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Challenge to the Food Engineering Due to a Hybrid Method of Chemical Engineering-Proton NMR Technique -Meat Jerky Design by the Scientific Parameters-

Yasuyuki Konishi[1*] and Masayoshi Kobayashi[2]
[1]Hokkaido Industrial Technology Centre
379 Kikyo-cho, Hakodate, Hakodate, 041-0801, Japan
[2]Advanced Technology Institute of Northern Resources
8-6, Tonden 2Jo 2Chome, Sapporo, Hokkaido, 002-0852, Japan

A hybrid method of chemical engineering and proton NMR technique was effectively applied to design a variety of commercially produced meat-jerkies. For the actual application of the hybrid method, twelve commercial meat-jerkies, 6 pork- and 6 beef-samples, were tested. The samples were widely characterized by variety of seasoning such as salt, soy sauce, smoke *etc*. The design parameters chosen for the 12 samples were four derived from the chemical engineering as moisture content (W_0, %-d.b.), effective moisture diffusivity (De, m^2/s), activation energy of De (E_D, kJ/mol), and hardness (N_P, Newton/m^2), and two derived from the proton NMR technique as correlation time (τ_C, s) and critical value of τ_C ($c\tau_C$). To characterize the 12 jerkies, three design parameters, W_0, De and N_P, were evaluated as a function of τ_C. The three parameters commonly demonstrated the existence of two different water species which was divided at the critical value of τ_C ($c\tau_C = 1.0\times10^{-8}$ s), called as water species-A_1 ($\tau_C < 1\times10^{-8}$s) and -A_2 ($\tau_C > 1\times10^{-8}$s). τ_C contributes to both the hardness (N_P) of the jerky's meat tissues and moisture mobility (De) in the jerky's muscle, both of which were strongly related to the specified seasoning used.
Based on the dynamism of the three parameters, W_0, De and N_P, as a function of τ_C derived from the hybrid method, one could recognize all jerkies to be designed by using the water species-A_2. It could be understood that the specified character appeared in the commercially distributed meat jerky products was reasonably designed by dynamically changing the value of τ_C. The 12 jerkies were characteristically classified into five groups by using a specified combination among the values of the four design parameters, De, N_P, W_0, and τ_C.

1.Introduction

In the field of food engineering, chemical engineering and bioengineering technologies have commonly been used referring the data obtained from physicochemical technique.

* Corresponding author. Tel + 81-138-34-2600. E-mail:konishi@techakodate.or.jp

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The water species, especially, is strongly related to food quality as has been demonstrated in the International Symposium on Properties of Water (Eds. Rockland and Stewart, 1981). The water species retained in foods, as is well known, exposes its multifunctional nature dynamically responding to the environmental conditions such as temperature, pressure, dehydration process, moisture content *etc*. For the scientific analysis of the multifunctional water species, a difficulty recognized is its nonlinear dynamic change influencing on food quality. To quantitatively evaluate the nature of the water species, a large number of researchers have demonstrated the diversity of its biological and physicochemical nature using various parameters. The water activity has commonly been used as a parameter for the deterioration of foods (Fennema, 1974). The effective moisture diffusivity parameter in foods has frequently been employed to evaluate the dehydration rate of food (Jason, 1958). In the view point of more direct identification for the multifunctional water species, magnetic resonance technique has recently been applied to evaluate the food quality as demonstrated in the International Conferences on Applications of Magnetic Resonance in Food Science (Eds. Belton *et al*, 2002). Figure 1 shows a schematic explanation of the specified two curves, the curve-1 for the water adsorption isotherm of food system as a function of water activity (the isotherm was divided into three regions, region-I, -II, and -III) and the curve-2 for the NMR-correlation time (τ_C) of water species retained in food as a function of moisture content (W_0). As can be seen from the comparison of the two curves in the figure, the water species adsorbed in the region-I with lower water activity contributes to the higher correlation time, which means higher restriction strength derived from the food tissues, and the water species adsorbed in the region-III with higher water activity, contributing to lower correlation time, which means lower restriction strength. These results would bring an inverse relation between the two parameters, τ_C and W_0. This relation can usefully be employed for the hybrid method as described in this paper.

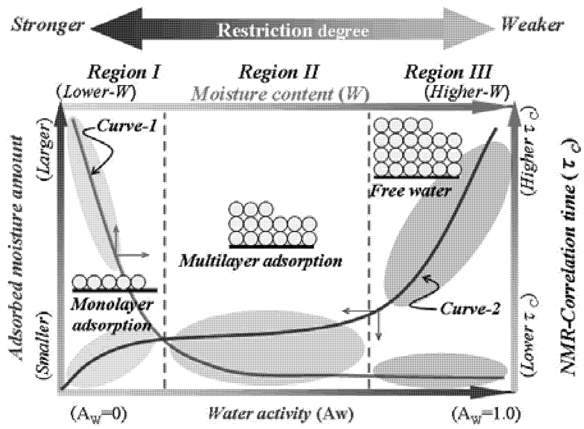

Fig. 1 Classification of the adsorbed water species in the food matrix.

In our previous papers (Konishi *et al*, 2001, 2003), using the chemical engineering and the proton NMR techniques, the water species retained in the fish past sausage and squid were roughly distinguished into two different species as a function of moisture content. The two species were species-A_1 to be recognized in the higher moisture content at W_0 >130%-d.b. accompanied with higher moisture diffusivity, *De,* and species-A_2, W_0 <130%-d.b. with lower *De*. This discrimination, however, was still not clear. For clearer discrimination of the two water species, a new technique should be requested for the design of food products. In the present study, responding to this request, the hybrid method was proposed as a new technique. The aims of this study are

(1) to propose the hybrid method of chemical engineering-proton NMR technique for the design of food products, using a specified NMR parameter, correlation time (τ_C, s); (2) to choose the specified design parameters visualizing both the two water species distinguished and the variety of food products; and (3) to classify the commercial jerky products by using the characteristics of the design parameters chosen.

2. Experimental

Six beef jerkies and six pork jerkies commercially distributed and a pork meat (designated PM which was used as a reference meat) produced in Hokkaido were chosen as the samples. All samples used in this study were tabulated in Table 1. The commercial jerkies were characterised as the moisture content range of 30 ~ 80 %-d.b, and the pork meat used as a reference sample had the initial moisture content of 230 ~ 280 %-d.b.(dry base, W_D). The moisture content of the samples was evaluated as a dry base, W_0 (%-d.b.). Each of the samples was 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 jerkies and the pork were within a falling-rate period.

Table 1. Features of the pork meat (PM) and the commercial jerkies used for this study. PJ-1~-6: pork jerkies; BJ-1~-6: beef jerkies.

	Features
PJ-1	soy-sauce base taste, about 1.0mm in thickness
PJ-2	soy-sauce base taste, 1.1~1.4 mm in thickness
PJ-3	light taste, oily, smoked flavour, 0.8~5.9mm in thickness
PJ-4	salt base taste, smoked flavour, strong taste, hard, 2.2~4.8 mm in thickness
PJ-5	salt base taste, smoked flavour, strong taste, soft, 1.3~2.7 mm in thickness
PJ-6	soy-sauce base taste, light taste, hard, 1.9~3.5mm in thickness
BJ-1	salt base taste, light taste, hard,1.4~2.2mm in thickness
BJ-2	salt base taste, strong taste, soft, about 2.2 mm in thickness
BJ-3	miso-sauce base taste, strong taste, soft, 4.2~5.9mm in thickness
BJ-4	salt base taste, light taste, soft, 1.6~3.1 mm in thickness
BJ-5	soy-sauce base taste, 、 strong taste, hard, 3.1mm in thickness
BJ-6	salt base taste, light taste, hard, 0.9~2.8mm in thickness
PM	pork meat, soy-sauce base taste, hard, about 2.9~3.4mm in thickness

For the effective discrimination of the water species in the jerkies and the pork meat, 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 jerkies and the pork meat samples cut into 2×2×10 mm 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. The hardness of the meat samples was measured by using a creep tester equipped with a V-shaped plunger of 30 mm 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.

3. Disadvantage of the Proton NMR Technique

As has been demonstrated by a large number of researchers, moisture content was one of the useful parameters to evaluate food products. Figure 2 illustrates τ_C as a function of moisture content of the samples. The solid line for the pork meat indicated a steep increase with decreasing W_0, between the values of $\tau_C = 1.0\times10^{-8}$s and $\tau_C = 1.1\times10^{-7}$s. Since τ_C means rotation time of water species, the steep increase of τ_C demonstrates the restriction strength of the water species in this region to strongly be increased due to the dehydration from W_0=120 to 20%-d.b. The τ_C for the jerkies, on the other hand, fell on around the solid line as shown in Fig.2. From these results, one can recognize that the three τ_C $-W_0$ curves for the pork jerkies, beef jerkies, and the pork meat are difficultly distinguished indicating a disadvantage of this plot.

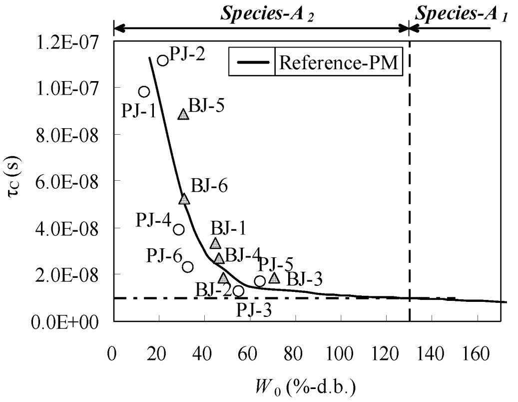

Fig.2 τ_C as a function of W_0 for the pork- and beef-Jerkies (open circle and triangle) and the pork meat (solid line)

4. Disadvantage of the Chemical Engineering Method

In the chemical engineering method, generally speaking, effective moisture diffusivity would be visualized as a function of moisture content. Figure 3 shows the effective moisture diffusivity for the pork meat and the commercial jerkies as a function of the moisture content. The plots of the jerkies were localized in the specified region between $14<W_0<71$%-d.b. and $3.1\times10^{-11}<$ *De* $<1.3\times10^{-10}$ m^2/s, whereas the pork meat data demonstrated a characteristic behavior indicating again two different water species, species-A_1 and -A_2, as shown in the figure. One may recognize all jerkies used to be fallen in the region of species-A_2. As can be seen from the localization of the jerky's data, it is difficult to discriminate among the jerky's characters. To solve this difficulty, one should choose another parameter instead of W_0 for newly visualizing *De*. The new hybrid method would thus be presented as shown in the next section.

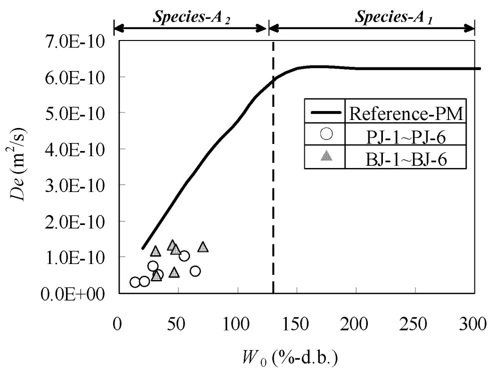

Fig.3 De as a function of W_0 for the pork- and beef-Jerkies (open circle and closed triangle) and the pork meat (solid line)

5. Advantage of the Hybrid Method of Chemical Engineering-Proton NMR Technique

As has been discussed in the previous section by using Fig.2, the correlation time (τ_C) derived from the proton NMR method means a rotation time of water molecule, indicating the larger τ_C the stronger restriction strength against water molecule due to the meat tissues. Based on this meaning, one can presume τ_C to reasonably be related to *De*. Figure 4 illustrates *De* as a function of τ_C for the pork meat and the jerkies, instead of W_0 in Fig. 3. One can clearly recognize the value of τ_C to widely be distributed from 6×10^{-9} to 1.2×10^{-7} s. In addition, the data of the pork meat demonstrates a drastic reduction of *De* at $\tau_C = 1\times10^{-8}$ s as seen on the solid line in Fig.4. This drastic change can be recognized again in the hardness (N_P) -τ_C curve for the pork meat and the jerkies as shown in Figure 5. As seen in the figure, the N_P of the pork meat clearly indicates a steep increase at $\tau_C = 1\times10^{-8}$ s, and the data of the jerkies scattered around the solid line in the region of the water species-A_2 higher than $\tau_C = 1\times10^{-8}$ s. For this specified value of τ_C, we call it as critical correlation time, $c\tau_C$ .On the physical meaning of the $c\tau_C$, it can reasonably be related to a drastic structure-change in the proteins consisting of the pork meat- and the jerky-tissues accompanied with the change in the restriction strength of water species. This drastic change derives an increase of the hardness and a pore structure change of the sample tissues, which can also be recognized by the drastic change of pre-exponential factor of *De*.

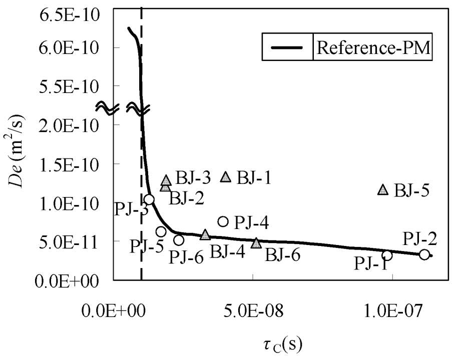

Fig.4 De as a function of τ_C.

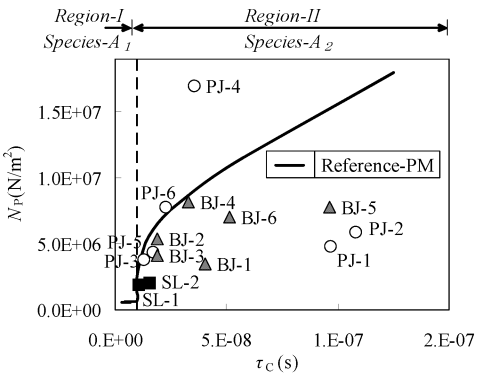

Fig.5 Hardness (N_P) as a function of τ_C .

6. Classification of the Jerky Products Due to the Design Parameters Proposed by the Hybrid Method

Our interest is focused on a classification of the 12 jerky-products influenced by the multifunctional water species. Figure 6 demonstrates the classification of the jerky products, which were classified into five groups according to the dynamic change in the values of the four design parameters, *De*, N_P, τ_C , and W_0. Group-1 was characterized by the higher N_P accompanied with the salty taste, group-2, by higher τ_C with the soy sauce base taste, group-3, by higher *De* with the salty taste, group-4, by higher W_0 with the smoked flavor, and group-5, by the intermediate values of the four parameters with the light taste. All the five groups are clearly characterized by the water species-A_2 not water species-A_1. The species-A_2 is dynamically varied with variously given process such as dehydration, aging, features, heating, seasonings *etc*. The hybrid method can usefully be used to design the desired jerky's products by changing the values of the four parameters, De, W_0, τ_C , and N_P.

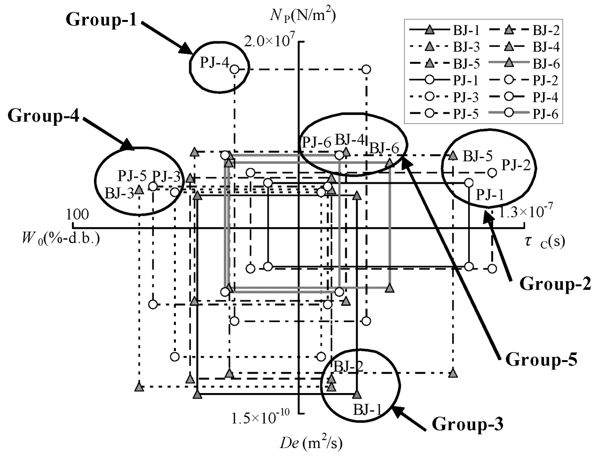

Fig.6 Classification of the jerkies visualized by the four design parameters.Group-1: PJ-4; group-2: PJ-1, PJ-2, BJ-5; group-3: BJ-1, BJ-2; group-4: PJ-3, PJ-5, BJ3; group-5: PJ-6, BJ-4, BJ-6.

7. Conclusions

The hybrid method derived from the chemical engineering-the proton NMR technique was proposed as a new design procedure to make the variety of jerky-products. The water species retained in the jerkies was distinguished into two water species, species-A_1 and -A_2. The two water species was clearly divided by the critical correlation time, $c\tau_C$. The water species-A_2 could effectively be used to design the variety of the jerky-products. The 12 commercial jerkies used were classified into five groups by using a distinction of four design parameters, De, N_P, τ_C , and W_0.

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