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

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A hybrid method of chemical engineering and proton NMR technique was effectively applied to design a variety of commercially produced meat-jerky. For the actual application of the hybrid method, twelve commercial meat-jerky, 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 ($r_c$, s) and critical value of $r_c$ ($cr_c$). To characterize the 12 jerky, three design parameters, $W_0$, $De$ and $N_P$, were evaluated as a function of $r_c$. The three parameters commonly demonstrated the existence of two different water species which was divided at the critical value of $r_c$ ($cr_c = 1.0 \times 10^8$ s), called as water species-$A_1$ ($r_c < 1.0 \times 10^8$ s) and -$A_2$ ($r_c > 1.0 \times 10^8$ s). $r_c$ 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 $r_c$ derived from the hybrid method, one could recognize all jerky 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 $r_c$. The 12 jerky 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 $r_c$.

1. Introduction

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

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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 ($\tau_C$) 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, $\tau_C$ and $W_0$. This relation can usefully be employed for the hybrid method as described in this paper.

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-A1 to be recognized in the higher moisture content at $W_0 > 130\%$-d.b. accompanied with higher moisture diffusivity, $D_e$, and species-A2, $W_0 < 130\%$-d.b. with lower $D_e$. 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 \( (\tau_c, s) \);
(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 jerky and six pork jerky 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 jerky was 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, \( W_0 \)). 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 \( (T_0) \) 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 jerky and the
pork were within a falling-rate period.

For the effective discrimination of the water species in the jerky and the pork meat, a
nuclear magnetic resonance (NMR) technique was used to measure the \(^1\text{H}-\text{NMR}\) spectra and a spin-spin relaxation time \( (T_2) \) of water protons. The jerky and the pork meat
samples cut into \( 2 \times 2 \times 10 \) mm pieces were inserted into an NMR sample tube (4mm in
inner diameter and 180mm in length). \(^1\text{H}-\text{NMR} \) 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 \( 2 \times 10 \times 50 \) mm evaluating the value of N/m².

<table>
<thead>
<tr>
<th>Features</th>
<th>( \text{PM} )</th>
<th>( \text{PJ-1} \sim \text{PJ-6} )</th>
<th>( \text{BJ-1} \sim \text{BJ-6} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>soy-sauce base taste, about 1.0mm in thickness</td>
<td></td>
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<td></td>
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<tr>
<td>soy-sauce base taste, 1.1~1.4 mm in thickness</td>
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<tr>
<td>light taste, oily, smoked flavour, 0.8~5.9mm in thickness</td>
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<td></td>
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<tr>
<td>salt base taste, smoked flavour, strong taste, hard, 2.2~4.8 mm in thickness</td>
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<tr>
<td>salt base taste, smoked flavour, strong taste, soft, 1.3~2.7 mm in thickness</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>soy-sauce base taste, light taste, hard, 1.9~3.5mm in thickness</td>
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<tr>
<td>salt base taste, light taste, hard, 1.4~2.2mm in thickness</td>
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<td>salt base taste, strong taste, soft, about 2.2 mm in thickness</td>
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<tr>
<td>miso-sauce base taste, strong taste, soft, 4.2~5.9mm in thickness</td>
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<tr>
<td>salt base taste, light taste, soft, 1.6~3.1 mm in thickness</td>
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<td>soy-sauce base taste, strong taste, hard, 3.1mm in thickness</td>
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<tr>
<td>salt base taste, light taste, hard, 0.9~2.8mm in thickness</td>
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<tr>
<td>pork meat, soy-sauce base taste, hard, about 2.9~3.4mm in thickness</td>
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</table>
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 $\tau_C$ 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 $\tau_C =1.0\times10^{-4}s$ and $\tau_C =1.1\times10^{-5}s$. Since $\tau_C$ means rotation time of water species, the steep increase of $\tau_C$ 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 $\tau_C$ for the jerky, on the other hand, fell on around the solid line as shown in Fig.2. From these results, one can recognize that the three $\tau_C - W_0$ curves for the pork jerky, beef jerky, and the pork meat are difficult to distinguish indicating a disadvantage of this plot.

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 jerky as a function of the moisture content. The plots of the jerky were localized in the specified region between $14<W_0<71\%$ d.b. and $3.1\times10^{-11}< D_e <1.3\times10^{-10}$ m$^2$/s, whereas the pork meat data demonstrated a characteristic behavior indicating again two different water species, species-A$_2$ and -A$_3$, as shown in the figure. One may recognize all jerky used to be falling 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 $D_e$. The new hybrid method would thus be presented as shown in the next section.
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 ($\tau_C$) derived from the proton NMR method means a rotation time of water molecule, indicating the larger $\tau_C$ the stronger restriction strength against water molecule due to the meat tissues. Based on this meaning, one can presume $\tau_C$ to reasonably be related to $De$. Figure 4 illustrates $De$ as a function of $\tau_C$ for the pork meat and the jerky, instead of $W_0$ in Fig. 3. One can clearly recognize the value of $\tau_C$ to widely be distributed from $6 \times 10^9$ to $1.2 \times 10^7$ s. In addition, the data of the pork meat demonstrates a drastic reduction of $De$ at $\tau_C = 1 \times 10^8$ s as seen on the solid line in Fig.4. This drastic change can be recognized again in the hardness ($N_p$) - $\tau_C$ curve for the pork meat and the jerky as shown in Figure 5. As seen in the figure, the $N_p$ of the pork meat clearly indicates a steep increase at $\tau_C = 1 \times 10^8$ s, and the data of the jerky scattered around the solid line in the region of the water species-A2 higher than $\tau_C = 1 \times 10^8$ s. For this specified value of $\tau_C$, 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 $De$.

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, $De$, $N_p$, $\tau_C$, and $W_0$. Group-1 was characterized by the higher $N_p$ accompanied with the salty taste, group-2, by higher $\tau_C$ 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, \( D_e \), \( W_0 \), \( \tau_C \), and \( N_p \).

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 jerky was distinguished into two water species, species-\( A_1 \) and \( A_2 \). The two water species was clearly divided by the critical correlation time, \( \tau_C \). The water species-\( A_2 \) could effectively be used to design the variety of the jerky-products. The 12 commercial jerky used were classified into five groups by using a distinction of four design parameters, \( D_e \), \( N_p \), \( \tau_C \), and \( W_0 \).

References

Fennema, O., 1976, In principles of Food Science, Part 1, Marcel Dekker, New York.