Chimika Chronika, New Series, 25, 11-28 (1996)

KINETICS OF TEXTURE DEGRADATION IN APPLES DURING THERMAL PROCESSING

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Running Title: THERMAL LOSS OF APPLE TEXTURE

Received: October 5, 1995 - In final form: March 6, 1996

SUMMARY

Instrumental Texture Profile Analysis can be used in studying thermal degradation of apple texture. Heating time and temperature significantly reduced fracturability, hardness, energy required during first compression and gumminess in both Red and Golden Delicious apples. Heating time did not significantly affect changes of springiness, cohesiveness and chewines in both varieties. The changes in energy required during second compression were significant for Red but not for Golden Delicious apples. Two first-order kinetic mechanisms (1 & 2) are required to describe changes of apple texture during thermal processing. The rate constant for 1 was at least 16 times that for 2; activation energy was 27.7-92.6 kJM^{-1} for both. The z values were 25-99°C and Q_{10} coefficients 1.26-2.50 for both mechanisms. Such results can be used to improve thermal processes for apples.

KEY WORDS: activation energy, first order kinetic mechanism, heat treatment, mechanical properties, rheology

INTRODUCTION

During heat treatment, foods undergo changes in nutrients, texture, flavour and colour; of these texture is the most apparent and the most important, especially in firm, fleshy fruits such as apples and pears[1]. The term texture is used to describe both sensory attributes and mechanical properties of food in response to applied forces, and there have been many attempts to correlate sensory and instrumental (rheological) measurements of texture[1,2,3,4,5,6]. Instrumental measurement was advanced by the General Foods Texture Profile Analysis (TPA) technique[2,7,8,9,10], in which the force-time curves yielded seven parameters, namely Fracturability, Hardness, Cohesiveness, Adhesiveness, Springiness, Gumminess and Chewiness.

As all plant species and individuals differ in chemical composition and histological structure[11], there is inherent variability and nonhomogeneity which increases the variance of instrumental measurements[12]. Holdsworth[13] has reviewed the effect of heating on fruits and Fletcher[14] reported that the variation in mechanical properties of apple slices was higher in processed than in raw fruit. Van Woensel and de Baerdemaeker[15] reported that the change of apple firmness with ripening and processing is a very complex phenomenon. Worthington and Yeatman[16] reported that firmness varies between trees, apples, varieties, type of probe, size of apple and position on apple. Bourne[17] attributed the lack of a reliable measure of apple texture to high fruit-to-fruit variability, substantial differences among seasons, moderate softening during storage and the tendency of attributes to change in different directions and at different rates.

Kinetic data on thermal degradation of food texture can be used for design of improved processes to reduce loss of all aspects of product quality. The rate of softening of various fruits and vegetables is apparently first-order[11,12,18,19,20]. Huang and Bourne[20] suggested that in several vegetables the rate of softening is consistent with two apparent first-order kinetic mechanisms, 1 and 2; mechanism 1 is probably due to pectin changes in the interlamellar spaces. The rate constants for mechanism 1 were more than 20 times greater than those of mechanism 2, and the apparent Arrhenius activation energy values ranged between 21.4 and 146.5 kJM^{-1} for both mechanisms. Anantheswaran et al.[12] reported that the loss of hardness in apples followed a first-order kinetics and the activation energy was found to be 107.2 and 65.3 kJM^{-1} for Cortland and Spigold varieties, respectively. They also reported z values of 24.8 and 42.4°C for the two varieties, respectively. Physical textural characteristics were found to be a function of heating time and temperature, and apple variety[12,21,22].

The present study was undertaken to determine the effect of short and long heating times and of temperature on loss of physical texture of apples, and to verify the "apparent first-order kinetic model" for various instrumental textural parameters.

MATERIALS & METHODS

Red and Golden Delicious apples, grown in Volos area, were purchased from the Central Fruit and Vegetable Market of Athens (Greece). They were held under refrigeration (0°C, 90% RH) for a few days until processing. Only undamaged apples were manually peeled and cored and then diced into 10 mm cubes in a dicer (SOLIA-M10, France) and kept under tap water. After removal of over- and undersized pieces, the processing method of Anantheswaran et al.[12] was applied with some modifications. Apple dice (120 g) were filled into a 401x200 (103x51 mm) can followed by 240 g water at a temperature equal to that of processing or 100°C when processing temperatures greater than 100°C were used. They were then promptly sealed and placed in a preheated, thermostatically controlled water or oil bath. Temperature varied from 60-120°C, heating times from 5 to 35 min (long heating times). At the end of heating, the cans were rapidly cooled by cold (10°C) running water. The processed cans were stored at 0-2°C for 24 h and then measured. Three to 5 cans per apple variety were used for each time-temperature combination.

Huang and Bourne[20] and Anantheswaran et al.[12] observed steep initial loss in several textural parameters, mainly softening, attributed to a first-order kinetic mechanism-1. These short heating time textural changes were measured as follows: Five replicates of apple dice (20-25 g) were added to preheated (60-90°C) test tubes (50x300 mm) in a water bath and water (50 ml) at the same temperature was quickly added. At the designated time (1-15 min), sufficient ice-water was added to cool the dice, which were drained, warmed to 25°C and then force-deformation curves were measured on at least 10 dice for Texture Profile Analysis (TPA) using an Instron Universal Testing Machine model 1140 (Instron, High Wycombe, England). Fracturability (the force at the first significant break), hardness 1 (first compression), hardness 2 (second compression), springiness, cohesiveness, chewiness and gumminess were determined from the curves. Each dice was compressed twice to 80% of its original height using a crosshead and chart speed of 100 $mm min^{-1}$.

Regression and analysis of variance were used to assess results.

RESULTS & DISCUSSION

The various textural parameters were determined from the force-time curves, which were typical of those normally obtained for apples[9,10]. Fracturability, hardness 1 and hardness 2, significantly ($p<0.001$) decreased with processing time and temperature for both varieties. The energy in Joules during the first compression (area A1) also significantly ($p<0.001$) decreased with heating time and temperature for Red and Golden Delicious apples. During second compression there was a significant ($p<0.001$) decrease in energy (area A2) with heating time and temperature for Red Delicious apples, while, for Golden Delicious apples, processing time and temperature had no significant effect. Springiness, a measure of sample elasticity, was found to change with an increase in temperature for both Red ($p<0.05$) and Golden ($p<0.01$) Delicious apples, while no significant changes occurred with changing heating time for either cultivar. Anantheswaran et al.[12] reported that in Spigold apples there were no significant changes in springiness with processing time and temperature, while in the case of Cortland significant ($p<0.05$) increases occurred with processing time. Cohesiveness was increased significantly with heating temperature for both varieties, whereas heating time had no significant effect. Anantheswaran et al.[12] found cohesiveness to change with heating temperature for Spigold and Cortland apples; heating time had no significant effect on cohesiveness for Cortland apples. Gumminess, as a product of hardness and cohesiveness, significantly ($p<0.001$) decreased with processing time and temperature for both varieties. Chewiness significantly decreased with temperature of heating for both cultivars. In Golden Delicious apples no significant changes occurred with heating time. Similar results for chewiness have been obtained by Anantheswaran et al.[12], who reported no significant changes with processing time in Spigold apples.

As it has been stated by Anantheswaran et al.[12] and showed here, textural changes in apples during thermal processing are very complex and very dependent on variety. It should be noted that there is a different behaviour of stem or root tissues and fruit tissues. The last showed larger deviation from the first-order kinetic model. Apples showed multiroute textural changes owing to the exceptionally high content of intercellular air and relative weak or thin cell walls normally occurring in apple parenchyma[11,23,24].

Semilogarithmic plots describing the change of several textural parameters showed two straight lines (Fig. 1 & 2). So, two first-order kinetic mechanisms, as proposed by Huang and Bourne[20], can be used to describe this behaviour. To calculate the rate constants during the first few minutes of heating, the graphical procedure of Huang and Bourne[20] was followed. The linear portion obtained after prolonged heating times (mechanism 2) was extrapolated to zero heating time and the extrapolated line subtracted from the line above it (Fig. 1 & 2). The straight line obtained in this way permitted the calculation of rate constants for mechanism 1 of Huang and Bourne[20].

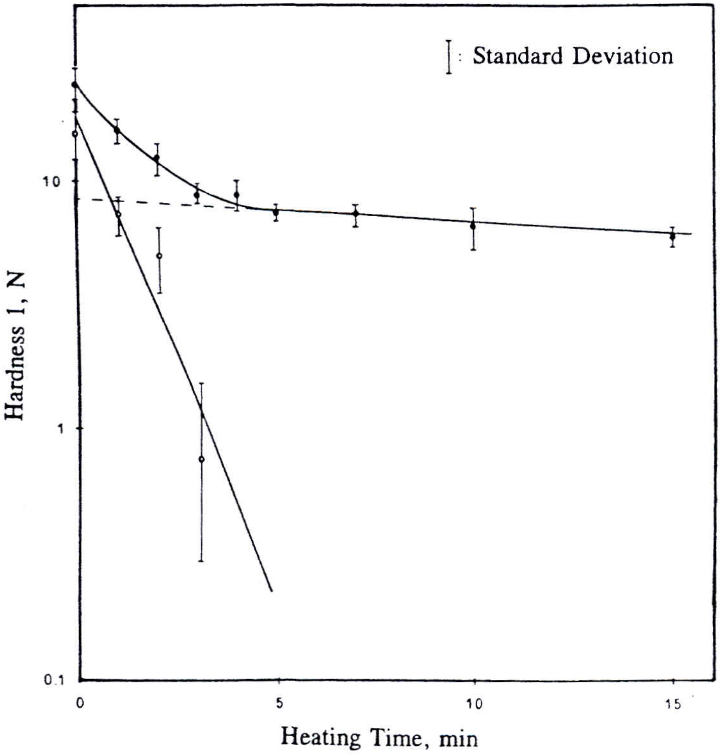

Figure 1: *Effect of heating time at 80°C on hardness of Red Delicious apples. (.) experimental points, (o) points representing differences between extrapolated line and experimental points.*

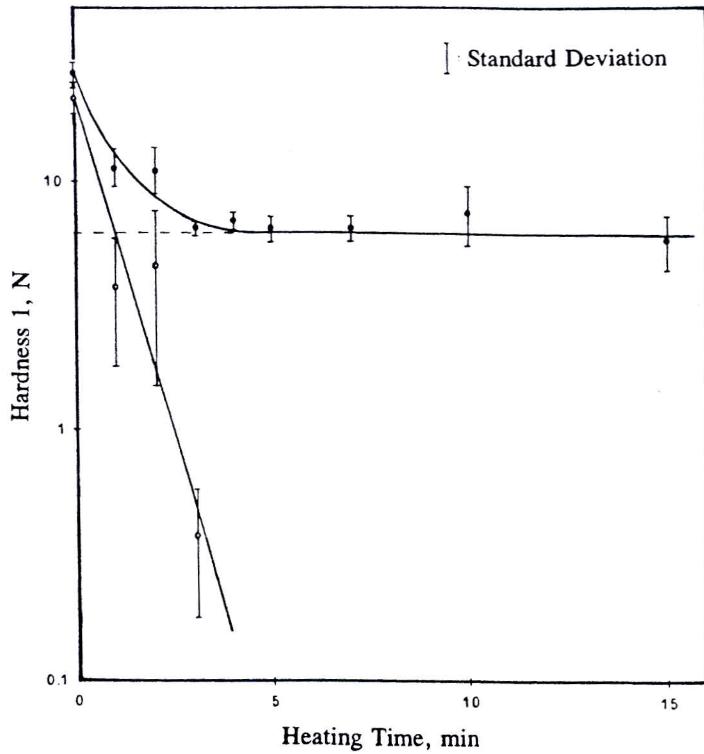

Figure 2: *Effect of heating time at 80°C on hardness of Golden Delicious apples. (.) experimental points, (o) points representing differences between extrapolated line and experimental points.*

Long Heating Times

The large drop in the magnitude of most of the textural parameters that occurred during the initial 3 min of heating, is attributed to mechanism 1[20]. Changes for heating times greater than 5 min could be attributed to mechanism 2 of Huang and Bourne[20].

The results obtained for all textural parameters were plotted vs heating time to evaluate the possibility of using the first-order kinetic model. The linear relationship between log values of fracturability, hardness 1 & 2, and heating time was significant (Table Ia & Ib) and the first-order kinetic model is adequate. Loh and Breene[11] have stated that fracturability is the best available objective parameter for monitoring decreases in crispness of fresh vegetables during the heating process. However, problems in its measurement may arise after prolonged heating times and at high temperatures when a rather smooth graph without the peak of fracturability is obtained by Instron due to loss of crispness and high softness, as well as to inadequate load cell sensitivity of the instrument. So, the peak force representing fracturability is not easily detectable. When such a problem is faced another parameter must be used for monitoring of texture degradation. Loh and Breene[11] have used chewiness for pineapple, papaya and zucchini. Anantheswaran et al.[12] have used hardness to describe the thermal degradation of apple texture. Indeed, log of hardness 1 and hardness 2 were found to decrease linearly with heating time (Table Ia & Ib) and are adequately described by the first-order model. Hardness can always be easily measured. Hardness 2 measures the residual amount of hardness left after the first compression and is highly related to hardness 1.

Tables Ia & Ib list the decimal reduction times or D values, the rate constants (k) and the correlation coefficients (r) for various textural parameters. The D values were calculated from the slope of log(parameter) vs time curves and are included as they are more familiar to food technologists than the rate constants.

The energy required during the first compression (area A1) was modelled as a first-order process, for both varieties, and decreased with increasing temperature (Table Ia & Ib). Hence, in cases where the force for fracturability or hardness or the maximum force during the compression is difficult to measure, the area A1 (expressed in Joules or arbitrary units) could be used for monitoring of texture changes. The energy during second compression (area A2) showed a similar behaviour for Red Delicious apples, while for Golden Delicious there were no significant changes with heating time and temperature. Good correlations were obtained for temperatures higher than 80°C.

Gumminess, as a product of cohesiveness and hardness 1, is greatly affected by changes in hardness and its decrease was also modelled as a first-order process. By the same kinetics, the decrease in chewiness, can also be described, especially at high processing temperatures (Table Ia & Ib). This last parameter has been already used in monitoring textural changes in edible plant tissues[11].

Table Ia

D values (min) and rate constants, k (min^{-1}) for Red Delicious apples - long heating times.

Temp. °C	Kinetic Parameter	Fracturability	Hardness 1	Hardness 2	A1	A2	Gumminess	Chewiness
	D	180.0±20.1	152.1±1.9	143.0±59.6	337.4±18.6	353.7±53.1	155.6±5.9	851.5±20.5
60	k	0.013±0.001	0.015±0.001	0.016±0.006	0.007±0.002	0.007±0.002	0.015±0.001	0.003±0.001
	r	0.87	0.93	0.97	0.50	0.45	0.94	0.14
	D	212.9±6.1	265.9±129.8	208.4±89.2	246.7±2.24	281.6±58.6	305.8±3.0	215.5±31.5
70	k	0.011±0.001	0.009±0.004	0.011±0.004	0.009±0.001	0.008±0.002	0.008±0.001	0.011±0.002
	r	0.85	0.73	0.94	0.64	0.53	0.56	0.65
	D	88.2±3.0	121.0±2.2	104.9±17.9	124.0±12.0	91.2±25.5	89.7±2.3	84.6±1.3
80	k	0.026±0.003	0.019±0.001	0.022±0.004	0.019±0.002	0.025±0.002	0.026±0.001	0.027±0.001
	r	0.94	0.83	0.90	0.89	0.93	0.89	0.89
	D	85.6±7.7	112.7±12.5	117.5±8.0	101.9±17.4	112.1±30.2	125.1±26.6	304.2±73.9
90	k	0.027±0.002	0.020±0.002	0.020±0.001	0.023±0.004	0.021±0.005	0.018±0.004	0.008±0.002
	r	0.97	0.97	0.95	0.97	0.90	0.88	0.28
	D	31.7±0.7	38.0±0.2	41.8±0.2	34.8±0.2	65.4±30.5	112.0±6.1	275.7±90.5
100	k	0.073±0.002	0.061±0.001	0.055±0.001	0.066±0.001	0.035±0.021	0.021±0.002	0.008±0.002
	r	0.99	0.99	0.99	0.99	0.88	0.54	0.33
	D	21.2±0.6	31.9±0.2	34.4±0.1	22.6±1.1	33.1±1.3	45.3±0.1	56.9±18.6
110	k	0.109±0.003	0.072±0.001	0.067±0.001	0.102±0.005	0.070±0.003	0.051±0.001	0.040±0.014
	r	0.98	0.95	0.95	0.97	0.96	0.94	0.80
	D	7.4±1.8	16.8±0.7	18.4±0.5	13.2±0.7	20.5±0.3	30.7±1.4	26.2±0.3
120	k	0.313±0.054	0.137±0.005	0.125±0.003	0.175±0.010	0.113±0.001	0.075±0.003	0.088±0.001
	r	0.98	0.84	0.89	0.92	0.90	0.84	0.87

r=correlation coefficient, ±=standard deviation

Table Ib
D values (min) and rate constants, k (min^{-1}) for Golden Delicious apples - long heating times.

Temp. °C	Kinetic Parameter	Fracturability	Hardness 1	Hardness 2	A1	A2	Gumminess	Chewiness
	D	313.5±55.7	275.3±238.3	297.2±70.6	241.2±67.6	694.5±75.5	146.0±19.8	90.9±16.8
60	k	0.007±0.001	0.008±0.005	0.008±0.002	0.010±0.007	0.003±0.005	0.016±0.002	0.025±0.005
	r	0.66	0.89	0.85	0.85	0.14	0.81	0.89
	D	146.2±23.1	159.6±22.0	165.3±14.0	158.6±53.8	141.3±4.6	138.6±63.5	188.1±47.2
70	k	0.016±0.002	0.014±0.002	0.014±0.001	0.015±0.004	0.016±0.001	0.017±0.006	0.012±0.008
	r	0.90	0.97	0.94	0.95	0.87	0.77	0.65
	D	177.1±112.7	304.1±207.5	276.2±34.5	40.0±25.5	605.0±32.3	196.1±180.3	189.4±10.9
80	k	0.013±0.007	0.008±0.004	0.008±0.003	0.058±0.007	0.004±0.002	0.012±0.015	0.012±0.001
	r	0.66	0.57	0.52	0.62	0.20	0.36	0.17
	D	50.0±11.5	64.5±17.3	62.7±18.7	59.7±16.4	76.8±38.7	84.8±43.9	142.2±10.4
90	k	0.046±0.010	0.036±0.009	0.037±0.010	0.039±0.010	0.030±0.013	0.027±0.012	0.016±0.018
	r	0.98	0.96	0.97	0.92	0.87	0.35	0.59
	D	19.7±2.5	28.1±0.9	30.3±0.6	24.6±0.8	34.1±2.1	44.5±3.0	44.4±13.0
100	k	0.117±0.019	0.082±0.003	0.076±0.001	0.094±0.003	0.068±0.004	0.052±0.003	0.052±0.008
	r	0.98	0.97	0.97	0.96	0.96	0.93	0.86
	D	17.0±1.0	21.7±0.5	23.2±0.7	17.8±0.7	22.3±0.3	28.6±1.4	26.1±1.1
110	k	0.136±0.008	0.106±0.026	0.099±0.003	0.129±0.005	0.103±0.002	0.081±0.004	0.088±0.004
	r	0.93	0.95	0.95	0.95	0.95	0.96	0.97
	D	15.9±0.6	20.8±0.9	22.9±1.1	16.6±0.7	27.0±3.0	40.5±6.3	37.4±8.0
120	k	0.145±0.005	0.111±0.005	0.101±0.005	0.139±0.006	0.085±0.009	0.057±0.008	0.062±0.012
	r	0.94	0.95	0.94	0.95	0.95	0.92	0.93

r=correlation coefficient, ±=standard deviation

From the slope of the plot of log(D_T) vs heating temperature (Fig. 3), the z values (the degres of temperature needed for a 10 times change in D values or in time) for the change of the above textural parameters were calculated (Table II). The z values that resulted from hardness 1 were found to be 53.7 and 45.7°C for Red and Golden Delicious apples respectively. A z value of 42.2°C has been reported[12] for Spigold apples, while a lower value of 24.8°C has been reported for Cortland apples. These differences show that apple variety is one of the dominant factors determining the changes of texture during thermal process. Using various TPA parameters a range of z values between 39-80°C was calculated (Table II).

Activation energies calculated from ln(k) vs 1/T plots for various TPA parameters were between 30.7±3.8 and 89.3±6.8 kJM^{-1} (Table II). These values were within the range of 21-182 kJM^{-1} reported for various fruits and vegetables[11,12,20] and dry legumes[25]. Based on hardness 1, the activation energy was 46.1±3.2 and 55.8±6.4 kJM^{-1} for Red and Golden Delicious apples respectively. Higher values for activation energy have been reported for Cortland (110.95±33.08 kJM^{-1}) and Spigold (65.31±15.91 kJM^{-1}) apples[12]. The Q_{10} values

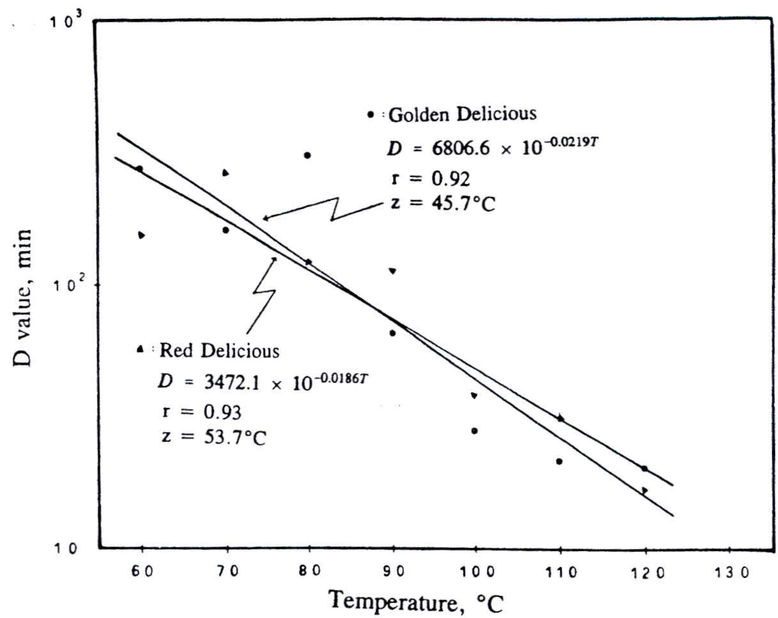

Figure 3. *Thermal degradation time curves for apple hardness.*

of the microbial death are usually greater than 10. Therefore, high processing temperatures could result in a thermally processed fruit with low or minimal degradation in texture.

Table II

Temperature dependence of texture degradation rate - long heating times.

Textural Parameter	z value, °C	E_a, kJM^{-1}	Q_{10}
Red Delicious			
Fracturability	42.4±0.8(0.96)	58.6±0.9(0.95)	1.72
Hardness 1	53.7±3.5(0.93)	46.1±3.2(0.92)	1.54
Hardness 2	60.4±9.0(0.93)	41.0±6.9(0.92)	1.46
A1	41.0±3.7(0.99)	61.1±6.1(0.98)	1.75
A2	49.0±0.6(0.97)	51.1±1.3(0.97)	1.60
Gumminess	76.1±1.0(0.85)	32.4±0.6(0.84)	1.35
Chewiness	54.1±11.9(0.78)	46.1±2.8(0.77)	1.53
Golden Delicious			
Fracturability	41.7±0.6(0.95)	50.6±1.2(0.82)	1.74
Hardness 1	45.7±4.5(0.92)	55.8±6.4(0.73)	1.66
Hardness 2	46.6±0.7(0.93)	53.8±1.1(0.93)	1.64
A1	50.0±1.4(0.94)	50.6±1.1(0.95)	1.58
A2	39.5±9.5(0.88)	89.3±6.8(0.91)	1.79
Gumminess	76.0±6.1(0.88)	32.8±2.1(0.87)	1.35
Chewiness	79.9±9.8(0.76)	30.8±3.8(0.74)	1.33

±=standard deviation, in parenthesis correlation coefficient

Short Heating Times

Table IIIa & IIIb list the D values, the rate constants (k) and correlation coefficients (r) for texture degradation during short heating times. As can be seen the rate constants for mechanism 1 were more than 16 times greater than the rate for mechanism 2 (Table Ia &

Table IIIa

D values (min) and rate constants, k, (min^{-1}) for Red Delicious apples - short heating times.

Temp. °C	Kinetic Parameter	Fracturability	Hardness 1	Hardness 2	A1	A2	Gumminess	Chewiness
	D	4.2±0.1	7.2±0.8	7.3±0.6	6.7±0.7	5.8±0.5	6.7±0.2	4.8±0.2
60	k	0.55±0.01	0.32±0.04	0.31±0.03	0.35±0.04	0.40±0.03	0.34±0.01	0.48±0.02
	r	0.98	1.00	0.98	0.97	1.00	0.96	0.95
	D	2.8±0.9	4.9±0.5	2.6±0.8	2.6±0.5	2.0±0.6	2.4±0.4	2.1±0.2
70	k	0.82±0.33	0.47±0.12	0.90±0.34	0.90±0.20	1.17±0.26	0.97±0.17	1.08±0.09
	r	0.81	0.96	0.99	0.77	0.84	0.97	0.98
	D	2.4±0.5	2.5±0.0	2.1±0.0	2.3±0.4	1.4±0.4	2.0±0.2	1.7±0.2
80	k	0.96±0.20	0.94±0.02	1.12±0.02	0.99±0.19	1.71±0.54	1.18±0.10	1.32±0.15
	r	0.98	0.95	0.97	1.00	0.97	0.91	0.91
	D	1.8±0.1	1.7±0.2	1.8±0.0	2.5±0.2	1.3±0.3	1.2±0.1	1.1±0.2
90	k	1.30±0.09	1.36±0.18	1.29±0.00	0.91±1.00	1.72±0.43	1.93±0.30	2.08±0.36
	r	1.00	0.94	0.98	0.59	0.94	0.98	0.99

±=standard deviation, r=correlation coefficient

Table IIIb

D values (min) and rate constants, k, (min^{-1}) for Golden Delicious apples - short heating times.

Temp. °C	Kinetic Parameter	Fracturability	Hardness 1	Hardness 2	A1	A2	Gumminess	Chewiness
	D	3.8±0.5	17.2±6.3	14.9±5.6	5.2±0.4	6.2±1.0	20.7±0.3	10.7±3.2
60	k	0.60±0.08	0.13±0.04	0.16±0.05	0.44±0.04	0.37±0.06	0.11±0.00	0.21±0.06
	r	0.97	0.82	0.90	1.00	0.99	0.97	0.99
	D	3.7±0.1	3.9±0.2	4.1±0.0	4.6±0.7	6.1±1.3	11.8±0.7	14.6±0.8
70	k	0.62±0.01	0.59±0.03	0.56±0.00	0.50±0.07	0.38±0.08	0.20±0.01	0.16±0.01
	r	0.94	0.95	0.95	0.94	0.99	0.99	0.93
	D	2.6±0.2	1.9±0.6	2.5±0.5	2.2±0.2	2.3±0.2	2.7±0.2	1.7±0.3
80	k	0.89±0.05	1.19±0.56	0.93±0.19	1.06±0.11	0.99±0.08	0.84±0.05	1.37±0.30
	r	0.56	0.92	0.91	0.92	1.00	0.98	0.97
	D	2.0±0.9	1.0±0.1	1.5±0.1	2.1±0.3	2.2±0.2	2.6±0.2	1.1±0.1
90	k	1.15±0.54	2.45±0.11	1.50±0.14	1.11±0.17	1.03±0.10	0.90±0.08	2.06±0.10
	r	0.95	0.93	0.98	0.93	0.98	0.95	0.99

±=standard deviation, r=correlation coefficient

Ib). The z values calculated using D_T values, were between 25 and 99°C for both varieties. Based on hardness, Golden Delicious apples exhibited a lower z value than Red Delicious, showing a greater dependence on temperature, which is also evident from the greater activation energies (Table IV) and Q_{10} values of 1.3-2.5 vs 1.3-1.7 respectively. This could be attributed to differences in flesh structure between the two cultivars. Diener et al.[26] have reported that the rate of firmness decrease for Golden Delicious during maturation was about 70% higher than Red Delicious apples. So, the maturity and condition of apples can affect textural changes. Activation energies were within the range reported for various fruits and vegetables[11,12,20] and Q_{10} coefficients lower than 2.50. The change of other textural parameters, namely chewiness, gumminess, and energy during first and second compression, was also modelled as a first-order process and kinetic constants can be obtained by following the above described procedure. Values for these parameters are shown in Table IV. The change of gumminess and chewiness in Golden Delicious apples showed a greater dependence on temperature than Red Delicious apples (Table IV).

CONCLUSIONS

The above data and analysis show that textural changes in apples during the heating process are very complex and affected by variety. Heating time and temperature greatly affect most textural parameters. Heating time did not significantly affect springiness and cohesiveness in both varieties, and chewiness in Golden Delicious apples.

The rate of change of various textural characteristics was consistent with two first-order kinetic mechanisms as proposed by Huang and Bourne[20]. During the first 2 or 3 minutes of heating there was a great decrease in various textural parameters which confirmed what had been reported by Anantheswaran et al.[12]. The rate constants for mechanism 1 were at least 16 times greater than those of mechanism 2. Activation energies were between 27.7 and 92.6 kJM^{-1} and Q_{10} values between 1.26 and 2.50 for both mechanisms. Q_{10} values show that the use of high temperature - short time (HTST) processes will result in a processed product of better texture. The z values for various parameters were between 25.1 and 99.0°C. The z values for loss of hardness, gumminess and chewiness due to mechanism 1 in Red Delicious apples was about twice of that in Golden Delicious apples.

Table IV

Temperature dependence of texture degradation rate - short heating times.

Textural Parameter	z value, °C	E_a, kJM^{-1}	Q_{10}
Red Delicious			
Fracturability	83.8±0.8(0.98)	27.2±0.0(0.99)	1.32
Hardness 1	45.8±6.5(0.99)	50.5±5.7(0.99)	1.65
Hardness 2	51.6±7.1(0.90)	45.4±5.6(0.91)	1.56
A1	76.2±0.9(0.78)	31.0±0.2(0.80)	1.35
A2	48.3±3.9(0.89)	48.5±5.0(0.91)	1.61
Gumminess	42.7±1.6(0.95)	60.0±2.3(0.96)	1.71
Chewiness	49.7±4.4(0.97)	46.7±4.1(0.97)	1.59
Golden Delicious			
Fracturability	99.0±3.6(0.96)	24.2±9.3(0.95)	1.26
Hardness 1	25.1±4.4(0.97)	92.7±15.5(0.98)	2.50
Hardness 2	31.5±5.9(0.96)	74.1±14.9(0.97)	2.08
A1	65.7±8.4(0.93)	35.0±4.4(0.93)	1.42
A2	57.4±5.1(0.91)	40.3±3.5(0.90)	1.49
Gumminess	29.8±0.9(0.95)	77.9±2.3(0.95)	2.16
Chewiness	25.7±2.0(0.89)	89.5±14.8(0.89)	2.45

±=standard deviation, in parenthesis correlation coefficient

Η ΚΙΝΗΤΙΚΗ ΤΗΣ ΥΠΟΒΑΘΜΙΣΗΣ ΤΗΣ ΥΦΗΣ ΤΩΝ ΜΗΛΩΝ ΚΑΤΑ ΤΗ ΘΕΡΜΙΚΗ ΕΠΕΞΕΡΓΑΣΙΑ

ΠΕΡΙΛΗΨΗ

Η ενόργανη TPA ανάλυση μπορεί να χρησιμοποιηθεί στη μελέτη της θερμικής υποβάθμισης της υφής των μήλων. Ο χρόνος και η θερμοκρασία θέρμανσης μείωναν σημαντικά την ευθραυστότητα, τη σκληρότητα, την ενέργεια που απαιτείται κατά την

πρώτη συμπίεση και το κομμιώδες και στις δύο ποικιλίες μήλων Red και Golden Delicious. Ο χρόνος θέρμανσης δεν επηρέαζε σημαντικά τις μεταβολές της ελαστικότητας, συνεκτικότητας και μασητικότητας και στις δύο ποικιλίες. Οι μεταβολές στην ενέργεια που απαιτείται κατά τη δεύτερη συμπίεση ήταν σημαντικές για την ποικιλία Red, αλλά όχι και για την ποικιλία Golden Delicious. Απαιτούνται δε δύο κινητικοί μηχανισμοί (1 & 2) πρώτης τάξεως για να περιγραφούν οι μεταβολές της υφής των μήλων κατά τη θερμική επεξεργασία. Οι σταθερές ταχύτητας του μηχανισμού 1 ήταν τουλάχιστον 16 φορές εκείνης για το μηχανισμό 2. Η ενέργεια ενεργοποίησης ήταν 27.7-92.6 kJM^{-1} και για τις δύο. Οι τιμές z ήταν 25-99°C και οι συντελεστές Q_{10} 1.26-2.50 και για τους δύο μηχανισμούς. Τέτοια στοιχεία μπορούν να χρησιμοποιηθούν για τη βελτίωση των θερμικών επεξεργασιών των μήλων.

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