and Chinnan (1987), who suggested that three factors (processing time, lye concentration, and temperature) mainly affect the process. Time was found to be by far the most important factor followed by lye concentration.

Application of severe treatments or processing of damaged peppers results in major loss of edible tissue due to action of lye deep inside the flesh and dissolution of several mesocarp cell layers. For an effective peeling, therefore, diffusion and action of lye should be controlled and restricted to epidermal and hypodermal regions of the skin. As a result, a 'double-stage' lye peeling process was conceptualized, in an effort to minimize the effect of lye on the mesocarp cells by employing milder treatments (Floros and Chinnan, 1988(a)).

Reeve (1976) discussed some changes in the structure of fruits and vegetables as affected by lye peeling, Walter and Schadel (1982) considered changes caused in sweet potato tissue due to heat mediation during lye peeling. Lye peeling at elevated temperatures is widely used as a means of skin removal prior to canning of sweet potatoes. This pre-canning treatment can cause discoloration. This discoloration occurs when heat penetrates into the tissue causing a temperature increase sufficient to inactivate the respiratory system but insufficient for the inactivation of polyphenoloxidase (PPO). The PPO then reacts with o-dihydroxyphenols (DP) to cause the discoloration. Discoloration can be prevented by presoaking the roots in a

75-80°C water bath immediately prior to lye peeling. This procedure raised the internal temperature sufficiently high to inactivate the PPO, thus preventing the PPO-DP reaction (Walter and Giesbrecht, 1982).

Major advantages of lye peeling include lower cost, rapid handling, reduced loss of fruit as compared to hand peeling, amenability to large scale operation, and suitability to all shapes, sizes and varieties (Cruess, 1958). Consequently, guava, peaches, pears, apricot, orange segment, nuts, potatoes, sweet potatoes, apples, bets, mandarins, tomatoes, papayas, yams, pimiento peppers, citrons are generally lye peeled. After the lye treatment, the material requires thorough water wash to remove not only the lye disintegrated peel, but also the residual lye on the surface of the peeled material. This step forms a critical part of the lye peeling process. In some cases, peeled and washed material is dipped in or sprayed with dilute citric acid solution to ensure the neutralization of residual alkali.

Main advantage is the requirement of smaller floor space. On the contrary, the main disadvantage is the pollution of large volumes of water (2600 gal/ton fruit peeled). The other disadvantages are high peeling losses and loss of damaged fruits (Woodroof and Luh, 1975).

Peeling is an important operation in the freezing or canning of white asparagus. Garrote et al (1994) determined the process conditions for chemical peeling of asparagus using Response Surface Methodology. The predicted models developed for product yield and peeling quality were used for examination of the system behavior and localization of the optimum conditions.

Economic and efficient peeling is very important in commercial processing of fruit and vegetable products (Reeve, 1976). The selected method depends upon the type and variety of products to be processed and the capacity of the industrial plant. Potatoes are commercially peeled by abrasion, high pressure steam, conventional caustic and dry caustic (Huxsoll et al., 1981). In food processing, potatoes are not well adapted to mechanical peeling because of their irregular shapes and cavities. In lye peeling, the peel is loosened because of starch gelatinization with the depth of the loosened peel found out by the residence time of the potatoes within the NaOH solution. The main problem of lye peeling potatoes is darkening after processing. When lye peeling conditions were selected to maximize heat penetration in the cambial area, no darkening was observed (Bayındırlı et al., 1997). The chemical

peeling of potatoes is a compromise between yield, peeling quality, NaOH consumption and the 'heat ring' formed, with processing conditions empirically adjusted according to specific requirements (Garrote et al., 1993). Processors generally maintain the lye bath temperature as high as practicable while varying the immersion time and lye concentration to obtain desired peeling effects. While large processors use a high temperature lye process, the low temperature process has been used to some extent in the pre-peeled potato industry where the presence of a 'heat-ring' may be particularly objectionable (Huxsoll and Smith, 1975).

In apple processing, peeling is an essential step. Various techniques are used for this purpose, such as mechanical, lye, high pressure steam and dry peeling (Setty et al., 1993). Apples are not well adapted to mechanical peeling, due to their irregular shape and cavities. Therefore, either lye peeling or steam peeling procedures is applied. Success of peeling depends on the rapid transfer of heat to the tissues to be peeled for a minimum duration, followed by cessation of heating and rapid cooling (Bayındırlı et al., 1996(a)). A major problem in the peeling of apples by chemical methods is the penetration of cutins (natural waxes) and the waxes which are commonly added post-harvest to increase in gloss and improve appearance. These waxes have an adverse effect on lye peeling. Surface active agents such as ethyl and isopropyl alcohol and sodium alkyl sulfanate were used to remove the waxes and enable faster penetration of lye. Bayındırlı et al. (1996(b)) conducted to determine a relation between isopropyl alcohol temperature and peeling time. The effects of alcohol dipping time on peeling time were determined. Moreover, the requirement for dewaxing operation was investigated. Apples were pretreated with isopropyl alcohol at different temperatures and dipping times before they were dipped in lye solutions. As the time of dipping apples in isopropyl alcohol increased, peeling time decreased. Also, Bayındırlı (1994) reported the time-temperature-concentration relations and the effect of pretreatment with 1% (w/w) sorbic acid for lye peeling of tomatoes.

Like fruits and vegetables, chemical peeling was tested at peanuts, walnuts and hazelnuts. Peanuts are probably the most important oil bearing seed in the world and are rapidly becoming a valuable source of plant protein (Cruess, 1958). Peanut of Antep variety were peeled at four different temperatures and for each temperature four different NaOH concentrations were selected and then minimum required times

for complete peeling was obtained. However, the physical properties were important for the result. Color is the most significant physical property as the temperature of the lye solution increases. The color darkens as the temperature increases and even it gets a brownish color as the temperature reaches to 80-90°C. Also penetration depth is important. As the concentration of the solution gets higher, there occurs more and more small cavities on the peanuts and the surface of the peanut gets rougher.This method results in decrease of some quality parameters color, odor and appearance of the products that will be consumed as a whole (Bayındırlı et al, 2001). The kernels of walnuts (belonging to *Juglans regia* Linn.) were peeled by using NaOH solutions. The walnut includes 65-70% oil and 15-18% nitrogenous substances which makes it quite important also from the nutritive standpoint. According to the observations on the application of the walnuts during the experiment and after the peeling, discoloration on the surface was seen. The color of walnut turned to be brown. The odor was also subject to change, since the concentrations for complete peeling was too high. Consequently, although the estimated mathematical model represented the case well, it is not applicable in the present form due to discolorization and disodorization of the walnuts at serious levels (Bayındırlı et al, 2002). Hazelnuts are used as an ingredient in the production of snacks, chocolate, ice cream, confectionery, cakes and biscuits. More than 50% of total production in Turkey is of the 'Tombul' cultivar. Kaleoğlu et al (2004) peeled the 'Tombul' hazelnuts and investigated the effects of NaOH solution, temperature and time on peeling and quality. The quality parameters of peeled hazelnuts such as protein, oil, free fatty acid, ash, peroxide number and L values showed no significant change if compared with untreated control samples. However, moisture content of the lye peeled hazelnut samples were altered significantly after the peeling process due to the absorption of water. Exposure time of the samples played an important role in the quality change of hazelnuts due to lye penetration. Beta-carotene and other carotenoid pigments are present in high concentrations just beneath the skin and it is likely some were easily removed during the peeling process. Thus loss of mesocarp and exposure of vascular tissue might have resulted in a difference between redness of untreated hazelnuts and peeled hazelnuts. When the samples were dipped in a 3% citric acid solution for 1 min after peeling the residual lye was completely neutralized and the neutralization resulted in a desired color recovery. Although lye peeling of walnuts and peanuts

weren't suitable, lye peeling can be an alternative for pellicle removal of hazelnuts.

1.2.2. Steam Peeling

Among the modern methods of peeling, the most popular is probably that of steam peeling. Steam peeling has been used in Europe to peel tomatoes for several years. Also in the United States various pressurized steam peeling machines are available for peeling fruits and vegetables (Schlimme et al., 1984). Steam peeling is widespread due to its high automation, precise control of temperature, pressure and time by electronically to decrease peeling loss and environmental pollution as compared to chemical peeling (Floros et al., 1988(b)). In a steam peeler, the fruits are placed on a moving belt, one layer deep, and passed through a steam box equipped with a series of spray heads, from which the steam is sprayed directly on the material. Treatment period depends on the nature of the material. Loosened peel is removed by soft brushes after cooling in cold water (Setty et al., 1993). Steam peeling involves exposure of the fruit to high temperature-high pressure steam for a certain period of time and then washing away the loosened skin by pressurized spray water (Floros et al., 1988(b)).

Steam peeling may be explained by two phenomena. First, the building up of internal pressure because of high temperature which causes mechanical failure of the cell. Second, the effect of heat on the tissue which results in loss of rigidity and reduces turgor pressure due to biochemical changes, melting and breakdown of substances and general disturbance and disorganization of the structure of the cell. As a result, several cell layers between exocarp and mesocarp will collapse, the skin will become loosened, and it will be removed by the pressurized spray water action which follows the steam process (Floros et al., 1988(b); Kertesz, 1951).

In high pressure steam peelers, the liquid beneath the skin gets vaporized, when a vegetable is exposed to high pressure steam. No reaction takes place as long as the surrounding pressure is same as the internal pressure. As soon as the chamber pressure is released, the surrounding pressure becomes lower than the internal pressure. The pressure differential causes forcing away the skin from the flesh (Setty et al., 1993).

Depending upon the peeling method used and the nature of the fruit or vegetable peeled, the material may undergo some changes in their color, appearance and constituents. Major problem in steam peeling is the formation of brown ring (heat ring) below the surface of the fruit due to the tissue damage and polyphenol enzyme activity like hot lye-peeling (Setty et al., 1993). Smith et al (1981) found that the width of heat ring was min (0.1 mm or less) in steam peeled apples as compared to 1.4 and 2.3 mm for lye peeled and abrasive pre-wash peeled apples, respectively, thereby indicating minimum damage to the tissues in steam peeled apples.

Color and appearance of steam peeled apples were rated excellent, as against less brilliant, but still highly acceptable lye peeled products. Water uptake, which resulted in lowering the total solids, was more in lye peeled apples than that in steam peeled product (Setty et al., 1993).

During steam peeling of potatoes, the tissue layers proximate to the surface are subjected to high temperatures for short times; as a consequence a more or less intense cooking of the tissue results accordingly to the thermal heating front advance. Breakdown during heating is usually due to cell separation and not to cell rupture. The cell wall and the middle lamella constituents are important for both cell separation and cell wall rupture. When potato tissue is heated in water, the pectin in the middle lamella is altered at 60±10°C; pectin in the primary and secondary walls change, causing the separation of the compact lamella into microfibrils. Also the amount of pectin has a local decrease. Finally, cell walls become easily fractured. Precooking of potato tissue at 65-80°C for 10-20 min causes partial cell separation due to the partial hydrolysis of the constituents of the middle lamella. However, cell rupture doesn't take place (Garrote et al., 2000).

For several potato sizes, and different peeling times, experimental penetrations of peeling front and the final potato radial coordinate after steam peeling, as well as the theoretical temperature predicted and cooking value estimated for that position. When peeling time increases, penetration of peeling front also increases. If the peeling time is short, then minimum temperature for peeling to take place is higher. During steam peeling due to the thermal treatment and pressure effect in decompression, integrity of the potato tissue structure is sufficiently weaken and peeling takes place (Garrote et al., 2000).

The cooking value which will thermally weaken the cellular structure and the temperature which will let that the internal vapor pressure developed during the peeling process be sufficient in the decompression stage to produce the mechanical failure of the thermally weaken cells, then the skin and part of the potato pulp up to where the peeling front advanced will be easily pulled off by the pressurized water applied after peeling (Garrote et al., 2000).

Garrote et al (1997) suggested that multi-stage steam peeling may improve efficiency and reduce peeling loss. During a multistage process, short consecutive heat treatments will provide the amount of heat needed to breakdown the first one or two layers of cells with minimum effect on the layers. They also studied the effect of time and number of cycles used on yield and quality of steam peeled potatoes and asparagus at 158°C. They assessed heat penetration of potatoes and peroxidase activity retention in asparagus, in order to explore the feasibily, in the last case, of combining the steam peeling process with the blanching operation necessary before asparagus is frozen. Best peeling quality, acceptable heat penetration and a yield of 90% were achieved for potatoes with a peeling time of 36s and three cycles. For asparagus, best peeling quality and an acceptable yield and peroxidase residual activity were obtained with a peeling time of 20s and one cycle. Steam peeling of asparagus followed by an adiabatic holding time after steam exhausting and before water cooling might inactivate peroxidase sufficiently so that blanching prior to freezing of asparagus won't be necessary.

Reeve (1976) reported that the skin of the tomato is composed of a cutinized epidermal layer and most of the cuticular wax is found in the cellulosic matrices of the outer and radial cell walls. It was indicated that scalding or steaming increased the ease of cell separation in the subepidermal tissue. Results of a study indicate that recovery of high (7 atm) pressure, short exposure time, steam peeled tomatoes is greater than for lye peeled tomatoes. However, the efficacy of peel and defect removal by steam peeling was inferior to that attained with lye peeling for the peeling variables employed. This is of major practical importance with regard to industry objectives although recovery was greater for steam peeled than for lye peeled fruit (Schlimme et al., 1984).

The high temperature of the steam resulted in melting and reorganization (phase transition) of the cuticular waxes on the surface of the fruit. Heat transfer

increased the temperature inside the fruit, which in turn caused vaporization of the cell fluids, increased internal pressure, occurrence of various biochemical reactions (hydrolysis of carbohydrates, breakdown of pectin) and finally rupture of cell walls and separation of the skin (Floros et al., 1988(b)).

Before the steam treatment, it isn't possible to distinguish between cytoplasm, cell wall and middle lamella as all three components, being close together, are structurally unified. As the fruits are treated with steam, the initial changes observed are in the cytoplasm. The high temperature probably causes denaturation of enzymes and other proteins, hydrolysis of carbohydrates and changes in the configuration of other macromolecules present in the cytoplasm. In severe treatments, the separation is total, and the cytoplasm is eventually washed away. The next component to be affected is the cell wall which is normally responsible for the structural rigidity of the plant tissue. The extensive application of high temperature results in degradation of the hemicellulosic polysaccharides present in the cell wall and breakdown of pectin (polygalacturonic acid) in the middle lamella. This is evident by the separation of the cell wall from the middle lamella. In more severe treatments, the rupture of cell walls and the breakdown or 'melting' of the middle lamella are extensive, resulting in mechanical failure and collapsing of cells. This total disorganization of the tissue is responsible for the final separation and removal of the skin (Floros et al., 1988(b); McNeil, 1984).

The mode of action associated with the effect of high temperature steam on the fruit (during a steam peeling process) is a complex phenomenon and probably a combination of physical as well as biochemical changes. The sudden increase in temperature around the fruit causes a phase transition, melting and reorganization of the waxy cuticle on the surface. Moreover, when the temperature rises inside the fruit, hydrolysis and degradation of polysaccharides, enzyme and other protein denaturation, as well as breakdown of pectic substances are likely to occur. When the temperature exceeds the boiling point of the liquids inside the cell, an internal pressure due to vaporization is created. If the external pressure (chamber pressure) is high, equilibration of the two opposite forces doesn't permit noticeable mechanical damage. When the external pressure is reduced to atmospheric, a pressure differential is created, and an enormous internal force acts on the cell walls resulting in physical damage such as cracks, rupture, breakdown (Floros et al., 1988(b)).

Present commercial peeling of sweet potatoes is generally accomplished with lye immersion followed by spray washing although some processors are using steam peeling. Either method produces a satisfactory processing product; however peeling depths are much greater than the optimum levels, and peeling and trimming losses are correspondingly high. These losses vary with the duration the peeling treatment and in the case of lye peeling with the concentration of the lye used. Prolonged peeling treatments increase peeling losses but reduce trimming and result in a more attractive product by decreasing oxidation darkening (Smith et al., 1980).

Steam peeling processes have been described in the literature for peeling produce by Eidt and McArthur (1944) and by Huxsol and Smith (1975). Harris and Barber (1957) showed that the depth and uniformity of the peel depends upon the steam pressure used and the rapidity of diffusion of steam among the produce being peeled (Smith et al., 1981). Smith et al (1980) also reported that rapid heating to peeling temperature and flash cooling by injection of cold water into the peeling chamber resulted in improved yields and quality of peeled sweet potatoes.

Commercial methodology for removal of peel from processing tomatoes destined for production of whole pack has undergone considerable change in the last few decades. Tomatoes are blanched in ambient pressure steam or in boiling water for 30 to 60 seconds. Peel loosening is achieved by cold water immersion or spray to crack the skin and thereby facilitate hand removal of peel. Light scalding treatments are often used to avoid excessive softening of pulp and flesh. However such treatments often necessitated the use of peeling knives for peel removal and therefore resulted in high labor cost and low throughput. More efficient peel removal is later achieved by immersion for different time intervals at high temperature solutions of NaOH containing various peeling aids. Currently, there is a trend back to the use of steam for peel removal from tomatoes for whole pack production as well as for other fruits and vegetables. In contrast to earlier methods involving ambient pressure steam, high pressure and short application times have been designed to achieve maximum yield (Corey et al., 1986).

1.3. Objectives of the Study

The objectives of this study are to optimize chemical peeling of carrots and to determine the effect of chemical peeling on quality of carrots. For this purpose, carrots were chemically peeled, time-temperature, time-concentration relations were estimated and a suitable combination of time-temperature-concentration was selected. The optimum time-temperature-concentration relations were analyzed mathematically. Optimum peeling time for steam peeling of carrots was determined. The finished product quality of carrots peeled by both caustic and high pressure steam methods under commercial conditions was evaluated and the percent recovery of the whole carrot was evaluated.

CHAPTER 2

MATERIALS AND METHODS

2.1 Raw Material

Carrots of 'Beypazarı' variety, cultivated during 2004 season, were purchased from local market. The carrots were of medium size and the average weights were in the range of 75-110 grams.

Caustic solutions of 0.25, 0.50, 0.75 and 1.00 %(w/v) of NaOH (Merck NaOH pellets pure) were used at temperatures 57, 67, 77 and 87°C for varying time intervals for peeling of carrots.

Steam peeling treatments were conducted with a Pressure Cooker (Solingen Germania 18/10 Cr/Ni Aluminium 18/10 Cr/Ni); a 7 liter capacity vessel at an inlet steam pressure of 130.70kPa and a constant temperature of 107°C was used. The time of exposure to steam was equal to the total time of processing. For peeling, different time intervals were used to find out the appropriate peeling conditions.

2.2. Experimental

2.2.1. Chemical Peeling of Carrots

Temperature controlled water bath (Nüve Scientific Shaker Water Bath, ST 402, Turkey) were used to hold the solutions at constant temperature. Only one carrot was used in each treatment. Treatments were repeated three times and averaged. The carrots were immersed in the solution for a predetermined time and cooled in tap water 15°C for 1min at a flow rate of 100ml/s. They were then evaluated according to degree of peeling. Unpeeled surface of the carrots were calculated by using transparent papers and samples were scored according to degree of peel removal from Table 2.1 (Bayındırlı, 1994).

Table 2.1. Degree of Peeling – Score Relation for Carrots

Very good peeling	Peeling higher than 98%	* * * *
Good peeling	Peeling higher than 75%	* * *
Slight peeling	Peeling higher than 50%	* *
No peeling	Peeling higher than 0%	*

2.2.2. Steam Peeling of Carrots

Only one carrot was put into the pressure cooker in each treatment. Treatments were repeated three times and averaged. The carrots were waited in the pressure cooker for a predetermined time and cooled in a tap water 15°C for 1min at a flow rate of 100ml/s. They were then evaluated according to degree of peeling. Unpeeled surface of the carrots were calculated by using transparent papers and samples were scored according to degree of peel removal (Table2.1)

2.2.3. Quality Evaluations After Chemical Peeling

All analyses were carried at all temperatures and all lye concentrations for very good peeling (>98%) of carrots. Samples were milled by a grater before analysis. Treatments were repeated three times and averaged.

2.2.3.1.Color

Color was measured by Minolta color reader (CR-10, Japan) and expressed by CIE coordinates (L*a*b*) system. L*, a* and b* indicates whiteness/darkness, redness/greenness, blueness/yellowness values, respectively. The samples were scanned at six different locations to determine average L, and b values. Total color difference (ΔE) was calculated from the following equation (Altunakar et al., 2004);

$$\Delta E = \sqrt{\left[\left(L^* - L_{s\,\tan dard}^*\right)^2 + \left(a^* - a_{s\,\tan dard}^*\right)^2 + \left(b^* - b_{s\,\tan dard}^*\right)^2\right]}$$

where, standard values referred to the $BaSO_4$ plate (L^*=96.9, a^*=0 and b^*=7.2).

2.2.3.2. Unpeeled Skin Surface Area

After the peeling treatment, the remaining skin on the carrot surface was measured as area (cm^2)/carrot by specially prepared transparent papers and referring to average carrot surface area as percent (%) (Garrote et al., 1993).

2.2.3.3. Peeling Yield

It was measured by weighing carrots before and after peeling and calculated as percent (%) (Garrote et al., 1993).

2.2.3.4. Total Soluble Solids

Triplicate readings were carried out at 20°C by using refractometer (RFM 330, Bellingham + Stanley Ltd.) and mean value calculated as °Brix (Setty et al., 1993).

2.2.3.5. Depth of NaOH Penetration

A peeled carrot was cut into two identical parts. From the central part of a one part, thin slices (1 mm) were cut. A few drops of phenolphthalein solution (3%; w/v) were applied to the slices and one slice was placed into a phenolphthalein solution. After waiting few minutes, if penetration occurs, the color turns into violet-pink. This change can be measured by using a scheduled magnifying glass and value expressed by mm (Garrote et al., 1993).

2.2.3.6. Pectin Analysis

The carrot sample was extracted with HCl and ethanol. The extract was filtrated and then washed with ethanol. After washing, extract was dried at 103°C. Dried extract was solved in ethanol and water. By using phenolphthalein indicator solution, extract was titrated with NaOH solution. The mixture was shaken with HCl solution and titrated again with NaOH solution with the help of phenolphthalein

indicator solution. The used up NaOH solution was used to calculate the amount of pectin of the sample (TS 10373, 1992).

2.2.3.7. Beta-Carotene (β-Carotene) Analysis

Chemicals

All solvents used were of high-pressure liquid chromatography (HPLC) grade and the other chemicals of analytical grade. They were purchased from Riedel-de Haën (Sigma-Aldrich Laborchemikalien GmbH, Germany). The β-carotene standard (type IV from carrots) was purchased from Sigma Chemical Company (St Louis, MO). Chloroform and ethanol were used for extracting β-carotene from carrot. (The Merck Index 12th ed. Sigma-Aldrich Chemie GmbH, Steinheim, Germany).

Extraction Procedure

For extraction of β-carotene, 5g of the carrot pulp was homogenized by the Ultra Turrax homogenizer (IKA ULTRATURRAX T18, Basic, Brazil) in the presence of 20 ml ethanol:chloroform (1:1, v/v) mix. After precipitation of the carrot pulp, the solvent was removed to the separating funnel. Then 20 ml chloroform was added to the carrot pulp and homogenized by the Ultra Turrax. To precipitate the carrot pulp, 5-10 ml of ethanol was used. After precipitation, the solvent was removed to the separating funnel again. These steps were repeated three times. Finally, the solvent was removed from carrot pulp by filtration and the filter cake reextracted with 20 ml ethanol:chloroform (1:1, v/v) until the color of filter cake was white.

The β-carotene extract, which was in the separating funnel, was washed with pure water and 0.1N KOH solution several times. Water was used for water soluble solids and 0.1N KOH was used for saponification of lipids other than carotenoids (C.deSá and Rodriguez-Amaya, 2003). The lower layer was separated, combined and evaporated under vacuum by using a rotary evaporator (Rotavapor,Brinkmann Instruments, Büchi Laboratoriums, Switzerland) until all chloroform was evaporated. The residue in the rotary balloon was dissolved with acetone and poured out to the balloon of 25 ml and filled with acetone. The acetone extract was filled to the

eppendorf tubes to store the extract until analyzed at below -20°C. Before analysis, samples were filtered through a 0,45µm Millipore (Bedford, USA) membrane filter and injected directly into the HPLC system immediately.

HPLC instrumentation and conditions

The analysis was performed by using a Shimadzu (Kyoto, Japan) VP series HPLC apparatus. For the analysis, a C18 column (Tracer Extrasil ODS2, 5µm, 25x0,46cm; Teknokroma, Barcelona, Spain), a degasser (Shimadzu model DGU-14A), a UV-vis photodiode array detector (Shimadzu model SPD-M10Avp) set at 438nm**,** an HPLC pump (Shimadzu model LC-10 AT-VP) and a system controller (Shimadzu model SCL-10A) were used. The injection volume was 20µl of solution at room temperature from a 100µl Hamilton LC syringe via a U6K injector. The mobile phase was composed of acetonitrile:chloroform (92:8, v/v) and the flow rate was set at 1ml/min.

2.2.4. Quality Evaluations After Steam Peeling

The analysis was carried at very good peeling(>98%) of carrots. Samples were milled by a grater before analysis. Treatments were repeated three times and averaged.

2.2.4.1. Color

Color was measured by Minolta color reader (CR-10, Japan) and expressed by CIE coordinates (L*a*b*) system. L*, a* and b* indicates whiteness/darkness, redness/greenness, blueness/yellowness values, respectively. The samples were scanned at six different locations to determine average L, and b values. Total color difference (ΔE) was calculated from the following equation (Altunakar et al., 2004);

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where, standard values referred to the $BaSO_4$ plate (L^*=96.9, a^*=0 and b^*=7.2).

2.2.4.2. Unpeeled Skin Surface Area

After the peeling treatment, the remaining skin on the carrot surface was measured as area (cm^2)/carrot by specially prepared transparent papers and referring to average carrot surface area as percent (%) (Garrote et al., 1993).

2.2.4.3. Peeling Yield

It was measured by weighing carrots before and after peeling and calculated as percent (%) (Garrote et al., 1993).

2.2.4.4. Total Soluble Solids

Triplicate readings were carried out at 20°C by using refractometer (RFM 330, Bellingham + Stanley Ltd.) and mean value calculated as °Brix (Setty et al., 1993).

2.2.4.5. Pectin Analysis

The carrot sample was extracted with HCl and ethanol. The extract was filtrated and then washed with ethanol. After washing, extract was dried at 103°C. Dried extract was solved by using ethanol and water. By using phenolphthalein indicator solution, extract was titrated with NaOH solution. The mixture was shaken with HCl solution and titrated again with NaOH solution with the help of phenolphthalein indicator solution. The used up NaOH solution was used to calculate the amount of pectin of the sample (TS 10373, 1992).

2.2.4.6. Beta-Carotene (β-Carotene) Analysis

Chemicals

All solvents used were of high-pressure liquid chromatography (HPLC) grade and the other chemicals of analytical grade. They were purchased from Riedel-de Haën (Sigma-Aldrich Laborchemikalien GmbH, Germany). The β-carotene standard (type IV from carrots) were purchased from Sigma Chemical Company (St Louis, MO). Chloroform and ethanol was used for extracting β-carotene from carrot. (The Merck Index 12th ed. Sigma-Aldrich Chemie GmbH, Steinheim, Germany).

Extraction Procedure

For extraction of β-carotene, 5g of the carrot pulp was homogenized by the Ultra Turrax homogenizer (IKA ULTRATURRAX T18, Basic, Brazil) in the presence of 20 ml ethanol:chloroform (1:1, v/v) mix. After precipitation of the carrot pulp, the solvent was removed to the separating funnel. Then 20 ml chloroform was added to the carrot pulp and homogenized by the Ultra Turrax. To precipitate the carrot pulp, 5-10 ml of ethanol was used. After precipitation, the solvent was removed to the separating funnel again. These steps were repeated three times. Finally, the solvent was removed from carrot pulp by filtration and the filter cake reextracted with 20 ml ethanol:chloroform (1:1, v/v) until the color of filter cake was white.

The β-carotene extract, which was in the separating funnel, was washed with pure water and 0.1N KOH solution several times. Water was used for water soluble solids and 0.1N KOH was used for saponification of lipids other than carotenoids (C.deSá and Rodriguez-Amaya, 2003). The lower layer was separated, combined and evaporated at under vacuum by using a rotary evaporator (Rotavapor,Brinkmann Instruments, Büchi Laboratoriums, Switzerland) until all chloroform was evaporated. The residue in the rotary balloon was dissolved with acetone and poured out to the balloon of 25 ml and filled with acetone. The acetone extract was filled to the eppendorf tubes to store the extract until analyzed at below -20°C. Before analysis, samples were filtered through a 0,45µm Millipore (Bedford, USA) membrane filter and injected directly into the HPLC system immediately.

HPLC instrumentation and conditions

The analysis was performed by using a Shimadzu (Kyoto, Japan) VP series HPLC apparatus. For the analysis, a C18 column (Tracer Extrasil ODS2, 5µm, 25x0,46cm; Teknokroma, Barcelona, Spain), a degasser (Shimadzu model DGU-14A), a UV-vis photodiode array detector (Shimadzu model SPD-M10Avp) set at 438nm**,** an HPLC pump (Shimadzu model LC-10 AT-VP) and a system controller (Shimadzu model SCL-10A) were used. The injection volume was 20µl of solution at room temperature from a 100µl Hamilton LC syringe via a U6K injector. The mobile phase was composed of acetonitrile:chloroform (92:8, v/v) and the flow rate was set at 1ml/min.

2.3. Data Analysis

Analysis of variance (ANOVA) with two ways and Tukey's Multiple Comparison Test ($P < 0.05$) were used to obtain statistical comparison of treatments. Also Multiple Regression was applied to the data by using Minitab for Windows (V14).

CHAPTER 3

RESULTS AND DISCUSSION

3.1. Chemical Peeling of Carrots

The peeling rates of carrots when put into various sodium hydroxide solutions at various pre-determined temperatures and concentrations were measured. A desired product represents conditions which would result in practically total removal of the skin, minimum peeling loss and maximum product yield. The time-temperature of the lye solution and time-concentration of the lye solution relationships for complete peeling of carrots were tried to be found experimentally. In Table A1, the minimum time for very good peeling is shown for each concentration at constant temperature as shaded area. As tabulated in the table, the minimum time to reach 'very good peeling' was dependent on the temperature and the severity of the lye concentration. The minimum required time for 'very good peeling' was the basic criteria for assessing each treatment. It was seen that peeling time was dependent on temperature and concentration of sodium hydroxide solution as temperature and concentration of lye increased, peeling time decreased (Table A1). The same result was obtained for peeling of tomatoes since the increase in lye concentration and temperature decreased the time necessary for efficient peeling (Bayındırlı, 1994).

After data collection, the time-temperature and time-concentration graphs were plotted according to the minimum time to reach 'complete peeling' score (Table A1) and the mathematical equations for both relationships were found by finding out the constants of the general equations determined before the analysis by the linear regression principle.

The time-concentration relations for chemical peeling of carrots were investigated. While plotting time versus concentration graph, it was seen that the data best fit an exponential equation of the form (Figure 3.1):

$$C = e^{(\lambda + \gamma t)} \quad (1)$$

And;

$$\text{Ln } C = \lambda + \gamma t \quad (2)$$

Equation (2) is the linear form of equation (1) and the parameters λ, γ and correlation coefficient obtained by regression analysis for each sodium hydroxide concentration are shown in Table A2 and the best fits are demonstrated in Figures 3.1 and 3.2.

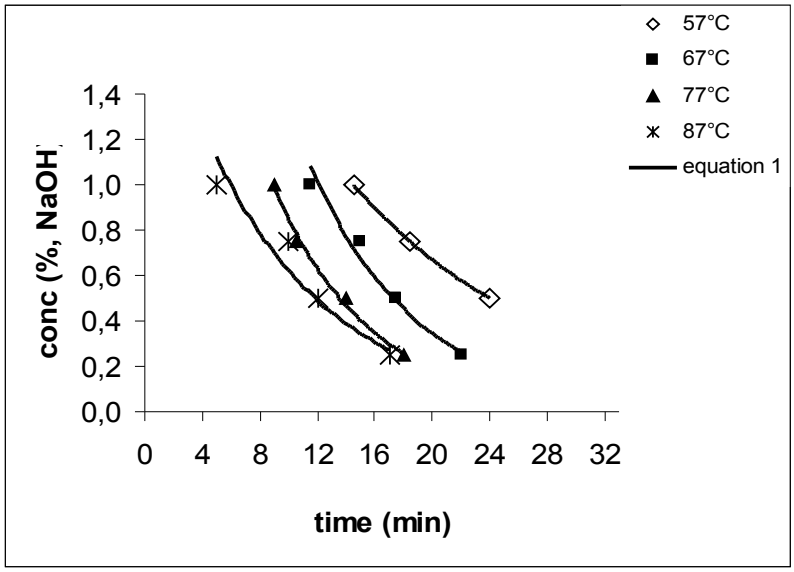

Figure 3.1.Time-concentration relations for chemical peeling of carrots.

Similarly, the effect of time-temperature relations was described by an exponential relationship:

$$T = e^{(\sigma + \beta t)} \quad (3)$$

And;

$$\text{Ln } T = \sigma + \beta t \quad (4)$$

The parameters σ, β and correlation coefficient are shown in Table A3 and the best fits for the equations (3) and (4) are shown in Figures 3.3 and 3.4 respectively.

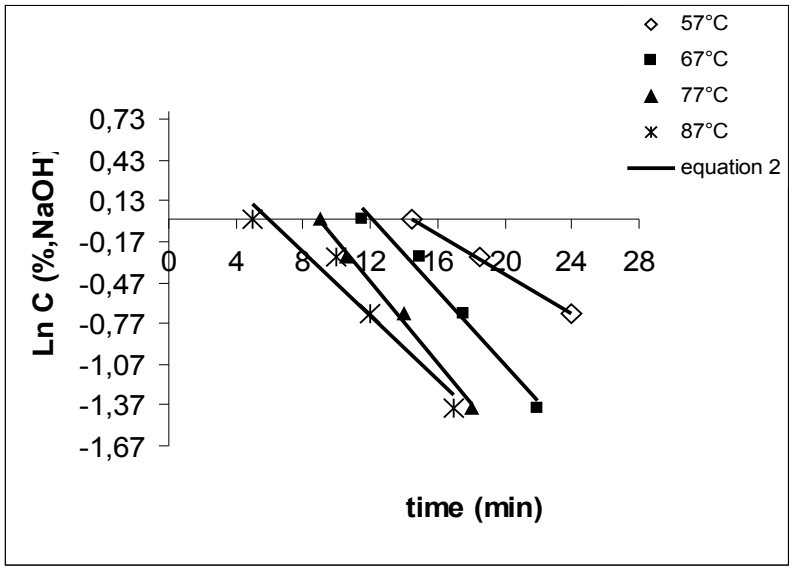

Figure 3.2.Time-concentration relations for chemical peeling of carrots.

As can be seen from Figures 3.1 through 3.4, experimental data fit well to the exponential equation model for both temperature and concentration. It is also observed that increase in both temperature and concentration of lye solution led to a decrease in peeling time. But temperature was the main variable affecting the peeling time as the change in the slope of the constant temperature lines in Figure 3.1 is greater than that of constant concentration lines in Figure 3.3. For example, when the temperature was increased from 57°C to 67°C at 0.50% NaOH, the minimum time for "very good peeling" was decreased about 6.5 min. When the temperature was increased from 67°C to 77°C at 0.25% NaOH, the minimum time for "very good peeling" was decreased about 4 minutes. While increase of concentration from 0.50% to 0.75% led to a 2.5min decrease at 67°C and increase of concentration from 0.75% to 1.00% led to a 1.5 min. decrease at 77°C in that time. A little change in the concentration did not seem to affect the peeling time as much as the temperature did. Another clue for this result is that no peeling was observed during the usage of 0.25% NaOH solution at 57°C. The effect of temperature was also obtained important at peeling of Antep peanut (Bayındırlı et al., 2001) and tomatoes (Bayındırlı, 1994).

Penetration of lye solution takes place via diffusion and chemical reactions depends strictly on temperature. Floros and Chinnan (1990) showed that diffusion of lye solution didn't occur at low temperatures because epicuticular waxes on the surface of fruits and vegetables were in the solid state. They did not allow NaOH to enter the fruit. At higher temperatures, the wax liquefied and NaOH readily diffused inside the tissue.

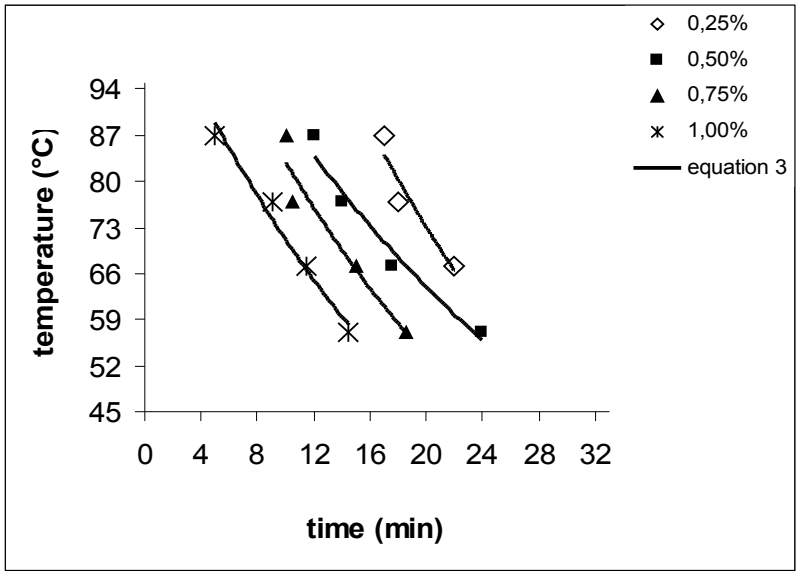

Figure 3.3.Time-temperature relations for chemical peeling of carrots.

In order to decide on optimum combination, we should consider minimum concentration, minimum time and minimum temperature. Before selecting concentration, temperature can be selected in that 77°C is the most effective. Because the difference in the peeling time for "very good peeling" between 67°C and 77°C at 0.25% concentration is 4min., that difference is only 1 min between 77°C and 87°C.

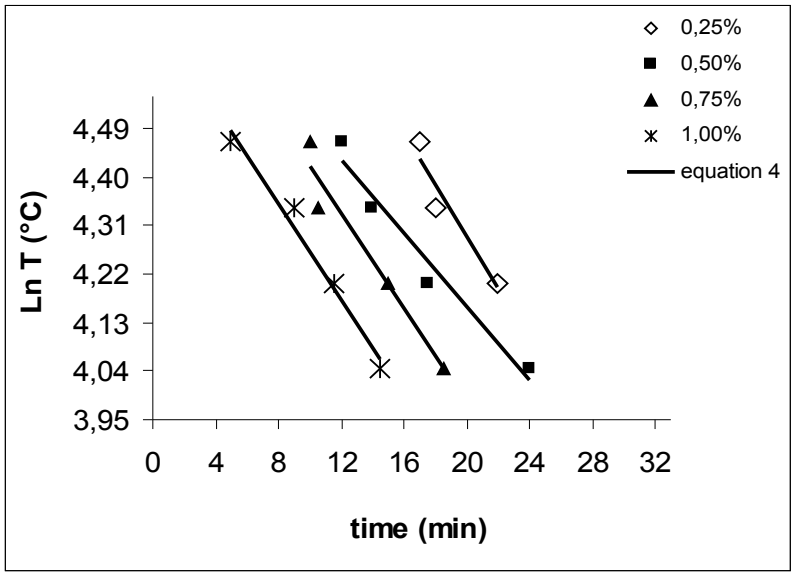

Figure 3.4.Time-temperature relations for chemical peeling of carrots.

Once the temperature is fixed, a decision could be made on concentration easily. At temperature of 77°C, the difference in the peeling time between 0.50% and 0.75% were 3.5min., while that was only 1.5min. between 0.75% and 1.00%. Thus it was not necessary to increase the concentration further as increasing concentration increased the amount of peeling aid and amount of possible chemical residue on the sample, with only a small decrease in peeling time. Decreasing the concentration on the other hand, increased the peeling time resulting in probably penetration depth of the chemical, so the peeling loss. Considering all of the items above therefore, a suitable set of conditions for chemical peeling of carrots was determined as 0.75% sodium hydroxide concentration at 77°C for 10.5 minutes.

According to multiple regression analysis, temperature and concentration of lye solution was significant for peeling time ($P<0.05$). The regression equation is:

$$t = 47.4 - 14.1\ C - 0.324\ T \qquad (5)$$

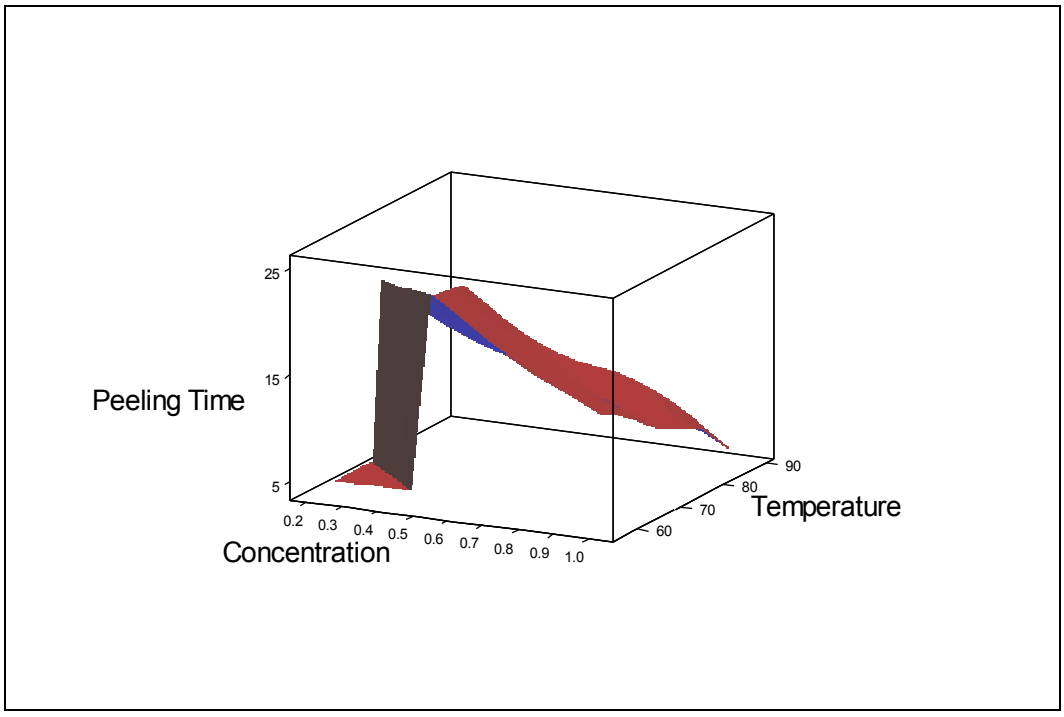

Figure 3.5. Temperature-concentration-peeling time relations for chemical peeling of carrots.

The temperature-concentration-peeling time relations are shown at Figures 3.5 and F1 and obtained by using Minitab. When the concentration of the lye solution was low, peeling time was long although temperature of lye solution increased. When the temperature of lye solution was low, the decrease of peeling time was not important enough to consider although the lye solution increased. The decrease of peeling time was measured when the increase of concentration and temperature of lye solution were considered together.

Consequently, the estimated exponential model represents the case quite well and this exponential model could be applied to all varieties simply by changing the constants in the expression.

3.2. Steam Peeling of Carrots

Within this work, the effect of heating treatment during the steam peeling of carrots was assessed. Saturated steam of 130.70 kPa at 107°C was applied to a carrot at different time intervals to evaluate the peeling degree. The minimal time was achieved to peel carrots rather than cooking at predetermined pressure and temperature of the steam. A desired process also represents conditions which would result in practically total removal of the skin, minimum peeling loss and maximum product yield. In Table A4 the applied time for peeling degree of carrots were shown. Temperature and pressure of the steam peeling is constant, and then the main variable affecting the peeling is time.

Peeled surface area for steam peeling mainly depended on the exposure time of the steam. The data could be fitted to an exponential line of the form (Figure 3.6):

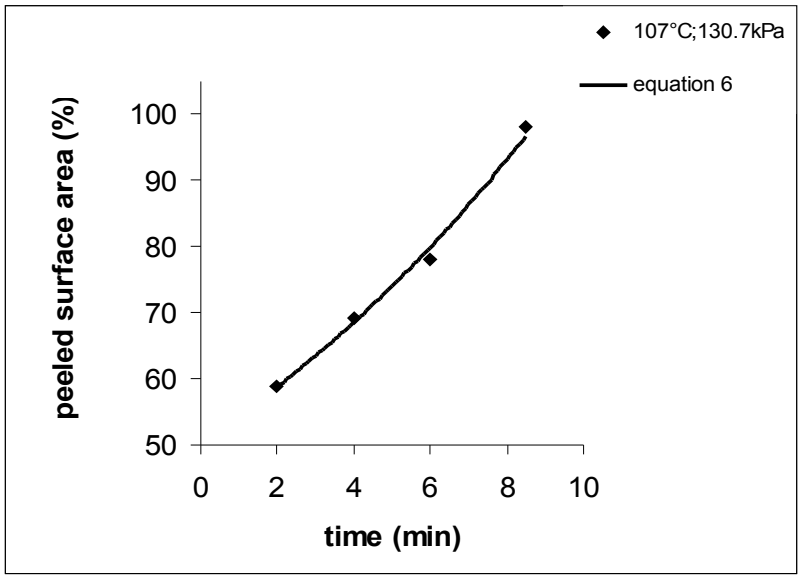

Figure 3.6.Peeled surface area-time relations for steam peeling of carrots.

$$P = e^{(a + b\,t)} \quad (6)$$

And;

$$\text{Ln } P = a + bt \quad (7)$$

Equation (6) is the linear form of equation (5) and the parameters a, b and correlation coefficient obtained by regression analysis is shown in Table A5 and the best fits are demonstrated in Figures 3.6 and 3.7.

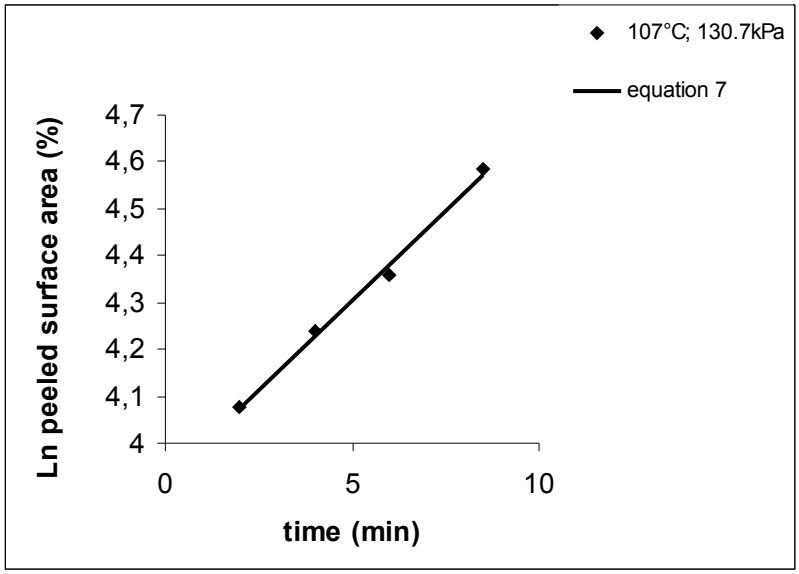

Figure 3.7.Peeled surface area-time relations for steam peeling of carrots.

As can be seen from Figures 3.6 and 3.7, experimental data fit well to the exponential model for the saturated steam of 130.7 kPa and 107°C. When mathematically complete peeling (100 %) was considered, a suitable time for peeling was determined as 8.92min.

Consequently, the estimated exponential model represents the case quite well and this model could be applied to all varieties simply by using saturated steam of 130.7 kPa and 107°C.

III.3.Effect of Chemical Peeling on Quality of Carrots

The results of analysis are shown in Tables A6 and A7 at appendix. There are two control samples for comparing the data efficiently. Control 1 (C1) is raw carrot and Control 2 (C2) is the mechanically peeled carrot. There was not a significant change of total soluble solids of samples as compared with control samples. Setty et al (1993) indicated that no significant changes in the important constituents such a °Brix have been reported in tomatoes peeled by hot water, steam or others. Statistically, temperature and concentration of lye solution was insignificant for total soluble solids ($P<0.05$). The regression equation is at Appendix F.

As the severity of lye concentration was increased, the time for complete peeling (peeling > 98 %) was decreased. Since lye solution penetrates into the fruits and vegetables via several chemical reactions, exposure time of sample played an important role on quality change of carrots. In fact as can be seen in tables in appendices, most of the quality factors showed more or less a change by exposure time.

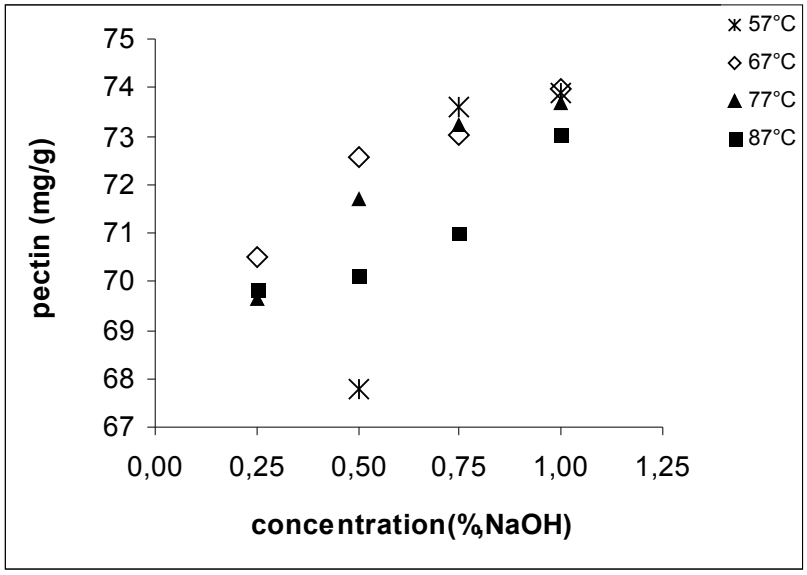

Figure 3.8.Pectin-concentration relations for chemically peeled carrots.

As the severity of the treatment was increased, the weight loss of the carrot increased. Exposure time of the sample was the main parameter to evaluate the peeling loss of the carrots. Table A7 shows the weight loss-peeling yield-treatment relations. Mechanical peeling is the more severe treatment although time is not a parameter for it.

Floros and Chinnan (1988) indicated that high temperature causes mechanical failure of the cell and then the effect of heat on the tissue causes biochemical changes, melting and breakdown of substances such as pectins and polysaccharides and general disturbance and disorganization of the structure of the cell. Cell walls are composite microstructures of cellulose microfibrils embedded in a matrix of polysaccharides and some proteins. Cellulose constituents some 15-28 % of the weight of the cell wall, hemicellulose 6-10 % and pectic substances 47-66 %. Heat penetration to the tissue altered the pectin in the middle lamella at above 60°C. Pectin in the primary and secondary walls changes, causing the separation of the compact lamella into fibrils and a local decrease in the amount of pectin is observed (Garrote et al., 2000).

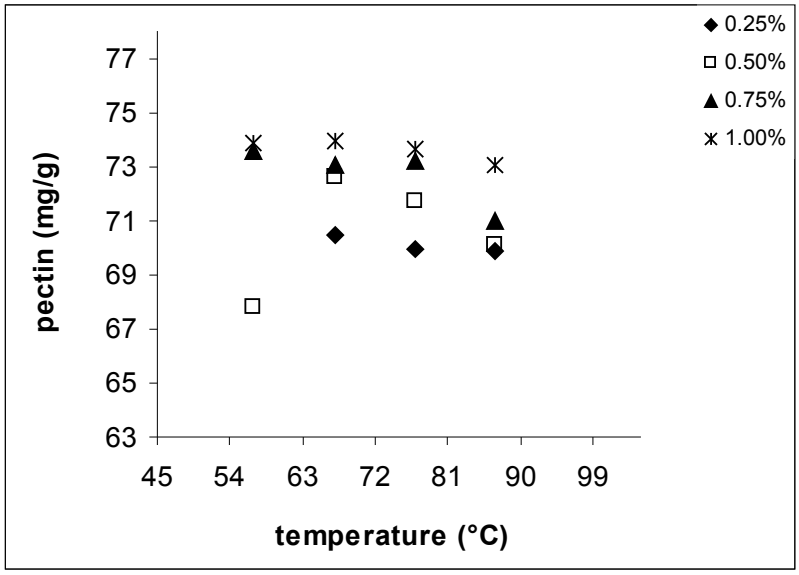

Figure 3.9.Pectin-temperature relations for chemically peeled carrots.

The effect of lye peeling on pectin amount of carrots was evaluated and the optimum temperature and concentration for the pectin amount was determined. Figure 3.8 shows pectin-concentration relations at constant temperature. The ordinate shows the amount of pectin after the peeling treatment. As seen from the figure from left to the right, concentration increases and then the amount of pectin of the peeled carrots increases. At 87°C values; time is not as high as other treatments. However; the pectin amount is low at 87°C 1.00 % NaOH concentration. The lowest pectin amount is at 57°C and 0.50 %. This demonstrates that temperature is the second important factor after the time. At 57°C and 0.50 % NaOH concentration, the time period is 24 minutes. Although temperature is the lowest, the pectin amount is the lowest than the others. The optimum concentration for peeling can be chosen from this figure. The optimum concentration for peeling is 0.75 % because the amount of pectin is higher than 0.50 % and also the pectin amount does not increase significantly when the concentration of solution is 1.00 %.

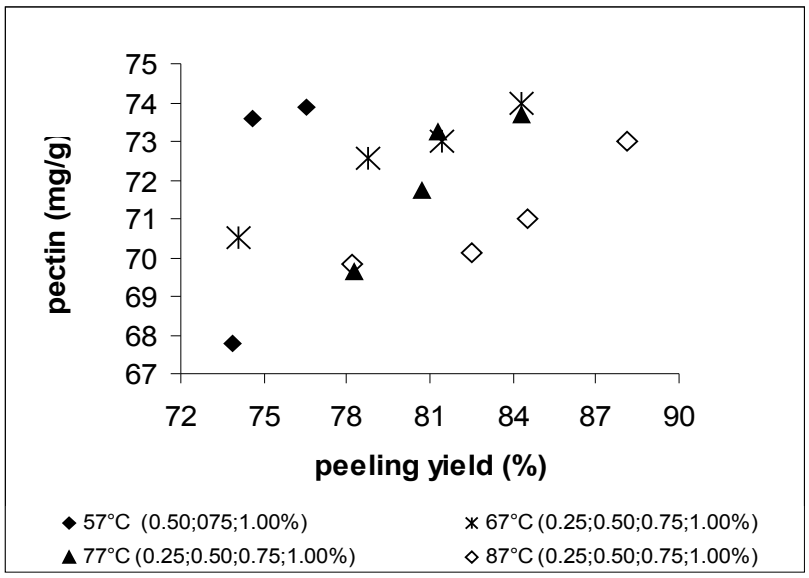

Figure 3.10.Pectin-peeling yield relations at constant temperature

The optimum temperature determination can be found by using Figure 3.9. According to Figure 3.9, the amount of pectin is the highest at every temperature when the concentration of the lye solution is 1.00 %. From Figure 3.8, we know that temperature is important for the amount of pectin; Figure 3.9 also confirms the same statement. Except for 57°C and 0.50 % value; the highest the temperature is, the lowest the pectin amount is.

In addition to the temperature, concentration values are arranged in increasing order. Once the concentration of lye solution increases, the waiting period of the carrot in the lye solution decreases; when time is short the amount of pectin of the sample increases. The concentration was determined 0.75 % according to Figure 3.8. In Figure 3.9, since the concentration of the lye solution is 0.75 %; the amount of pectin of the peeled carrots were indicated nearly the same; except for 87°C. The determination of the temperature, the 57 and 77°C values were compared because 67°C value is lower than these two. By the help of peeling yield from Figure 3.10, the optimum temperature of the quality evaluation was 77°C because the peeling yield was higher than 57°C value. As mentioned before, the peeling period at 57°C was longer than 67 and also 77°C.

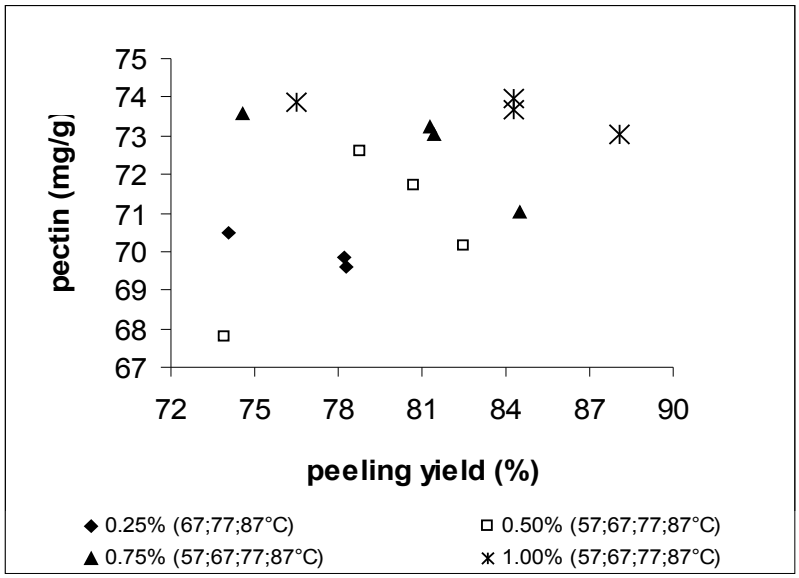

Figure 3.11. Pectin-peeling yield relation at constant concentration

The estimated mathematical model represented that the optimum peeling condition for chemically peeled carrots was 77°C 0.75% and 10.5 minutes. The quality evaluation determined the optimum chemical peeling condition of the carrot as 0.75% NaOH concentration at 77°C for 10.5 minutes by the help of pectin. It can be clearly said that the estimated mathematical model fitted to the quality evaluation.

While examining the Figure 3.10; the value which included the lowest amount of pectin showed the lowest yield of peeling. Separation of the peel indicates a local decrease of the amount of pectin (Garrote et al., 2000). From that important information; peeling yield, in other words weight loss, also determined the amount of pectin of the peeled carrot. From Figures 3.9 and 3.10, increased concentration decreased time, then pectin amount increased; but, the peeling yield did not change significantly at 57°C. In Figure 3.10, the amount of pectin at 67, 77 and 87°C increased when the peeling yield increased. Pectin degraded due to heat at 87°C; so, the amount of pectin was the lowest. The slope of 77°C is highest than the slope of 67°C, by the help of this information, peeling yield of 77°C values were highest than the values of 67°C. The highest amount of pectin region, which is the top of the Figure 3.10, demonstrates the points of different temperature values. From left to right, peeling yield increases; however, the amount of pectin does not increase like peeling yield at that region. There are two points on the graph which the 67 and 77°C values are nearly the same. The lowest pectin and peeling yield value, as mentioned before in figures 3.8 and 3.9, confirms the mathematical optimum here again at that point.

Like Figure 3.10, from left to right, peeling yield increases at constant concentration at Figure 3.11. From left to right, the concentration points changes in increasing order. At the maximum peeling yield point, the amount of pectin does not reach at maximum value. However, that point is the 1.00 % NaOH concentration point. According to figures 3.8, 3.9 and 3.10, it was the value of 87°C and at that temperature, the amount of pectin was not the maximum. The other 1.00 % values have much pectin. The peeling yield of that pectin value is the lowest at 57°C. Peeling yield were nearly the same at 67 and 77°C. The increase of concentration decreased peeling time, increase in concentration increased peeling yield at the same time. When the 0.75 % NaOH values were evaluated, the highest pectin with the

highest peeling yield which is the optimum value for chemical peeling can be seen clearly.

According to multiple regression for peeling yield, the temperature and concentration of lye solution were significant for peeling yield of the carrots ($P<0.05$). The regression equation of peeling yield is:

$$PY = 56.3 + 10.6\,C + 0.232\,T \quad (8)$$

Figure 3.12 and 3.13 are the reverse graphs for Figures 3.10 and 3.11, respectively. The hot lye solution dissolves and removes the epicuticular and cuticular waxes of the outer pericarp surface, penetrates the skin and diffuses uniformly into the fruit. The diffusion of lye causes breakdown of the epidermal and hypodermal cells and solubilization of the pectic substances in the middle lamella, separating the skin from the edible part of the fruit. More severe action of lye causes destruction of cell walls especially of the mesocarp cells resulting in increased peeling loss (Floros et al., 1987). Prolonged peeling treatments increase peeling losses (Smith et al., 1980). The increase of peeling loss of the carrot caused the decrease of the amount of pectin of the peeled carrot.

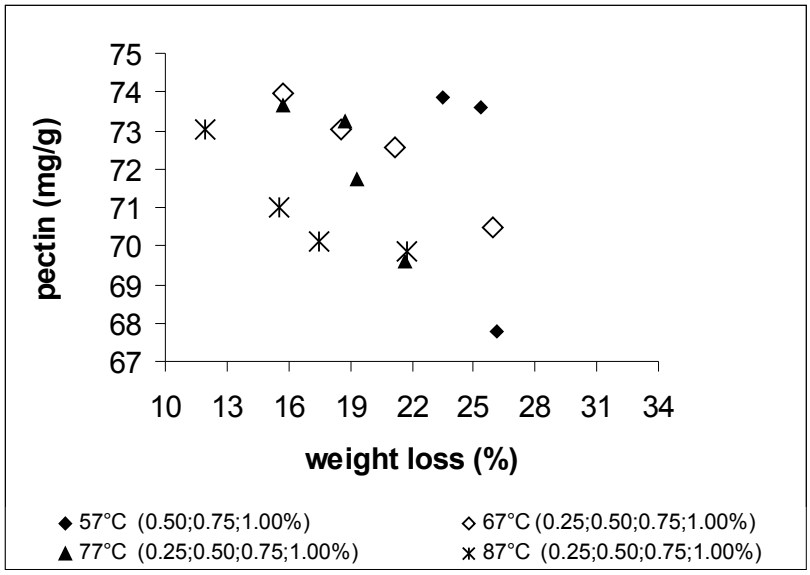

Figure 3.12.Pectin-weight loss relation at constant temperature.

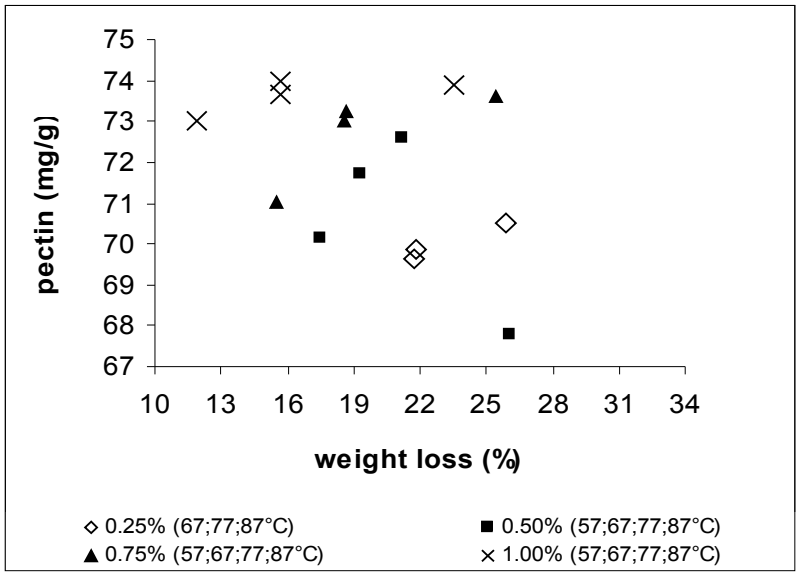

Figure 3.13.Pectin-weight loss relation at constant concentration.

According to statistical analysis, temperature and concentration were insignificant for the amount of pectin. However, the model fit to the pectin relation. Then, it can be understood from figures 3.8 to 3.12; the difference was not significant.

According to multiple regression obtained for pectin amount, the temperature of lye solution and peeling time were significant for pectin, but the concentration of lye solution was not significant for the amount of pectin ($P<0.05$). The regression equation is of pectin is:

$$PE = 109 - 0.283\ T - 6.45\ C - 0.832\ t \quad (9)$$

The pectin content also determines the finished product quality of carrots. Texture is an important quality attribute of frozen fruits and vegetables. A major result of freezing on fruits and vegetables is usually a loss of tissue firmness. Freezing causes disruption of the membranes of cells and excessive softness. Before freezing there must be an application of preheating needed. (Fuchigami et al., 1995 (a)). The chemical peeling of carrots provides the preheating treatment at the same time. A correlation between pectic composition in cell walls and softening of cooked vegetables reported. Excessive softness could be overcome by low temperature

blanching. The firming effects of a low temperature, long-time treatment was useful for improvement in texture of carrots. By the help of this treatment, softening of carrots was greatly diminished, but cell damage was observed.(Fuchigami et al., 1995 (a), (b)). Figures 3.8 and 3.9 expressed the lowest pectin amount. Low temperature-long time caused high peel loss. Also, pectin degradation was high and the amount of pectin was the lowest However; the firmness of the carrot was the best. Although the amount of removed pectin develops the firmness of the carrots, the health quality of carrot diminishes. Baker (1997) suggested that dietary supplementation with pectin may reduce levels of serum total cholesterol, decrease low density lipoprotein cholesterol, and moderate the glucose response. Fuchigami et al (1995 (a)) determined the firmness of carrots at various temperatures. The temperature of 70°C was an important level. The below and above of 70°C, the pectin degradation was low. The temperature of 70°C neighborhood caused carrots firmer than the others. Below 70°C, the needed time for degrading pectin was long. For instance, 60°C for 30 min. was enough for pectin degradation. However, long time caused high peel loss. The temperature above 80°C needed short time for degradation. The level of pectin was lower, then the carrots were firmer, but the treatment was not economic. Also for health concerns the amount of pectin was very low than 77°C values. Generally, the chemical peeled carrots were firmer due to the applied temperatures. Finally, the pectin level of mathematical optimum value also suggests the optimum firmness of carrot.

The severity of lye action and the depth of penetration depend primarily upon the concentration of the solution and the time it is permitted to act on the fruit. If the lye peeling process is carried out satisfactorily, diffusion and action of lye will be controlled and cell wall degradation effects will be restricted to epidermal and hypodermal regions with a minimum effect on parenchymatous mesocarp cells. If the lye solution is applied for too long a time, or it is highly concentrated, severe action will take place deeply inside the flesh, and some loss of the edible part of the fruit will occur (Floros et al., 1987). In our study, the concentration is the most important parameter for that condition because, when the concentration is high, the penetration time decreases. The penetration depth of the chemical peeling could not be measured because the NaOH residue was removed with the peel. The NaOH solution did not penetrate to the edible part of the carrot. The applied concentrations were chosen low

for that reason. In addition to concentration, time is the second important factor for penetration depth. Low concentration regulation is important because of time. Very low concentration of lye solution causes the increase of the waiting time. At that waiting time, carrot was exposed lye solution for a long time.

Diffusion of lye solution into the carrot causes chemical reactions. Cell wall degradation, pectin loss and then the unfavorable result is the removal of the edible parts. For this reason the regulation of the concentration-time relation is very important. The edible part was recovered by the help of these parameter combinations.

When penetration occurs, firstly there is color change with an indicator on the surface of the fruit. Diffusion of lye solution causes penetration of lye solution into the carrot. Figure 3.14 shows the color change of the carrot when the penetration occurs. The carrots on the photograph were dipped in a lye solution for peeling and after dipping they were washed with water to remove the peels. They were completely peeled. However, the second one had a color change with an indicator. Carrot 2 had NaOH residue on the surface. Carrot 1 demonstrates the complete peeling conditions of Table A1, carrot 2 demonstrates the complete peeling of a carrot which was peeled to see the difference and it was not a condition of this study's peeling.

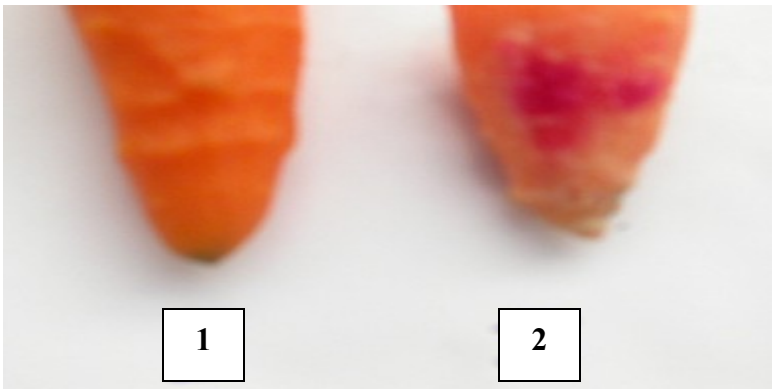

Figure 3.14.Penetration depth measurement. Carrot 1: There is not penetration of lye solution. Carrot 2: There is penetration of lye solution.

In Figure B3, carrot 1 demonstrates carrot before peeling and carrot 2 demonstrates chemical peeling of carrots. There was not any color difference before and after peeling. All of the complete peeling conditions of Table A1 were tested then same result was obtained. In Figure 3.15 the two carrots show the peeled carrots. There is no penetration inside the skin occurred. Depending on the concentration, the chemical peeling process is effective on carrots.

Figure 3.15.Carrots after peeling.

Analysis of the heat-affected tissue indicated that less carotenoids were present in the chemical peeling treatment than in the unheated (mechanical peeling) control. This was most likely due to easier extraction from the raw tissue (control) than from the heated peeled samples. It was not known if β-carotene (pro-vitamin A) is adversely affected by heat-caused cellular disruption (Walter and Giesbrecht, 1982).

Analysis of heat-affected vegetables has problems somewhat different from those of raw samples. Cooking softens the cell walls and makes the extraction of carotenoids easier. However, formation of degradation products during cooking may pose some analytical difficulties. Obtaining data on heat-affected foods are considered expensive, difficult and time-consuming, requiring considerable material resources and trained analysts (C.deSá and Rodriguez-Amaya, 2004).

Carotenoids are prone to degradation because of their structure. Their double bond results in oxidation quickly. The reaction rate increases with heat and light. Prooxidants and antioxidants affect the reaction rate, too. The second important factor after oxidation for degradation of carotenoids is the high temperature.

Furthermore, the applied temperature during the process not only increases the rate of carotenoid degradation, but also reverses the carotenoids from high vitamin A activity to low vitamin A activity (Tüzün, 1992; Cemeroğlu et al., 2001).

In Appendix C the chromatograms of chemical peeling treatments were shown. Standard chromatogram for β-carotene and the spectrum of β-carotene was shown for understanding the results. Mechanically peeled carrot was control chromatogram. In control, the peak showed its maximum absorbance and the presence of β-carotene was recognized. However, as mentioned before, heat caused degradation of β-carotene and also the difficulty of extraction of β-carotene from the heat-affected tissue. It is clearly understood that the chemical peeling changes the structure of β-carotene. The formula of β-carotene is at Appendix E. The amount of β-carotene could not be calculated due to these facts. Figure 3.16 expresses the chromatogram of the mathematical optimum value.

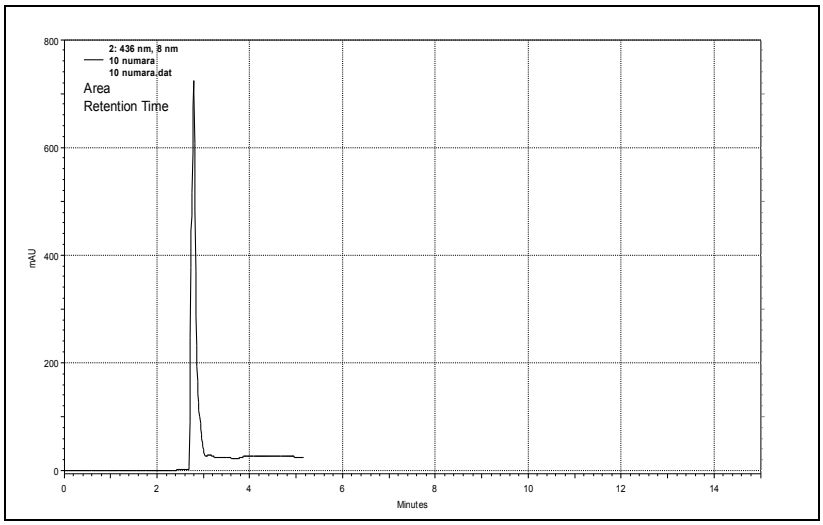

Figure 3.16. Chromatogram of mathematical optimum value of chemical peeling of carrots (77°C; 0.75%; 10.5 min).

The physical properties were also determined during the experiments. The color is the most significant physical property for consumer acceptance of the peeled product. Very good peeling (peeled surface higher than 98 %) was achieved for all concentrations and temperatures except 0.25 % at 57°C, and green color formation was observed on the surface of the carrot. Statistically, for total color difference

temperature is insignificant, however; concentration is significant. For complete peeling conditions, Figure 3.17 demonstrates total color difference values of the chemically peeled carrots.

According to statistical analysis, the total color difference (ΔE) of carrots only changes with concentration. The NaOH concentrations of 0.50 and 0.75% peeled carrots were alike. However; the NaOH concentration of 0.25 and 1.00% were alike. The reason for that result is at 0.25% the concentration was very low and at 1.00% the time was very low. So, the effect of solution to the color of carrot could be the same. In any case, the NaOH concentrations of 0.50 and 0.75% demonstrated the same effect due to the peeling time-concentration of lye solution relations. Finally, the ΔE results were only significant with concentration ($P<0.05$).

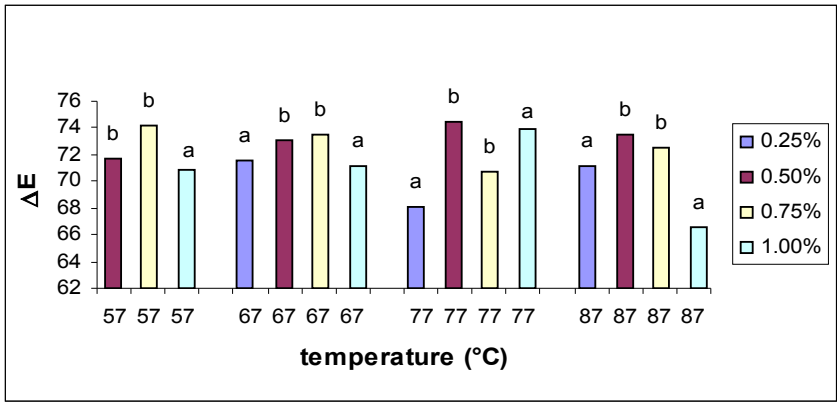

Figure 3.17. Variation of total color difference (ΔE) of carrots by peeling concentrations at different temperatures of caustic solutions. Each bar represents mean of three replications. Bars with the same letters are not significantly different at the $P< 0.05$ level.

Figure 3.18 demonstrates difference between raw carrot (C1) and chemical peeling. The total color difference (ΔE) of raw carrot and chemically peeled carrots were different from each other. The chemical peeling process changed the appearance of the product. However; the appearance of raw carrot is not good and the peel must be removed. The main comparison for total color difference is between the peeling methods. The other peeling method is conventional peeling method, which is mechanical peeling (C2). Figure 3.19 expresses the difference between

mechanical and chemical peelings. The ΔE of mechanically peeled carrot value was very closely to 0.50 and 0.75% values of all temperatures. There was difference between 0.50, 0.75% values of all temperatures and mechanical peeling.

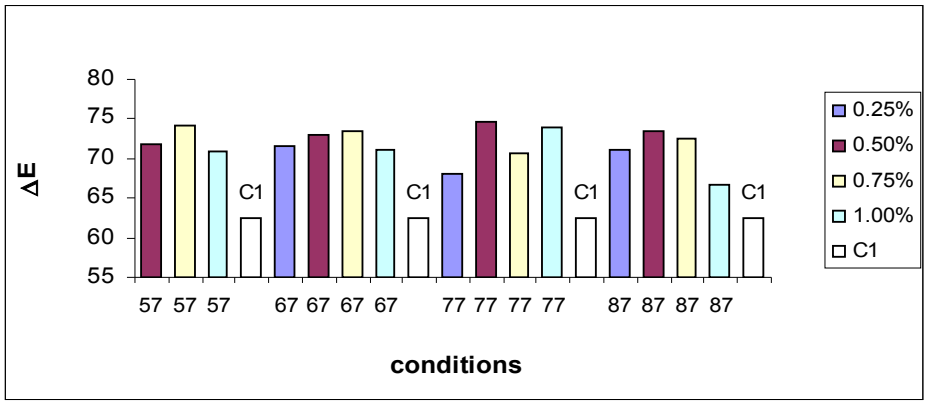

Figure 3.18. Variation of total color difference (ΔE) of carrots by peeling concentrations at different temperatures of caustic solutions with raw carrot (C1).Each bar represents mean of three replications.

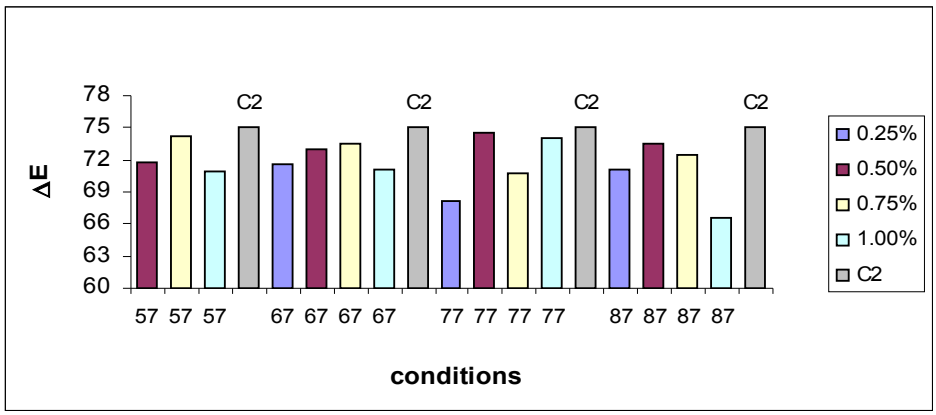

Figure 3.19. Variation of total color difference (ΔE) of carrots by peeling concentrations at different temperatures of caustic solutions with mechanically peeled carrot (C2). Each bar represents mean of three replications.

The lightness of the sample was expressed as (L*) value and temperature and concentration were responsible for the difference of the samples in chemical peeling, statistically. Figure 3.20 expresses the lightness of carrots by peeling concentrations at different temperatures of caustic solutions. An interesting result was obtained. The lightness of carrots was both significant and insignificant to the other carrots when the concentration of the lye solution was 0.75%. Also the L* value of carrots were insignificant when the concentration of lye solution was 0.50 and 1.00%.In addition, the L* value of carrots were significant when the concentration of the lye solution was 0.25% ($P<0.05$). Considering the concentration, the evaluation of lightness is complex. However; for chemical peeling, the more bright carrots were peeled at all concentrations of 57°C.

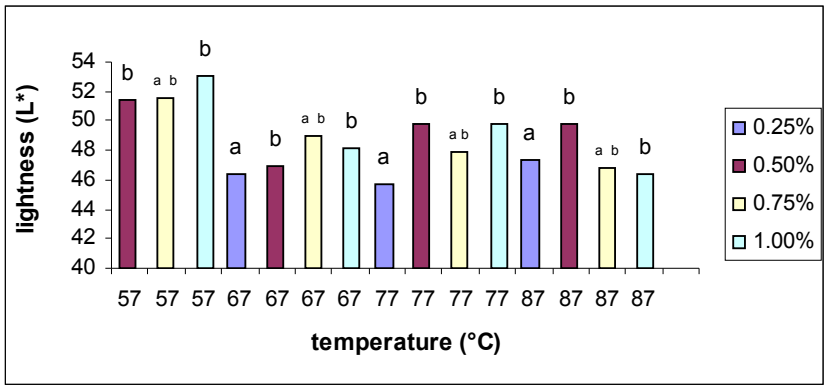

Figure 3.20. Variation of lightness (L*) of carrots by peeling concentrations at different temperatures of caustic solutions. Each bar represents mean of three replications. Bars with the same letters are not significantly different at the $P< 0.05$ level.

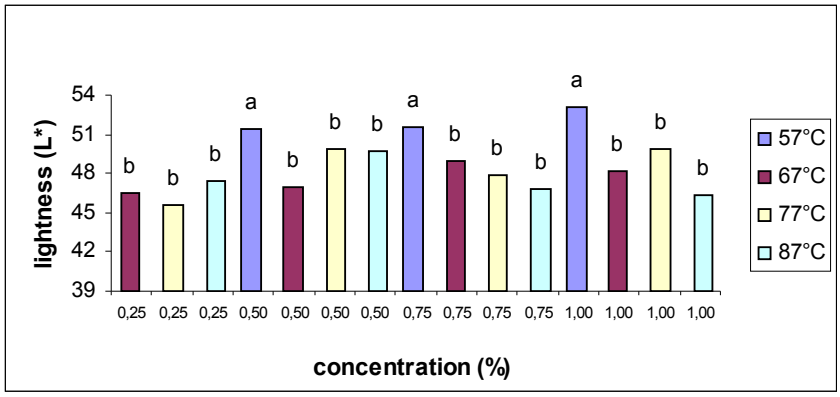

Figure 3.21. Variation of lightness (L*) of carrots by peeling temperatures at different concentrations of caustic solutions. Each bar represents mean of three replications. Bars with the same letters are not significantly different at the P< 0.05 level.

Figure 3.21 expresses the lightness of carrots by peeling temperatures at different concentrations of caustic solutions. The significant difference was between 57°C with other temperature samples. As stated before from Figure 3.20, more bright colors were obtained by using the 57°C solutions for peeling. They were also statistically different than others (P<0.05).

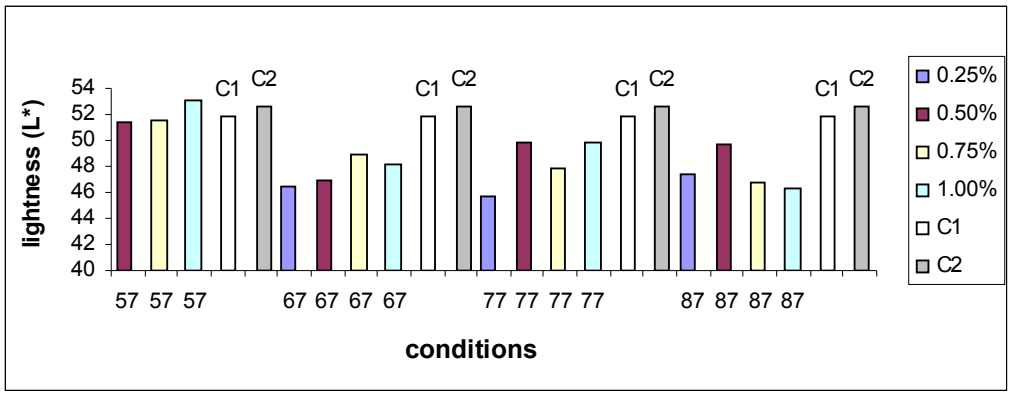

Figure 3.22. Variation of lightness value (L*) comparison with C1:raw carrot and C2:mechanically peeled carrot. Each bar represents mean of three replications.

Figure 3.22 expresses the difference between two control values with chemical peeling. The lightness of mechanically peeled carrot (C2) was like the raw carrot (C1). These two results were near only with 57°C chemically peeled carrots. The increase of temperature of the lye solution decreases the brightness of the product. Although they were less brilliant, they were still highly acceptable.

The other color measurements are the intensity of redness and yellowness for carrots because orange color is obtained by suitable combination of these two values. Redness and yellowness are coded by a* and b*, respectively. As mentioned before, total color difference (ΔE) is calculated by using lightness L*, redness a* and yellowness. For redness a* value, the temperature and concentration of the lye solution were significant, however; for yellowness b* value, only concentration is significant, statistically. Figure 3.23 demonstrates the a* values of carrots by peeling concentrations at different temperatures of caustic solutions. When the value of a* increases, the intense of redness increases. According to the figure, the evaluation of redness from one concentration to other had different behavior like the one in lightness values. The redness of carrots was both significant and insignificant to the other carrots when the concentration of lye solution was 1.00%. Except from 1.00%, the carrots which peeled with NaOH concentration of 0.50 and 0.75% were insignificant to each other, however, significant with 0.25 %($P<0.05$).

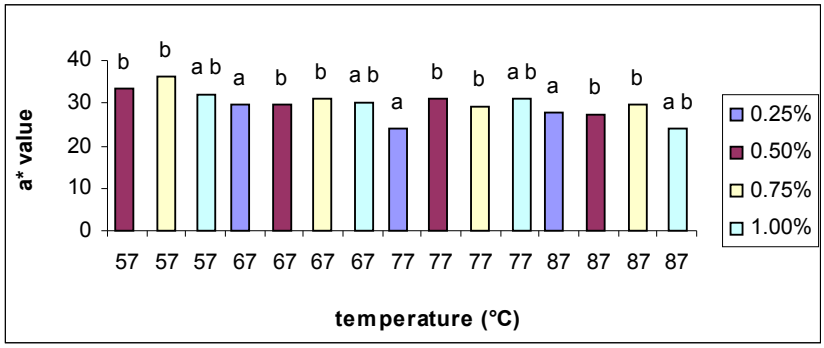

Figure 3.23. Variation of a* values of carrots by peeling concentrations at different temperatures of caustic solutions. Each bar represents mean of three replications.

Figure 3.24 demonstrates the a* values of carrots by peeling temperatures at different concentrations of caustic solutions. The redness intensity of chemically peeled carrots was recognized from this figure. The intense red carrots were peeled by the lye solution of 57°C. Also, they were statistically different from other lye temperature peeled samples ($P<0.05$). The intensity of redness of chemically peeled carrots was between C1 and C2 values. They were all compared with steam peeling values at appendix D.

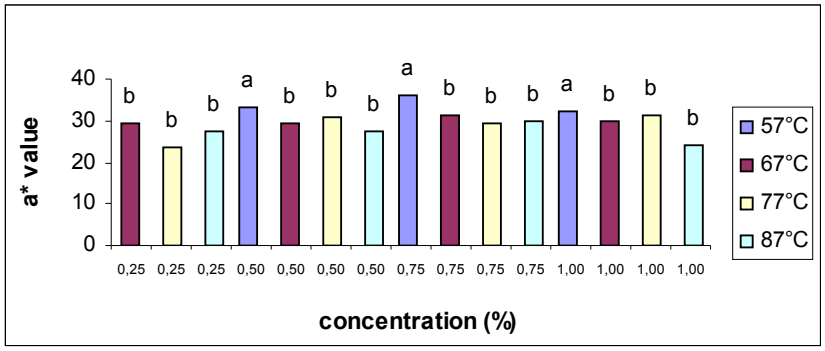

Figure 3.24. Variation of a* values of carrots by peeling temperatures at different concentrations of caustic solutions. Each bar represents mean of three replications.

The b* values show the intensity of yellowness. Intense red and intense yellow produces intense orange color. Statistically, temperature was insignificant, but concentration was significant. Figure 3.25 expressed the concentration significance of b* values. The yellowness of carrots was both significant and insignificant to the other carrots when the concentration of lye solution was 1.00%. The b* value of peeled carrots were insignificant when the lye concentration of 0.50 and 0.75% were used. However; they were significant when peeled with 0.25% lye solution ($P<0.05$).

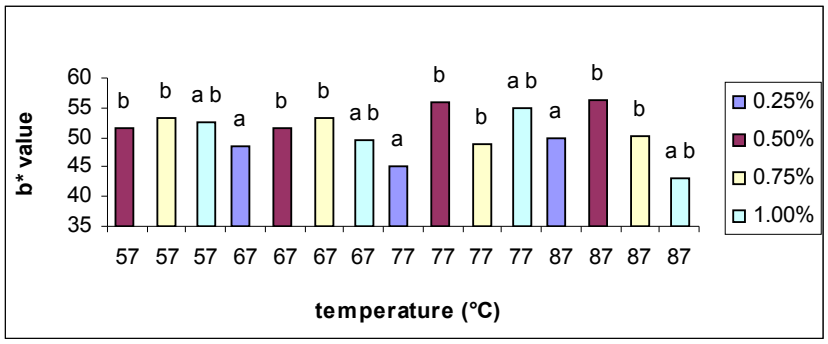

Figure 3.25. Variation of b* values of carrots by peeling concentrations at different temperatures of caustic solutions. Each bar represents mean of three replications.

The lye concentration of 0.50% had the intense yellow value than others, especially at 77 and 87°C. The intensity of yellowness of chemically peeled carrots was between C1 and C2 values. Finally, the chemically peeled carrots orange color was slightly good. As stated before, they were all compared with steam peeling values at appendix D.

The image of the chemical peeled carrot, which was mathematical optimum value, was at Appendix B.

3.4. Effect of Steam Peeling on Quality of Carrots

The results of analysis are shown in Tables A6 and A7 at appendix. There are two control samples for comparing the data efficiently. Control 1 (C1) is raw carrot and Control 2 (C2) is the mechanically peeled carrot. There was not a significant change of total soluble solids of steam peeled samples as compared with control samples. Setty et al (1993) indicated that no significant changes in the important constituents such a °Brix have been reported in tomatoes peeled by hot water, steam or others.

Floros and Chinnan (1988) indicated that high temperature causes mechanical failure of the cell and then the effect of heat on the tissue cause biochemical changes, melting and breakdown of substances such as pectins and polysaccharides. Heat penetration to the tissue altered the pectin in the middle lamella at above 60°C. Pectin in the primary and secondary walls changes, causing the separation of the compact lamella into fibrils and a local decrease in the amount of pectin is observed (Garrote et al., 2000).

As the severity of the treatment was increased, the weight loss of the carrot increased. Exposure time of the sample was the main parameter to evaluate the peeling loss of the carrots. Table A7 shows the weight loss-peeling yield-treatment relations. Mechanical peeling is the more severe treatment although time is not a parameter for it.

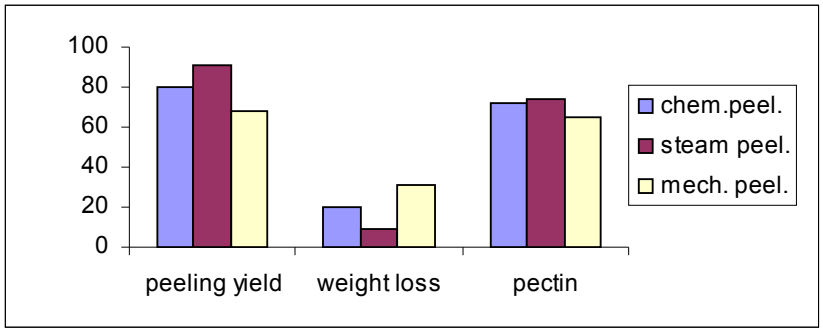

Figure 3.26. Peeling yield (%)-weight loss (%)-pectin(mg/g) relations of chemical, steam and mechanical peeling methods. Each bar represents mean of three replications.

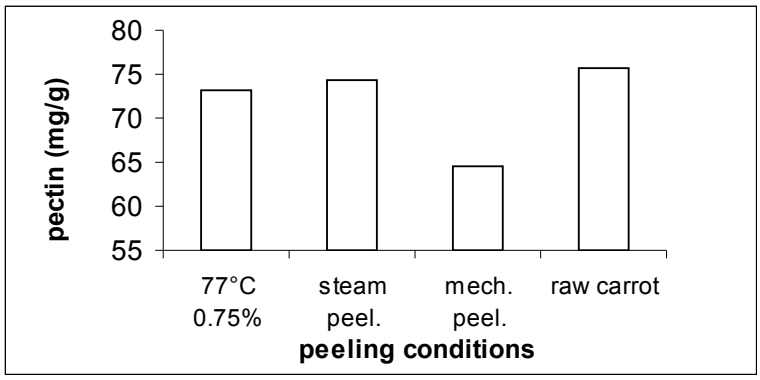

Figure 3.27. The comparison of the amount of pectin of raw carrot with steam, mechanical and chemical (77°C; 0.75%;10.5min.-optimum conditions) peeling methods. Each bar represents mean of three replications.

The time interval for steam peeling was not low, but the effectiveness of treatment was higher than chemical peeling. So, the weight loss was lower than chemical peeling. In addition to that, pectin amount was higher than chemical peeling results. Figure 3.26 expressed the relationship between the average values of chemical peeling data with mechanical and steam peeling. The peeling yield was, proportional with the amount of pectin.

Figure 3.27 expressed the amount of pectin difference between the three peeling methods with raw carrot. The amount of pectin of steam peeled carrot was very close to raw carrot value. The mechanically peeled carrot had the lowest pectin because it had the highest peel loss.

As mentioned before, the level of heat treatment was important in peeling treatments. The peel loss of steam peeling was lower than chemical peeling applications. The amount of pectin was higher. Carrots preheated above 85°C softened quickly as temperature rose (Fuchigami et al., 1995 (a)).The steam peeled carrot was expected less firm than the chemically peeled carrots, especially mathematical optimum value.

Analysis of the heat-affected tissue indicated that less carotenoids were present in the steam peeling treatment than in the unheated (mechanical peeling) control. This was most likely due to easier extraction from the raw tissue (control) than from the heated peeled samples. It was not known if β-carotene (pro-vitamin A) is adversely affected by heat-caused cellular disruption (Walter and Giesbrecht,

1982). Analysis of heat-affected vegetables has problems somewhat different from those of raw samples. Cooking softens the cell walls and makes the extraction of carotenoids easier. However, formation of degradation products during cooking may pose some analytical difficulties. (C.deSá and Rodriguez-Amaya, 2004).

Carotenoids are prone to degradation because of their structure. Their double bond results in oxidation quickly (Appendix E). The reaction rate increases with heat and light. The second important factor after oxidation for degradation of carotenoids is the high temperature. (Tüzün, 1992; Cemeoğlu et al., 2001).

In Appendix C the chromatograms of peeling treatments were shown. Standard chromatogram for β-carotene and the spectrum of β-carotene was shown for understanding the results. Mechanically peeled carrot was control chromatogram. In control, the peak showed its maximum absorbance and the presence of β-carotene was recognized. However, as mentioned before, heat caused degradation of β-carotene and also the difficulty of extraction of β-carotene from the heat-affected tissue. It is clearly understood that the steam peeling changes the structure of β-carotene. The amount of β-carotene could not be calculated due to these facts like chemical peeling.

The physical properties were also determined during the experiments. The color is the most significant physical property for consumer acceptance of the peeled product. In Figure 3.28 the total color difference values were compared. At 87°C 1.00% lye concentration value was very close to steam peeled carrot. The steam peeled product was also insignificant with 0.25 and 1.00% lye peeled products.

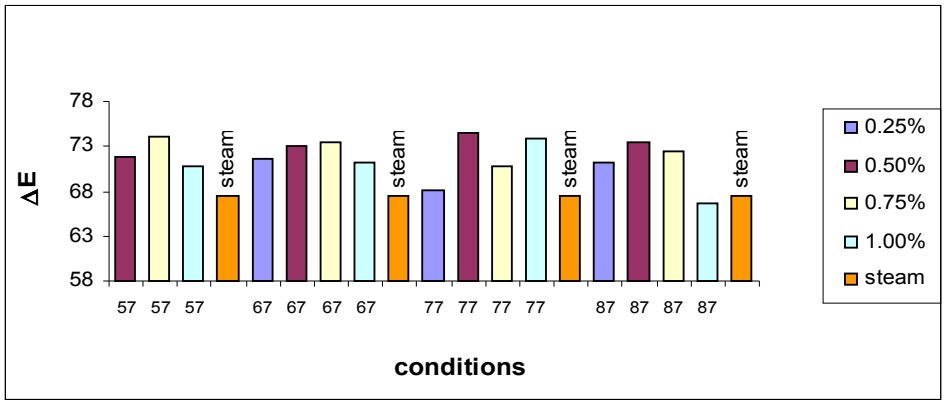

Figure 3.28. Variation of total color difference (ΔE) of carrots by peeling concentrations at different temperatures of caustic solutions with steam peeled carrots. Each bar represents mean of three replications.

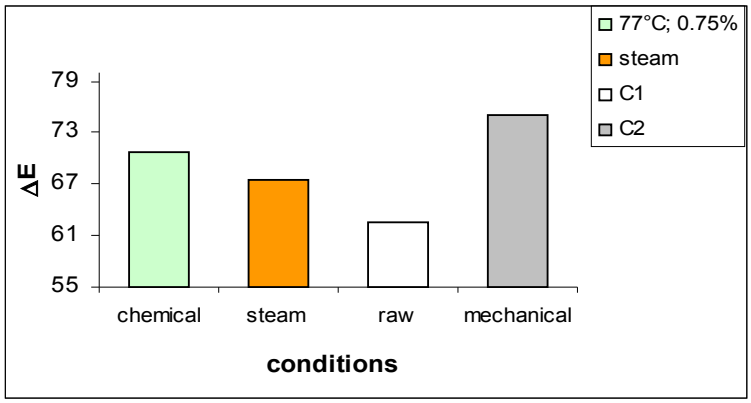

Figure 3.29. Comparison of total color difference (ΔE) of peeling treatments with raw carrot. Each bar represents mean of three replications.

In Figure 3.29, the total color difference values were compared. Chemical and steam peeled products close to each other. However; mechanical peeling was very different. Steam peeled carrot was close to raw carrot. Also, chemical peeled carrot was close to mechanical peeled carrot. Finally, there is a little difference between chemical and steam peeled products for ΔE.

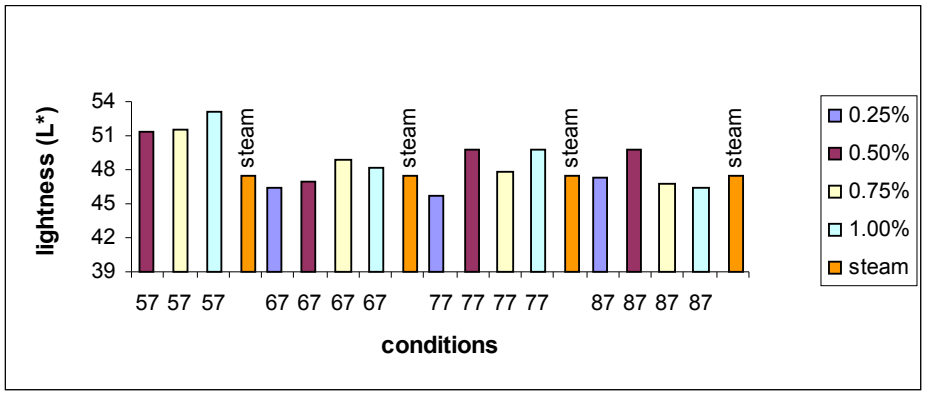

Figure 3.30. Variation of lightness (L) of carrots by peeling concentrations at different temperatures of caustic solutions with steam peeled carrot. Each bar represents mean of three replications.

In Figure 3.30, chemical and steam peeled products were compared. The brightness of steam peeled product was nearly close to chemical peeled products except for 57°C values. Steam peeled product was less brilliant but still highly acceptable.

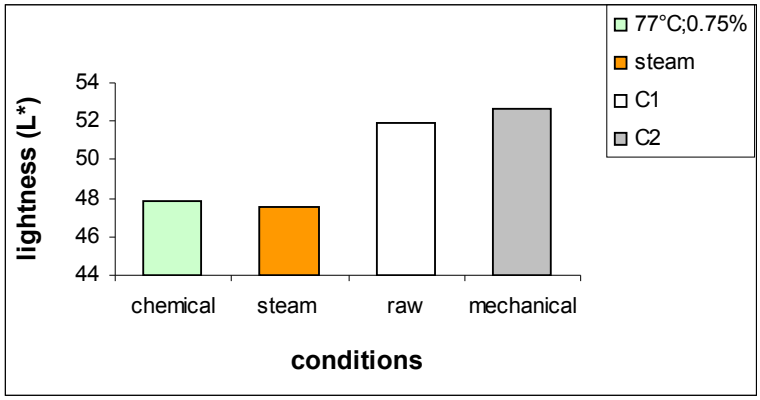

Figure 3.31. Comparison of lightness (L) of peeling treatments with raw carrot. Each bar represents mean of three replications.

There is a comparison between all products in Figure 3.31. Raw and mechanical peeled product was brighter than steam and chemically peeled product. The lightness of chemically peeled carrot was very close to steam peeled carrot. Heat-affected peeled carrots lost their lightness.

The redness and yellowness of peeled products were expressed as a* and b*, respectively. The intensity of redness can be understood from the Figure 3.32. The intense red value was mechanically peeled product. However, the redness of chemically peeled carrot was near to raw carrot. Steam peeled product was the less intense one.

The photograph of steam peeled carrot is at Appendix B.

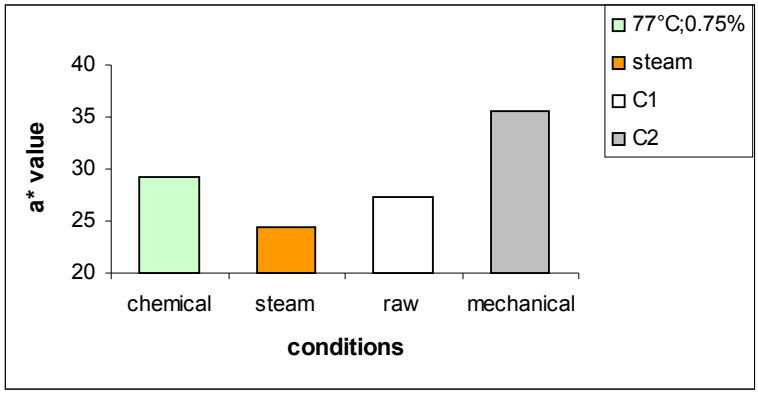

Figure 3.32. Comparison of a* value of peeling treatments with raw carrot. Each bar represents mean of three replications.

The intensity of yellowness produces the intensity of orange color. The highest yellowness is again the mechanical peeled product. The yellowness of steam peeled product is higher than raw carrot. The steam peeled product was yellowish orange color than the others. The chemically peeled product had the nearest b* value with steam peeled product (Figure 3.33). The other comparisons for a* and b* values were at Appendix D.

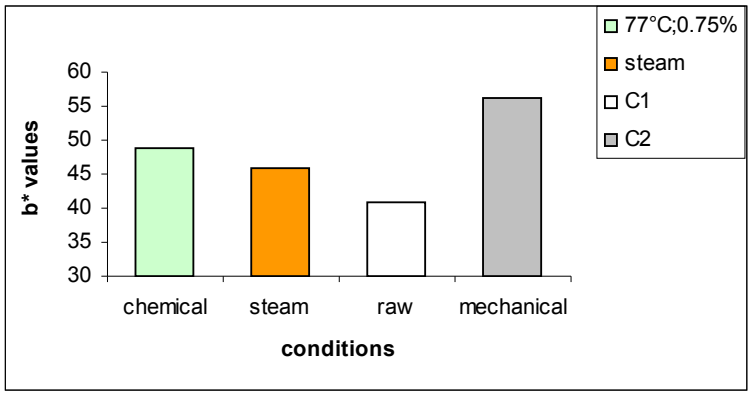

Figure 3.33. Comparison of b* value of peeling treatments with raw carrot. Each bar represents mean of three replications.

As clearly stated that, steam peeled product was less brilliant and yellowish but it was still highly acceptable.

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In chemical peeling of carrots, time-concentration and time-temperature relations are exponential. Peeling temperature other than concentration and time was found to be the most important factor affecting the peeling. Increases in both temperature and lye solution led to a decrease in peeling time. At low temperatures the time for complete peeling was considerably higher.

Very good peeling was achieved for all concentrations and temperatures except 0.25% at 57°C, and green color formation was observed on the surface of the carrot.

Treatment with 0.75% NaOH at 77°C for 10.5min was found to be optimum to peel the carrots mathematically.

In steam peeling mathematically complete peeling was achieved at 8.92min. The time-peeled surface area relations were exponential.

Depending on the temperature, concentration and time; chemical peeling process is superior to mechanical peeling, since it is effective on carrots having irregular shapes and cavities. Chemical peeling of carrots is not only an efficient method, but also reduces peeling losses. So, increases the yields and saves labor as well.

Comparing of steam peeling, chemical peeling of carrots is not as efficient as steam peeling due to the peel losses. The conditions for steam peeling will be developed and the time for the peeling can be decreased.

The lye solution did not affect the carrot after peeling. There was not any residue of NaOH on the surface and also inside of the carrot.

The color and brightness of chemically and steam peeled carrots were not significantly different from each other. However, they are different from mechanically peeled carrot. They were less brilliant than mechanically peeled carrot; but they were still acceptable. The chemically peeled carrot was more brilliant than steam peeled carrot.

For steam peeling, the development of the applied process may be possible. The higher steam temperature and lower waiting period can help to develop the finished quality of the carrot.

Considering the similarities between steam and chemical peeling mechanisms, it is reasonable to expect improved efficiency and reduced peeling loss in the case of steam as well. However; the two methods for peeling carrots are suitable when considering the needs for the processes. For cooking industries such as canning, the two processes are suitable. The need and conditions of the plant are important for selecting the method.

For freezing, the pectin degradation is important. The degraded amount of pectin determines the firmness of the carrot. The finished product quality mainly depends on the product quality. However, the dietary concerns indicate that the pectin amount is important. Also the peeling yield of the treatment and saving labor are important, too. The peeling condition of 0.75% at 77°C for 10.5min was selected due to these facts.

According to multiple regression for pectin amount, the temperature of lye solution and peeling time were significant for pectin, although the concentration of lye solution was insignificant for the amount of pectin ($P<0.05$). The temperature and concentration of lye solution were significant for peeling yield of the carrots ($P<0.05$)

The further research for heat-used peeled carrots is the determination of β-carotene content by developing the used method. The heat affected the tissue, so that the separation of the peaks was not obtained. This was due to the decrease of β-carotene content of carrots. Moreover, it was not known if β-carotene (pro-vitamin A) is adversely affected by heat-caused cellular disruption.

According to multiple regression analysis, temperature and concentration of lye solution was significant for peeling time ($P<0.05$).

Finally, the models represent the case quite well and such an equation is applicable to all varieties of carrots by simply inserting new constants into the equation for the variety and condition of the carrot used in the next operation. However, the two peeling methods are efficient than mechanical peeling and saves labor. The selection of the proper method mainly depends on the conditions of the application and the plant design of the next process.

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APPENDIX A

PEELING DATA FOR CARROTS

Table A1. Time-Temperature-Concentration-Score Relation for Chemical Peeling of Carrots.

57°C

0,25%	**0,50%**	**0,75%**	**1%**
22 min **	15 min **	8 min **	7min **
25 min **	18 min ***	11 min ***	10 min ***
27 min **	20 min ***	15 min ***	12 min ***
30 min ***	24 min ****	18,5 min ****	14,5 min****

67°C

0,25%	**0,50%**	**0,75%**	**1%**
12 min **	10 min **	7 min **	5 min **
15 min **	12 min ***	11 min ***	7 min ***
18 min ***	15 min ***	13 min ***	9 min ***
22 min ****	17,5min ****	15 min ****	11,5min****

77°C

0,25%	**0,50%**	**0,75%**	**1%**
10 min **	7 min ***	3,5 min ***	3,5 min***
12 min ***	10 min ***	5 min ***	5 min ***
14 min ***	12 min ***	7 min ***	7 min ***
18 min****	14 min ****	10,5 min ****	9 min ****

87°C

0,25%	**0,50%**	**0,75%**	**1%**
10 min **	7 min ***	5 min ***	3,5 min***
12 min ***	10 min ***	7 min ***	5 min ****
15 min ***	12 min ****	10 min ****	7 min ****
17 min****	14 min ****	12 min ****	8 min ****

Table A2. Operational Parameters & Constants for Time – Concentration Relations

Concentration (%, NaOH)	**Temperature (°C)**	**λ**	**γ**	**r^2**
0.25, 0.50, 0.75, 1.00	57	1.0602	-0.0730	0.9999
0.25, 0.50, 0.75, 1.00	67	1.6325	-0.1348	0.9806
0.25, 0.50, 0.75, 1.00	77	1.3323	-0.1494	0.9926
0.25, 0.50, 0.75, 1.00	87	0.7049	-0.1179	0.9484

Table A3. Operational Parameters & Constants for Time – Temperature Relations

Temperature (°C)	**Concentration (%, NaOH)**	**σ**	**β**	**r^2**
57, 67, 77, 87	0.25	5.2359	-0.0473	0.9150
57, 67, 77, 87	0.50	4.8374	-0.0340	0.9645
57, 67, 77, 87	0.75	4.8599	-0.0441	0.9491
57, 67, 77, 87	1.00	4.7123	-0.0448	0.9784

Table A4. Time-Score Relation for Steam Peeling of Carrots

107°C 130,7 kPa
2 min **
4 min **
6 min ***
8,5 min ****

Table A5. Operational Parameters & Constants for Time – Peeled Surface Area Relations

Temperature(°C)	**Pressure (kPa)**	**a**	**b**	**r^2**
107	130,7	3,9212	0,0767	0,9939

Table A6. Total Soluble Solids for Carrots (°Brix).

a. Chemically Peeled Carrots.

sample no	temp(°C)	conc(% NaOH)	time(min)	°Brix
1	57	0.50	24	8.4
2	57	0.75	18.5	8.3
3	57	1.00	14.5	8.2
4	67	0.25	22	8.4
5	67	0.50	17.5	8.3
6	67	0.75	15	8.1
7	67	1.00	11.5	7.9
8	77	0.25	18	8.3
9	77	0.50	14	8.2
10	77	0.75	10.5	7.9
11	77	1.00	9	7.8
12	87	0.25	17	8.3
13	87	0.50	12	8.1
14	87	0.75	10	7.9
15	87	1.00	5	7.7

b. Total Soluble Solids for Carrots (°Brix).

sample no	condition	°Brix
16	steam peeling	7.9
17	mechanical peeling	7.7
18	raw carrot	7.8

Table A7. Peeling yield-weight loss-pectin relations.

application	peeling yield(%)	weight loss(%)	pectin(mg/g)
1 57°C 0.50%	73.90	26.10	67.80
2 57°C 0.75%	74.60	25.40	73.59
3 57°C 1.00%	76.50	23.50	73.88
4 67°C 0.25%	74.09	25.91	70.50
5 67°C 0.50%	78.80	21.20	72.58
6 67°C 0.75%	81.45	18.55	73.02
7 67°C 1.00%	84.29	15.71	73.96
8 77°C 0.25%	78.30	21.70	69.62
9 77°C 0.50%	80.70	19.30	71.71
10 77°C 0.75%	81.30	18.70	73.23
11 77°C 1.00%	84.31	15.69	73.67
12 87°C 0.25%	78.20	21.80	69.85
13 87°C 0.50%	82.50	17.50	70.13
14 87°C 0.75%	84.50	15.50	71.01
15 87°C 1.00%	88.10	11.90	73.02
average	80.10	19.90	71.84
16 steam peel.	91.30	8.70	74.32
17 mech. peel.	68.50	31.50	64.55
18 raw carrot			75.77

APPENDIX B

CARROT IMAGES

Chemically Peeled Carrot

Figure B1. Mathematical optimum value (77°C; 0.75%; 10.5min).

Steam Peeled Carrot

Figure B2. 107°C; 130.7kPa; 8.5 min.

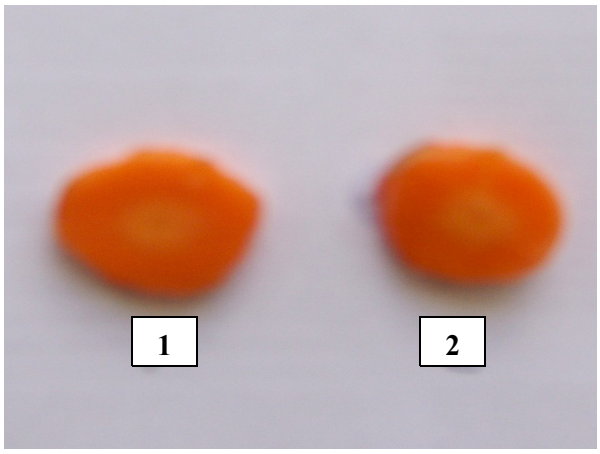


Figure B3.Carrots before and after peeling.

APPENDIX C

CHROMATOGRAMS

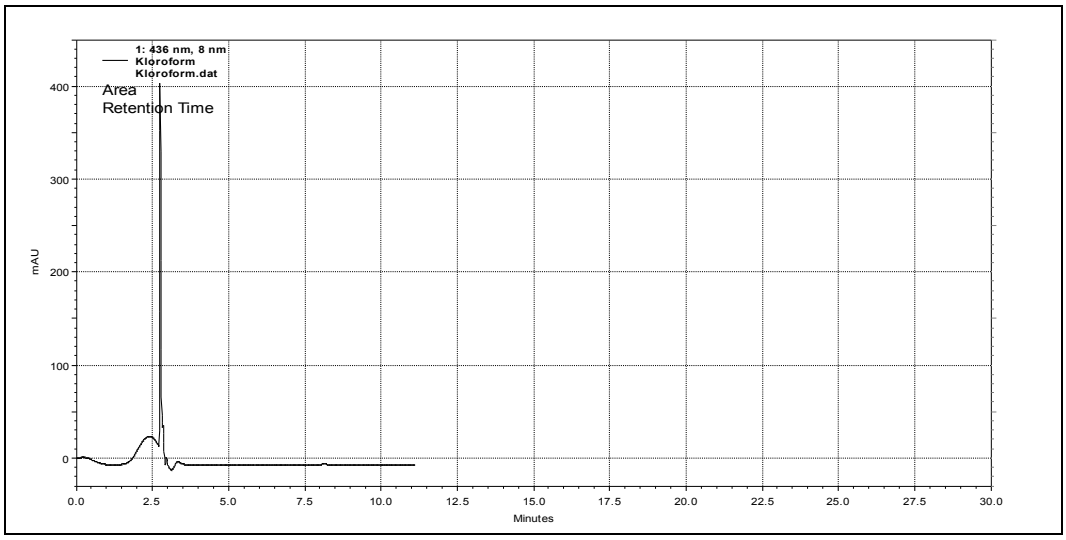


Figure C1: Mechanically peeled carrot (control)

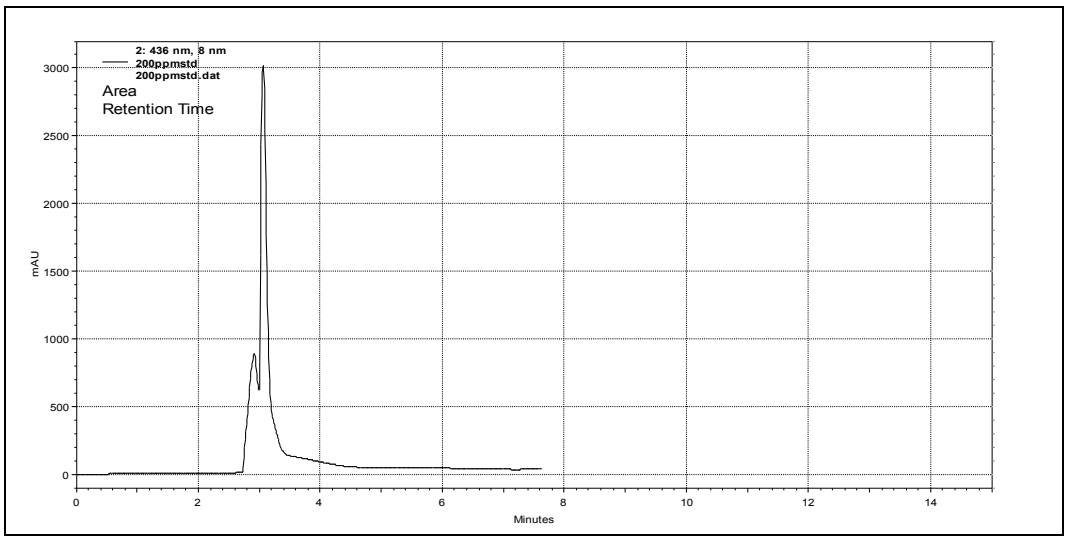


Figure C2: β-Carotene Standard Chromatogram (200 ppm)

Chemical Peeling

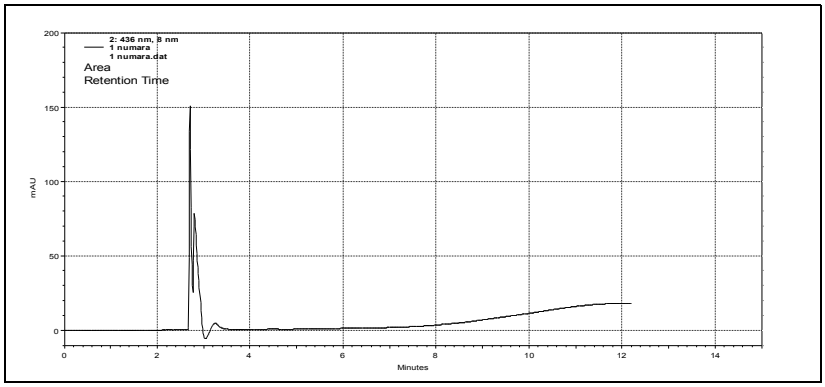


Figure C3: 57°C; 0.50% NaOH; 24min

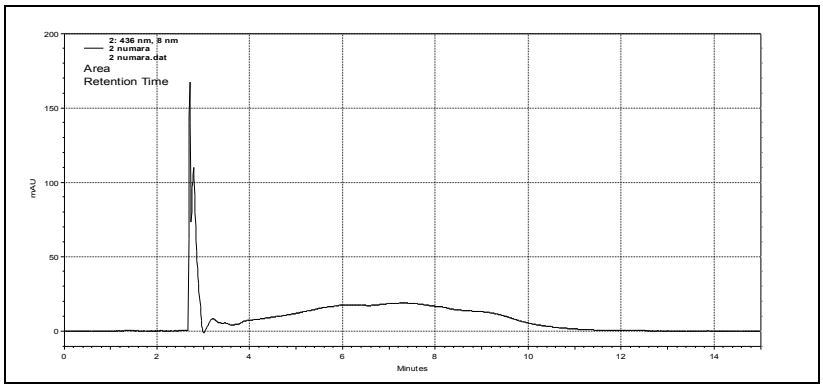


Figure C4: 57°C; 0.75% NaOH; 18.5 min

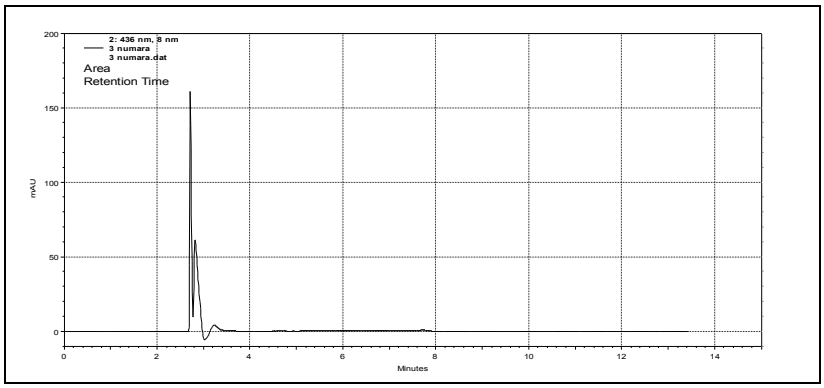


Figure C5: 57°C; 1.00% NaOH; 14.5 min

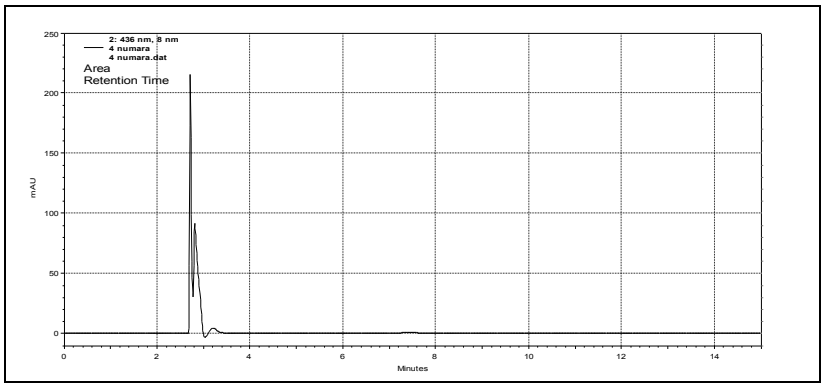


Figure C6: 67°C; 0.25% NaOH; 22 min.

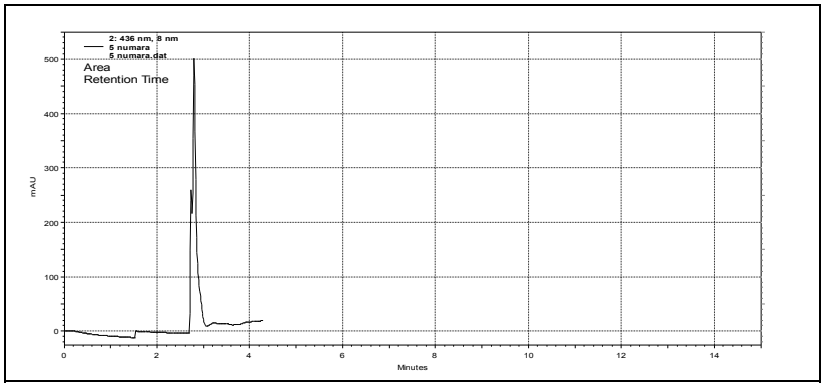


Figure C7: 67°C; 0.50% NaOH; 17.5 min.

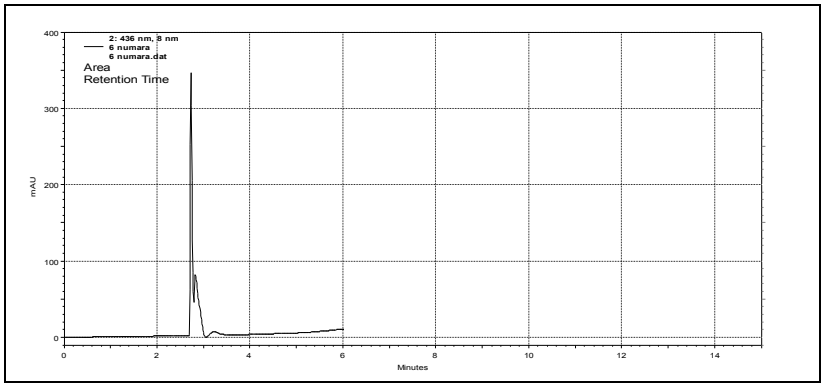


Figure C8: 67°C; 0.75% NaOH; 15 min.

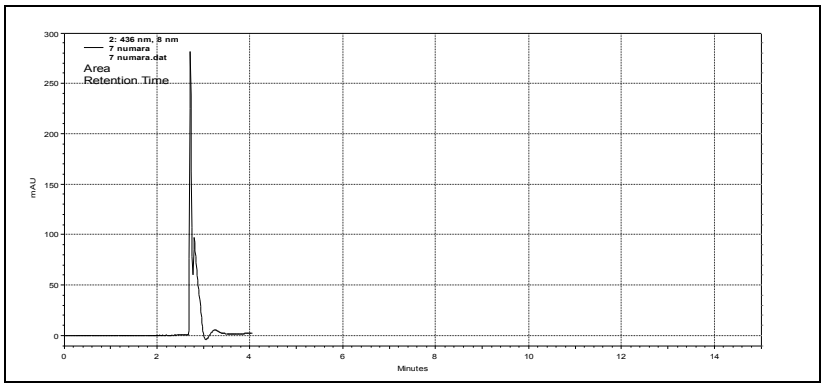


Figure C9: 67°C; 1.00% NaOH; 11.5 min.

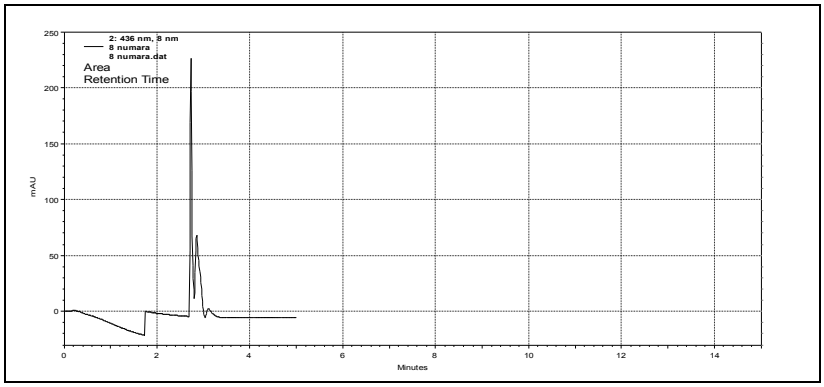


Figure C10: 77°C; 0.25% NaOH; 18 min.

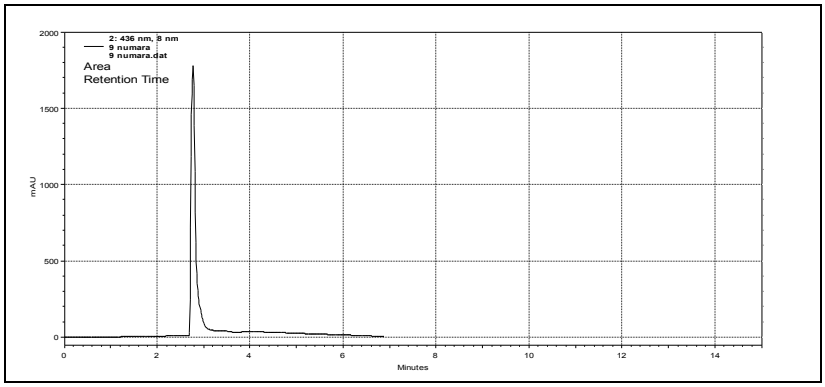


Figure C11: 77°C; 0.50% NaOH; 14 min.

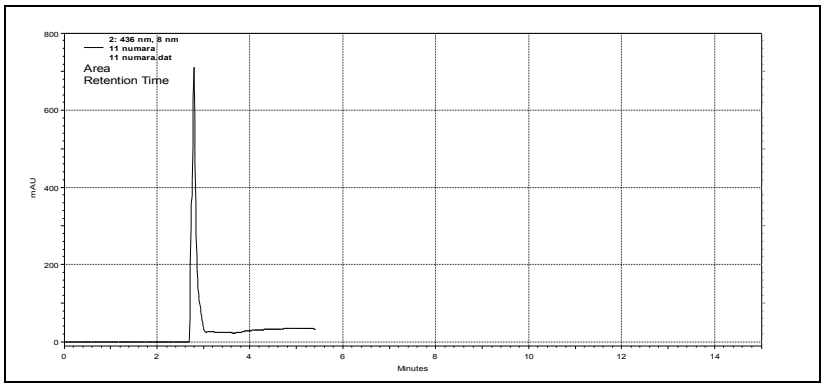


Figure C12: 77°C; 1.00% NaOH; 9 min.

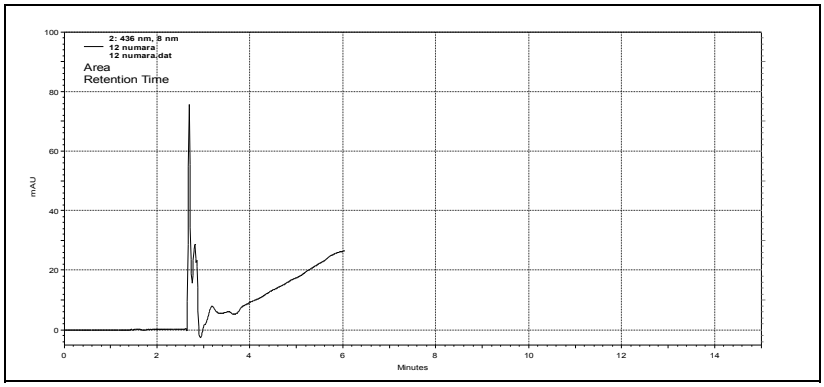


Figure C13: 87°C; 0.25% NaOH; 17 min.

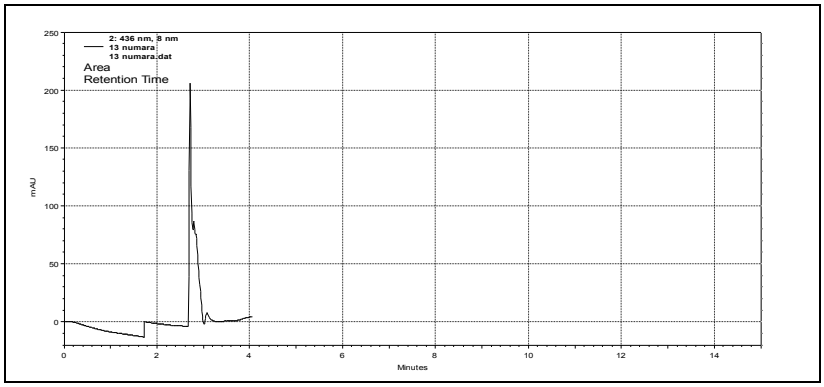


Figure C14: 87°C; 0.50% NaOH; 12 min.

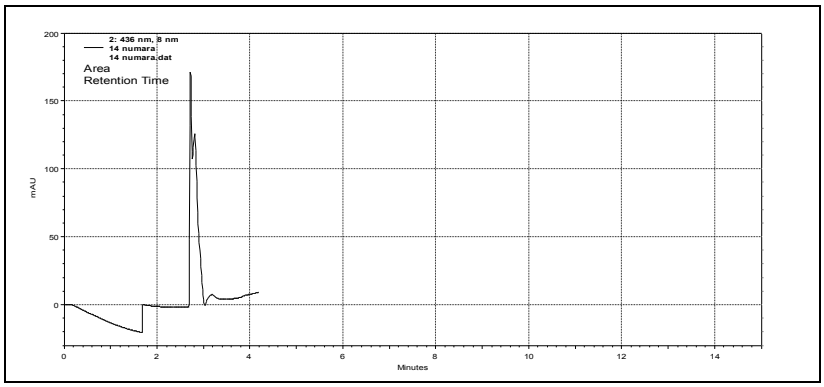


Figure C15: 87°C; 0.75% NaOH; 10 min.

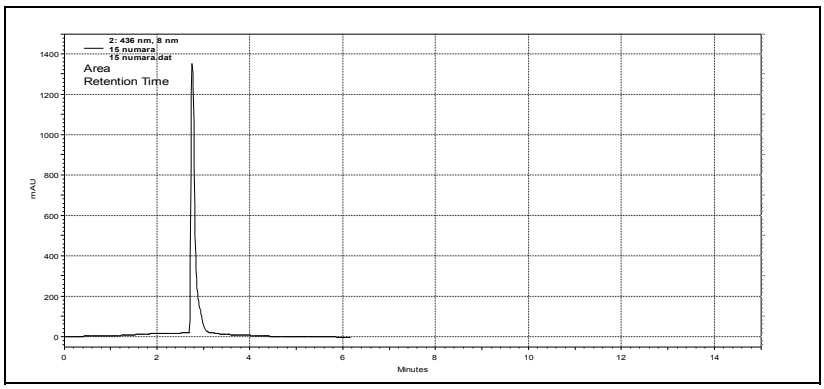


Figure C16: 87°C; 1.00% NaOH; 5 min.

Steam Peeling

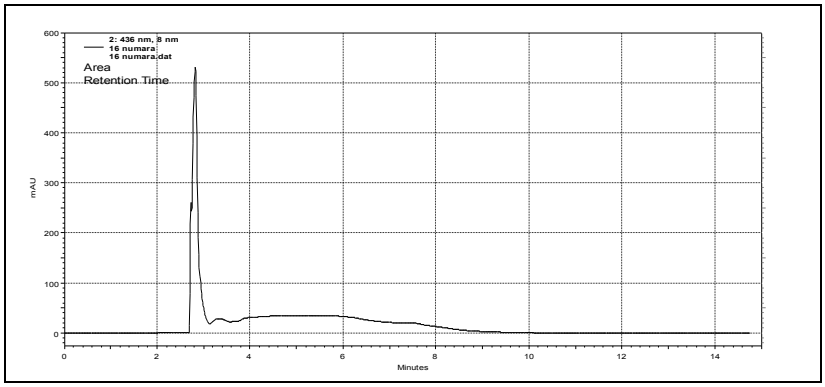


Figure C17: 107°C; 130.7kPa; 8.5 min.

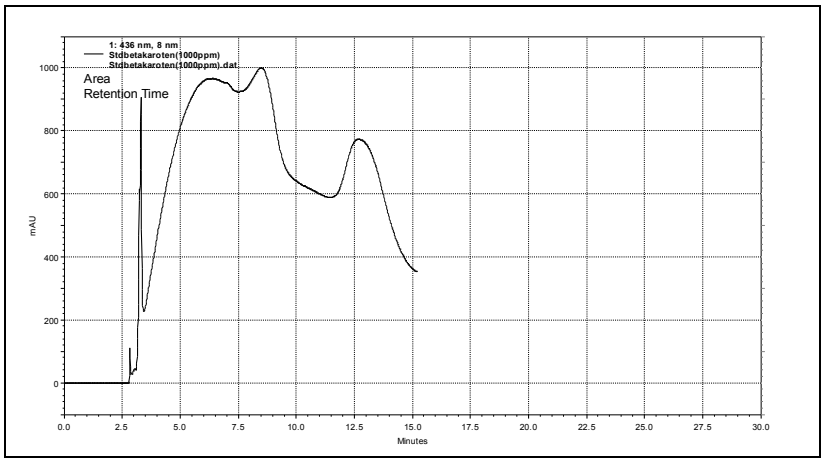


Figure C18: β-Carotene Standard Chromatogram (1000 ppm)

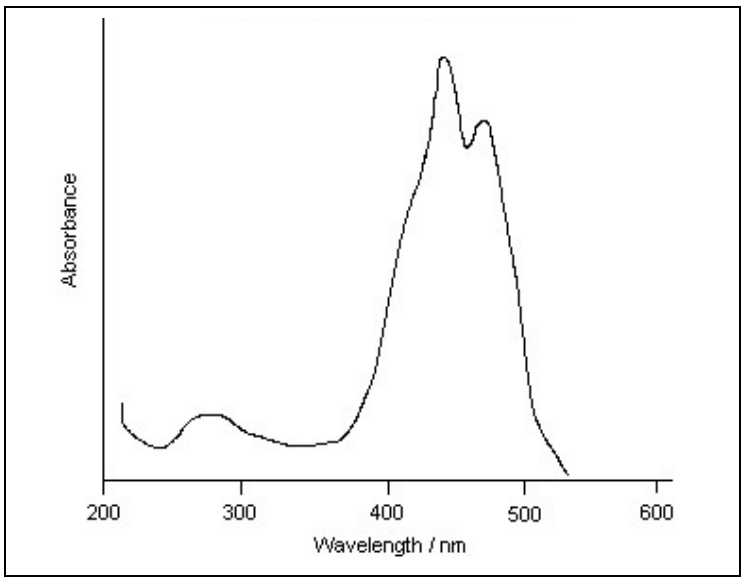


Figure C19: Absorption spectrum of β-Carotene

APPENDIX D

COLOR

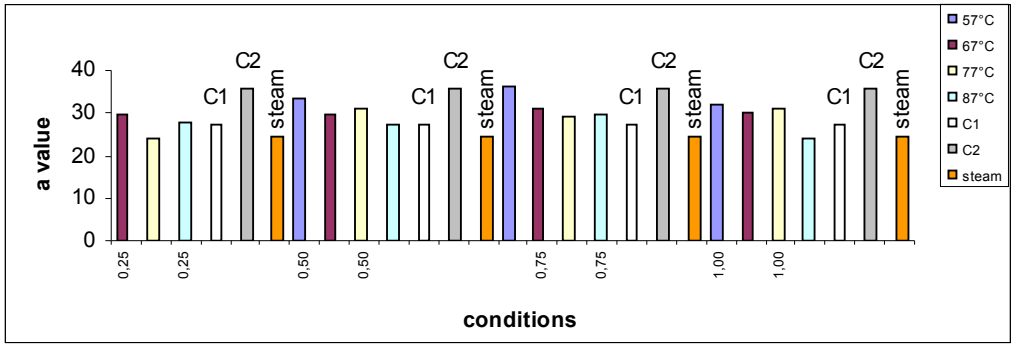


Figure D1: Variation of a* value comparison with chemical peeling,C1 ,C2 and steam peeling. Each bar represents mean of three replications.

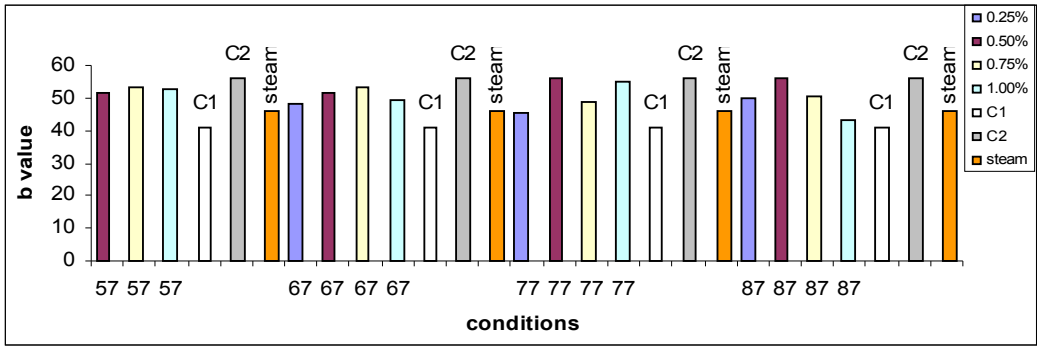


Figure D2: Variation of b* value comparison with chemical peeling,C1 ,C2 and steam peeling. Each bar represents mean of three replications.

APPENDIX E

Table E1.Full Nutritional Analysis

Name	Unit	Amount	Male %RDA	Female %RDA
Food energy	KCal	30.960	1.1%	1.4%
Protein	Gms	0.742	1.2%	1.5%
Total lipid (fat)	Gms	0.137	0.1%	0.2%
Carbohydrate, by diff.	Gms	7.301	1.6%	2.2%
Total saturated fat	Gms	0.022	0.1%	0.1%
Total monounsaturated fat	Gms	0.006		
Total polyunsaturated fat	Gms	0.055		
Cholesterol	Mg	0.000	0.0%	0.0%
Sodium	Mg	25.200	5.0%	5.0%
Total dietary fiber	Gms	2.160	8.6%	8.6%
Vitamin A	Re	2025.360	202.5%	253.2%
Vitamin A	IU	20252.880		
Ascorbic acid	Mg	6.696	11.2%	11.2%
Thiamin	Mg	0.070	4.7%	6.3%
Riboflavin	Mg	0.042	2.5%	3.3%
Niacin	Mg	0.668	3.5%	4.5%
Vitamin B6	Mg	0.106	5.3%	6.6%
Vitamin B12	Mcg	0.000	0.0%	0.0%
Folacin	Mcg	10.080	5.0%	5.6%
Potassium	Mg	232.560	11.6%	11.6%
Calcium	Mg	19.440	2.4%	2.4%
Phosphorus	Mg	31.680	4.0%	4.0%
Magnesium	Mg	10.800	3.1%	3.9%
Iron	Mg	0.360	3.6%	2.4%
Zinc	Mg	0.144	1.0%	1.2%
Pantothenic acid	Mg	0.142	2.8%	2.8%
Copper	Mg	0.034	1.7%	1.7%
Manganese	Mg	0.102	2.9%	2.9%
Ash	Gms	0.626		
Water	Gms	63.209		
Food energy	KJ	130.320		
Lauric acid (12:0)	Gms	0.001		
Myristic acid (14:0)	Gms	0.001		
Palmitic acid (16:0)	Gms	0.017		
Stearic acid (18:0)	Gms	0.001		
Palmitoleic acid(16:1)	Gms	0.001		

Oleic acid (18:1)	Gms	0.004		
Linoleic acid (18:2/n6)	Gms	0.048	0.8%	1.0%
Linolenic acid(18:3/n3)	Gms	0.007	0.4%	0.6%
Phytosterols	Mg	8.640		
Histidine	Gms	0.012	1.2%	1.5%
Isoleucine	Gms	0.030	3.7%	4.7%
Leucine	Gms	0.031	2.8%	3.5%
Lysine	Gms	0.029	3.0%	3.8%
Methionine	Gms	0.005		
Cystine	Gms	0.006		
Methionine+Cystine	Gms	0.011	1.0%	1.3%
Phenylalanine	Gms	0.023		
Tyrosine	Gms	0.014		
Phenylalanine+Tyrosine	Gms	0.037	3.4%	4.3%
Threonine	Gms	0.027	5.0%	3.1%
Tryptophan	Gms	0.008	2.8%	3.6%
Valine	Gms	0.032	4.0%	5.0%
Arginine	Gms	0.031		
Alanine	Gms	0.042		
Aspartic acid	Gms	0.099		
Glutamic acid	Gms	0.145		
Glycine	Gms	0.022		
Serine	Gms	0.025		

Recommended dietary allowances:

Vitamin A is the name for a group of compounds which have the biological activity of retinol. Vitamin A is measured in retinol equivalents (RE) which allows the different forms of vitamin A to be compared. One retinol equivalent equals 1 mcg of retinol or 6 mcg of beta carotene. Vitamin A is also measured in international units (IU) with 1 mcg RE equivalent to 3.33 IU.

Data source: USDA Nutrient Values Web Site

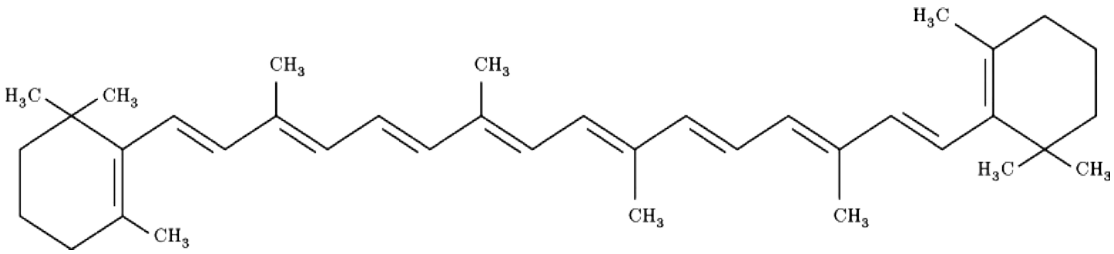
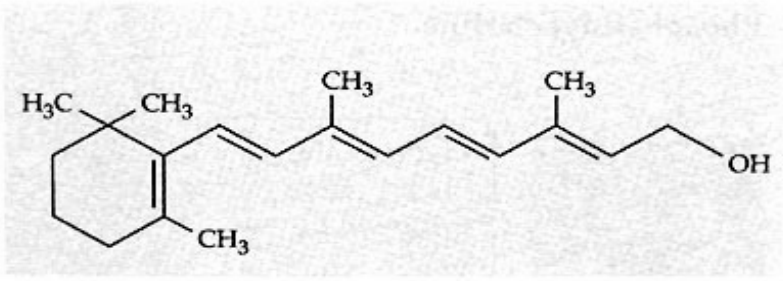


Figure E1. β-Carotene



Vitamin A

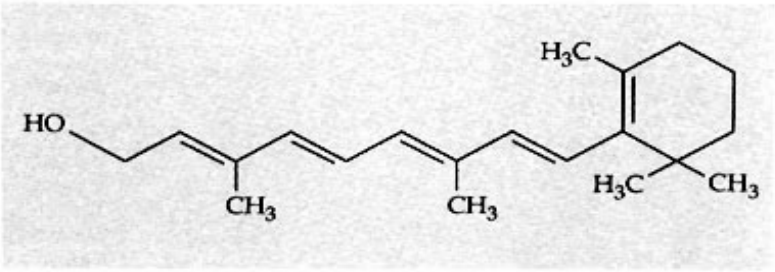


Figure E2. Vitamin A

APPENDIX F

STATISTICAL ANALYSIS

General Linear Model: TSS versus Temperature, Concentration

Factor	Type	Levels	Values
Temperature	fixed	4	57, 67, 77, 87
Concentration	fixed	4	0.25, 0.50, 0.75, 1.00

Analysis of Variance for TSS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	1.5939	1.5495	0.5165	1.73	0.177
Concentration	3	1.3962	1.3962	0.4654	1.56	0.215
Error	38	11.3419	11.3419	0.2985		
Total	44	14.3320				

S = 0.546324 R-Sq = 20.86% R-Sq(adj) = 8.37%

Regression Analysis: TSS versus Temperature-Concentration-Time

Predictor	Coef	SE Coef	T	P
Constant	8.8586	0.8168	10.84	0.000
Temperature	-0.008260	0.005739	-1.44	0.178
Concentration	-0.4963	0.2476	-2.00	0.070
Time	0.01284	0.01703	0.75	0.467

S = 0.06536 R-Sq = 93.5 %

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	0.67701	0.22567	52.82	0.000
Residual Error	11	0.04699	0.00427		
Total	14	0.72400			

The regression equation is:

TSS = 8.86 - 0.00826 T- 0.496 C+ 0.0128 t

General Linear Model: Pectin versus Temperature, Concentration

Factor	Type	Levels	Values
Temperature	fixed	4	57, 67, 77, 87
Concentration	fixed	4	0.25, 0.50, 0.75, 1.00

Analysis of Variance for Pectin, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	9.68	11.99	4.00	0.16	0.925
Concentration	3	67.85	67.85	22.62	0.88	0.467
Error	23	592.27	592.27	25.75		
Total	29	669.79				

S = 5.07452 R-Sq = 11.57% R-Sq(adj) = 0.00%

Regression Analysis: Pectin versus Temperature, Concentration, Time

Predictor	Coef	SE Coef	T	P
Constant	108.82	11.52	9.44	0.000
Temperature	-0.28321	0.08097	-3.50	0.005
Concentration	-6.451	3.494	-1.85	0.092
Time	-0.8315	0.2403	-3.46	0.005

S = 0.9221 R-Sq = 81.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	41.614	13.871	16.31	0.000
Residual Error	11	9.353	0.850		
Total	14	50.967			

General Linear Model: L, a, b versus Temperature, Concentration

Factor	Type	Levels	Values
Temperature	fixed	4	57, 67, 77, 87
Concentration	fixed	4	0.25, 0.50, 0.75, 1.00

Analysis of Variance for L, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	254.407	191.639	63.880	21.88	0.000
Concentration	3	50.366	50.366	16.789	5.75	0.001
Error	83	242.370	242.370	2.920		
Total	89	547.143				

S = 1.70884 R-Sq = 55.70% R-Sq(adj) = 52.50%

Analysis of Variance for a, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	483.45	382.29	127.43	29.72	0.000
Concentration	3	135.47	135.47	45.16	10.53	0.000
Error	83	355.92	355.92	4.29		
Total	89	974.83				

S = 2.07079 R-Sq = 63.49% R-Sq(adj) = 60.85%

Analysis of Variance for b, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	64.98	29.60	9.87	0.82	0.488
Concentration	3	353.92	353.92	117.97	9.77	0.000
Error	83	1002.27	1002.27	12.08		
Total	89	1421.17				

S = 3.47499 R-Sq = 29.48% R-Sq(adj) = 24.38%

Tukey Simultaneous Tests
Response Variable L

All Pairwise Comparisons among Levels of Temperature

Temperature = 57 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
67	-3.890	0.5454	-7.133	0.0000
77	-3.236	0.5454	-5.933	0.0000
87	-3.952	0.5454	-7.247	0.0000

Temperature = 67 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
77	0.65417	0.4933	1.3261	0.5491
87	-0.06250	0.4933	-0.1267	0.9993

Temperature = 77 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
87	-0.7167	0.4933	-1.453	0.4705

Tukey Simultaneous Tests
Response Variable L

All Pairwise Comparisons among Levels of Concentration

Concentration = 0.25 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.50	2.064	0.5454	3.785	0.0016
0.75	1.352	0.5454	2.479	0.0708
1.00	1.956	0.5454	3.587	0.0031

Concentration = 0.50 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.75	-0.7125	0.4933	-1.444	0.4757
1.00	-0.1083	0.4933	-0.220	0.9962

Concentration = 0.75 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
1.00	0.6042	0.4933	1.225	0.6130

Tukey Simultaneous Tests
Response Variable a

All Pairwise Comparisons among Levels of Temperature

Temperature = 57 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
67	-3.275	0.6609	-4.956	0.0000
77	-4.525	0.6609	-6.847	0.0000
87	-6.067	0.6609	-9.180	0.0000

Temperature = 67 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
77	-1.250	0.5978	-2.091	0.1645
87	-2.792	0.5978	-4.670	0.0001

Temperature = 77 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
87	-1.542	0.5978	-2.579	0.0556

Tukey Simultaneous Tests
Response Variable a

All Pairwise Comparisons among Levels of Concentration

Concentration = 0.25 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.50	2.238	0.6609	3.386	0.0059
0.75	3.500	0.6609	5.296	0.0000
1.00	1.213	0.6609	1.835	0.2646

Concentration = 0.50 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.75	1.263	0.5978	2.112	0.1578
1.00	-1.025	0.5978	-1.715	0.3227

Concentration = 0.75 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
1.00	-2.288	0.5978	-3.827	0.0014

Tukey Simultaneous Tests
Response Variable b

All Pairwise Comparisons among Levels of Temperature
Temperature = 57 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
67	-0.844	1.109	-0.761	0.8717
77	-0.206	1.109	-0.186	0.9977
87	-1.494	1.109	-1.347	0.5359

Temperature = 67 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
77	0.6375	1.003	0.6355	0.9203
87	-0.6500	1.003	-0.6480	0.9160

Temperature = 77 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
87	-1.287	1.003	-1.283	0.5760

Tukey Simultaneous Tests
Response Variable b

All Pairwise Comparisons among Levels of Concentration

Concentration = 0.25 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.50	5.710	1.109	5.149	0.0000
0.75	3.364	1.109	3.034	0.0167
1.00	1.981	1.109	1.786	0.2872

Concentration = 0.50 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.75	-2.346	1.103	-2.338	0.0976
1.00	-3.729	1.103	-3.717	0.0020

Concentration = 0.75 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
1.00	-1.383	1.103	-1.379	0.5160

General Linear Model: DE versus Temperature, Concentration

Factor	Type	Levels	Values
Temperature	fixed	4	57, 67, 77, 87
Concentration	fixed	4	0.25, 0.50, 0.75, 1.00

Analysis of Variance for DE, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Temperature	3	27.795	23.303	7.768	2.01	0.119
Concentration	3	139.445	139.445	46.482	12.02	0.000
Error	83	320.835	320.835	3.865		
Total	89	488.074				

S = 1.96608 R-Sq = 34.27% R-Sq(adj) = 29.51%

Tukey Simultaneous Tests
Response Variable DE

All Pairwise Comparisons among Levels of Temperature

Temperature = 57 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
67	0.5182	0.6275	0.826	0.8421
77	0.0694	0.6275	0.111	0.9995
87	-0.8460	0.6275	-1.348	0.5352

Temperature = 67 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
77	-0.449	0.5676	-0.791	0.8585
87	-1.364	0.5676	-2.404	0.0843

Temperature = 77 subtracted from:

Temperature	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
87	-0.9154	0.5676	-1.613	0.3771

Tukey Simultaneous Tests
Response Variable DE

All Pairwise Comparisons among Levels of Concentration

Concentration = 0.25 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.50	2.9294	0.6275	4.6687	0.0001
0.75	2.4565	0.6275	3.9150	0.0011
1.00	0.3574	0.6275	0.5695	0.9409

Concentration = 0.50 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
0.75	-0.473	0.5676	-0.833	0.8385
1.00	-2.572	0.5676	-4.532	0.0001

Concentration = 0.75 subtracted from:

Concentration	Diff. of Means	SE of Diff	T-Value	Adj. P-Value
1.00	-2.099	0.5676	-3.699	0.0022

REGRESSION ANALYSIS

Peeling Time versus Temperature, Concentration

Predictor	Coef	SE Coef	T	P
Constant	47.365	2.172	21.81	0.000
Concentration	-14.063	1.066	-13.19	0.000
Temperature	-0.32408	0.02666	-12.16	0.000

S = 1.108 R-Sq = 95.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	347.71	173.85	141.66	0.000
Residual Error	12	14.73	1.23		
Total	14	362.43			

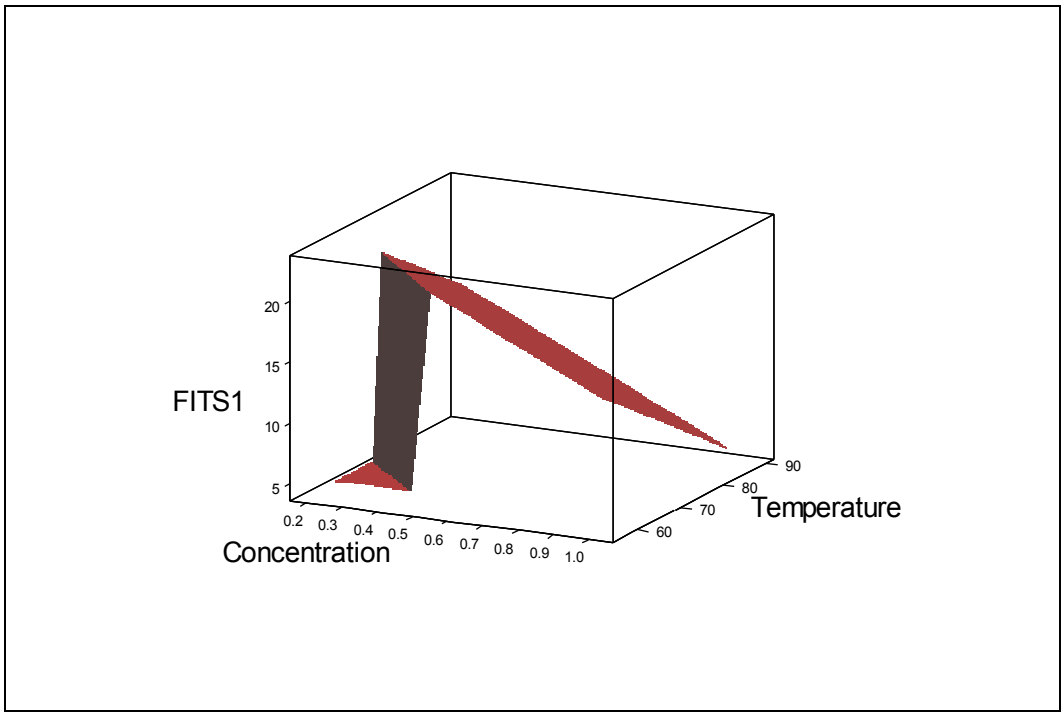


Figure F1. Temperature- concentration-peeling time(fitted time for regression equation) relations for chemical peeling of carrots.

Peeling Yield versus Concentration, Temperature

Predictor	Coef	SE Coef	T	P
Constant	56.282	4.607	12.22	0.000
Concentration	10.551	2.262	4.66	0.001
Temperature	0.23237	0.05655	4.11	0.001

S = 2.350 R-Sq = 73.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	188.057	94.029	17.03	0.000
Residual Error	12	66.275	5.523		
Total	14	254.333			