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Optimizing Conditions for Thermal Processes of Soy Milk

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Mathematical and kinetic models were set up for heat-induced quality changes in soy milk, including inactivation of trypsin inhibitor activity (TIA) and degradation of thiamin, riboflavin, color, and flavor over a wide range of time−temperature combinations with particular interest in the ultrahigh-temperature (UHT) range. On the basis of these models, multiresponse optimization of the thermal processes for soy milk was carried out to obtain the following effects simultaneously: (1) maximum destruction of bacterial spores, (2) maximum inactivation of TIA, and (3) minimum degradation of sensory and nutritional qualities. By a suitable selection of high temperatures and extended heating times, for example, 143 °C/60 s, it is possible to use a single-step UHT process to produce a commercially sterile soy milk with satisfactory TIA inactivation, highly acceptable color and flavor, and thiamin retention between 90 and 93%.

KEYWORDS: Soy milk; optimization; thermal process; trypsin inhibitors

INTRODUCTION

Conventional soy milk manufacturing procedures include heating freshly prepared soy milk or slurry to boiling in an open vessel for ~30 min. This partly destroys the antinutritional factors and improves flavor. Commercial soy beverages in tin cans or glass bottles are sterilized batchwise in retorts or continuously in a hydrostatic sterilizer to achieve commercial sterility (*1*). The boiling step and the in-container sterilization process are inefficient and energy-consuming. Nowadays, in large-scale production, thermal processes are often substituted by a continuous high-temperature−short-time (HTST) process. The development of an optimized HTST process, however, requires reliable data on the kinetics of heat-induced quality changes in soy milk.

An ideal thermal process for a commercial food product is one that maximizes the destruction of bacterial spores to achieve commercial sterility while minimizing heat damage on nutritional and sensory qualities. Thermal destruction of spores, which has a higher activation energy than heat-damage reactions, is optimized by HTST treatments such as the ultrahigh-temperature (UHT) processes (132 °C or above). In processing soybean products, destruction of antinutritional factors is another important concern. Assessment of the overall nutritional quality of a soybean product depends not only on its nutrient content but also on the antinutritional factors present. It has been shown that heat inactivation of antinutritional factors such as trypsin inhibitors parallels the nutritive value improvement of the soy protein (*2*, *3*). In soybeans, trypsin inhibitor activity (TIA) is a combination of inhibitor activity of two different proteins with different heat labilities. These are the Kunitz soybean trypsin inhibitor (KSTI) and the Bowman−Birk inhibitor (BBI). The KSTI is generally heat labile, whereas the BBI is very heat stable. At 143 and 154 °C (in the UHT range), the heating times required to inactivate 90% of the total TIA in soy milk at pH 6.5 were determined by Kwok et al. (*4*) to be 62 and 29 s, respectively. These heating times, which are far higher than those necessary for spore destruction, may also cause considerable heat damage to the sensory and nutritional qualities of soy milk. The *Z* value (temperature difference in °C effecting a 10-fold change in the rate of the reaction) of heat inactivation of TIA in soy milk was estimated to be 28 °C (*5*). This value is close to those of most heat-damage reactions, indicating the similarity in temperature dependence of these reactions. Therefore, in soy milk processing, the question arises as to whether there is a conflict between an ideal UHT process designed to give maximum bacterial destruction together with minimum heat-damage effects and a process that should bring about the destruction of heat-resistant trypsin inhibitors.

Kwok and co-investigators have carried out a systematic study on the kinetics of heat-induced quality changes in soy milk (*4*−*8*) over a wide range of heating temperatures and times. These studies have included the heat inactivation of TIA and thermal degradation of sensory (color and flavor) and nutritional properties (thiamin, riboflavin, and available lysine content). In the present study, kinetic and mathematical models were set up on the basis of experimental data obtained previously (*4*−*8*) for various heat-induced reactions occurring in soy milk. The thermal processes involved two processing variables (temper-

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ature and time) and more than one desirable response (maximum destruction of bacteria spores, maximum inactivation of trypsin inhibitors, and minimum degradation of sensory and nutritional quality). The optimum processing conditions were searched in a computer program for all of the responses simultaneously to satisfy some predetermined quality requirements.

MATERIALS AND METHODS

Experimental Studies. Experimental studies on the kinetics of the heat inactivation of TIA and thermal degradation of color, taste, thiamin, and riboflavin in soy milk have been performed and reported by Kwok et al. (*4*, *6*−*8*). Heat treatment of soy milk was carried out in stainless steel capillary tubes in a temperature-controlled water/oil bath using water or polyethylene glycol as the heating medium. The capillary tubes (2-mm internal diameter, 0.56-mm wall thickness, and 6-m length, spiral-coiled with a valve at each end), which had a thin wall and large surface area, were highly efficient in heat transfer. The heating temperatures and times used covered ranges from 80 to 154 °C and from 0.5 to 180 min, respectively. At the end of the heating period, the tubes were immediately transferred to a cold water bath for cooling. The temperature of the soy milk during heating and cooling was measured by a type T thermocouple inserted into the capillary tube. The time was precisely measured from the instant of immersing the tube in the water bath to the instant of immersing in the cold water bath. The time required to heat the soy milk in the tubes to temperatures between 80 and 154 °C varied between 6 and 10 s, whereas cooling took 3−7 s. With these procedures, the errors due to the lag periods for heating and cooling times were canceled out or minimized and were considered to be negligible in comparison with the total heating time.

Setting up Kinetic and Mathematical Models. The application of chemical kinetics to quality deterioration of foods has been reviewed and discussed by several authors (*9*−*11*). The analytical approach to calculating and predicting food quality deterioration involves a kinetic or mathematical model. The kinetic approach is based on the process rate, which can be generalized and correlated with environmental factors (temperature, pressure, etc.) and composition factors (concentration, pH, etc.). The rate equation describes the dependence of the reaction rate on the concentrations of the reactants. Most literature data for change in food quality (based on some chemical reactions, microbial growth, death, or sensory quality) follow a zero- or first-order reaction kinetics. The most common and generally valid assumption is that temperature dependence of the reaction rate will follow the Arrhenius equation. Combining the rate equation and the Arrhenius equation, kinetic models, which describe the concentration of a quality factor with processing temperature and time, can be derived.

From the experimental results obtained in previous studies (*6*, *8*), kinetic models were developed for the changes in the thermal destruction of thiamin and riboflavin and sensory quality (based on a hedonic score of a sensory evaluation) in soy milk during processing. The kinetic data enabled the determination of the order of reaction and the kinetic parameters (activation energy and frequency factor). The kinetic model for the thermal destruction of bacterial spores was derived on the basis of literature data (*12*).

Response surface methodology (RSM) was used to investigate the effects of processing temperature and time on the inactivation of trypsin inhibitors in soy milk. A quadratic polynomial equation, relating log(% TIA retained) as a function of heating time and temperature, was fitted to the experimental data by least-squares regression (*4*).

Searching for Multiple Response Conditions by Graphical Analysis and by the RSREG Procedure (SAS). From the experimental results, curves were prepared on a semilog time−temperature diagram to show the relationships between heating temperature and time on the thermal destruction of bacteria spores, heat inactivation of TIA, and degradation of thiamin, color, and flavor in soy milk. By graphical analysis of this diagram, an overall picture of the responses of various quality parameters to the input factors (heating time and temperature) was obtained.

Optimization of conditions for the heat treatment of soy milk was performed by combining the kinetic and mathematical models of several critical quality parameters and solving these equations simultaneously. The solutions were obtained by a computer search using the RSREG procedure of SAS (*13*).

RESULTS AND DISCUSSION

Kinetic Model for Destruction of *Clostridium sporogenes* (PA 3679) Spores. National Canners Association strain of putrefactive anaerobe (PA) 3679, a resistant strain of *C. sporogenes*, is widely used in the canning industry for determining safe sterilizing times and temperatures. The *Z* and *F* values that characterize the thermal death time curve of this organism are given in the *Laboratory Manual for Food Canners and Processors* (*12*). The *Z* and *F* values were reported to be 10 °C (18 °F) and 7.5 min, respectively, when the pH of the heating medium was 6.2 (canned beans). Because the pH of soy milk was close to 6.2, these values were used by Lo et al. (*14*) to estimate the minimum processing time required for sterilization of bottled soy milk. On the basis of the reported values of *Z* and *F*, a kinetic model for the destruction of PA 3679 can be set for soy milk heated in a stainless steel capillary tube. It is assumed that the heating and cooling of soy milk in this apparatus are almost instantaneous. Logarithmic order of death (first-order kinetics) may be assumed for bacterial spores:

$$\log(N_0/N) = kt/2.303 \tag{1}$$

or

$$\log(N_0/N) = t/D \tag{2}$$

N_0 = concentration of spores at time zero, N = concentration of spores at time t, k = rate constant (min^{-1}), D = decimal reduction time (min) (time for 90% destruction of the spores), and t = heating time (min).

Because

$$D = D_{121} \times 10^{(121-T)/Z} \tag{3}$$

and

$$m = \log(N_0/N) \tag{4}$$

where D_{121} = decimal reduction time at 121 °C (min), T = processing temperature (°C), and m = reduction exponent, which is the number of log cycle destruction of the spores, thus

$$m = t/[D_{121} \times 10^{(121-T)/Z}] \tag{5}$$

PA 3679 is a nontoxic obligate anaerobic spore former that is significantly more resistant to heat than *Clostridium botulinum*, and it is used to determine safe thermal processes for low-acid foods. For this organism, $m = 5$ ($F = 5D$) is adopted to keep the spoilage rate at a level economically tolerable to the processor (*12*, *15*). This means the thermal process should give 99.999% destruction of these spores in order to achieve commercial sterility. For PA 3679, $Z = 10$ °C and $F = 7.8$ min. D_{121} is calculated to be 1.56 min using the relationship $F = 5D$. Equation 5 becomes

$$m = t/[1.56 \times 10^{(121-T)/10}] \tag{6}$$

Equation 6 describes the temperature/time combination necessary to bring the spores of PA 3679 in soy milk down to a desired level (m).

Kinetic Model for Thermal Degradation of Food Components in Soy Milk. The kinetic parameters for the changes of color, taste, thiamin, and riboflavin calculated from the experi-

Table 1. Summary of Calculated Kinetic Parameters for the Thermal Destruction of Food Components in Soy Milk

component		n^a	$k_0{}^b$	E_a,[c] kJ/mol
color[d]	L^*	1	3.99×10^6	71.7
	a^*	0	5.92×10^8	77.7
	b^*	0	7.99×10^8	75.3
	C^*	0	8.84×10^8	75.8
	h^*	0	1.31×10^9	73.5
	$1/R$	1	8.02×10^7	77.0
color score[e]		0	7.22×10^9	80.6
taste score[e]		0	7.18×10^{11}	94.6
thiamin		1	1.19×10^{11}	97.0
riboflavin		1	5.93×10^8	83.0

[a] n = order of reaction. [b] k_0 = frequency factor. The units for k_0 are (concentration) (min^{-1}) and min^{-1} for zero- and first-order reactions, respectively. [c] E_a = activation energy. [d] L^*, a^*, b^*, C^*, h^*, and $1/R$ are color attributes measured instrumentally using CIELAB uniform color space (*9*). [e] Color and taste scores are based on a 9-unit hedonic scale (*10*).

Table 2. Kinetic Models for the Thermal Destruction of Food Components in Soy Milk

component	n^a	model[b]
color:[c] a^*, b^*, C^*, h^*	0	$C = C_0 - k_0 \exp(-E_a/RT_a)(t)$
color and taste scores[d]	0	
color:[c] L^*, $1/R$	1	$\log(C/C_0) = -k_0/2.303 \exp(-E_a/RT_a)(t)$
thiamin and riboflavin	1	

[a] n = order of reaction. [b] T_a = absolute temperature in K; $R = 8.314 \times 10^{-3}$ kJ mol^{-1} K^{-1}; t = time in minutes. k_0 and E_a (kJ/mol) for each component can be obtained from **Table 1**. [c] L^*, a^*, b^*, C^*, h^*, and $1/R$ are color attributes measured instrumentally using CIELAB uniform color space (*9*). [d] Color and taste scores are based on a 9-unit hedonic scale (*10*).

mental results (*6*−*8*) are presented in **Table 1**. The thermal degradation of the color, taste, thiamin, and riboflavin in soy milk can be described by either a zero- or a first-order reaction kinetics. The kinetic models relating the quality deterioration as a function of temperature and processing time are summarized in **Table 2**. From the experimental results, thiamin is more sensitive to heat than riboflavin. It is therefore chosen as one of the critical response variables, representing the extent of nutrient retention, in the optimization of thermal processes for soy milk. Ideally, nutrient retention should be maximized, but in practice it is inevitable to sacrifice some nutrients to achieve simultaneously satisfactory destruction of bacterial spores and inactivation of antinutritional factors. In this study, the target was 90−95% retention of thiamin in soy milk after the thermal process.

In this study, color change in heated soy milk was measured instrumentally using CIELAB uniform color space (*8*) and also evaluated by a taste panel (*9*). The instrumental method characterized the browning of soy milk in terms of CIELAB L^*, a^*, b^* values, chroma, and hue. These values are accurate measurements of the intensity of various color attributes in soy milk, but the identification of the visual perception threshold of browning still has to rely on sensory tests. For the purpose of optimization, the data based on sensory tests were used instead of the CIELAB values because the former reflects the desirability of the sensory quality, whereas the latter shows only the intensity. Statistical analysis by the rank sum method showed that a mean score of 6.0 was not significantly different ($p = 0.05$) from the average color and flavor score of the reference soy milk, indicating an acceptable quality level (*8*).

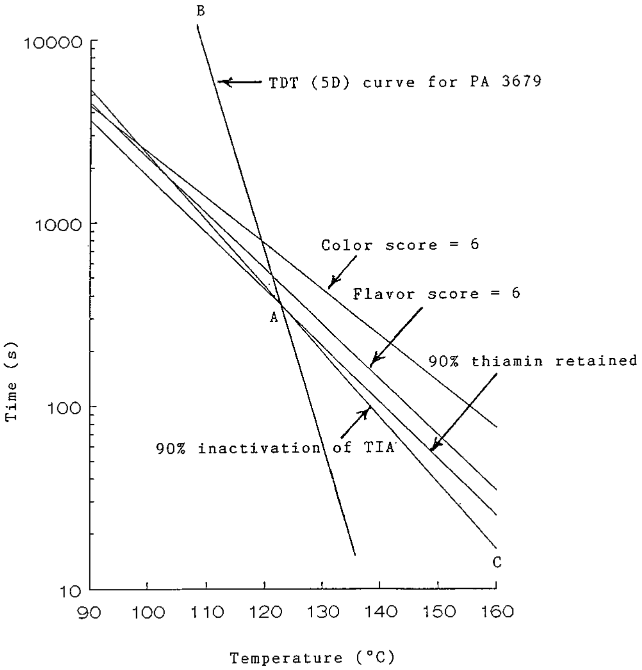

Figure 1. Relationship between heating time and temperature in soy milk processing for (1) 5D destruction of the spores of PA 3679, (2) 90% inactivation of TIA, (3) 90% retention of thiamin, and (4) color and flavor corresponding to a score of 6 on a 9-unit hedonic scale.

Mathematical Model for the Heat Inactivation of Trypsin Inhibitors in Soy Milk. The mathematical model for the heat inactivation of trypsin inhibitors in soy milk set up by Kwok et al. (*4*) has the form

$$Y = -3.209066 + 0.085725X_1 + 0.013253X_2 - 0.000350X_1^2 + 0.000103X_2^2 - 0.000244X_1X_2 \quad (7)$$

where $Y = \log(\%\ \text{TIA retained})$, X_1 = temperature in °C (121−154 °C), and X_2 = heating time in seconds (10−90 s).

Within the range of the heating times investigated (10−90 s), TIA in soy milk was satisfactorily destroyed to 10% retained at 143 and 154 °C with 62 and 29 s of heating time, respectively. It should be noted that the regression equation should be applied only to temperature and time within the experimental range.

Due to the necessity of achieving a balance between the heat necessary to destroy the trypsin inhibitors and that which can potentially damage the nutritional value or functional properties of the protein, most commercially available edible-grade soybean products actually retain 5−20% of the TIA present in the original raw soybean from which they were prepared (*16*). The extent of destruction of TIA in soy milk for maximum nutritive value or protein efficiency ratio was reported to be 90% (*17*). In this study, this level was considered to be optimum.

Searching for Optimum Time—Temperature Combinations by Graphical Analysis and by the RSREG Procedure (SAS). The following curves are shown in the semilog time−temperature diagram in **Figure 1**: (1) thermal death time (TDT) curve for 99.999% (5*D*) destruction of the spores of PA 3679, calculated according to eq 12; (2) line for 90% inactivation of TIA in soy milk, derived from previous works (*4*, *5*); (3) line for 90% retention of thiamin, calculated according to the kinetic parameter and model in **Tables 1** and **2**, respectively; (4) lines for color and flavor, corresponding to a score of 6 on a 9-unit hedonic scale, calculated according to the kinetic parameters and model in **Tables 1** and **2**, respectively.

As evident in **Figure 1**, the TDT curve of PA 3679 has the steepest slope (Z value = 10 °C) of all the lines, indicating that thermal destruction of bacterial spores is most temperature-dependent. Of all the quality parameters to be controlled, the color and taste of soy milk are relatively more heat stable. Hence, thermal destruction of spores, inactivation of TIA, and retention of thiamin are the more crucial quality factors in soy milk processing. It is noted that at temperatures below 123 °C, a longer time was required to kill PA 3679 than to inactivate TIA, but above 123 °C the situation is reversed. At ~123 °C (point A in **Figure 1**), inactivation of TIA and sterilization of the soy milk should be accomplished with the same heating time (~330 s). This time–temperature combination should also produce a soy milk with 90% of the thiamin retained and color and flavor scores >6. Below this critical temperature, the time–temperature combination along the line AB must be followed in order to achieve commercial sterility. However, such heat treatments would lead to deterioration of thiamin, color, and taste greater than the desired levels. At temperatures >123 °C, the line AC represents the time–temperature conditions that should be applied. Along this line, using HTST processing would result in greater preservation of thiamin as well as the sensory qualities. Commercial UHT processing of soy milk involves the use of high temperatures (135–150 °C) for short times (a few seconds) to achieve a product that is commercially sterile. The heating times used in these UHT processes are too short to give satisfactory inactivation of TIA. From the results of this study, it can be seen that the heating time in the UHT soy milk process can be extended to inactivate TIA (for example, 62 s at 143 °C or 29 s at 154 °C) without significant degradation of thiamin and sensory qualities.

The graphical analysis from **Figure 1** reveals an overall picture of the responses of various quality parameters to the input factors, heating time and temperature. To find the heating time and temperature combinations that produce responses in a certain region of desired quality levels, the RSREG procedure of SAS (*13*) was applied to solve this multiple-response optimization problem. The problem was approached by checking conditions in the computer across a grid of values in the range of interest. From the graphical analysis, it was concluded that heat treatments at temperatures <123 °C to destroy the spores of PA 3679 would cause considerable degradation of thiamin and deterioration of sensory qualities. Thus, the search for multiple-response conditions was carried out only in the high-temperature range from 121 to 154 °C. The heating times of interest were in the range from 0 to 90 s. Heating times >90 s were not considered because they are beyond the experimental range for TIA inactivation and such long times also result in excessive heat damage, especially in the UHT region. In this example, the desired levels of the responses are (1) destruction of the spores of PA 3679 ≥5D, (2) log(% TIA retained) ≤1 (% TIA retained < 10), (3) % retention of thiamin ≥90, (4) color score ≥6, and (5) taste score ≥6. Just for the purpose of illustration of this method, the search was done for every 3 °C increase in temperature and every 5 s increase in time within the time and temperature ranges selected. An incomplete list of the output of the computer search using the RSREG procedure of SAS is given in **Table 3**.

Table 3. Incomplete List of the Output of a Computer Search for Optimum Conditions (X_1 and X_2) in Soy Milk Processing Such That $Y_1 \geq 5$, $Y_2 \leq 1$, $Y_3 \geq 90$, $Y_4 \geq 6$, and $Y_5 \geq 6$[a]

obs	X_1	X_2	Y_1	Y_2	Y_3	Y_4	Y_5
1	139	75	50.557	0.97401	93.1355	7.13037	6.79460
2	139	80	53.928	0.95052	92.6950	7.09906	6.74091
3	139	85	57.298	0.93218	92.2566	7.06775	6.68722
4	139	90	60.669	0.91899	91.8303	7.03645	6.63352
5	145	55	147.600	0.95690	92.4683	7.12106	6.72205
6	145	60	161.018	0.90549	91.8124	7.07752	6.64224
7	145	65	174.437	0.85923	91.1612	7.03398	6.56242
8	145	70	187.855	0.81812	90.5145	6.99044	6.48261
9	151	40	427.350	0.97622	91.8944	7.12011	6.66146
10	151	45	480.769	0.90204	90.9285	7.06012	6.54414
11	154	35	746.092	0.96685	91.4171	7.10879	6.60839
12	154	40	852.676	0.88386	90.2526	7.03861	6.46673

[a] X_1 = heating temperature in °C; X_2 = heating time in s; Y_1 = number of log cycle destruction of the spores of PA 3679; Y_2 = log(% TIA retained); Y_3 = % thiamin retained; Y_4 = color score based on a 9-unit hedonic scale; Y_5 = flavor score based on a 9-unit hedonic scale.

Table 4. Comparison of Predicted and Experimental Values of Responses in Soy Milk after Various Heat Treatments

	experimental[a]	predicted
heat treatment 1:[b] 139 °C, 90 s		
Y_1	ND[c]	60.7
Y_2	1.05	0.92
Y_3	93.45	91.82
Y_4	6.8	7.0
Y_5	7.1	6.6
heat treatment 2:[b] 145 °C, 60 s		
Y_1	ND	161
Y_2	0.96	0.91
Y_3	89.17	91.82
Y_4	6.6	7.1
Y_5	6.8	6.6
heat treatment 3:[b] 154 °C, 40 s		
Y_1	ND	852
Y_2	0.81	0.88
Y_3	92.37	90.25
Y_4	7.2	7.0
Y_5	6.8	6.5

[a] Experimental values for Y2 and Y3 were results of duplicate analyses; Y4 and Y5 were obtained from the mean scores of 8 assessors. [b] Y_1 = number of log cycle destruction of the spores of PA 3679; Y_2 = log(% TIA retained); Y_3 = % thiamin retained; Y_4 = color score based on a 9-unit hedonic scale; Y_5 = flavor score based on a 9-unit hedonic scale. [c] ND = not determined.

All of the time–temperature combinations shown in **Table 3** produce responses that meet all of the constraints. It can be seen that the maximum level of retention of thiamin is ~93%. Under the given constraints, preservation of thiamin in soy milk better than this level is not possible. The color scores are higher than the taste scores, indicating that color is less affected by the heat treatments. It should be noted that results in **Table 3** are part of the possible solutions and only cover the time range 0–90 s. If the heating time is extended beyond this range, it is possible to accomplish the desired levels of the responses at some lower temperatures. For example, heat treatment of soy milk at 123 °C for ~330 s (**Figure 1**) also satisfies the requirements.

Experimental Validation of Results. To determine the validity of the mathematical and kinetic models developed in this study, determinations of the responses were carried out experimentally in soy milk heated at three different time–temperature combinations selected from **Table 3**. The experimental values of the responses were compared with the model-predicted values. The results, as shown in **Table 4**, show that there is a close correspondence between predicted and experimental values. Therefore, the mathematical models are reliable and the predicted values are valid. The experimental results confirm that the three heat treatments (139 °C/90 s, 145 °C/60 s, and 154 °C/40 s) produced soy milk with adequate inactivation of TIA (∼90% inactivation), satisfactory retention of thiamin (∼90%), and highly acceptable color and flavor. Microbiological analysis for bacterial spores in the heated soy milk was not done, but there is no doubt that these heat treatments could render sterile soy milk as the heating times used far exceed those adopted in commercial UHT soy milk (normally only a few seconds at 140−150 °C).

Optimization of UHT Heat Treatment. The major beneficial effects of heat treatment of soy milk include (1) extending its storage life by reduction or elimination of microorganisms, (2) improving the nutritional value by destroying antinutritional factors and increasing protein digestibility (*1*). On the other hand, overheating will cause undesirable chemical changes that may lead to the destruction of amino acids and vitamins, browning, and development of cooked flavor. Heat treatment is mainly defined by temperature and time. The best process design for thermal processing of soy milk is one in which the chosen temperature−time combination of heating maximizes the desirable effects but detrimental effects are kept to a minimum. Generally speaking, to preserve the quality of the product as far as possible, the heat treatment should be as mild as possible. However, adequate heating of soy proteins is essential to their nutritional quality. Results based on experimental animals showed that nutritive value improvement closely follows trypsin inhibitor inactivation (*2*, *3*). In the UHT range (above 132 °C), inactivation of TIA must be used as the basis of the process because the destruction rate of TIA is less than that of microorganisms (*5*). Excessive heating, however, causes adverse effects on the nutritive value due to the destruction of certain essential amino acids (e.g., lysine and cystine) and vitamins (e.g., thiamin). Severe heat treatment may also result in development of brown color and cooked flavor in the soy foods. From the results in a previous work by Kwok et al. (*6*), it is important to note that lysine in soy milk is rather heat stable. Its heat stability can be ascribed to (1) the low content of reducing sugar present and therefore, slow rate of Maillard reactions and (2) the compact quaternary structure of soybean globulin. The observation that optimum heat processed soy milk at 120 and 140 °C gave higher measured values of available lysine than did soy milk processed at 95 °C (*6*) further points out the importance of proper control of both temperature and time in soy milk processing. Color changes in soy milk due to Maillard reactions were found to be slower and less temperature sensitive as compared to those in cow's milk (*7*). Sensory qualities were still very acceptable (with sensory scale >6 on a 9-unit hedonic scale) even after heating at 154 °C for 60 s (*8*). The quality parameter that is most likely to suffer from the thermal process is thiamin, but there are many possible time−temperature conditions, as illustrated in **Table 3**, under which 90−93% of the thiamin in soy milk can be retained. All of these results lead to the conclusion that it is possible to use a single-step high-temperature−long-time heat treatment at UHT range (143 °C/60 s) to produce a commercially sterile soy milk with satisfactory TIA inactivation without significant deleterious effects on the nutritional and sensory qualities. Another approach is a two-step process, with spore destruction and trypsin inhibitor inactivation each being carried out separately, under optimal conditions. The two-step process may consist of a normal UHT process (143 °C/4 s) in combination with a low-temperature−long-time (95 °C/60 min) heating.

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