TEXTURAL CHANGES IN VEGETABLES DURING THERMAL PROCESSING. I. A DESCRIPTIVE METHOD TO SEGREGATE EFFECTS OF PROCESS TREATMENTS

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Accepted for Publication June 2, 1994

ABSTRACT

Criteria for assessing the effect of processing treatments on the texture of processed foods were developed. Five parameters were defined, relating the hardening or softening of a food material and allowing for the comparison between different processing procedures. In order to determine the usefulness of this method, the parameters were applied to experimental data reported in literature for thermal processing of fruits and vegetables. Three parameters were defined for identifying the effect of a given preprocessing treatment on the raw material texture, the effect of the preprocessing treatment on the sensitivity of the vegetable tissue to the thermal processing and the overall effect. The two remaining parameters were used to describe additional information regarding the process kinetics, that is, to assess the effect of time and temperature on the rate of softening/hardening.

INTRODUCTION

The increasing demand for better quality products from consumers has led to an increasing interest from the processors in developing methods to improve

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the texture of processed vegetables. Texture is one of the most important sensory characteristics of vegetables and perhaps the one most affected by thermal processing.

Preprocessing treatments, such as blanching and addition of calcium chloride, are commonly carried out before vegetable processing (i.e., canning, freezing). Both these pretreatments have been associated with a firming effect and are well-known to improve the texture of the processed product.

It is clear, however, that an adequate development of products with optimum texture depends on the understanding and quantification of the softening process and of the effect of pretreatments on it (Bourne 1989).

Similar to the treatment of chemical reactions, the description of the textural changes due to processing has been attempted using kinetic models, and the textural changes are associated to a time-temperature dependent process. A review of kinetic models used for quantifying the thermal softening of vegetable tissues is given by Bourne (1989). In general, texture of a given sample is characterized by a physical quantity, like the maximum force load obtained from an Instron Universal Testing Machine, and this property is measured as a function of time and temperature. Two models have been generally applied to analyze experimental data: a first order model, where it is assumed that the rate of softening at a fixed temperature is proportional to the property value, the rate will therefore approach zero exponentially; and a two-fraction model, where it is assumed that the vegetable tissue has two fractions, each with its own kinetic parameters, and each following a first order model; for smaller times the fastest process dominates the response, with the fraction associated to it rapidly approaching zero, and for longer times the slowest kinetic process is the fraction observed. In the limiting case of the second fraction with its kinetics being very slow (its rate constant approaches zero), the two-fraction model becomes equal to a single fraction first order with offset.

The interpretation of experimental data is therefore dependent on the identification of one or two straight lines on a semi-logarithmic graph of the property value versus time, for a given temperature. It would be useful if additional methods could be found to clearly identify if there is one first order process (with or without offset) or two processes taking place. In any model, it is usually assumed that the rate constant varies with temperature according to the Arrhenius law.

It is generally concluded that first order models (with one or two fractions) and the Arrhenius dependence of the rate on temperature can represent many experimental results on texture variations (Huang and Boume 1983; Bourne 1989).

It is important to note that if a given pretreatment is used, there are two effects on texture that should be assessed independently: the effect of the pretreatment on the texture of the raw vegetable (which corresponds to a

different texture before the main processing, depending on the pretreatment used) and the effect that the pretreatment has on the sensitivity of the vegetable tissue to the main processing (which means that the softening/hardening kinetics during processing can be different as a result of the pretreatment). In fact, it is not necessarily true that if a pretreatment improves the texture prior to main processing of a vegetable product, the final texture of the processed product is better: the opposite can be true if the tissue becomes more sensitive to the processing method as a result of the changes caused by the pretreatment. This fact will be explored further in this paper.

The interpretation of experimental results on textural changes in foods with the use of kinetic models has a very important role, but also two important limitations: it is only applied to time-temperature dependency and to time temperature evolution that are fairly simple (i.e., it does not account for discontinuities or changes in the type of behavior; e.g. blanching can have a firming effect due to the activation of the pectinmethylesterase enzyme (PME), leading to a situation where a maximum may exist). Thus, there is a need for methods, that complement kinetic analysis, particularly for interpreting and comparing results when certain complex changes in food texture occur.

The objective of this work was the development of a new method to quantify textural changes due to pretreatments and processing steps that would follow an integrated approach and allow to distinguish between the effect of a pretreatment on the texture of the raw product and on the sensitivity of the vegetable tissue to the processing conditions in such a way that the combination of both would also describe total changes in texture. Furthermore, it was intended to analyze the time and time-temperature dependency of a given process without requiring that a model is established *a priori*.

MATERIALS AND METHODS

In order to achieve the proposed objectives, five parameters were defined. These parameters are summarized in Table 1. The definitions are proposed in terms of the different values of the textural property (which can be a firmness reading, a load force, an extrusion force, etc., and is usually expressed in Newtons). The first three parameters are logarithms of ratios, which makes them additive. All parameters can have positive or negative values, with zero meaning that there is no effect, positive values indicating hardening/ less softness and negative values correspond to softening/ less hardness. The values of these parameters for a first order kinetic model are also shown.

Figure 1 shows the relationship between the processing sequences and the nomenclature used for the texture property. As a result of a given process, the

TABLE 1.
SUMMARY DESCRIPTION OF THE PARAMETERS

Parameter	Acronym	Definition	Possible Values	Physical Meaning	Value for 1st order kinetics
Pre processing effect on the Initial Texture	PIT	$\text{Ln} \frac{F_{T0}}{F_{R0}}$	$+\infty \uparrow$ hardening 0 • no effect $-\infty \downarrow$ softening	Effect of the pre-processing treatment on the texture of the product (compared to the raw product)	$-k_T \Delta t_T$
Pre processing effect on the texture Variation due to Processing	PVP	$\text{Ln} \frac{(F_T / F_{T0})}{(F_R / F_{R0})}$	$+\infty \uparrow$ more hard/ less soft 0 • no effect $-\infty \downarrow$ more soft/ less hard	Changes in the texture of the pre processed product (compared to the raw product)	$-(k_P - k_R) \Delta t_P^{(1)}$
Total (pre processing + processing) effect on Product Texture	TPT	$\text{Ln} \frac{F_T}{F_R}$	$+\infty \uparrow$ hardening 0 • no effect $-\infty \downarrow$ softening	Comparison between the texture of the pre-processed and the raw product after processing (TPT=PIT + PVP)	$-(k_P \Delta t_P - k_T \Delta t_T)$
Time Step Effect on texture	TSE	$\frac{\text{Ln} (F_{t2} / F_{t1})}{(t2-t1)}$	$+\infty \uparrow$ hardening 0 • no effect $-\infty \downarrow$ softening	Time effect on texture, at constant temperature	$k_P \cdot k_T$
Time/Temperature Effect on texture	TTE	$\frac{\text{Ln} (F_{T2} / F_{T1})}{(T2-T1) (t2-t1)}$	$+\infty \uparrow$ more hard/ less soft 0 • no effect $-\infty \downarrow$ more soft/ less hard	Effect of temperature and time on texture TTE = $\frac{\text{TSE}(T2) - \text{TSE}(T1)}{T2-T1}$	$\alpha^{(2)}$

(1) if the same time is considered

(2) if $k_T = k_{T0} + \alpha T$

FIG. 1. SCHEMATIC REPRESENTATION OF THE RELATIONSHIP OF NOMENCLATURE WITH PROCESSING STEPS

texture of a raw vegetable changes from F_{R0} to F_R . As a result of a pretreatment, the texture of a raw vegetable changes from F_{R0} to F_{T0} and a subsequent process causes the texture to change from F_{T0} to F_T . The effect of the pretreatment on the final texture of a product is therefore obtained by comparing F_T with F_R .

The Preprocessing effect on the Initial Texture (PIT parameter) quantifies the softening (if it is negative) or the hardening (if it is positive) of the raw material due to the preprocessing treatment itself.

The PVP (Preprocessing effect on the texture Variation due to Processing) compares the change in texture that occurs during the main processing for a product that was pretreated and the one that would occur if no pretreatment had been used. When this parameter is zero, the pretreatment did not affect the sensitivity of the vegetable tissues to the processing conditions; if it is positive, then less softening (or more hardening) has occurred during processing as a result of the changes promoted by the pretreatment and the reverse, if it is negative.

The Total (preprocessing + processing) effect on Product Texture (TPT parameter) is the mathematical sum of the two previous parameters and quantifies the overall effect on texture. Positive values mean that the final product is less soft than if no pretreatment had been made. The higher this parameter, the more effective the pretreatment was in preventing texture softening.

The Time Step Effect on texture (TSE parameter) evaluates the effect of processing time (at constant temperature). It can be referred to as processing time or preprocessing treatment time. This parameter describes the sensitivity of the product texture to temperature: if a first order model applies, it is simply equal to the rate constant; if a two fraction model is valid, then there will be a set of time intervals at the beginning of the process for which this parameter has a higher value and another at the end of the process for which it has a lower value, with an intermediate region.

The Time Temperature Effect on texture (TTE parameter) combines the effect of time intervals with temperature changes. It can be seen that it is equal to the difference of the TSE parameters at two different temperatures divided by the temperature difference. For a first order rate, it can be determined that if the temperature difference is sufficiently small for the rate constant to have an approximately linear variation with temperature, then the TTE parameter is simply equal to the slope of that linear relationship. Thus, the TTE parameter will increase with temperature, for equal temperature steps, for an Arrhenius law.

The first three parameters quantify the softening caused by the given processing conditions. By comparing against a control sample, it is possible to quantify immediately the effect of a given preprocessing treatment or of changing operating conditions on the final texture. The higher the value of the TPT parameter, the greater the effect. The usefulness of the PVP parameter is to show that a product texture is improved by a given preprocessing treatment, it does not necessarily imply that the final texture of the processed product is better.

The last two parameters are related to the kinetics of the softening process: the effect of time on texture at a given temperature and the combined effect of temperature and time. A processing time/processing temperature that leads to a greater value in the TTE parameter is more beneficial in terms of texture retention.

The best way to visualize the usefulness of these parameters is by applying them to experimental data and to see how conclusions may be drawn easily. Some of the conclusions discussed in the following were left undetected by the original researchers, for lack of an adequate method to analyze and understand the data obtained.

RESULTS AND DISCUSSION

The parameters developed in this paper were tested using data on texture found in literature for processed vegetables. Four sets of experimental data were selected for this work as case studies (Harada *et al.* 1985; Bourne 1987; Canet and Hill 1987; Monsalve-Gonzalez *et al.* 1993).

Case Study I. Softening During Potato Cooking (Harada *et al.* 1985): Application of the Parameter TSE

Harada *et al.* (1985) studied the softening occurring during the cooking of

temperatures. Figure 2 shows the TSE parameter plotted for the data. It can be seen that softening occurs since all values are negative. It should be noted, however, that if a first order decay would be valid, the TSE parameter would be constant at each temperature. For 100 and 110C, this is approximately the case (with the second time interval giving an odd point), but at 90C, the first two time intervals gave TSE values clearly lower than the other three: this would suggest a two fraction model. In fact, Harada *et al.* (1985) had reported for potatoes a much lower correlation for this temperature (0.91) than for the others. If a two fraction model is used, the residual (square root of the sum of the squares of the difference between model and experimental points, divided by the number of degrees of freedom) is 0.61, whereas it would be 5.99 for the single fraction reported by Harada *et al.* (1985). Thus a two fraction model would be more suitable for representing the data at 90C.

FIG. 2. A COLUMNAR REPRESENTATION OF THE TSE PARAMETER
Calculated from the data of Harada *et al.* (1985).

Case Study II. Carrot Softening During Blanching (Bourne 1987): Application of the Parameters TSE, PIT, PVP and TPT

The analysis of rate kinetic data using the TSE parameter is illustrated again with research done by Bourne (1987) on softening of diced Nantes carrots subjected to two different types of blanching and then thermally processed. The TSE values for the two different blanching temperatures are shown in Fig. 3. It can be clearly seen that a single fraction first order model cannot be applied. A two fraction model can be inferred from the first 5 to 6 points, with much lower values (varying around -4.0) and the final 7 to 8 points with values closer to zero. Bourne (1987) had applied the two fraction model to the data, with a good correlation.

Since no standard blanching process is available, the two different blanching conditions may be compared with each other. If a value for a control sample or

FIG. 3. A COLUMNAR REPRESENTATION OF CHANGE IN THE TSE PARAMETER
Calculated from the data of Bourne (1987).

process did exist, then the PIT value for each blanching condition could be calculated as $\ln(F_{TO}/F_{RO})$ and $\ln(F_{TO}'/F_{RO})$. The difference between the two PIT would be $\ln(F_{TO}'/F_{TO})$. For the PVP and TPT parameters the same procedure can be used. For such a case the parameters are determined taking one as a standard (e.g., blanching at 74°C) and calculating the parameters for the other (i.e., each parameter is the difference between the true parameters). The results illustrate the effect of one process compared to the effect of the other. Using this approach the results are the following: PIT = -1.00; PVP = 0.156; TPT = -0.84. These values indicate that the blanching process at 100°C led to a softer carrot tissue before the thermal processing (negative PIT) and that although slightly more softening occurred during processing for the carrots blanched at

74C (positive PVP), the final texture is softer for this case (negative TPT: the change caused more softening than the standard).

Case Study III. Effect of Blanching on Cooked Potatoes (Canet and Hill 1987): Application of the Parameters PIT, PVP and TPT

Useful conclusions can be drawn from the data reported by Canet and Hill (1987), most of which were not apparent in the original work. These authors considered thermal processing (cooking) of potatoes, subjected to five different blanching conditions. The different preprocessing treatments are shown in Table 2.

TABLE 2.
THE PREPROCESSING TREATMENTS FOR POTATOES
Used by Canet and Hill (1987).

Reference number	Pre processing treatment
I	Conventional blanching, 97 °C, for 2 min
II	Stepwise blanching, 70 °C. for 10 min, followed by cooling and then 97 °C for 2 min
III	30 s microwave, cooling, then 97 °C for 2 min
IV	60 s microwave, cooling, then 97 °C for 1.5 min
V	30 s microwave, no cooling, then 97 °C for 1.5 min
VI	60 s microwave, no cooling, then 97 °C for 1 min

Using the calculated parameters, one can immediately sort the different conditions in terms of their effect on texture before processing, during processing and the total effect. This is shown in Fig. 4. The best final texture is obtained for the preprocessing case identified as number III, since it has the highest TPT, although being negative, which means the potato is softer than the raw potato. It is interesting to note that as a result of the preprocessing using microwaves (numbers III to VI), the potatoes actually harden during the cooking process, thereby compensating for the greater softening that the preprocessing treatment in itself had caused in the raw tissues. The increased hardening during

FIG. 4. THE PIT, PVP AND TPT PARAMETERS CALCULATED
From the data of Canet and Hill (1987).

cooking was obtained for preprocessing treatment number VI, but this was not enough to compensate for a too-large softening that occurred in the blanching process. The blanching process that affected the raw potatoes the least was the number II, but since in this case further softening occurred during processing, the final texture was not so good. The use of the above mentioned parameters is particularly useful in situations, such as the one by Canet and Hill (1987). They carried out a cooking process that did not involve a fixed time. The potatoes were cooked until they exhibited the same degree of cooking. Since there are no time-temperature relationships reported, the use of kinetic analysis for interpretation of the data is not possible.

Case Study IV. Osmotic Drying of Apples (Monsalve-Gonzalez *et al.* 1993): Application of the Parameters TSE and TTE

Monsalve-Gonzalez *et al.* (1993) studied the osmotic drying of apples in a sugar solution at three different temperatures (30, 40 and 50°C). The effect of acidifying with a mixture of citric and ascorbic acids was analyzed. The data reported by Monsalve-Gonzalez *et al.* (1993) can be used to illustrate the parameters TTE and TSE.

Figure 5 shows the TTE parameters, from which it can be seen that for the nonacidified product, increasing the temperature from 30 to 40°C leads to a

FIG. 5. A COLUMNAR REPRESENTATION OF THE TTE PARAMETER
Calculated from the data of Monsalve-Gonzalez *et al.* (1993).

positive change, since there is less softening, but when the temperature is increased from 40 to 50C, the change is disadvantageous. The best temperature should therefore be 40C. With acidification, however, the increase in temperature is always beneficial, meaning that for acidified samples the best temperature is 50C.

Figure 6 shows the TSE parameter for the data of Monsalve-Gonzalez *et al.* (1993). It can be seen that the softening process cannot be well-described by a single fraction first order model. For the higher times (above 180 min), a first order model may be applied to one fraction of the product, since the TSE parameter is then roughly constant. However, it is evident that an Arrhenius law will not apply for this fraction, since there are many cases, particularly for the nonacidified samples, for which the TSE does not increase with temperature (note that for first order reaction, the TSE parameter is equal to the rate constant k). For shorter time intervals, an increase in the rate constant with time is

FIG. 6. A COLUMNAR REPRESENTATION OF THE TSE PARAMETER
Calculated from the data of Monsalve-Gonzalez *et al.* (1993)

apparent. This conclusion, however, depends on the certainty of the data, since it depends mostly on the measurements of the second and third point. In this process the variation in texture is very small. Therefore, one is working in a range where differences are of the order of magnitude of experimental errors.

CONCLUSIONS

The five parameters proposed in this paper provide a simple method to analyze data on texture variation due to processing. The parameters are particularly useful when determining the best processing option that maximizes product texture. This approach can be used to complement kinetic modelling, particularly for situations when a simple overall model could not be applied.

NOMENCLATURE

F_R	Maximum load force value in the raw product after processing (N)
F_{Ro}	Maximum load force value in the raw product before processing (N)
F_T	Maximum load force value in the preprocessed product after processing (N)
F_{To}	Maximum load force value in the raw product after preprocessing (N)
F_{T1}	Maximum load force value in the processed product at temperature T_1 (N)
F_{T2}	Maximum load force value in the processed product at temperature T_2 (N)
F_{t1}	Maximum load force value in the processed product at time t_1 (N)
F_{t2}	Maximum load force value in the processed product at time t_2 (N)
k_p	Rate constant for textural changes in the preprocessing, following first order kinetics (s^{-1})
k_R	Rate constant for textural changes in the processing of raw product, following first order kinetics (s^{-1})
k_T	Rate constant for textural changes in the processing of preprocessed product, following first order kinetics (s^{-1})
k_{To}	Rate constant for textural changes in the processing of preprocessed product, following first order kinetics, at a reference temperature (s^{-1})
T	Temperature (C)
α	Slope of the variation of the rate constant with temperature, when a linear dependence can be considered ($C.s^{-1}$)
D_{tp}	Preprocessing time (s)
D_{tr}	Processing time, for both raw and preprocessed product (s)

REFERENCES

- BOURNE, M.C. 1983. Physical properties and structure of horticultural crops. In *Physical Properties of Foods*, (M. Peleg and E.B. Bagley, eds.) pp. 207-228, Van Nostrand Reinhold/AVI, New York.
- BOURNE, M.C. 1987. Effect of blanch temperature on kinetics of thermal softening of carrots and green beans. *J. Food Sci.* 52, 667-668(690).
- BOURNE, M.C. 1989. Applications of chemical kinetic theory to the rate of thermal softening of vegetable tissue. In *Quality Factors of Fruits and Vegetables*, (J.J. Jen, ed) pp. 98-139, American Chemical Society, Washington, DC.

- CANET, W. and HILL, M.A. 1987. Comparison of several blanching methods on the texture and ascorbic acid content of frozen potatoes. *Int. J. of Food Sci. Technol.* 22, 273-277.
- HARADA, T., TIRTOHUSODO, H. and PAULUS, K. 1985. Influence of temperature and time on cooking kinetics of potatoes. *J. Food Sci.* 50, 459-472.
- HUANG, Y.T. and BOURNE, M.C. 1983. Research note: kinetics of thermal softening of vegetables. *J. Texture Studies* 14, 1-14.
- MONSALVE-GONZALEZ, A., CANOVAS, G.V.B. and CAVALIERI, R.P. 1993. Mass transfer and textural changes during processing of apples by "combined methods". *J. Food Sci.* 57, 928-931.