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Quantitative Evaluation of the Design-Parameters Requested in a Drying Operation of Beef and Pork

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For the design-parameters requested in the drying operations of beefs (produced in Australia, B_A, and Hokkaido, B_H) and pork (produced in Hokkaido, P_H), five design parameters, effective moisture diffusivity (De, m^2/s), activation energy of De (E_D, kJ/mol), correlation time (τ_C, s) determined by a proton NMR technique, lipid ratio (LR, %) and hardness (N_P, Newton/m^2), were quantitatively evaluated as a function of a variety of the water species retained in the food tissues. All the five parameters, through the beefs and the pork without depending on their produced geographic area, demonstrated a critical value of moisture content (cW, %-d.b.) which was strongly related to a critical value of τ_C (cτ_C) . They were evaluated as cW = 130%-d.b. and cτ_C = 1.0×10^{-8}s. At the two values, the five design parameters showed a drastic dynamism indicating two different water species to be existed in the tissues of the beefs and pork as water species-A_1 (at $\tau_C = 0.1 \sim 0.8\times10^{-8}$s < c$\tau_C$) and water species-$A_2$ (at $\tau_C = 1.0 \sim 10\times10^{-8}$s > c$\tau_C$) . The water species-$A_1$ was characterized as a weakly restricted water species indicating almost identical values of De, E_D, τ_C , LR and N_P without depending on τ_C. The water species-A_2 was demonstrated as a strongly restricted water species indicating characteristic behaviour depending on each of the five design parameters. The pre-exponential factors, δD_0's, for the De's of the beefs and pork were evaluated as the ranges of $1.3 \sim 4.0\times10^{-7}$ for the species-A_1 and less than 9×10^{-8} m^2/s for the species-A_2. On the influence of LR on De, the species-A_1 gave an identical value of De whereas De for the species-A_2 was decreased with increasing the amount of LR.

The five parameters to design the drying-products of the B_A, B_H and P_H influenced by the water species-A_1 and -A_2 were effectively and clearly distinguished by visualizing the character of the three meats as a function of τ_C.

1. Introduction

As has been described by various authors, a large number of parameters such as taste, nutrition, flavour, colour, etc should be concerned to design food products requested in commercial activities. For the quantitative evaluation of design parameters, physical and physicochemical identification of the parameters should be requested (Belton *et al*, 2003). To respond this necessity, five parameters, hardness (N_P, Newton/m^2), amount of

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lipid (*LR,* g/g), correlation time of water species (τ_C, s), diffusivity of water species (*De,* m^2/s) and activation energy of *De* (E_D, kJ/mol), can be chosen. Konishi, Miura and Kobayashi (2003) demonstrated that the dehydration dynamics of squid was strongly influenced by the moisture content which effectively brought a variety of restriction strength of water molecules in the squid tissues, and the dynamism of water species was drastically changed at W_0 = 100%-d.b., indicating a variety of multifunctional water species to be existed. This multiplicity of the water species strongly influenced on the five parameters, *De* (Konishi *et al*, 2001(a), 2001(b)), E_D (Konishi *et al*, 1999), N_P (Konishi *et al*, 2008), *LR* (Konishi *et al*, 2008) and τ_C (Konishi *et al*, 2008). Ruiz-Cabrera *et al* (2004) demonstrated that the content of lipid in pork meat contributed to the reduction of *De*.

The objectives of this study are: (1) to characterize the five design parameters responding to the quantitative evaluation of food quality, (2) to demonstrate a critical point of the multifunctional water species exhibiting a drastic change influenced on the five design parameters and (3) to clearly discriminate the five design parameters between different meats.

2. Experimental

Two beef meats (produced in Australia, B_A and Hokkaido, B_H; 50mm square and 8±1.0mm in thickness) and a pork meat (produced in Hokkaido, P_H; 50mm square and 6±1.0mm in thickness) were used, all of which had the initial moisture content of 230~280%-d.b.(dry base, W_D). The sample placed in a stainless steel net tray (4 meshes) that was mechanically hung from a strain gage transducer in the dryer. The sample weight was continuously recorded by the output of strain-gage transducer using a data-logger. Drying temperatures (T_D) of 40, 50, 60, 70 and 80°C were chosen. In the present experimental drying conditions, it was reconfirmed that the drying operations for the beefs and pork were within a falling-rate period.

For the effective discrimination of the moisture species in the beef and pork meats, a nuclear magnetic resonance (NMR) technique was used to measure the ^{1}H-NMR spectra and a spin-spin relaxation time (T_2) of water protons. The beef and pork meats samples cut into 2×2×10mm pieces were inserted into an NMR sample tube (4mm in inner diameter and 180mm in length). ^{1}H-NMR spectra were obtained using a JEOL A-500 FT-NMR spectrometer operating at 500MHz for protons. The observed frequency width was 20 kHz. The 90° pulse width was 12.5 μs, and the number of pulse repetitions was 8. The proton chemical shifts were measured by using a slight amount of water containing deuterium oxide as an external reference. All the NMR measurements were performed at 23.5±0.5°C. The spin-spin relaxation times, T_2, were obtained by the spin locking method and from the obtained T_2, the correlation time of a water proton, τ_C, was evaluated.

The hardness of the meat samples was measured by using a creep tester equipped with a V-shaped plunger of 30 in width and 1 mm in thickness to press a 60% of a meat size of 2~8×10×50 mm evaluating the value of N/m^2. The lipid ratio was evaluated by using a calibration curve which was determined by the NMR method using the proportion change of the meat-lipid mixture, similar to the Nagy and Kormendy's report (2003).

3. Results and Discussion

3-1. Discrimination of Dehydration Curves for the B_A, B_H and P_H

τ_C can be evaluated at any moisture content during the dehydration operation. Fig.1 shows three dehydration response curves of the three meats, B_A, B_H and P_H, obtained under a continuous drying operation at W_0= 270%-d.b. and T_D = 50°C, even exhibiting τ_C as a function of W_0 (designated as τ_C-W_0 curve). The drying time should progress from the light hand side to the left hand side of the horizontal axis in the figure. The three experimental τ_C-W_0 curves strongly demonstrate two different regions (designated as regions-I and -II) divided at W_0=130%-d.b. At region I (W_0 >130%-d.b.), the τ_C -W_0 curves give an identical value, τ_C =1.0(±0.3)×10^{-8}s, without depending on W_0-value. In the region-I, the water species has lower restriction• • strength because of the lower τ_C, named as species-A_1. At the region II (W_0 <130%-d.b.), the τ_C -W_0 curve gives a steep increase of τ_C with decreasing W_0. In the region-II, the water species has strongly restricted strength because of higher τ_C, named as species-A_2. On the three experimental τ_C -W_0 curves, one can clearly recognize that all the B_A, B_H and P_H produced from the three different origins commonly agree with one identical curve. This unclear discrimination of the three τ_C-W_0 curves exhibits a difficulty to use these curves as a design tool for characterising each of the meat jerky products.

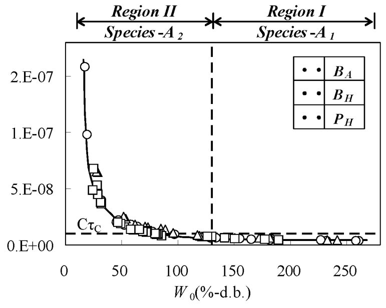

Fig.1 τ_C as a function of W_0.

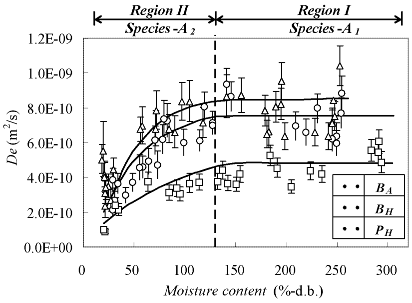

Fig.2 Effective moisture diffusivity of B_A, B_H and P_H as a function of moisture content (T_D=50°C).

To break this difficulty for the discrimination of the three curves, a new visualization of the dehydration parameters should be realized. Responding to this request, the moisture diffusivity (*De*) can be chosen. As has been mentioned in the previous section, the dehydration operation is limited in a falling rate period. In this period, the *De* can be evaluated by using eq.(1) (Jason, 1958).

$$\frac{W - We}{W_D - We} = \left(\frac{8}{\pi^2}\right)^3 \cdot exp\left(-\frac{\pi^2 \cdot De \cdot t}{4} \cdot \left(L_a{}^2 + L_b{}^2 + L_c{}^2\right)\right) \cdots (1)$$

Where W is moisture content at the drying time t [%-d.b.], We is Equilibrium moisture content [%-d.b.], W_D is initial moisture content of drying flesh sample [%-d.b.], t is drying time [s] and L_a , L_b and L_c are half distance of rectangular sample [m]. Fig.2 represents the effective diffusivity of water species as a function of moisture content. As seen from the three curves, even though the data were scattered, the dynamism of *De* for the three curves of B_A, B_H and P_H also demonstrated two regions divided at W_0=130%-d.b. indicating an identical *De* at the region-I and a gradual decrease of *De* at the region-

II with decreasing W_0. One may recognize a clear discrimination of the De's for the three meats.

For further characterization of the design parameters, the De can be re-expressed as a function of τ_C instead of the moisture content by using Fig.1. Fig.3 represents a dynamism of De as a function of τ_C. Focusing the boundary between the regions-I and -II, one can recognize the critical value of $\tau_C = 1.0 \times 10^{-8}$s which corresponds to W=130%-d.b., designating as $c\tau_C$. The $c\tau_C$ will be examined further in the next section.

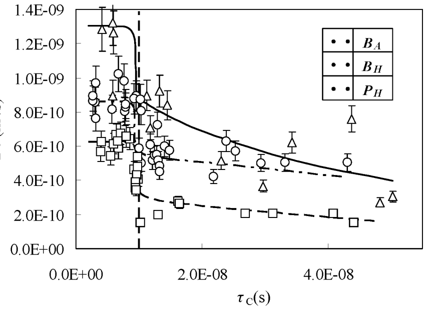

Fig.3 Comparing behaviour of De between B_A, B_H and P_H as a function of τ_C at 70°C.

The activation energy (E_D) of the De can be evaluated using a simple Arrhenius-type relationship, eq.(2).

$$De = De^0 \cdot exp\left[\frac{-E_D}{R \cdot (T_D + 273)}\right] \cdots (2)$$

Where De^0 is pre-exponential factor [m²/s], R is gas constant [=8.314J/K·mol] and T_D is drying temperature [K]. The Arrhenius plots of De-values obtained at T_D = 50~70°C for the beefs and pork evaluated E_D's. Fig.4 shows the E_D's as a function of τ_C for the B_A, B_H and P_H. One can recognize the three curves of E_D to be divided again into two regions at the $c\tau_C = 1.0\times10^{-8}$s as regions-I ($\tau_C < 1.0\times10^{-8}$s) and -II($\tau_C > 1.0\times10^{-8}$s). In the region-I, E_D's of the three curves fall on 17±2 kJ/mol with no depending on τ_C. In the region II, the E_D's for the three meats were steeply decreased to reaching 7.8 for B_A, 5.5 for B_H and 1.2 kJ/mol for P_H with increasing τ_C. This different behaviour between the two regions strongly suggests that the two moisture transfer mechanisms in the three meat muscles should be existed and drastically be changed at the $c\tau_C$, because of a physicochemical change of the three meat tissues due to the dehydration.

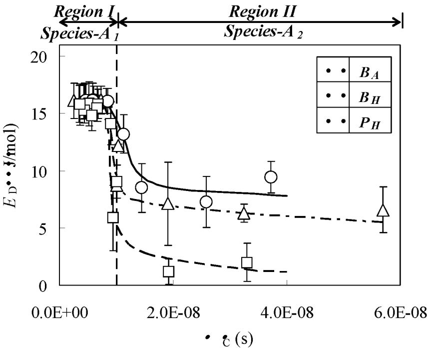

Fig.4 Comparing behaviour of E_D between B_A, B_H and P_H as a function of τ_C at 50~70°C.

3-2. Physicochemical discrimination of B_A, B_H and P_H due to the *LR* and N_P as the design parameters.

Our interest is focused on a clear discrimination of the design parameters for the B_A, B_H and P_H during their drying processes. Fig.5 shows De as a function of LR. Comparing the character of the three

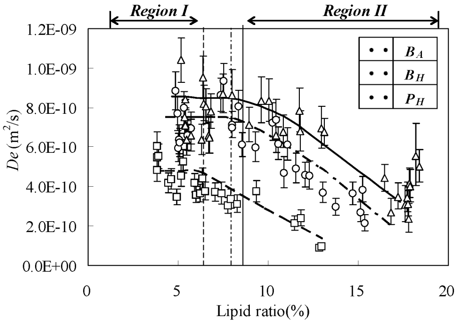

Fig.5 Comparing behaviour of De as a function of lipid ratio between B_A, B_H and P_H at 60°C.

curves, the increase of *LR*-value for the B_A, B_H and P_H commonly contributes to the decrease of *De* which is similar result to Ruiz-Cabrera *et al*, 2004. Comparing the absolute values of *De* between the three meats, one may recognize the *De*-value of P_H to be 0.6 times of B_H. These results can effectively be used to design the meat products requested. Since the P_H has a low *De*-value accompanied with lower lipid ratio, the quality of the pork meat products can be kept for long period of time because of its lower dehydration rate than both B_A and B_H. In addition, using the three *De*-*LR* curves, one can easily choose a better meat between B_A, B_H and P_H based on the *De* -*LR* curves in Fig.5. The P_H should be chosen because of the difficulty of the dehydration in air indicating an advantage for longer store.

For the actual design of meat products, hardness of meat product (N_P) should be one of the important parameters. Fig.6 represents the N_P as a function of τ_C. One can clearly recognize again the two regions, regions-I and -II, divided at the $c\tau_C = 1.0\times10^{-8}$s. At the region-I, the N_P gives an identical value of $0.8(\pm0.7)\times10^5$ N/m^2 without depending on the kind of meats. In the region-II, the increase of τ_C commonly contributes to the steep increase of N_P for the three meats. One should recognize again the $c\tau_C$ to design own desired meat products because of, at the $c\tau_C$, the drastic change of N_P to be happened. The physical meaning of this drastic change will be discussed in the next section.

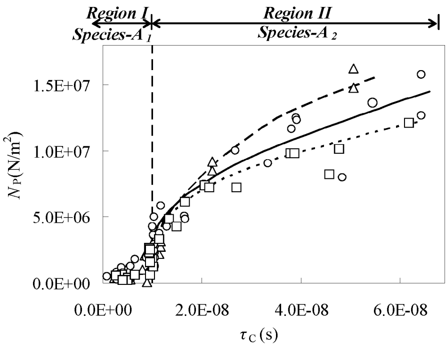

Fig.6 Comparing behavior of N_P as a function of τ_C between B_A, B_H and P_H at 50°C.

3-3. Physicochemical identification of the $c\tau_C$ as the design parameters recognized by the pre-exponential factor of *De*

On the physical meaning of the $c\tau_C$, it would be one of the important understandings to design the three meat products. As has been well known, the effective moisture diffusivity, *De*, is expressed by eq.(3).

$$De = \left(\frac{\varepsilon}{\chi}\right)\cdot D = \delta \cdot D_0 \cdot exp\left[\frac{-E_D}{R\cdot(T_D+273)}\right]\cdots(3)$$

Where ε is porosity of the meat tissue, χ is labyrinth factor of the meat tissue, D is moisture diffusion coefficient, δ is diffusibility and D_0 is frequency factor of D.

Taking the E_D-τ_C curves presented in Fig.4 into account Eq.(3), the pre-exponential factor,•δD_0, can reasonably be evaluated as shown in Fig.7. One can clearly recognize the pre-exponential factor to drastically be changed at the $c\tau_C$. In the region-II, one may recognize that the drastic change of δD_0

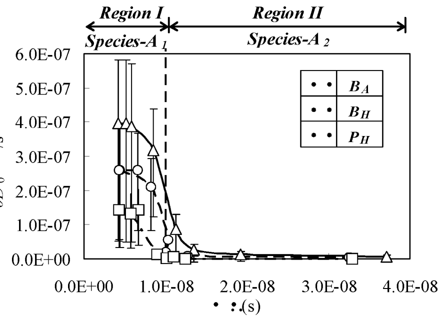

Fig.7 Comparing behavior of the pre-exponential factor between B_A, B_H and P_H at 50°C as a function of τ_C .

value strongly contributes to three reasons, the reduction of *De* in Fig.3, the steep reduction of E_D in Fig.4 and the steep growth of N_P in Fig.6. These evidences indicate a dynamic variation of the porosity and labyrinth factor due to the progress of dehydration process. Based on these quantitative evaluations for the design parameters presented above, one should make a design framework for the commercially requested meat products.

5. Conclusions

(1)For the quantitative evaluation of the meat products requested, three meat jerkies, B_A, B_H and P_H, and five design parameters, *De*, E_D, N_P, *LR* and τ_C, were chosen.

(2)In the drying process of the jerkies, a specified moisture content (=130%-d.b.) characterized by the $c\tau_C$ (=1.0×10^{-8}s) was demonstrated as a critical value for the design parameters.

(3)The $c\tau_C$ was characterized by the physicochemical meaning resulted from the biological tissue change of beef and pork meats such as porosity and labyrinth factor derived in the course of the dehydration process.

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