GIDA (2010) 35 (2): 89-95 *Research* / Araştırma

# MATHEMATICAL ANALYSIS OF PEELING OF CARROTS

**Özlem Aydın[1], Levent Bayındırlı[1], Nevzat Artık[*2]**

[1] Middle East Technical University, Dept. of Food Engineering, Ankara, Turkey
[2] Ankara University, Department of Food Engineering, Dışkapı, Ankara, Turkey

*Received* / Geliş tarihi: 24.05.2009
*Received in revised form* / Düzeltilerek geliş tarihi: 17.09.2009
*Accepted* / Kabul tarihi: 29.09.2009

**Abstract**
In this study, carrots of Beypazarı variety were chemically and steam peeled. Effects of temperature, concentration of NaOH solutions and immersion time on lye peeling of carrots were studied. The optimum time-temperature-concentration relations of lye peeling of carrots were analyzed mathematically. Experiments were carried out for NaOH solutions of 2.5, 5.0, 7.5 and 10.0 g NaOH / kg at 57, 67, 77 and 87 °C for various immersion times, until more than 98 % peeling was achieved. Complete peeling was achieved for all concentrations and temperatures except 2.5 g NaOH / kg at 57°C. Treatment with 7.5 g NaOH / kg at 77 °C for 10.5 minutes was found to be optimum to peel the carrots. In steam peeling, saturated steam of 130.7 kPa and 107 °C was used. Complete peeling was achieved at 8.5 minutes. In steam peeling, complete peeling was achieved at 8.5 minutes.

**Keywords:** Carrot, chemical peeling, steam peeling, mathematical analysis

# HAVUÇLARIN SOYULMASININ MATEMATİKSEL ANALİZİ

**Özet**
Bu çalışmada, Beypazarı havuçlarının kabukları, kimyasal yöntem ve buharla soyma yöntemleriyle soyulmuştur. NaOH çözeltisinin konsantrasyonu, sıcaklığı ve daldırma süresinin etkileri araştırılmıştır. Kimyasal yöntemle kabuk soymada optimum süre-sıcaklık-konsantrasyon ilişkileri matematiksel olarak analiz edilmiştir. Deneyler, NaOH konsantrasyonu olarak 2.5, 5.0, 7.5 ve 10.0 g NaOH/kg, sıcaklık olarak 57, 67, 77 ve 87 °C'lerde, %98'den daha fazla soyulma elde edilene kadar uygulanmıştır. 57 °C'de NaOH konsantrasyonu 2.5 g NaOH/kg olan çözelti haricinde diğer sıcaklık ve konsantrasyonlarda tam soyulma gerçekleşmiştir. Optimum soyulma koşulları, 77 °C'de 7.5 g NaOH / kg çözelti konsantrasyonu ve 10.5 dakika daldırma süresi olarak belirlenmiştir. Buharla soyma yönteminde ise doymuş buhar basıncı 130.7 kPa ve sıcaklığı 107 °C olarak uygulanmıştır. Tam soyulma 8.5 dakikada gerçekleşmiştir.

**Anahtar kelimeler:** havuç, kimyasal yöntemle kabuk soyma, buharla kabuk soyma, matematiksel analiz

* Corresponding Author / Yazışmalardan sorumlu yazar
artik@eng.ankara.edu.tr, ✆ (+90) 312 596 1152, 🖷 (+90) 312 317 8711

## INTRODUCTION

The carrot belongs to the family *Apiaceae (Umbelliferae)* which is a member of the parsley family. The cultivated carrot belongs to the genus Daucus L. which contains many wild forms. In Turkey, Beypazarı variety is the most popular. Beypazarı provides 60% of carrot production of Turkey. 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 (1).

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. 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. 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 (2, 3). Other advantage is the requirement of smaller floor space. On the contrary, the main disadvantage is the pollution of large volumes of water. The other disadvantages are high peeling losses and loss of damaged fruits (4).

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 (5). 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. 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 (6).

In steam peeling, it was 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 (7). It was 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 (8).

The objectives of this study were to optimize chemical and steam peeling of carrots. For this purpose, carrots were chemically peeled, time-temperature-concentration relations were estimated and a suitable combination of time-temperature-concentration was selected and analyzed mathematically. Optimum peeling time for steam peeled carrots was determined.

## MATERIALS AND METHODS

### Raw Material

Carrots of 'Beypazarı' variety, cultivated during 2007 season, were bought from local market. The carrots were of medium size and the average weights were in the range of 75-110 grams.

### Experimental

Chemical Peeling

Caustic (lye) solutions of 2.5, 5.0, 7.5 and 10.0 g NaOH/kg peeling solution (Merck NaOH pellets pure) were used at temperatures 57, 67, 77 and 87 °C for varying time intervals for peeling of carrots. For peeling, different time intervals were used to find out the appropriate peeling condition. In chemical peeling, the carrots were immersed in the lye solution for a predetermined time and cooled in tap water at 15 °C for 1 min at a flow rate of 100 ml/s.

Steam Peeling

Steam peeling treatments were conducted with a Pressure Cooker (Solingen Germany 18/10 Cr/Ni Aluminum 18/10 Cr/Ni); a 7 liter capacity vessel at an inlet steam pressure of 130.7 kPa 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 condition. In steam peeling, the carrots were left in the pressure cooker for a predetermined time and cooled in tap water at 15 °C for 1min at a flow rate of 100 ml/s.

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 (%). They were then evaluated according to degree of peeling. The minimum time for very good peeling (i.e. peeling higher than 98%) is used in experiments (9, 10). In Table 1, the classification of peeling degree of carrots was shown.

Table 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% | * |

*: Peeling degree scores.

Depth of NaOH Penetration

A chemically peeled carrot was cut into two identical pieces. From the central part of a one piece, 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 (9).

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).

## RESULTS AND DISCUSSION

### Chemical Peeling

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. 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. Then, temperature and concentration values were determined by the help of time intervals. 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. In Table 2, the time intervals used in chemical peeling were seen.

Table 2. Time-Temperature-Concentration-Score Relation for Chemical Peeling of Carrots.

| Temp. | 2.5 g/kg | 5.0 g/kg | 7.5 g/kg | 10.0 g/kg |
|---|---|---|---|---|
| 57 °C | 22 min ** | 15 min ** | 8 min ** | 7 min ** |
| | 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 | 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 | 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 | 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 **** |

*: Peeling degree scores (Table 1).

The same result was obtained for peeling of tomatoes, Amasya apples and hazelnuts since the increase in lye concentration and temperature decreased the time necessary for efficient peeling (10-12). After data collection, the time-temperature and time-concentration graphs were plotted according to the minimum time to reach 'complete peeling' score (Table 2) and the mathematical equations for both relationships were derived by finding out the constants of the general equations determined before the analysis by the linear regression principle.

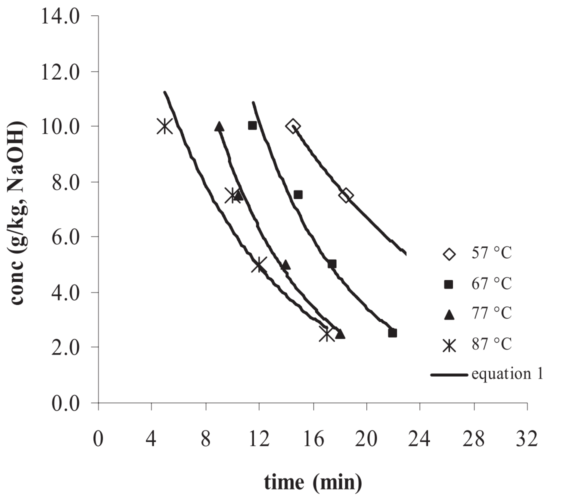


Figure 1. Time-concentration relations for chemical peeling of carrots.

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 1):

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

And;

$$LnC = \lambda + \gamma \cdot t \quad (2)$$

Equation (2) is the linear form of equation (1) and the parameters $\lambda$, $\gamma$ and correlation coefficient obtained by regression analysis for each sodium hydroxide concentration are shown in Table 3 and the best fits are demonstrated in Figures 1 and 2.

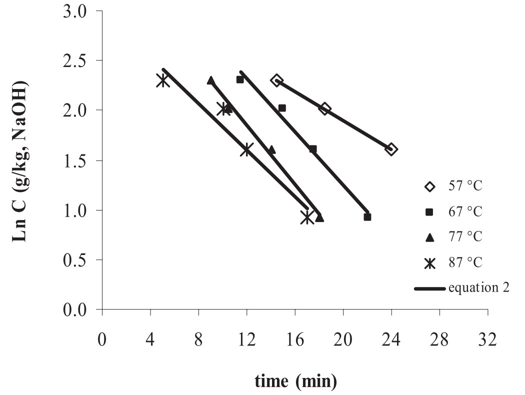


Figure 2. Time-concentration relations for chemical peeling of carrots

Table 3. Operational Parameters & Constants for Time-Concentration Relations

| Temperature (°C) | λ | γ | $r^2$ |
|---|---|---|---|
| 57 | 1.0602 | -0.0730 | 0.9999 |
| 67 | 1.6325 | -0.1348 | 0.9806 |
| 77 | 1.3323 | -0.1494 | 0.9926 |
| 87 | 0.7049 | -0.1179 | 0.9484 |

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

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

And;

$$LnT = \sigma + \beta \cdot t \quad (4)$$

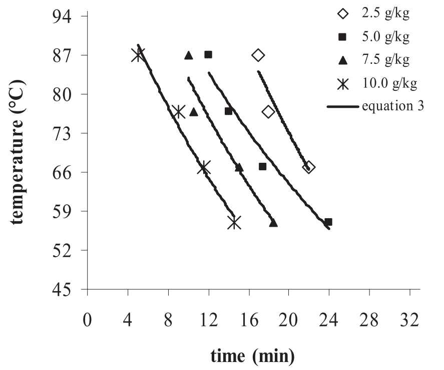


Figure 3. Time-temperature relations for chemical peeling of carrots.

The parameters $\sigma$, $\beta$ and correlation coefficient are shown in Table 4 and the best fits for the equations (3) and (4) are shown in Figures 3 and 4 respectively.

Table 4. Operational Parameters & Constants for Time-Temperature Relations

| Concentration (g NaOH kg$^{-1}$) | σ | β | $r^2$ |
|---|---|---|---|
| 2.5 | 5.2359 | -0.0473 | 0.9150 |
| 5.0 | 4.8374 | -0.0340 | 0.9645 |
| 7.5 | 4.8599 | -0.0441 | 0.9491 |
| 10.0 | 4.7123 | -0.0448 | 0.9784 |

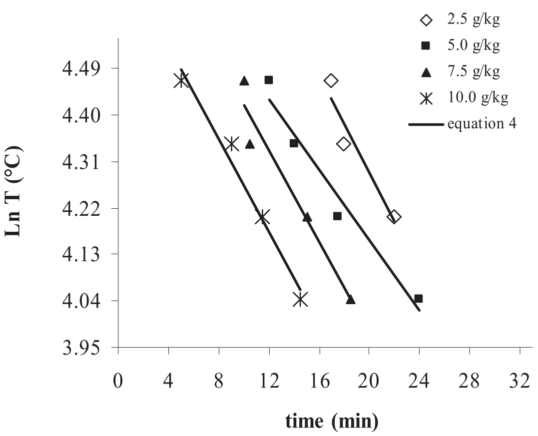


Figure 4. Time-temperature relations for chemical peeling of carrots.

As can be seen from Figures 1 through 4, experimental data fit well to the exponential 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 1 is greater than that of constant concentration lines in Figure 3. Another clue for this result is that no peeling was observed during the usage of 2.5 g NaOH / kg peeling solution at 57 °C. The effect of temperature was also obtained important at peeling of Antep peanut (13); walnut (14) and tomatoes (10).

In order to decide on optimum combination; minimum concentration, minimum time and minimum temperature should be considered. 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 2.5 g NaOH / kg peeling solution concentration is 4min., that difference is only 1 min between 77 °C and 87 °C (Table 2).

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 5.0 and 7.5 g NaOH / kg peeling solution were 3.5 min, while that was only 1.5min between 7.5 and 10.0 g NaOH / kg peeling solution. 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 7.5 g NaOH / kg peeled product yield.

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.

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

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

## Steam Peeling

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 Figure 5 the time intervals vs peeled surface area of carrots were shown. Temperature and pressure of the steam peeling is constant, and then the main variable affecting the peeling is time.

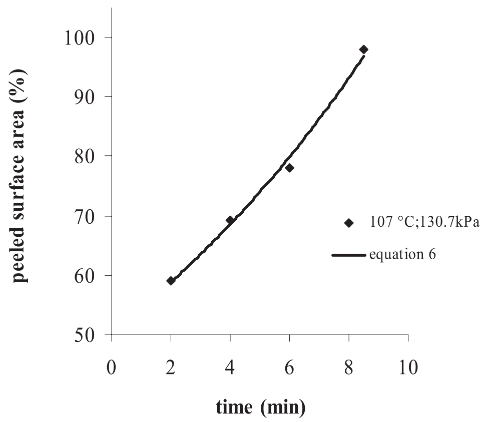


Figure 5. Peeled surface area-time relations for steam peeling of carrots.

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 5):

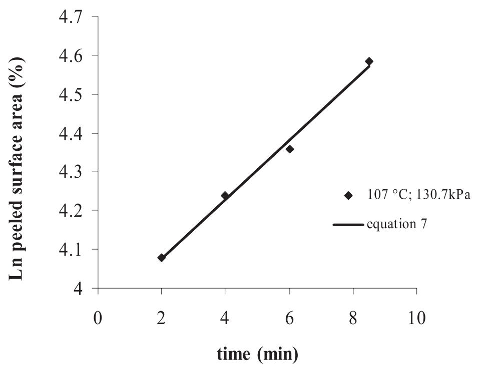


Figure 6. Peeled surface area-time relations for steam peeling of carrots.

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

And;

$$LnP = a + b \cdot t \quad (7)$$

Equation (7) is the linear form of equation (6) and the parameters *a*, *b* and correlation coefficient obtained by regression coefficient obtained by regression analysis is shown in Table 5 and the best fits are demonstrated in Figures 5 and 6.

Table 5. Operational Parameters & Constants for Time-Peeled Surface Area Relations

| Temperature (°C) | Pressure (kPa) | α | β | $r^2$ |
|---|---|---|---|---|
| 107 | 130.7 | 3.9212 | 0.0767 | 0.9939 |

Nomenclature

C : Concentration of caustic solution (g NaOH / kg peeling solution)

T : Temperature of caustic solution (°C)

t : Peeling time (min)

P : Peeled surface area

γ : Constant

σ : Constant

λ : Constant

β: Constant

*a* : Constant

*b* : Constant

$r^2$ : Correlation coefficient

As can be seen from Figures 5 and 6, experimental data fit well to the exponential model for the saturated steam of 130.7 kPa and 107 °C. When complete peeling was considered, a suitable time for peeling was determined as 8.5 minutes.

## CONCLUSIONS

Depending on the temperature, concentration and treatment time, lye peeling process is superior to mechanical (conventional) peeling, since it is effective on carrots having irregular shapes and cavities. Moreover, the lye solution did not penetrate into the carrot. That is an advantage for the peeling process. Most satisfactory results are obtained with 7.5 g NaOH/kg peeling solution at 77 °C for a dipping time of 10.5 minutes. In steam peeling, very good peeling (>98%) was achieved at 8.5 min.

Finally, the exponential 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. The selection of the proper method mainly depends on the conditions of the application and the plant design of the process.

## REFERENCES


1. Bolin HR, Huxsoll CC. 1991. Color of Minimally Processed Carrot *(Daucus carota)* Surface Discoloration Caused by Abrasion Peeling. *J Food Sci*, 56(2):416-418.

2. Bayındırlı L, Bayındırlı A, Şahin S, Şumnu G, Gider S.1996. Studies on Caustic Peeling of Apples. *J Food Sci and Tech*, 33(3), 240-242.

3. Cruess WV. 1958. *Commercial Fruit and Vegetable Products*. 4th edn. McGraw-Hill Book Co, New York.

4. Setty GR, Vijayalakshmi MR, Devi AU. 1993. Methods for Peeling Fruits and Vegetables: A Critical Evaluation. *J Food Sci Technol*, 30(3):155-162.

5. Schlimme DV, Corey KA, Frey BC. 1984. Evaluation of Lye and Steam Peeling Using Four Processing Tomato Cultivars. *J Food Sci*, 49, 1415-1418.

6. Floros JD, Chinnan MS. 1988. Microstructural Changes during Steam Peeling of Fruits and Vegetables. *J Food Sci*, 53(3): 849-853.

7. Smith DA, Dozier WA, Griffey WA, Rymal KS. 1981. Effect of Steam Temperature, Speed of Cooling and Cutin Disruption in Steam and Lye Peeling of Apples. *J Food Sci*, 47, 267-269.

8. Smith DA, Harris H, Rymal KS. 1980. Effect of Cold Water Injection during High Pressure Steam Peeling of Sweet Potatoes. *J Food Sci*, 45, 750-751.

9. Garrote RL, Coutaz VR, Luna JA, Silva ER, Bertone RA. 1993. Optimizing Processing Conditions for Chemical Peeling of Potatoes using Response Surface Methodology. *J Food Sci*, 58(4):821-826.

10. Bayındırlı L. 1994. Mathematical Analysis of Lye Peeling of Tomatoes. *J Food Eng*, 23:225-231.

11. Bayındırlı L, Sumnu G, Özkal SG. 1996. Effects of Isopropylalcohol on Lye Peeling of 'Amasya' Apples. *Fruit Processing, Flüssiges Obst*, 6:237-239.

12. Kaleoğlu M, Bayındırlı L, Bayındırlı A. 2004. Lye Peeling of 'Tombul' Hazelnuts and Effect of Peeling on Quality *Trans IChemE, Part C, Food and Bioproducts Processing*, 82(C3):201-206.

13. Bayındırlı L, Altan A, Sevimli M. 2001. Mathematical Analysis of Lye Peeling of Peanuts. *Gıda Teknolojisi*, 5(5): 60-64.

14. Bayındırlı L, Tuncer E, Öztürk SB. 2002. Mathematical Analysis of Lye Peeling of Walnuts. *GIDA*, 27(4):241-245.