MATHEMATICAL ANALYSIS OF CAUSTIC PEELING OF KIWIFRUITS

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ABSTRACT
The aims of this present syudy were to investigate time, temperature and concentration relations for caustic peeling of kiwifruits and to develope a mathematical model. Caustic soda (NaOH) solutions with different concentrations (14, 17, 20 and 23 %) were used in the experiments at 80, 85, 90 and 95 ºC for varying time intervals. According to results obtained, either the time- temperature or the time-concentration correlations were linear. As the most effective peeling method, treatment with % 23 caustic soda at 95 ºC for 4.5 min was determined. The accomodation between the model developed and the peeling values was tested with regression analysis.

Introduction

The homeland of kiwifruit is China. It was taken to New Zealand at the beginning of 1900' s and called as Chinese gooseberry. Later, spread over Europe and America and was named as kiwifruit at the beginning of 1960' s. It is known that the fruit is also named as ichang gooseberry, groseille de China, kiwiberry, maoerh-tao, monkey peach, sheep peach, souris vegetale and yang-tao (1). The amount of annual production is about 200.000 tons. The plantation of kiwifruit in Europe and America started 40 or 50 years ago (2). In many countries, it is accepted as a garden product having a high economic value. Is is observed that the plantation of the fruit in our country rises rapidly in Black Sea, Mediterrenean and Marmara Regions. In addition to its having a rich mineral composition, it's superior to many fruits as it has high amount of vitamin C. The amount of vitamin C in it is ten times as much as an apple and three times as much as an orange. The varieties of kiwifruit (*Actinidia chinensis* planch) having a commercial importance are Hayward, Allison, Bruno and Monty. The variety which is grown widely in our country is Hayward. The fruit is utilized in many ways such as fruit juice, frozen food, wine, jam, marmalade, canned food and dried product; and it is used to soften meat as well.

Hand peeling is a process requiring a high labour cost and so it increases the cost of product. It has 60 % of the total labour cost (3). Flame, steam and chemicals are used for the peeling process of fruit and vegetables. The application of flame can cause combustion and a cooked flavour comes out (4). Further more the taste is never desired in fruits, the application field becomes limited. Due to not adjusting steam and temperature properly, an over-boiling comes out and as a result of this, the loss of product tissue (or weight loss) with the peel increases (5). Being the oldest and the most common meth-

od today, caustic soda (NaOH) is used in chemical peeling (6). Peeling with caustic started at the beginning of 1900' s (3). The concentration of NaOH used begins from 1-2 % and can reach to 25 %. Concentration, process duration, temperature, variety and size of the product, maturity and quality of chemicals are important factors in caustic peeling. While in some horticultural products boiling temperature is used as process temperature, for instance, membranes of grapefruit segments are peeled at 80-85 ºC. The process duration in chemical peeling of fruit begins from 30-40 seconds and can reach to 10 minutes. The type of peeling machine is also important and it affects the comsumption of caustic solution as well as the product variety and the fruit' s maturity. As a result of scanning literature , it was observed that the concentration of caustic soda used in peeling kiwifruit changed between 15 % and 25 % and that the temperature focused between 80º C and 100 ºC (4, 7, 8). Not only a physical peel removing comes out but also a diffusion and several complex chemical reactions appear during the peeling with NaOH (9, 10).

The aim of this research is to determine the changes in process variables (concentration, time and temperature) during the caustic peeling of kiwifruit, to form a mathematical model using the data and to search the optimum peeling variables.

Materials and Methods

Kiwifruits used in this research belong to the variety of Hayward and they were supplied from Atatürk Research Intitution of Horticultural Crops (Yalova). The fruits in good condition having the size of about 72x52 mm and water soluble solids of which are about 9 % were used.

In the research, literature data was taken as a base when determining the temperature degrees and the concentration of dipping solutions. Four different temperature degrees (80, 85, 90 and 95 ºC) and for each temperature degree four concentration values (14, 17, 20 and 23 %) were determined. To establish the process duration (for the temperature/ concentration combinations defined above), the shortest time values (as minute) when the complete peeling was done were taken as main criteria. As it was considered that the more the temperature and the concentration were increased, the easier the peeling became, time intervals were made narrower.

First, solutions with different concentrations (14, 17, 20 and 23 %) having the volume of 2 litres were prepared. Eight kiwifruits being put into each solution were waited at 80 ºC during 3, 6, 9 and 12 minutes. Same process steps were repeated for 85, 90 and 95 ºC with decreasing time intervals. After that, the fruits were cooled being washed under the tap water with 20 ºC and flowing 100 mL/s for 2-3 minutes. The peeling scores of kiwifruits were designated as in Table 1. The ones peeled between 0-25 % as not peeled, the ones peeled between 25-50 % as badly peeled, the ones peeled between 50-75 % as slightly peeled, the ones peeled between 75-98 % as well peeled and the ones peeled above 98 % as completely peeled were accepted and so scoring was done in five categories (3). To determine the optimum time-temperature and time-concentration relations, the scores of complete peeling were considered.

Results and Discussion

In this research, time-temperature and time-concentration relations required to peel the kiwifruit completely were tried to be put out. Minimum time values when the complete peeling was achieved were taken as a base. Applying the least squares method, a simple regression analysis was performed (**Ta-**

ble 2 and 3) and it was shown on linear model. To form a model, general equation coefficients were determined and different mathematical equations were found for both time-temperature and time-concentration relations.

Regresion analysis and determinations on formed models showed that the relations between time-temperature and time-concentration data were linear. That both time-temperature and time- concentration relations are linear firstly derives from that the data are related to each other. In both relations, as the temperature and concentration values obtaining the complete peeling increases the process duration decreases. The data belonging to time-concentration relation and obtained from the regression analysis made for each NaOH concentration are defined in Table 2. Graphics relating to the table and drawn with the data obtained from the model formed are seen

in **Fig. 1.** The data belonging to time-concentration relation and obtained from the

TABLE 1

Time/Temperature/Concentration/Score Relation for Caustic Peeling of Kiwifruits

80°C	Conc. %14	Conc. %17	Conc. %20	Conc. %23
T	3.0 min*	3.0 min*	3.0 min*	3.0 min*
I	6.0min*	6.0 min*	6.0 min*	6.0 min**
M	9.0 min*	9.0 min*	9.0 min**	9.0 min**
E	12 min**	12 min**	12 min***	12 min***

85°C	Conc. %14	Conc. %17	Conc. %20	Conc. %23
T	2.5 min*	2.5 min*	2.5 min**	2.5 min**
I	5.0 min.**	5.0 min**	5.0 min***	5.0 min***
M	10 min***	10 min****	9.0 min****	9.0 min****
E	16 min*****	15 min*****	13 min*****	12 min*****

90°C	Conc. %14	Conc. %17	Conc. %20	Conc. %23
T	2.0 min**	2.0 min**	2.0 min**	2.0 min**
I	4.0min.***	4.0 min***	4.0 min**	4.0 min***
M	7.0 min****	6.0 min***	5.5 min***	5.0 min****
E	8.0 min*****	7.0 min*****	6.5 min*****	5.5 min*****

95°C	Conc. %14	Conc. %17	Conc. %20	Conc. %23
T	2.0 min**	2.0 min**	2.0 min***	2.0 min***
I	3.5min.**	3.5 min***	3.0 min***	3.0 min****
M	5.5 min***	5.0 min****	4.5 min****	4.0 min****
E	7.0min*****	6.0 min*****	5.5 min*****	4.5 min*****

* No peeling : Higher than 0 %
** Bad peeling : Higher than 25 %
*** Slight peeling : Higher than 50 %
**** Good peeling : Higher than 75 %
*****Complete peeling : Higher than 98 %

TABLE 2

Regression Coefficients, Correlation and Determination Values for the Model T=a-bt

Temperature (ºC)	Concentration (% NaOH)	b*	a*	r[a]	r[2 b]
85/90/95	14	-0.900	91.330	-0.912	0.832
85/90/95	17	-0.900	90.330	-0.912	0.832
85/90/95	20	-0.750	75.830	-0.921	0.848
85/90/95	23	-0.750	74.830	-0.921	0.848

*****Regression coefficients; [a] Correlation value; [b] Determination value

TABLE 3

Regression Coefficients, Correlation and Determination Values for the Model T=a-bc

Concentration (% NaOH)	Temperature (ºC)	b*	a*	r[a]	r[2 b]
14/17/20/23	85	-0.460	22.510	-0.990	0.9801
14/17/20/23	90	-0.266	11.671	-0.990	0.9801
14/17/20/23	95	-0.266	10.671	-0.992	0.9840

*Regression coefficients; [a] Correlation value; [b] Determination value

regression analysis made for each temperature degree is given in Table 3. Graphics relating to the table and drawn with the data obtained from the model formed are seen in **Fig. 2.**

As a result of regression analyses, it was found that the relation between time and temperature is explained with the equation **T=a-bt** and the one between time and concentration is explained with the equation **T=a-bc** . In both equations; **T** is time, **a** and **b** are coefficients, **t** is temperature and **c** is concentration.

That time-temperature and time-concentration relations are linear were confirmed with the models established. In both models (or functions), when the coordinates shown by temperature (t) and concentration (c) values appearing when the data of dependent variable time(T) was put into its place in functions were plotted and connected, the linear graphic functions with negative slope seen in Figure 1 and 2 were obtained. To determine if the lines have negative slope or not, correlation coefficients (r) were defined (Table 2 and 3) and they were found to be very close to -1.

The determination coefficients (r^2) in time-temperature relation is about 84 % and the one in time-concentration relation is about 98 %. It can be seen that how much the variables independent or effecting (temperature and concentration) from the importance of determination coefficient affect the variable dependent or effected (time). The determination coefficients' being

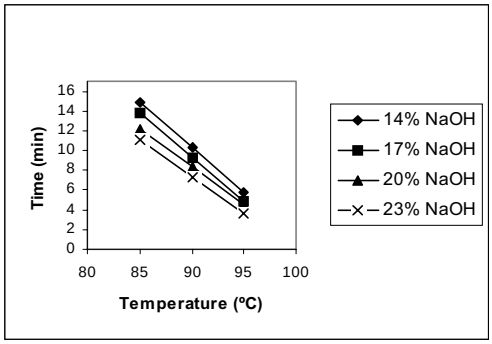

Fig. 1. Temperature-Time Relation.

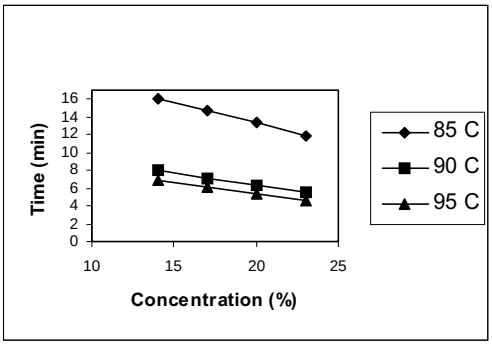

Fig. 2. Concentration-Time Relation.

high in both relations states that peeling durations are effected by temperature and concentration largely.

Increasing the concentration or the temperature of caustic soda solution such as in apples and peanuts, causes the peeling duration to decrease (3, 11). It is observed that temperature is the most effective variable among the process variables. This can be understood from the slopes of lines placed in **Fig. 1.** Increases in concentration did not affect the peeling duration as much as the temperature degree (**Fig. 2**). In other words, only increasing the concentration of NaOH does not have any effect on peeling. As seen from Table1, when the temperature must be fixed, increasing the concentration values did not cause significant changes in peeling durations. The peeling duration over 90ºC became clearly shorter. The complete peeling durations changing between 12 and 16 minutes at 85 ºC decreased from 8 minutes to 4.5 minutes when the temperature was increased to 90 and 95 ºC.

As a result of some peeling treatments, a yellowish layer appeared in the tissue of fruit periphery depending on the process duration. During the treatments when the duration is beyond 8 minutes at 80 ºC, 7 minutes at 85ºC, 6 minutes at 90 ºC and 5.5 minutes at 95 ºC, it was observed that the colour started to change from green into yellow in fruit periphery. When the process durations at which the complete peeling was achieved and the temperatures are 85 ºC, 90 ºC and 95 ºC were increased to 7.5 minutes 6.5 minutes and 6 minutes respectively, it was observed that the thickness of this layer reached to 0.5-1.0 mm and that it became thicker as the process duration increased. For this reason, the time values in which the colour change in tissue and the weight loss because of the heat intensity did not come out were taken basically. The values achieving the complete peeling and in which the abnormal physical changes in fruit did not appear were selected as the most suitable peeling variables. The kiwifruit is best peeled in NaOH solution with 23 %, at 95 ºC and in 4.5 minutes.

The reason for a yellowish layer appeared in fruit periphery was that when going beyond the defined temperature and time values, the green coloured chlorophyll pigment in outer tissue of fruit directly contacting the heat changed into pheophytin being affected by the heat. According to Zhenzhen and Tingyao(12), a similar transformation occurs at 100 ºC, in 5 minutes during the process of heating applied to canned kiwifruit.

It is proposed that this method be applied in

kiwifruit which will be used for the production of jam and marmalade and so it will be possible to save on both time and labour cost when processing a large amount of fruits.

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