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Predicting color kinetics during red Asian ginseng (*Panax ginseng*) preparation

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A red Asian ginseng preparation was prepared as follows: fresh Asian ginseng (*Panax ginseng*) roots were first steamed for half an hour to several hours, and then the steamed roots were dried into died roots (red Asian ginseng, 10% moisture content, on a dry basis). During steaming, the color of ginseng (white) turned yellow and brown during subsequent steaming. Color is an important index for grading red Asian ginseng. In this study, the effects of drying time and temperature on the surface color formation (L, a/b) of the Asian ginseng, and the color formation (L, a/b) of the red Asian ginseng powder were investigated. The value of L decreased, while the value of a/b increased as drying proceeded; the value of L was slightly influenced by the drying temperature, but the value of a/b was markedly influenced. With respect to the color of the final product (red ginseng), the value of L was slightly influenced by steaming time and temperature, while the value of a/b was increased as steaming time and drying temperature increased. Based on the nth-order rate equation and Arrhenius equation, a kinetic model for describing these effects was established, and the results were satisfactorily fitting.

1. Introduction

Asian ginseng (*Panax ginseng*) is the most famous species of ginseng in the world, its roots and leaves are used as Chinese traditional medicine and health food. China and South Korea are the main producers [1, 2].

High-quality fresh Asian ginseng roots are chosen for preparing red Asian ginseng through steaming and subsequent drying, and the rest are processed into white ginseng through hot air or sun drying. Red Asian ginseng is the most important Asian ginseng product. In South Korea, its manufacturing is regulated by the office of monopoly [3]; in China, many famous brands of red Asian ginseng have been developed [4]. Its price is several times that of the white Asian ginseng. Red Asian ginseng is known to be able to reinforce the vital energy, remedy collapse, restore the normal pulse, invigorate *'qi'* and arrest bleeding [5].

Color appears to be a very important property for the initial acceptability of the red ginseng product by the market. It is chosen as the index for red ginseng grading [6]. It develops during preparation. Red Asian ginseng preparation includes steaming of the fresh roots (white) for about 2 h, followed by drying of the steamed roots at 50–70 °C for about 30–40 h until the moisture content of the roots drops to approximately 13% [7, 8].

Color formation of red ginseng is mainly due to the nonenzymatic reaction of amino-carbonyl, namely Maillard reaction [9], which is accelerated with an increase in steaming time or the addition of amino acids or sugar [10, 11]. Usually, temperature and time are important parameters for the Maillard reaction, and many related studies on food systems have been done [12–14]. However, for red Asian ginseng no similar work has been reported. The objective of this study was to investigate the effects of temperature and time on color formation during red ginseng preparation, and to develop a kinetic model for describing this process.

2. Investigations, results and discussion

The chromaticity of the dry red ginseng surface and the powder was measured in L (the degree of lightness), a (the degree of redness) and b (the degree of yellowness). For color changes, the value of L decreased and the value of a/b increased as drying progressed, the value of L was slightly influenced by drying temperature, while the value of a/b was markedly influenced (Figs. 1, 2). The color of the red ginseng comes from the browning pigments, which absorb at 420 nm, and are formed by Maillard reac-

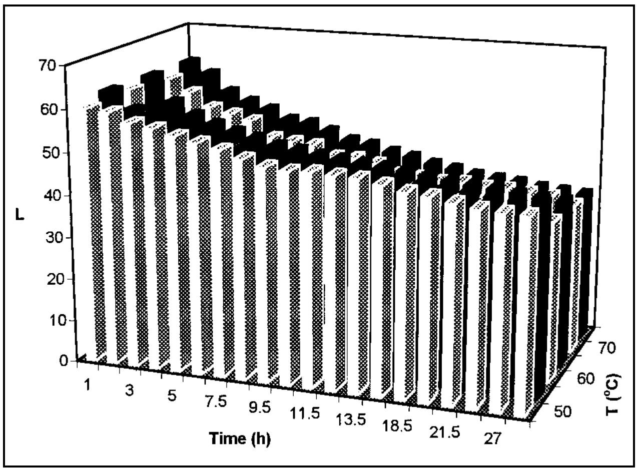

Fig. 1: Effects of drying time and drying temperature on the surface color (L) change of steamed Asian ginseng (□ white column, experimental values; ■ black column, predicted values)

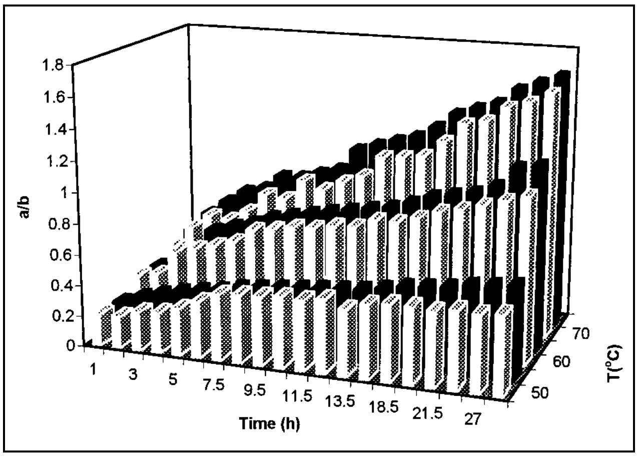

Fig. 2: Effects of drying time and drying temperature on the surface color (a/b) change of steamed Asian ginseng (□ white column, experimental values; ■ black column, predicted values)

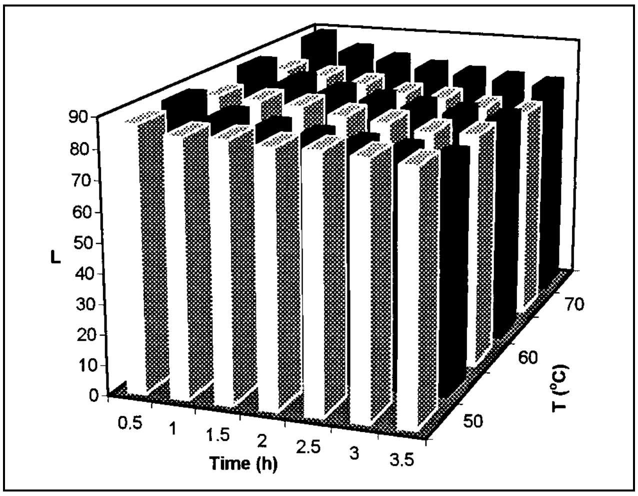

Fig. 3: Effects of steaming time and drying temperature on color parameter (L) of red Asian ginseng powder (□ white column, experimental values; ■ black column, predicted values)

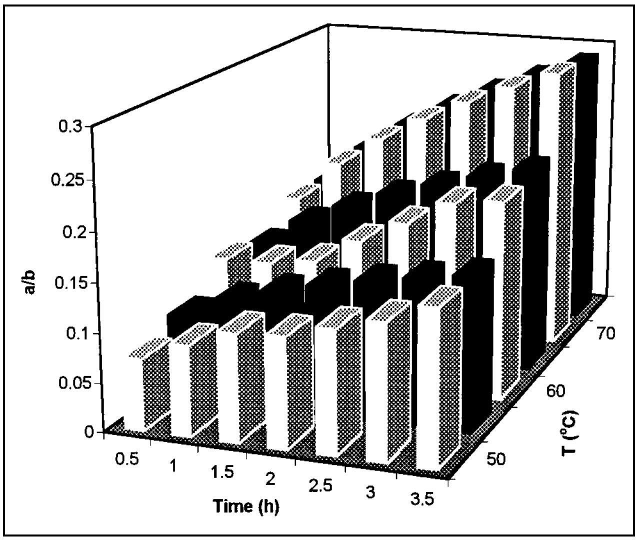

Fig. 4: Effects of steaming time and drying temperature on color parameter (a/b) of red Asian ginseng powder (□ white column, experimental values; ■ black column, predicted values)

tion during steaming and drying [15]. Similar to the other food systems, the rate of reaction was accelerated by temperature in Asian ginseng [10]. This may explain why the color of ginseng processed at higher temperatures is less light (L) and more red (a/b) than that processed at lower temperatures.

For the color of products (red ginseng), the value of L decreased, but the value of a/b increased as the steaming time or drying temperature increased (Figs. 3, 4). This result was in agreement with the reports in which the browning reaction of red ginseng was accelerated with an increase in steaming time, and a great extent of browning occurred between 60–90 min of steaming at 100 °C [10].

By fitting the experimental data, the following equations were obtained:

$$L = 325.9877 e^{\frac{-1110.6897}{RT}} \, t^{-179.8594\, e^{\frac{-4807.3875}{RT}}} \qquad (1)$$

$$\frac{a}{b} = 14277.7508 e^{\frac{-7185.7314}{RT}} \, t^{43.0371\, e^{\frac{-3125.5883}{RT}}} \qquad (2)$$

$$L = 90.1575 e^{\frac{-47.1698}{RT}} \, t^{-0.2878\, e^{\frac{-871.0255}{RT}}} \qquad (3)$$

$$\frac{a}{b} = 494.3509 e^{\frac{-5424.1027}{RT}} \, t^{32.0922\, e^{\frac{-2979.0348}{RT}}} \qquad (4)$$

The experimental data and model predictions are plotted in Figs. 1–4. It is clear that mathematical equations well represent the experimental results. These models could be used for predicting similar processes.

3. Experimental

3.1. Fresh Asian ginseng roots

The fresh Asian ginseng (*Panax ginseng*) roots were obtained from the Institute of Special Plants and Wild Animals, Chinese Academy of Agricultural Sciences, Zoujia town, Jilin City, People's Republic of China. The fresh ginseng roots were, subsequently, shipped to Hong Kong and stored in a refrigerator at 4 °C.

3.2. Steaming and drying of Asian ginseng

Two sets of experiments were done.

Experiment 1: About 2500 g of fresh Asian ginseng roots were selected. Then the roots were washed to remove soil. The roots without soil ($7 \times 3 \times 100$ g) were steamed at 100 °C for 0.5, 1, 1.5, 2, 2.5, 3 and 3.5 h respectively, and subsequently dried at 50 °C, 60 °C and 70 °C, respectively. The experiment was repeated 3 times.

Experiment 2: About 400 g of fresh Asian ginseng roots was selected. Then the roots were washed to remove soil. The roots without soil (3×100 g) were steamed at 100 °C for 2 h, and dried at 50 °C, 60 °C and 70 °C, respectively. The experiment was repeated 3 times.

3.3. Color measurements

In experiment 2, the surface color measurements of the roots started at the beginning of drying. The color was measured at 1, 2, 3, 4, 5, 6, 7.5, 8.5, 9.5, 10.5, 11.5, 12.5, 13.5, 15, 18.5, 20, 21.5, 24, 27 and 30 h. At the end of the drying process, the moisture of red ginseng roots was reduced to about 10%.

At the end of experiment 1, the red Asian ginseng roots were cut into small pieces, then ground with a blender, and screened using a 200 mesh sieve.

The chromaticity of the dry red ginseng surface and the powder was measured in L (the degree of lightness), a (the degree of redness) and b (the degree of yellowness) coordinates using a Chroma Meter (Minolta Chroma Meter, CR-300, Minolta Camera CO. Ltd.). The Chrom Meter was calibrated against a standard calibration plate of a white surface with L, a and b values of 97.38, 0.02 and 1.55, respectively. All the measurements were tripled for each sample, and the average for L, a and b of each sample was reported here.

3.4. Model development

Many chemical reactions usually follow the following n^{th}-order rate equation:

$$\frac{dY}{dt} = mY^n \qquad (5)$$

where Y is the concentration of a reactant, t is the reaction time, m is the rate constant, and n is the reaction order. One of the integrated solutions to eq. (5) may have the following form:

$$Y = Y_{ini} t^k \qquad (6)$$

where Y_{ini} is the initial concentration of Y at time $t = 1$, k is the reaction rate constant. In this study eq. (6) was employed to describe the relationship between the color parameters (L, lightness; and the ration a/b) and the drying time. However, the equation did not take into account the effect of temperature (T) on color changes. The activated complex theory for chemical reaction rates is the basis for the Arrhenius equation, which relates reaction rate constants to the absolute temperature. The Arrhenius equation is:

$$k = k_0 e^{\frac{-E_a^k}{RT}} \qquad (7)$$

where E_a^k is the activation energy, k_0 is the rate constant as temperature T approaches infinity, and R is gas constant (1.987 Cal/g mol K). The negative sign is placed on the exponent of the Arrhenius equation so that a positive activation energy will indicate increasing reaction rate constant with increasing temperature. Here eq. (7) was used to describe the effect of temperature on the rate constant. The initial reactant concentration Y_{ini} is also variable under different temperatures; hence eq. (7) was formulated accordingly:

$$Y_{ini} = Y_0 e^{\frac{-E_a^Y}{RT}} \qquad (8)$$

Substituting eqns (7) and (8) into eq. (6), the following equation was given:

$$Y = Y_0 e^{\frac{-E_a^Y}{RT}} t^{k_0 e^{\frac{-E_a k}{RT}}} \quad (9)$$

where Y is the color parameter L or a/b; the ratio a/b is a convenient way of reducing two colour parameters to one [16], a higher a/b ratio indicates a darker (more red) product [17]. Y_0 is the concentration of Y at time $t = 1$ and temperature $T = \propto$, E_a^Y is the activation energy that indicates an increased reactant concentration with increasing temperature (cal/g mol), and E_a^k is the activation energy that indicates an increased reaction rate constant with increasing temperature (cal/g mol). T is the absolute temperature (K).

Parameter estimations were performed using a Simplex Search Method; the principal idea of this method is to search the best value of the objective function in a space of points P_i which represent the feasible solution. The first point P_1 is arbitrarily selected as the starting point (base point). The second point P_2 is chosen and compared with P_1. If P_2 is found to be a better solution than P_1, then P_2 is selected as the new base point; if not, P_1 stays as the base point. This process continued until the best operating point is found. The details were described previously [18].

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