



Mathematical Model for the Chemical Peeling of Spherical Foods

J. A. Barreiro, V. Caraballo* & A. J. Sandoval

Departamento de Tecnología de Procesos Biológicos y Bioquímicos, Universidad Simón Bolívar, Apartado 89000, Caracas 1080-A, Venezuela

(Received 1 May 1993; revised version received 30 April 1994; accepted 9 May 1994)

ABSTRACT

A model for the chemical peeling process of foods with spherical geometry, using the concept of the unreacted core model, has been developed. Equations for the prediction of peeling times, weight losses and texture changes during peeling, as a function of the variables involved in the process were established. The model was experimentally evaluated using guava, showing significant or highly significant relationships for the fitting of the experimental data to the equations comprising the model. A general procedure to calculate peeling maps relating different ranges of alkali concentration (0.8–15%), peeling temperatures (70–100°C) and texture in the peeled product (7–12 mm penetration) for various peel thickness (1–7 mm) was illustrated for this fruit.

NOTATION

$A_{\text{(aqueous)}}$	Alkali in aqueous media of concentration Ca (% w/v)
$B_{\text{(solid)}}$	Solid product being reacted
b, q	Stoichiometric coefficients
b''	Constant ($\text{gmol min/cm}^3 \text{ cm}$)
C_a	Alkali concentration (% w/v)
E_a	Energy of activation for chemical peeling (cal/mol)
E_a	Energy of activation for texture changes (cal/mol)
K_i	Velocity constant in the texture equation (cm/min)
K_o	Constant (cm/min)

* Deceased.

K_s	Surface reaction constant (cm/min)
M	Apparent molecular weight of the peel (g/g mol)
N_A	Moles of alkali reacting (g mol)
N_B	Moles of food peel reacting (g mol)
$P_{(\text{solid})}$	Product converted after reaction
R	Universal gas constant (cal/K mol)
R_e	External radius of the fruit before peeling (cm)
R_o	Average apparent density of the peel (g/cm ³)
r	Radius of the product at any moment during peeling (cm)
r_c	Radius of the unreacted core (cm)
r^i	Correlation coefficient
S	Solution remaining after reaction
T	Peeling temperature (K, °C)
T_{ex}	Texture (mm penetration)
T_{exo}	Initial texture (mm penetration)
t	Peeling time (min)
v	Volume of the product (cm ³)
W, w	Weight losses during peeling (g)
θ	Peeling time to remove all the peel of thickness (min)

INTRODUCTION

Peeling is a unit operation frequently used during the processing of fruit and vegetable products. It is directly related to pulp losses which can take place due to defective peeling, therefore affecting production yields and organoleptic quality.

Different peeling procedures are used, involving methods such as manual, mechanical, steam, flame, abrasive and chemical peeling, and sometimes their combinations (Cruess, 1958; Hersom & Hulland, 1964; Woodroof & Luh, 1975). Manual peeling is done in many food processing industries, however it has serious disadvantages such as high weight loss during peeling, reduced yields and high labour costs. Steam, mechanical, flame and abrasive peeling, and other methods such as laser peeling, are used for certain products with specific characteristics that can be adapted to such processes.

Chemical peeling may be used with a large number of fruits and vegetables. Normally it is done using a hot solution of caustic soda (lye peeling), in which the product is immersed for a certain period. Afterwards, the lye residues and the reacted peel are removed by mechanical means that include washing and neutralization of caustic residues with an acid treatment, usually using an organic acid such as citric acid.

The phenomena taking place during chemical peeling are complex and involve mass diffusion and chemical reactions. Once the lye is in contact with the peel it acts by dissolving the natural epicuticular and cuticular waxes, diffusing afterwards into the fruit, reacting and breaking down the epidermal and hypodermal cell walls, solubilizing the middle lamella, resulting in the separation of the skin (Floros *et al.*, 1987). The rate of peeling is a function of the lye concentration, temperature and treatment time, as well as other variables

intrinsic to the product, such as form and geometry, ripeness, peel thickness, and type or variety. The process combines both chemical and thermal treatment. The effect of the lye in peeling is increased as its temperature nears the boiling point. The relationship between lye concentration, temperature and treatment time must be determined for each product in order to avoid pulp and weight losses by over-peeling. On the other hand, high temperatures for excessive periods could have a cooking effect, affecting texture and the organoleptic and nutritional properties of the product (Woodroof *et al.*, 1942; Reeve, 1976; Powers *et al.*, 1977; Walter & Giesbretch, 1982; Walter & Schadel, 1982; Floros & Chinnan, 1988; Floros & Chinnan, 1990).

Various research works have been done in order to establish a relationship between lye concentration, temperature and time, and to obtain practical results for the chemical peeling of various fruits and vegetables, including products such as peaches (Olsen, 1941; Lankler & Morgan, 1944); pears (Lankler & Morgan, 1944); carrots (Havighorst, 1943; Stateler, 1945; Lee & Downing, 1973); potatoes (Mazzola, 1943); sweet potatoes (Woodroof & Atkinson, 1944); beets (Lee & Downing, 1973); apples (Powers *et al.*, 1977; Smith *et al.*, 1981); mandarins (Athanasopoulos & Vagias, 1987); pimiento peppers (Floros & Chinnan, 1987, 1988); tomatoes (Hart *et al.*, 1974; Weaver *et al.*, 1980; Schline *et al.*, 1984); papayas (Cancel *et al.*, 1970); citrons (Cancel *et al.*, 1972); yams (Rivera-Ortiz & González, 1972). In Woodroof *et al.* (1942, 1984) practical conditions for peeling several fruits and vegetables are presented, including figs, peaches, sweet potatoes, potatoes, carrots, pears and pumpkins. Practical recommendations for many products are also presented by Cruess (1958) and Woodroof and Luh (1975).

Most of these investigations present empirically determined peeling conditions, with the exception of those of Athanasopoulos and Vagias (1987), who adjusted the results for peeling mandarin segments to a zero and first order reaction for peeling temperature and lye concentration, respectively, and Floros and Chinnan (1987, 1988) who used response surface methodology to optimize the peeling process of pimiento peppers, based on empirical peeling data in one and two stage processes.

No theoretical models for the chemical peeling process of fruits and vegetables were found in the literature reviewed. The objective of this research work was to develop a mathematical model for the chemical peeling process of foods with spherical geometry. The model was experimentally evaluated with peeling data obtained for guava (*Psidium guajava* L., var. Dominica Roja).

DEVELOPMENT OF THE CHEMICAL PEELING MODEL

Basic considerations

The following assumptions and considerations were taken into account for the development of the model:

1. The food to be peeled has a spherical geometry, with external radius R_e and peel thickness $(R_e - r_c)$ (see Fig. 1).
2. The reaction mechanism follows an unreacted core model. The reaction starts at the external surface of the food, proceeding towards the inner

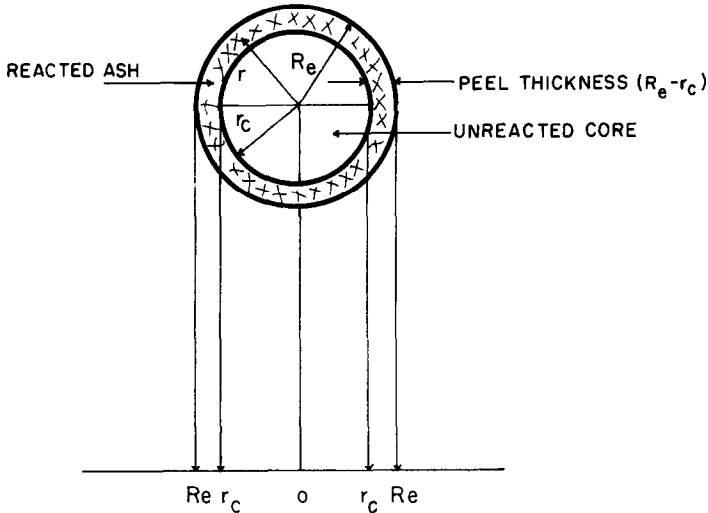
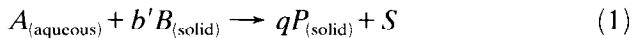


Fig. 1. Unreacted core model for spherical geometry showing a section of the fruit with the geometrical parameters related.

parts, leaving a layer of completely converted reacted material on the surface and a central core of unreacted product in the center. As the process takes place the inner core diameter is reduced (Levenspiel, 1988). Reaction takes place uniformly over the product surface.

3. The reaction rate for a product with specific characteristics (dimensions, maturity, ripeness, variety and texture among others) is dependent on the alkali concentration, temperature and time of peeling.
4. The temperature of the product at the location being reacted is similar to that of the aqueous peeling medium. This assumption supposes a high surface heat transfer coefficient.
5. The temperature and concentration of the lye solution remain constant during the peeling process.
6. Mode of reaction. The chemical reaction is controlled by the following equation:



The reaction rate is independent of diffusion of alkali through the reacted product ash, defined as the amount of reacting product proportional to the available surface of the unreacted core.

Development of the model

Peeling equation

The surface reaction rate for a product with spherical geometry can be determined by the equation (Levenspiel, 1988)

$$-(1/4\pi r^2)(dNE/dt) = -(b'/4\pi r^2)(dNA/dt) = b' K_s C_a \tag{2}$$

The amount (moles) of peel reacting per volume reacted is given by

$$dNE = (R_o/M) dv = (R_o/M) d(4\pi r^3/3) = 4\pi(R_o/M) r^2 dr \quad (3)$$

Substituting eqn (3) into eqn (2) leads to

$$-(R_o/M) dr/dt = b' K_s C_a \quad (4)$$

Separating variables and integrating between the limits R_e and r (i.e. the peel thickness being peeled) and 0 and t (peeling time), and solving for t

$$t = (R_o/M)(R_e - r)/(b' K_s C_a) \quad (5)$$

Equation (5) can be used to calculate the peeling time required for a thickness of peel ($R_e - r$) for a given alkali concentration C_a .

The time required to react a peel of total thickness ($R_e - r_c$) is

$$\theta = (R_o/M)(R_e - r_c)/(b' K_s C_a) \quad (6)$$

If the total reaction time is exceeded ($t > \theta$), pulp will be reacted and the weight losses will increase.

The effect of the alkali temperature in the reaction rate was taken into account by the Arrhenius equation

$$K_s = K_o \exp(-E_a/RT) \quad (7)$$

Substituting eqn (7) into eqn (5)

$$t = ((R_o/M)/(b' K_o) \exp(-E_a/RT)) ((R_e - r)/C_a) \quad (8)$$

where $(R_o/M)/(b' K_o)$ is a constant (b'') for a given food product with defined characteristics. Substituting into eqn (8) gives

$$t = b'' \exp(E_a/RT) ((R_e - r)/C_a) \quad (9)$$

Equation (9) can be linearized in the following form

$$\ln(t/((R_e - r)/C_a)) = \ln b'' + E_a/RT \quad (10)$$

Equations (9) and (10) represent the mathematical model for the chemical peeling of foods with spherical geometry, and permit the calculation of the peeling time as a function of the variables involved in this process.

Weight losses during peeling

The weight loss during peeling (W) can be calculated, knowing the density of the peel, by the following equation

$$dw = -R_o dv \quad (11)$$

Substituting for the volume of a sphere as a function of the radius, integrating between the limits 0 and W and R_e and r

$$W = (4\pi/3) R_o (R_e^3 - r^3) \quad (12)$$

solving for r

$$r = (R_e^3 - (3W/(4\pi R_o)))^{1/3} \quad (13)$$

The radius of peel remaining after some time of peeling, resulting in a weight loss W , can be estimated using eqn (13).

Texture changes during peeling

During chemical peeling, the fruit is subjected to a heat treatment that affects its texture. Texture is dependent on temperature and time of treatment but is independent of the alkali concentration (Caraballo, 1991). It was postulated that the change of texture during peeling followed an apparent first order kinetics (Huang & Bourne, 1983; Anantheswaran *et al.*, 1985; Bourne, 1987), and the rate constant followed the Arrhenius equation for changes with temperature:

$$d(\text{texture}) = K_i dt \quad (14)$$

and

$$K_i = K'_o \exp(-E'_a/RT) \quad (15)$$

Combining eqns (14) and (15), and integrating between the limits (T_{ex}) and (T_{exo}) and 0 and t , for constant peeling temperature, the following equation was obtained

$$\ln(T_{ex}) = \ln(T_{exo}) + K'_o \exp(-E'_a/RT) t \quad (16)$$

This equation represents the model for the changes in texture during chemical peeling as a function of temperature, and is independent of alkali concentration.

MATERIALS AND METHODS

Raw material

Guava (*Psidium guajava* L., var. Dominica Roja), grown in the northern part of the Zulia state, western Venezuela, were harvested when physiologically mature but unripe, with external green color and firm texture. The product was transported by car to the laboratory in Caracas at ambient temperature in a period of about 10 h.

The fruit was selected according to its uniformity in size and form. Fruits showing bruises, disorders, diseases and other abnormalities were discarded. The fruits were processed when still firm and when the color started to turn yellow, appropriate for the manufacture of guava shells.

Methods of analysis

The following physical properties were determined by the methods indicated below.

Apparent density of the peel. The test was done in quintuplicate. The peel of each of five guavas was carefully removed with a knife and weighed in a balance (Sartorius, model 2351, ± 0.1 g). The peel was immersed in vegetable oil (25°C) contained in a 100 ml graduated cylinder (± 1 ml), avoiding the presence of air bubbles, in order to determine the volume displaced. The apparent density was determined dividing the weight of the peel by the volume displaced.

Peel color. The color of the peel was determined using a Gardner Triestimulus colorimeter (Mod. XL-23) on five fruits selected at random. The colorimeter was standardized with the color standard that best matched the color of the peel. The peel was cut in strips that were placed in the glass sample plate for measurement.

Texture. Texture was assessed before and after peeling using a penetrometer (Arthur Tomas, Mod. Junior Precision). The five fruits comprising each lot were tested for this analysis. After leveling and adjusting the zero of the apparatus, the cone probe was placed at four different points on the surface of each fruit and the penetration in tenths of millimeter measured after 5 s.

Radius of the fruit. The radii of the fruit before and after peeling was measured using a caliper (Tesa, ± 0.02 mm). The small dimension was measured for all the fruits in each lot at four different points of the periphery (Czyhrnciw, 1967).

Weight of the sample batches. The weight of the samples before and after peeling was determined using a balance (Sartorius, Mod. 2351, ± 0.1 g).

Caustic soda solutions. The peeling solutions (70 l) were prepared on the day of the experiments by dilution of technical caustic soda in tap water. Aliquots were drawn by duplicate and titrated with 0.96 N HCl using phenolphthalein solution (1% in ethanol) as an indicator in order to calculate the concentration. The HCl solution was standardized using Na_2CO_3 as primary standard.

Citric acid solution. A 3% (w/v) solution of citric acid was prepared by direct weighing of citric acid and dilution in tap water.

All the reagents used were Merck, analytical grade, with the exception of the caustic soda.

Chemical peeling experiments

The caustic soda solution was placed in a caustic peeler (Dixie Canner Equip. Co.), $0.60 \times 0.45 \times 0.33$ m, and indirectly heated with saturated steam flowing in an immersed coil. The temperature in the peeler was measured with a mercury thermometer (Linare Scientific with a range $0-100^\circ\text{C}$, $\pm 1^\circ\text{C}$) and was regulated with a steam control valve. The peeler was provided with a second compartment ($0.45 \times 0.45 \times 0.33$ m) containing a 3% citric acid solution that was used for cooling and neutralizing the caustic soda residues over the fruit, when the batches were removed from the peeling tank after a specified peeling time. The concentrations of caustic soda used were 2.1, 3.5, 7.5 and 11.9% (w/v). The concentration of caustic soda during peeling was maintained within a range of $\pm 0.1\%$, by making up the initial level of solution in the peeler every 4 min to compensate for evaporation, and measuring the concentration by titration with 0.96 N HCl solution using phenolphthalein as indicator.

For each experiment, six batches of five fruits each were weighed, placed in plastic nets (provided with weights to avoid floating) and immersed simultaneously, at time zero, in a solution of caustic soda with a given concentration and preheated to the temperature under study. Peeling temperatures of 70, 80, 90 and 96°C , and peeling times ranging from 0 to 12 min with intervals of 2 min for

each temperature-concentration combination were used. A total of 16 experiments, four for each concentration of caustic soda, at each of the four temperatures indicated above were performed. After the peeling time elapsed the lots were removed and immersed in a citric acid (3%) bath at ambient temperature in order to cool the product and neutralize the residues of caustic soda over the fruit.

After neutralization, the processed fruits were drained, immersed in tap water and the reacted peel crust removed by means of a rotary washer (Dayton, mod. 2Z153A) fitted with water sprays. The peeled fruits were allowed to drain at ambient temperature for about 4 h before the physical and chemical analysis was performed.

Experimental data analysis

The statistical analysis of the experimental data obtained was performed using the Statistical Graphics System (STATGRAPHICS, version 2.6).

RESULTS AND DISCUSSION

Experimental evaluation of the model

The constants in the equations developed in this study must be known in order to apply the model to a food product with spherical geometry. In order to illustrate the procedure, guava (*Psidium guajava* L. var. *Dominica Roja*) was selected. Guava for making guava shells must be peeled while at the same time receiving a mild heat treatment, in order to avoid over-cooking that results in loss of texture, therefore reducing the marketing value of the final product. The physical characteristics determined for the raw material used are presented in Table 1.

TABLE 1
Physical Characteristics of the Fruit used to Evaluate the Chemical Peeling Model:
Psidium guajava L. (var. *Dominica Roja*)

Parameter	Average	Standard deviation	Interval; 95% confidence
Peel: apparent density (g/cm ³)	0.93	0.02	0.93 ± 0.03
Texture (mm of penetration)	4.6	0.23	4.6 ± 0.13
Color of the shell/apparent ripeness			
<i>L</i>	42.47	2.00	42.37 ± 3.13
<i>a</i>	-6.56	0.75	-6.56 ± 1.17
<i>b</i>	19.73	0.20	19.73 ± 0.31
Radius of the fruit (cm) (shortest dimension)	3.090	0.081	3.090 ± 0.019

Weight losses during peeling

The suitability of eqn (12) for predicting weight losses during peeling as a function of the peeled radius of the fruit was assessed.

The radii of the fruit before and after peeling and the weight loss during the process were experimentally evaluated according to the procedures described earlier, for different peeling temperature, time and alkali concentration. A total of 96 determinations were done in 16 experiments. The experimental values for the average weight loss per lot as a function of the weight loss predicted using eqn (12), with an apparent density $R_o = 0.93 \text{ g/cm}^3$ (Table 1), are presented in Fig. 2. A correlation coefficient $r' = 0.84$ was obtained. The regression analysis gave a highly significant linear relationship between the variables tested ($p \ll 0.01$). Therefore, eqn (13) was used to estimate the radius peeled as a function of the experimental weight loss in this research work. The average weight loss can be determined in a more accurate manner than the fruit radius for a given lot.

Chemical peeling model

In order to determine the constants b'' and (E_a/R) in eqn (10), the following procedure was used: since the right side of eqn (10) depends only on the peeling

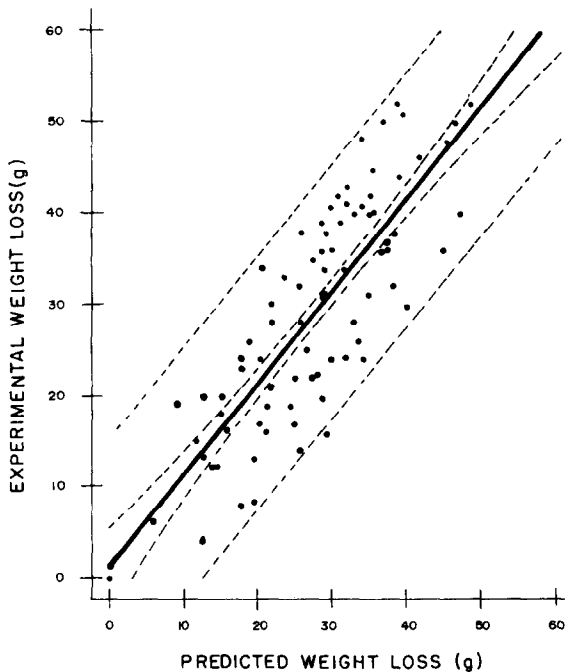


Fig. 2. Linear regression relating the experimental weight loss during peeling and that predicted by the model (eqn 12). Dotted lines represent the 95% confidence and prediction bands.

temperature, the left side of the equation must therefore be constant for a given temperature, in such a way that the variables C_a , t and r must change accordingly to make this term constant. For each temperature tested, the left side of eqn (10) was calculated for different C_a , t and r values determined according to the experimental design presented earlier. A total of 24 values of $\ln(t/((R_e - r)/C_a))$ were obtained for each temperature tested (4 concentrations \times 6 peeling times). The means and the standard deviations for these values were 4.9 ± 0.2 , 4.8 ± 0.2 , 4.7 ± 0.2 and 4.6 ± 0.3 min cm^2/g , for temperatures of 70, 80, 90 and 96°C respectively. The values of $\ln(t/((R_e - r)/C_a))$ so obtained were plotted as a function of $1/T$ (Fig. 3). A correlation coefficient $r' = 0.99$ was obtained. The regression analysis gave a significant linear regression between those variables ($p < 0.05$). From the slope and the intercept, the values of $E_a/R = 1.4 \times 10^3$ K and $b'' = 2.5$ min g/cm^4 were calculated. Substituting the values obtained in eqn (9) gives

$$t = 2.5 \exp(1.4 \times 10^3 / (T + 273)) ((R_e - r) / C_a) \quad (17)$$

Equation (17) represents the mathematical model for the chemical peeling process of guava with the physical characteristics presented in Table 1.

Texture changes during peeling

The cooking effect in the fruit texture during peeling was studied. The average texture for all the fruits comprising each batch of the 16 experiments (four alkali

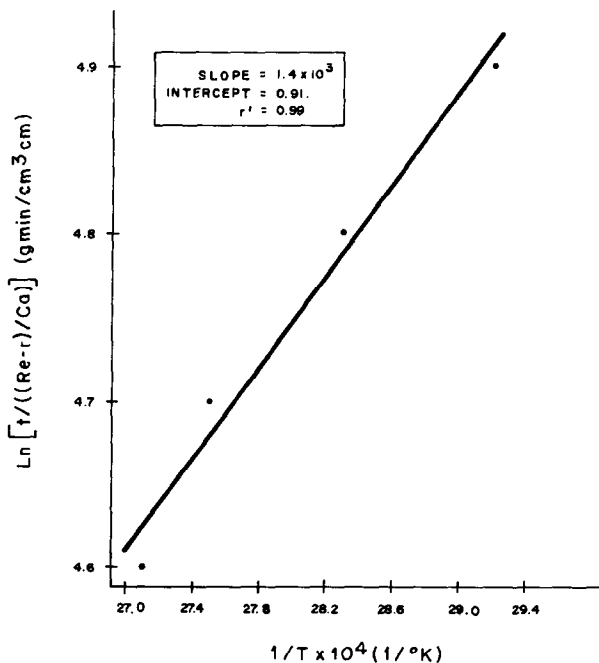


Fig. 3. Linear regression of experimental data to determine constants b'' , from the intercept, and E_a/R from the slope of eqn (17) for the chemical peeling process of guava.

concentrations \times four peeling temperatures for each of the six peeling times studied: 2, 4, 6, 8, 10 and 12 min) was determined using a penetrometer with a conical probe. A previous statistical analysis showed that, as expected, texture was independent of alkali concentration, being dependent only of temperature and time (Caraballo, 1991).

The experimental data obtained was adjusted to the model for texture change given by eqn (16), plotting $\ln(T_{ex})$ as a function of time for each peeling temperature. This equation implies apparent first order kinetics for the texture change and a rate constant following the Arrhenius equation, in spite of the fact that a true kinetic study was not performed due to practical limitations (such as the initial texture not being measured at the initial temperature of each experiment, but at room temperature (25°C) when the fruit was initially immersed in the peeling solution). In the same way, there was a transient heat transfer process within the fruit from the moment it was immersed in the peeling solution until it reached the peeling temperature. Therefore, the average temperature of the fruit was less than that of the peeling solution, especially for short peeling times, so that the temperature in the inner part of the fruit was not that of the peeling medium. On the other hand, the variable measured was the texture in the outer part of the fruit, that is, in the shell, where the penetrometer probe was located. The texture determined in this manner is of practical interest for the development of this work, and to estimate the shell texture changes during chemical peeling.

The results obtained for the study are summarized in Table 2. The regression analysis gave high correlation coefficients and a highly significant linear relationship ($p < 0.01$) in all the cases of fitting the experimental data to the apparent first order kinetics equation, in spite of the limitations recognized above. The values given by the intercepts represent the initial texture at each experimental temperature at zero time. As indicated above, these values could not be measured experimentally, therefore they were adjusted to an empirical linear relationship, as a function of temperature. The following equation was obtained for guava with the characteristics given in Table 1

$$\ln(T_{exo}) = 1.1 + 7.7 \times 10^{-3} T \quad (18)$$

The regression analysis gave a correlation coefficient of $r' = 0.91$ and a significant linear relationship ($p < 0.10$).

The Arrhenius plot of the values obtained in Table 2 gave values of $-E'_a/R = 2.1 \times 10^3$ K and $K'_o = 25$ cm/min. The regression analysis gave a

TABLE 2
Results for the Adjustment of the Experimental Data to the First Order Model for Texture Changes as a Function of the Peeling Temperature

Peeling temperature (°C)	K_i (1/cm) slope $\times 10^2$	Intercept $\ln(T_{ex})$	r'
70	4.3	3.8	0.96
80	6.1	3.8	0.99
90	6.3	3.9	0.97
96	7.6	4.0	0.97

correlation coefficient $r' = 0.95$ and a significant linear relationship ($p < 0.05$) between the variables in the linearized Arrhenius equation. Substituting eqn (18) and the values of the constants previously obtained in eqn (16), the model for the prediction of texture changes as a function of the temperature of the peeling medium and peeling time was obtained

$$\ln(T_{ex}) = 1.1 + 7.7 \times 10^{-3} T + 25 \exp(-2.1 \times 10^3/T) t \quad (19)$$

Application of the model to the chemical peeling process

General peeling maps for guava to manufacture guava shells, interrelating the alkali temperature and concentration, the peeling time, the thickness of the peel and the texture resulting from each treatment were generated in the following manner.

Theoretical peeling times were calculated, using eqn (17) for temperatures from 70 to 100°C with constant alkali concentration (ranging from 0.8 to 15% (w/v)), for a given thickness of the peel ($R_e - r$).

In the same way, five ranges of texture covering the practical range found in industry were selected, with texture values (mm of penetration) of (a) 7–8, (b) 8–9, (c) 9–10, (d) 10–11 and (e) 11–12. With these texture values and employing eqn (19), the peeling time corresponding to each peeling temperature was calculated for each peel thickness studied. Different graphs were obtained for each theoretical peel thickness to be removed, from 0.1 to 0.7 cm. The values calculated with eqns (17) and (19) were plotted on the same graph. The peeling

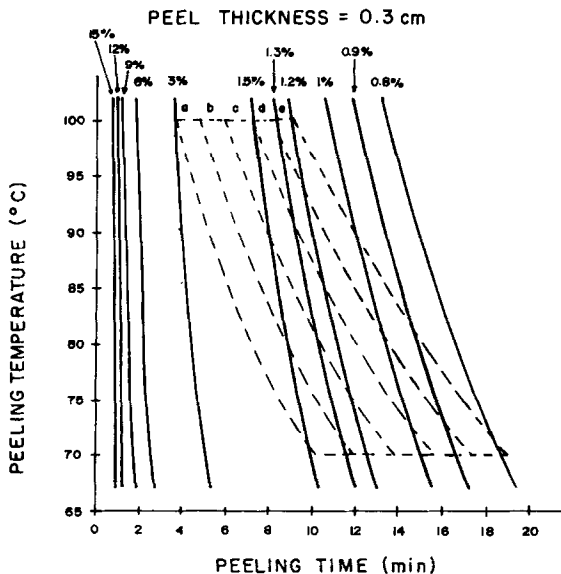


Fig. 4. Chemical peeling map of guava for peel thickness of 0.3 cm relating the variables involved in the process. The parameters of the lines come in % of caustic soda (w/v). Texture ranges after peeling (mm of penetration): (a) 7–8; (b) 8–9; (c) 9–10; (d) 10–11; (e) 11–12.

map for a theoretical peel thickness of 0.3 cm, the most representative of the raw material used, is shown in Fig. 4. Similar peeling maps could be obtained for other peel thickness.

The texture after peeling should be compatible with subsequent thermal processes that affect this parameter, such as cooking (to reach osmotic equilibrium with sugar) and pasteurization, in such a way that a given texture in the final product could be obtained. The texture range after peeling given by zone (e) (11–12 mm of penetration) is normally preferred for the manufacturing of guava shells in syrup (Alicamposa, 1990). Any processing combinations (concentration, temperature and time) along this zone in Fig. 4 can be used satisfactorily.

Similar peeling maps could be developed for other foods with spherical geometry using the model and procedures presented in this research work, even if texture change during peeling is not taken into account. In such a case the peeling maps should be calculated using only the peeling model given by eqn (17).

The model developed in this study would be useful in improving process yields, by reducing the losses of alkali and raw material due to excessive peeling, and by improving texture by selecting appropriate peeling temperatures and times.

REFERENCES

- Alicamposa. (1990). Personal communication. Alimentos del Campo, Alicamposa, Barquisimeto, Venezuela.
- Anantheswaran, R. C., McLellan, M. R. & Bourne, M. C. (1985). Thermal degradation of texture in apples. *J. Food Sci.*, **50**(4), 1136.
- Athanasopoulos, P. & Vagias, G. (1987). Lye peeling of mandarins. *J. Food Process Eng.*, **9**(4), 227.
- Bourne, M. E. (1987). Effect of blanch temperature on kinetics of thermal softening of carrots and green beans. *J. Food Sci.*, **52**(3), 667.
- Cancel, L., Hernández, I. & Rodríguez-Sosa, E. (1970). Lye peeling of green papaya (*Carica papaya*, L.). *J. Agric. Univ. P. R.*, **54**(1), 19.
- Cancel, L., Rivera-Ortiz, J. & Montalvo de, M. (1972). Lye peeling of citron (*Citrus medica*, L.). *J. Agric. Univ. P. R.*, **56**(2), 164.
- Caraballo, V. (1991). Estudio del Pelado Químico de la Guayaba Variedad *Dominica Roja*. Tesis de Magister en Ciencia de los Alimentos. Universidad Simón Bolívar. Caracas.
- Cruess, W. (1958). *Commercial Fruit and Vegetable Products*, 4th edn. McGraw-Hill Book Co., Inc., NY, USA.
- Czyhrinciw, N., Mosqueda, M. & y Garcés, M. (1967). *Análisis Industrial en la Fabricación de Alimentos*, Vol. I. Facultad de Ciencias, Universidad Central de Venezuela, Caracas.
- Floros, J. & Chinnan, M. (1987). Optimization of pimiento peppers lye peeling process using response surface methodology. *Trans. ASAE*, **30**, 560.
- Floros, J. & Chinnan, M. (1988). Seven factors response surface optimization of a double-stage lye (NaOH) peeling process for pimiento peppers. *J. Food Sci.*, **53**(2), 631.
- Floros, J. & Chinnan, M. (1990). Diffusion phenomena during chemical (NaOH) peeling of tomatoes. *J. Food Sci.*, **55**(2), 552.

- Floros, J., Werzstein, H. & Chinnan, M. (1987). Chemical (NaOH) peeling as viewed by scanning electron microscopy: pimiento peppers as a case study. *J. Food Sci.*, **52**(5), 1312.
- Hart, M., Graham, R., Williams, G. & Hanni, P. (1974). Lye peeling of tomatoes, using rotating rubber discs. *Food Technol.*, **28**(12), 11.
- Havighorst, C. (1943). New dehydration plant handles record quantities. *Food Ind.*, **15**(12), 81.
- Hersom, A. C. & Hulland, E. D. (1964). *Canned Foods, an Introduction to their Microbiology (Baumgartner)*, 5th edn. Chem. Pub. Co. Inc., NY, USA.
- Huang, Y. T. & Bourne, M. C. (1983). Kinetics of thermal softening of vegetables. *J. Text. Stud.*, **14**, 1.
- Lankler, J. & Morgan, O. (1944). How wetting agent improves the chemical peeling process. *Food Ind.*, **16**(5), 888.
- Lee, C. & Downing, D. (1973). Dry caustic peeling of beets and carrots reduces pollution. *Food Technol.*, **27**(12), 40.
- Levenspiel, O. (1988). *Ingeniería de las Reacciones Químicas*. Ed. S. A. Reverté, Barcelona, Spain.
- Mazzola, L. (1943). New caustic peeling method reduces waste and saves labor. *Food Ind.*, **15**(1), 53.
- Olsen, I. (1941). Wetting agents speed chemical peeling: experiments with peaches show value of adding sulphonates to alkaline or acid peeling solutions. *Food Ind.*, **13**(4), 51.
- Powers, M., Adams, H. & Iritani, W. (1977). Chemical and physical factors in peeling apples and potatoes. *J. Food Sci.*, **42**(3), 784.
- Reeve, R. (1976). Histological structure affects peeling of fruits and vegetable. *Food Technol.*, **30**(12), 48.
- Rivera-Ortiz, J. & González, M. (1972). Lye peeling of fresh yams, *Dioscorea alata*. *J. Agric. Univ. P.R.*, **56**(1), 57.
- Schlimme, D., Corey, K. & Frey, B. (1984). Evaluation of lye and steam peeling using four processing tomato cultivars. *J. Food Sci.*, **49**(6), 1415.
- Smith, D., Dozier, W., Griffey, W. & Rymal, K. (1981). Effect of steam temperature, speed of cooling and cutting disruption in steam and lye peeling of apples. *J. Food Sci.*, **47**(8), 267.
- Stateler, E. (1945). Now-quick dehydration. *Food Ind.*, **174**(3), 1450.
- Walter Jr., W. & Giesbrecht, F. (1982). Effect of lye peeling conditions on phenolic destruction, starch hydrolysis, and carotene loss in sweet potatoes. *J. Food Sci.*, **47**(3), 810.
- Walter Jr., W. & Schadel, W. (1982). Effect of lye peeling conditions on sweet potato tissue. *J. Food Sci.*, **47**(3), 813.
- Weaver, M., Huxsoll, C. & Ng, K. (1980). Sequential heat-cool peeling of tomatoes. *Food Technol.*, **34**, 40.
- Woodroof, J. & Atkinson, I. (1944). Preserving Sweet Potatoes by Freezing. *Bull. 232, Ga. Expt. Sta.*
- Woodroof, J., Cecil, S., Shelor, E. & Cecil, I. (1942). Peeling with lye. *J. Agr. Res. USDA*, **5**(10), 1956.
- Woodroof, J., Cecil, S., Shelor, E. & Cecil, I. (1948). Peeling with lye. *Food Ind.*, **20**(6), 862.
- Woodroof, J. & Luh, B. (1975). *Commercial Fruit Processing*. Avi. Pub. Co., Inc., CT, USA.