Induction Periods for Lipid Crystallization of Various Vegetable Oils

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Abstract: The induction period for crystallization, defined as the time required to crystallize, was discussed during isothermal storage at −5 to −45°C for various vegetable oils; olive, safflower, rapeseed, corn, rice bran, soybean, and linseed oils. The induction periods, largely dependent on the oil type and storage temperature, were classified into two groups. The induction periods of corn, rice bran, soybean, and linseed oils were monotonically shortened as the storage temperature decreased. On the other hand, the induction periods for rapeseed, olive, safflower oils and the mixtures of rapeseed and soybean oils, and of olive and safflower oils did not simply change or elongate with a decrease in storage temperature. The induction periods could be formulated using two parameters. One was an expected value of the melting point of the oil, which was calculated from its fatty acid composition. The other was a molar fraction of triacylglycerol composed of the same fatty acids in the oil. The crystallization and melting processes of the oils under non-isothermal conditions were also analyzed by differential scanning calorimetry (DSC). It was suggested that the induction period was also predictable from the peak shape, peak number, onset temperature, and peak area in the DSC curve of the oil during the crystallization process.

Key words: crystallization, induction period, low-melting point, vegetable oil

1 INTRODUCTION

Lipids have wide applications, including in foods, pharmaceuticals, and cosmetics. In food products, lipids play important roles not only as an essential nutrient for humans¹ but also as a preservative² and heating medium³–⁵. Furthermore, lipids also improve the taste and texture of food for enrichment of our diet⁶–⁵. Controlling lipid crystallization is important during lipid refining, and during production and preservation of lipid-containing foods. In the lipid refining process, the precipitation of lipid crystals with a lower liquid-phase content is required to improve refining efficiency⁶,⁷. The fine appearance and texture of foods with high-lipid content such as chocolate are created by appropriately controlling crystal polymorphism⁷. The appearance or texture of dressings and chocolate can be spoiled by crystal growth or polymorphic transition during storage⁸–⁵. It is also reported that lipid crystallization could affect its oxidation⁹.⁸

Studies on crystallization behaviors have been focused on many factors, such as the time at which lipid crystallization starts, the crystallization rate, crystalline polymorphs, polymorphic transition, crystal morphology, crystal size, and so on; these factors are mutually related. In particular, the time at which the lipid starts to crystallize—the induction period for crystallization—plays an important role in predicting the expiration date of food with a high lipid content¹⁰. Crystallization of the oil in O/W emulsion, such as mayonnaise, occurs during storage at low temperature to deteriorate the emulsion due to oil-water separation¹¹,¹². To our knowledge, only a few studies have been reported on the induction periods of vegetable oils with a low melting point. We reported the induction periods of vegetable oils, mainly rapeseed oil, during isothermal storage¹³–¹⁶. An unusual pattern was observed for the induction period of rapeseed oil during isothermal storage in a temperature range of −15 to −30°C. The induction period was shorter at lower storage temperatures. However, the induction period at around −23°C was longer than that expected from the periods at other storage temperatures. This peculiar temperature dependence of the induction period suggests that the period could be affected by the fatty acid composition and chemical structure of rapeseed oil triacylglycerols (TAGs)¹⁶. Further investigation is necessary to clarify the phenomena taking place during isothermal storage.
storage. The investigation of the induction periods of other vegetable oils would deepen our understanding of the mechanisms occurring during the lipid crystallization process.

Crystallization behaviors under non-isothermal conditions have been commonly investigated using differential scanning calorimetry (DSC)\(^ {17}\), although we mainly investigated the induction period during isothermal storage to understand the processes transpiring during chilled or frozen storage of lipid-containing food. A difference in the melting behavior of rapeseed oil has been recognized between isothermal and non-isothermal storages\(^ {10}\). However, insufficient knowledge in this area exists to reasonably explain the difference.

In this study, the induction periods for the crystallization of vegetable oils with low melting points were measured, and the factors affecting the induction period were discussed. The oils discussed were olive, safflower, rapeseed, corn, rice bran, soybean, and linseed oils, as well as mixtures of two of the oils. Crystallization behaviors of the oils under non-isothermal conditions were also investigated using DSC for comparison of the behavior under isothermal storage.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

Olive (chemical grade), high-oleic safflower (first grade), rapeseed (first grade), corn (biochemical grade), and soybean (first grade) oils were purchased from Wako Pure Chemical Industries (Osaka, Japan), and linseed oil (chemical grade) was purchased from Nacalai Tesque (Kyoto, Japan). Rice bran oil (edible grade) was supplied by Tsuno Food Industrial (Wakayama, Japan). Each oil was used alone, and olive and safflower oils were mixed at a weight ratio of 3:1, 1:1 or 1:3. Methanol, 28% sodium methoxide, methanol solution, n-hexane, and sodium sulfate were purchased from Wako Pure Chemical Industries.

2.2 Measurements of fatty acid composition

Fatty acids in the vegetable oils were methylated as follows: A hundred microgram of a vegetable oil was mixed with 3 mL of methanol and 0.8 mL of 28% sodium methoxide methanol solution, and heated at 75°C for 15 min. After cooling, 3 mL of n-hexane and 2 mL of distilled water were added to the mixture, and then the hexane layer was removed. The hexane layer was dehydrated with a sufficient amount of sodium sulfate, and was centrifuged at 10,000 rpm at 3 min. The methylated fatty acids in the supernatant were analyzed by a gas chromatograph equipment, GC-2014 (Shimadzu, Kyoto, Japan), with a flame ionization detector, using a capillary column, DB-23 (30 m × 0.250 mmϕ; 0.25 μm film thickness, Agilent Technologies, CA, USA). The injector and detector temperatures were 245 and 250°C, respectively, and helium was used as the carrier gas. The column temperature was maintained at 150°C for 0.5 min, then increased to 170°C at 4°C/min, increased to 195°C at 5°C/min, increased to 215°C at 10°C/min and then maintained at the temperature for 5 min. The fatty acid was identified by comparing the retention time of the standard. Each peak area was calculated by a Chromato-PRO data processor (Run Time Instruments, Tokyo, Japan), and the composition ratio in weight percent was determined. The fatty acid composition was expressed by mean ± standard deviation (n = 3).

2.3 Measurement of the induction period for crystallization

The induction period for lipid crystallization was measured according to our previous method\(^ {15}\). Briefly, oil (about 10 mL) was poured into a glass cylindrical tube (18 mmϕ, 90 mm) with a K-type thermocouple, AD-1214 (accuracy: ±3°C (−50 to 0°C)), A & D, Tokyo, Japan) installed in the center, and was kept in a thermostatic chamber, DO-300FA (As One, Osaka) at 30°C for 2 h or longer. Since the K-type thermocouple had been used after calibration with a guaranteed thermometer, the error of the recorded temperature was within ±0.5°C. The oil was allowed to stand in a temperature-controlled chamber, SU-261 (Espec, Osaka) at a temperature between −7 and −45°C, and the sample temperature during storage was measured at every 20 s. The induction period for crystallization was defined as the time duration from the beginning of isothermal storage to the time when an exothermic change was detected. Measurements were made in triplicate or more. Only the averaged values will be plotted without error bars in figures. The coefficient of variation was within 5% for 60% of points or more and within 10% for all the points.

2.4 DSC analysis

Thermal changes in the freezing and thawing processes of each oil were measured using a differential scanning calorimeter, DSC7020 (Hitachi High-Tech Science, Tokyo). Approximately 5 mg of the oil was put into an Alodine-coated aluminum pan. After holding the sample at 50°C for 10 min, the sample was cooled to −80°C at a rate of 3°C/min. Immediately after reaching at −80°C, the sample was heated to 80°C at a rate of 3°C/min. An empty pan was used as the reference. For all the tested oils, good reproducibility was confirmed for the DSC curves during temperature-descending and raising processes.
3 RESULTS AND DISCUSSION

3.1 Induction period for lipid crystallization during isothermal storage

Figure 1 shows the temperature changes for rapeseed oil stored at different temperatures, identified in our previous study. A temperature rise due to lipid crystallization was observed after a certain period had elapsed from the beginning of isothermal storage. The storage temperature significantly affected the shape of the exothermic peak. Similar experiments were performed for olive, safflower, rice bran, corn, and linseed oils. Figure 2 shows the induction periods of these oils. It also involved our previous results for rapeseed and soybean oils, and mixtures of these oils at a weight ratio of 3:1, 1:1 or 1:3. The induction period depended on both the oil type and the storage temperature. The crystallization would be a phenomenon different from the crystallization due to random cancellation of supercooling, such as formation of ice from water, and the induction period showed good reproducibility as mentioned above.

The induction periods for corn, rice bran, soybean, and linseed oils monotonically shortened as the storage temperature decreased. Such oils are designated as normal oils. On the other hand, the induction periods for rapeseed, olive, safflower oils and the mixtures of rapeseed and soybean oils, and of olive and safflower oils showed a peculiar temperature dependence, that is, the period did not change or elongate with a decrease in storage temperature. Such oils are designated as peculiar oils. The induction period during isothermal storage was in the order of from shortest to longest: olive, safflower, rapeseed, corn, rice bran, soybean, and linseed oils, although the order changed somewhat depending on the storage temperature. In other words, the order changed for olive and safflower oils at $-25^\circ C$ and for soybean and linseed oils at $-30^\circ C$. As will be described in 3.3, the order changed very complicatedly for the mixed oils.

3.2 DSC measurement of oil under non-isothermal conditions

Crystallization behavior is usually ascertained from the exothermic process under temperature-programmed cooling conditions where the sample temperature is linearly decreased using a DSC. As reported previously, different phenomena occur in the non-isothermal process and during isothermal storage, and the shape of the endothermic peak derived from the melting of the lipid crystal also varies greatly. The differences can be ascribed to large and small degrees of supercooling in the non-isothermal process and during isothermal one is insufficient. In this context, crystallization behavior in the non-isothermal process was examined using the DSC.

Large and small exothermic peaks were observed in the DSC for safflower, olive, and rapeseed oils during their...
The onset temperature of melting descended in the order of safflower, olive, rapeseed, rice bran, corn, soybean, and linseed oils, and the temperatures were -19, -24, -35, -43, -44, -45 and -50°C, respectively (Fig. 3B). A good correlation was found between the onset temperature of a large exothermic peak in the crystallization process and the melting onset temperature of the melting process (Table 1).

The induction period was longer for vegetable oil with a lower onset temperature of the large exothermic peak (the peak at the lowest temperature for rice bran oil), that is, the lower onset temperature of melting (Fig. 3B). Regarding the large peak (the peak at lower temperature) that appeared during the crystallization process, the normal oils exhibited a relatively small peak (small enthalpy change, ΔH), while the peculiar ones displayed a large and sharp peak (small half-width). The onset temperature of the small exothermic peak observed in the crystallization was higher, and the peaks were broader for the normal oils than for the peculiar ones. That is, the ΔH values of the large and small peaks became large and small, respectively, as the half width of the large peak was small. As will be discussed in detail in section 3.3, peculiar oils have a large proportion of specific unsaturated fatty acids (Table 2). Normal oils consist of mainly unsaturated fatty acids with lower melting points than peculiar oils, and also have a high proportion of saturated fatty acids with high melting points. That is, the difference in the melting points of the constituent fatty acids was large between normal and peculiar oils. Therefore, peculiar oils had a small half-width and a small number of peaks because most of the oil crystallized rapidly at once. On the other hand, since normal oils were gradually crystallized from the oil having a high melting point to that having a low melting point, some peaks would appear and the half width of the peak became large. The sum of ΔH for all the peaks was about 40 J/g and 50 J/g for normal and peculiar oils, respectively. Since

**Table 1** DSC analyses of vegetable oils during crystallization processes.

<table>
<thead>
<tr>
<th>Vegetable oil</th>
<th>Saflower oil</th>
<th>Olive oil</th>
<th>Rapeseed oil</th>
<th>Corn oil</th>
<th>Rice bran oil</th>
<th>Soybean oil</th>
<th>Linseed oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small peak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Onset temperature* [°C]</td>
<td>-18.2</td>
<td>-10.6</td>
<td>-15.5</td>
<td>-14.9</td>
<td>-6.0</td>
<td>-10.0</td>
<td>-3.9</td>
</tr>
<tr>
<td>ΔH** [J/g]</td>
<td>1</td>
<td>16</td>
<td>7</td>
<td>17</td>
<td>27</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>Large peak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Onset temperature [°C]</td>
<td>-35.2</td>
<td>-36.7</td>
<td>-42.2</td>
<td>-51.1</td>
<td>-52.0</td>
<td>-54.3</td>
<td>-56.8</td>
</tr>
<tr>
<td>Half width</td>
<td>3.2</td>
<td>4.7</td>
<td>4.2</td>
<td>6.4</td>
<td>8.7</td>
<td>10.4</td>
<td>5.7</td>
</tr>
<tr>
<td>ΔH [J/g]</td>
<td>49</td>
<td>33</td>
<td>43</td>
<td>26</td>
<td>14</td>
<td>20</td>
<td>27</td>
</tr>
</tbody>
</table>

*The highest onset temperature for the peaks.
** The sum of two peaks, excluding safflower oil.
normal oils have more components with a higher melting point, that is, components are close to solids, than peculiar ones, the energy required for crystallization might be smaller for normal oils than peculiar ones. These results suggest that the peak shape, number, onset temperature, and area in the DSC could be a promising index for predicting the induction period.

### 3.3 Effects of fatty acid composition and chemical structure of triacylglycerol on the induction period

We considered the reason for the longer induction period of rapeseed oil at $-23^\circ\text{C}$ than the period presumed from the periods at other temperatures as follows$^{16,19}$: vegetable oil contains various TAGs with different melting points. At the beginning of isothermal storage, TAGs are in liquid and semi-solid states, and in liquid and solid states at a relatively high and low temperatures, respectively$^{16}$. The rapeseed oil is thought to crystallize through the melt-mediated transition$^{16,19}$. Melt-mediated transition means crystallization in which crystal in an unstable form changes to a melt once and then it transforms into crystal in a more stable form$^{20,21}$. Because the melt-mediated transition is less likely to occur in TAGs in a solid state, crystallization of such TAGs hardly develops. At lower storage temperatures, crystallization through the melt-mediated transition does not occur, but it directly crystallizes from liquid to solid. That is, the transition from liquid to solid is more strongly promoted at the lower storage temperatures. The chain length structure of the crystal was different between crystallization through melt-mediated transition and that through direct crystallization from the liquid to the solid$^{16}$. The induction period changed in an unexpected manner in the temperature range where the crystallization mechanism changed. That is, the induction period was prolonged in the temperature range where the melt-mediated transition hardly occurred.

**Figure 4** shows temperature changes of rapeseed and soybean oils, and their mixture, during isothermal storage at $-35^\circ\text{C}$. The induction period of the mixture became more prolonged as the content of soybean oil became larger. However, at $-35^\circ\text{C}$ the induction period of soybean oil was slightly shorter than that of the 1:3 mixture of rapeseed and soybean oils, and was almost the same as that of the 2:2 mixture. For the mixture of olive and safflower oils stored at $-15^\circ\text{C}$ or higher temperatures, the induction period prolonged with as the safflower oil contents increased, and was close to that of safflower oil alone. At temperatures lower than $-15^\circ\text{C}$, the induction period was longer than that of safflower oil (Fig. 2). An induction period longer than that expected from those at other temperatures was observed at $-35^\circ\text{C}$ and near $-20^\circ\text{C}$, which

### Table 2  Fatty acid composition of vegetable oils, and the fraction of TAGs with three same fatty acid molecules against all TAGs in an oil, $\phi$.

<table>
<thead>
<tr>
<th>Vegetable oil</th>
<th>$\phi$</th>
<th>Palmitic acid</th>
<th>Stearic acid</th>
<th>Oleic acid</th>
<th>Linoleic acid</th>
<th>Linolenic acid</th>
<th>Arachidic acid</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safflower oil</td>
<td>0.445</td>
<td>$4.5 \pm 0.1$</td>
<td>$1.9 \pm 0.1$</td>
<td>$79.6 \pm 0.1$</td>
<td>$12.9 \pm 0.1$</td>
<td>$0.1 \pm 0.0$</td>
<td>$0.4 \pm 0.0$</td>
<td>$0.6 \pm 0.0$</td>
</tr>
<tr>
<td>Olive oil</td>
<td>0.452</td>
<td>$12.2 \pm 0.2$</td>
<td>$2.4 \pm 0.4$</td>
<td>$74.7 \pm 0.4$</td>
<td>$8.5 \pm 0.1$</td>
<td>$0.6 \pm 0.0$</td>
<td>$0.4 \pm 0.0$</td>
<td>$1.3 \pm 0.0$</td>
</tr>
<tr>
<td>Rapeseed oil</td>
<td>0.254</td>
<td>$3.9 \pm 0.0$</td>
<td>$1.8 \pm 0.0$</td>
<td>$64.1 \pm 0.2$</td>
<td>$19.6 \pm 0.0$</td>
<td>$0.8 \pm 0.2$</td>
<td>$0.6 \pm 0.0$</td>
<td>$2.1 \pm 0.0$</td>
</tr>
<tr>
<td>Corn oil</td>
<td>0.250</td>
<td>$11.0 \pm 0.2$</td>
<td>$1.6 \pm 0.0$</td>
<td>$31.3 \pm 0.1$</td>
<td>$53.6 \pm 0.1$</td>
<td>$1.4 \pm 0.0$</td>
<td>$0.4 \pm 0.0$</td>
<td>$0.7 \pm 0.0$</td>
</tr>
<tr>
<td>Rice bran oil</td>
<td>0.159</td>
<td>$16.1 \pm 0.2$</td>
<td>$1.8 \pm 0.0$</td>
<td>$44.6 \pm 0.0$</td>
<td>$35.0 \pm 0.1$</td>
<td>$1.0 \pm 0.0$</td>
<td>$0.7 \pm 0.0$</td>
<td>$0.9 \pm 0.0$</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>0.205</td>
<td>$10.3 \pm 0.1$</td>
<td>$3.6 \pm 0.0$</td>
<td>$25.6 \pm 0.1$</td>
<td>$53.0 \pm 0.0$</td>
<td>$6.2 \pm 0.0$</td>
<td>$0.3 \pm 0.0$</td>
<td>$0.9 \pm 0.0$</td>
</tr>
<tr>
<td>Linseed oil</td>
<td>0.265</td>
<td>$5.2 \pm 0.1$</td>
<td>$3.4 \pm 0.0$</td>
<td>$19.4 \pm 0.1$</td>
<td>$17.0 \pm 0.1$</td>
<td>$53.9 \pm 0.2$</td>
<td>$0.1 \pm 0.0$</td>
<td>$0.9 \pm 0.0$</td>
</tr>
</tbody>
</table>
were relatively low storage temperatures, for the mixtures of rapeseed and soybean oils, and of olive and safflower oils, respectively, at any mixing ratio. The soybean and olive oils were rich in stearic and palmitic acids with high melting points (Table 2). Therefore, the reversal of induction period could be explained by the above-mentioned consideration of the induction period. That is, it was presumed that the state of TAGs containing palmitic acid changed with decreasing temperature, and that the processes leading to crystallization also changed. The corn and rice bran oils were also rich in palmitic acid as well as soybean and olive oils (Table 2). However, the induction periods for corn, rice bran, soybean, and linseed oils monotonically decreased with decreasing temperature. The reason for such a simple temperature dependence could be considered to be as follows: the TAGs containing palmitic acid existed in a solid state at the beginning of isothermal storage due to the low storage temperature, and the mechanism leading to crystallization did not change.

The major fatty acid was oleic acid for olive (ca. 75%), safflower (ca. 75%), rapeseed (ca. 60%), and rice bran (ca. 40%) oils; linoleic acid for corn (ca. 55%) and soybean (ca. 50%) oils; and linolenic acid for linseed oil (ca. 45%). The values in the parentheses are the molar fractions of the major fatty acid. The melting points of oleic acid in the α form, linoleic acid and linolenic acid are 13.3, −5, and −11°C, respectively. Therefore, the induction period of oils containing a lesser content of fatty acids with a lower melting point can be inferred to be longer. Based on the fact that the induction period of oil was affected by both the melting point of constituent fatty acids and its fraction, a method to estimate the induction period of any oil is proposed.

The expected melting point, $T_{mp}$, was defined by weight-

$$T_{mp} = \sum T_{mp,FA}$$

(1)

The $T_{mp}$ values of the oils used were evaluated from their fatty acid compositions, which are almost the same as those determined by GC analysis in this study, and the melting points of fatty acids. The plots of the induction period against the difference between the storage temperature and the expected melting point, $T_s - T_{mp}$, could be roughly divided into two groups (Fig. 5A): one group contained olive and safflower oils, and their mixture, and another did corn, rice bran, soybean and linseed oils. The rapeseed oil was located between the two groups. The $T_s - T_{mp}$ could be regarded as the degree of supercooling of the oil.

The main component of vegetable oil is TAG, in which three molecules of fatty acids are ester-bonded to a molecule of glycerol. The crystal structure of TAG depends on its constituent fatty acids. When the three fatty acids constituting TAG are all equal or similar, crystals of a double chain-length structure would be formed. TAG consisting of three fatty acids different in degree of unsaturation and/or carbon number is prone to produce crystals of a triple chain-length structure. Therefore, not only fatty acid composition but also the chemical structure of TAG affects the crystallization process. The TAG found in the greatest proportion by HPLC analysis is triolein for olive and rapeseed oils, trilinolein for soybean oil, and trilinolenin for linseed oil. Triolein accounts for about 45% of olive oil, and trilinolenin about 25% of linseed oil. Since the induction period tended to be longer for oils which contained a higher proportion of TAGs consisting of three similar fatty acids, the fraction of TAGs with three
same fatty acid molecules against all TAGs in an oil, $\phi$, affects the induction period (Table 2). The $\phi$ values of oils used in this study were calculated based on their chemical structures.21,22

The $\phi$ values of olive and safflower oils, and their mixture, which had relatively short induction periods, were about 45%, while those of corn, rice bran, soybean and linseed oils, the induction periods of which were relatively long, ranged from 16 to 25%. Noting these points, we conceived to plot the induction period against the product of the fraction and the difference between the storage temperature and the melting point of oil, $\phi(T_a - T_{mp})$, which corresponded to the degree of supercooling for the TAG governing the crystal structure (Fig. 5B). All of the plots lay roughly on a single curve. The curve could be empirically expressed by the following equation:

$$\ln IP = \exp[4.3 \ln(-\phi(T_a - T_{mp}))]^{-1}$$

where $IP$ is the induction period. The coefficient of determination $R^2$ for $\ln IP$ was 0.716 with high correlation. Although it is known that minor components contained in vegetable oil affect crystallization behavior, this fact indicates that the chemical structure of TAG affects the induction period for lipid crystallization as well as the storage temperature and fatty acid composition. In order to further improve the accuracy of the prediction, it will be necessary to consider the influence of minor components. The difference in the $\phi$ value among the oils was also reflected in their DSC. The oil with the smallest $\phi$ value had three small exothermic peaks in the DSC. On the other hand, the oil with the largest $\phi$ value exhibited two peaks with largely different areas. One of the two peaks had a very large area. These findings suggest that the induction period can be predictably controlled by mixing oils with different properties.

4 CONCLUSION

The induction periods for crystallization were observed for olive, safflower, rapeseed, corn, rice bran, soybean, and linseed oils stored at a temperature from $-5$ to $-45^\circ$C. The induction period largely depended on both the oil type and storage temperature. It was suggested from the DSC observation of the crystallization process that the peak shape and its onset temperature were possible indicators in the prediction of the induction period. The induction period could be classified into two groups by the difference between the storage temperature $T_a$ of oil and the expected melting point $T_{mp}$ of vegetable oil, which was weighed by its fatty acid composition. The molar fraction of TAGs consisting of three similar fatty acids to all TAGs, $\phi$, was calculated. The plots of induction period against the product of $\phi$ and the difference between $T_a$ and $T_{mp}$ lay on a single curve for all the oil used. This fact indicated that we can estimate the induction period of vegetable oil with low melting point based on its storage temperature, fatty acid composition, and chemical structure.

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