Composition and Structure of Oil and Fats and its Relationship to Health and Nutrition

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OIL AND FATS HEALTH PERCEPTIONS

Animal Fats not good for health

- high cholesterol, high saturates

High amount of saturates

- bad for health

High amount of trans

- bad for health

High amount of unsaturates

- good for health
Cholesterol Content in Edible Oil and Fats

<table>
<thead>
<tr>
<th>Oil</th>
<th>Cholesterol Content (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lard</td>
<td>3000 - 4000</td>
</tr>
<tr>
<td>Butter</td>
<td>2200 - 4100</td>
</tr>
<tr>
<td>Tallow</td>
<td>800 - 1400</td>
</tr>
<tr>
<td>Soybean oil</td>
<td>20 - 35</td>
</tr>
<tr>
<td>Palm oil</td>
<td>13 - 19</td>
</tr>
<tr>
<td>Palm Kernel oil</td>
<td>9 - 40</td>
</tr>
</tbody>
</table>

Effects of Fatty Acid on cardiovascular diseases

- Saturated fatty acids has always been linked to Coronary Artery diseases. Palmitic Acid is less cholesterololaemic than Myristic Acid + Lauric Acid in diets of low dietary cholesterol (<250mg/ day)
  
  (Hayes et. al, 1995, J Nutr Biochem 6:188-194)

- Palmitic Acid do not result in significant plasma total cholesterol content (Sundram et. al, 1997, J. Nut 127: p 514S-520S).

- Stearic acid appears to be a neutral fatty acid
  
Effects of Fatty Acid on cardiovascular diseases

Lauric and Myristic acid seems to be the worst.

Therefore all saturated fatty acids are not the same in cholesterol lowering effects.

Longer chains fatty acid better than shorter chain?
Effects of Fatty Acid on cardiovascular diseases

• Studies on Trans fatty acid effects on CHD has shown that it may be more detrimental than saturated fatty acids due to its negative impact on LDL/ HDL ratio


• The consumption of 2-7% Elaidic Acid (C18:1 trans) demonstrate the increase in the HDL/ LDL ratio due to its activity in reducing the HDL cholesterol and increase the LDL cholesterol content.

Mean Blood Lipid Values when high saturated fat and high trans fat diets are consumed

Lipoprotein levels

- **TC**
- **LDL**
- **HDL**
- **TG**

High saturated fat
High trans fat

* p < 0.05

Sundram et. al, 2003, Eur J Nutr
Since Trans Fatty Acid in oil and fats is viewed as a health hazard, can interesterification of fully hydrogenated hard fats with soft oil be used as a substitute?
INTERESTERIFICATION

An oil and fats reaction in which the fatty acid esters react with other esters or fatty acids to produce new esters by the interchange of fatty acid groups. There are 2 methods of interesterification:

1. Chemical Interestesterification
2. Enzyme Interestesterification
INTERESTERIFICATION

Chemical Interestesterification (random)

\[ \begin{align*}
X \left[ \begin{array}{c}
\text{O} \\
\text{O}
\end{array} \right] + Y \left[ \begin{array}{c}
\text{S} \\
\text{S}
\end{array} \right] & \xrightleftharpoons{\text{NaOCH}_3} \\
\left[ \begin{array}{c}
\text{S} \\
\text{O}
\end{array} \right] & \left[ \begin{array}{c}
\text{S} \\
\text{X}
\end{array} \right] & \left[ \begin{array}{c}
\text{S} \\
\text{Y}
\end{array} \right] \quad \text{etc}
\end{align*} \]

Enzyme Interestesterification (1,3 specific)

\[ \begin{align*}
\text{TG 1} \quad & \left[ \begin{array}{c}
\text{O} \\
\text{O}
\end{array} \right] + \quad \text{TG 2} \quad & \left[ \begin{array}{c}
\text{S} \\
\text{S}
\end{array} \right] & \xrightleftharpoons{\text{Lipase}} \\
\left[ \begin{array}{c}
\text{X} \\
\text{O}
\end{array} \right] & \left[ \begin{array}{c}
\text{S} \\
\text{S}
\end{array} \right] & \left[ \begin{array}{c}
\text{S} \\
\text{X}
\end{array} \right] & \left[ \begin{array}{c}
\text{S} \\
\text{Y}
\end{array} \right] \quad \text{etc}
\end{align*} \]
However, recent studies also show that random interesterification can be just as bad as Trans Fatty Acid.
The mechanism of how the oil and fats are metabolized in our body is in the form of triglycerides and not as fatty acids.

**THEREFORE**

How do the structure and position of the triglycerides play a part in terms of functionality?
Does the position of the fatty acids matter?
Fat Absorption

- Gut pancreatic lipases hydrolyse FAs in \( sn1,3 \) positions

- \( sn1,3 \) fatty acids are absorbed as free fatty acids (FFA) and metabolised independently

- \( sn2 \) monoglycerides (MG) are absorbed intact and serve as the primary backbone for TG synthesis.

- \( sn2 \) MGs also involved in gut and liver phospholipid synthesis, especially during extensive fat absorption

- Thus any change in the TG structure should impact fat metabolism
The original speculation that triglyceride structure might influence lipid metabolism was based on observed differences in fat absorption by infants fed breast milk or infant formula milk.

- Infant formula milk contained “natural fats” but they contain triglycerides with different orientations.

- Fat from breast milk (and lard based formulas) has palmitic in the $sn2$ position was better absorbed than fat with $sn1,3$ palmitic acid from palm oil.
<table>
<thead>
<tr>
<th></th>
<th>Position</th>
<th>Fatty Acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>16:0</td>
</tr>
<tr>
<td>Palm Oil</td>
<td>sn 1</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>sn 2</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>sn 3</td>
<td>72</td>
</tr>
<tr>
<td>Human Milk</td>
<td>sn 1</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>sn 2</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>sn 3</td>
<td>6</td>
</tr>
<tr>
<td>Lard</td>
<td>sn 1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>sn 2</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>sn 3</td>
<td>trace</td>
</tr>
<tr>
<td>Cocoa Butter</td>
<td>sn 1</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>sn 2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>sn 3</td>
<td>37</td>
</tr>
</tbody>
</table>

(Christie W. W. et. al, 1970, Biochim Biophys)
(Brockerhoff H.et. al, 1991, J Lipid Res)

<table>
<thead>
<tr>
<th>Fatty Acid</th>
<th>16:0</th>
<th>18:0</th>
<th>18:1</th>
<th>18:2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palm Oil</td>
<td>60</td>
<td>3</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>Human Milk</td>
<td>16</td>
<td>15</td>
<td>46</td>
<td>11</td>
</tr>
<tr>
<td>Lard</td>
<td>10</td>
<td>30</td>
<td>51</td>
<td>6</td>
</tr>
<tr>
<td>Cocoa Butter</td>
<td>34</td>
<td>50</td>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>
sn2 Distribution

• Human milk has more C16:0 (palmitic acid) (58%) and less C18:0 (stearic acid) (3%) in the sn-2 position; their amounts in the sn-1/3 positions (16% and 15% respectively)
  (Christie W. W. et. al, 1970, Biochim Biophys)
  (Brockerhoff H. et. al, 1991, J Lipid Res)

• In contrast, the sn2 position in Palm Oil is occupied by predominantly oleic acid (68%) compared to Palmitic acid (13%) and linoleic (18%)
  (Christie W. W. et. al, 1970, Biochim Biophys)
  (Brockerhoff H. et. al, 1991, J Lipid Res)
sn2 Distribution

- Lard is closer to human milk in terms of its palmitic acid distribution in the \textit{sn2} position of the triglyceride. Fat from human milk and lard based formulations with palmitic acid (C16:0) in the \textit{sn2} position was better absorbed than fat with \textit{sn1,3} palmitic acid from palm oil.

( C. Wijesundera, 2004; AAOCS Annual Meeting)
sn2 Distribution

In palm oil the saturated fatty acids, namely palmitic and stearic mainly occupy the \textit{sn1} and \textit{sn3} positions of the TG molecule while the unsaturated fatty acids are preferentially at the \textit{sn2} position.

As a result, the major TG species in palm oil are POP, POO and POL with minor occurrence of PPP, PPS or other trisaturated TAGs.
It is an important consideration when palm oil is used in infant formulations to provide palmitic acid. Unfortunately, palm oil or olein in its natural state carry very little C16:0 in the \textit{sn}-2 position, which is required for optimum nutrition in infants.
Cocoa Butter are essentially made up of 3 types of triglycerides: POS, SOS and POP. Despite having a high percentage of saturated fat (~60%), cocoa butter is still regarded as an acceptable fat due to the \textit{sn2} position of the triglyceride is predominantly occupied with oleic acid.
Interesterification and *sn2* Distribution

- Natural oils have a non-random distribution of FA. The *sn-2* position is predominantly occupied by unsaturated fatty acids eg. POP, POO, OOL.

- Chemical Interesterification results in a random distribution of FA, increasing the amount of unsaturated FA’s at the *sn-1/ sn-3* while placing saturates in the *sn-2* position.
Interesterification and sn2 Distribution

- Positional distribution of fatty acids in dietary triglyceride alters metabolism

- Interestered (IE) fat blend containing more palmitic acid (16:0) in the sn-2 position has been shown to

  - Enhance fat and 16:0 absorption in rats and human infants
  - Increase atherosclerosis in rabbits
  - Adversely affect lipoproteins in human infants

(Kritchevsky D)
(Nelson et. al, 1999, Am J Clin Nutr)
### Serum lipids and weights of rabbits maintained on diets containing special fats after 15 weeks*

<table>
<thead>
<tr>
<th></th>
<th>WEIGHT (g)</th>
<th>CHOLESTEROL (mMol/L)</th>
<th>TRIGLYCERIDES (mMol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOS</td>
<td>2262 ± 201</td>
<td>5.87 ± 1.42</td>
<td>0.99 ± 0.08</td>
</tr>
<tr>
<td>SSO</td>
<td>2140 ± 100</td>
<td>7.68 ± 1.84</td>
<td>1.17 ± 0.33</td>
</tr>
<tr>
<td>POP</td>
<td>2070 ± 185</td>
<td>7.71 ± 1.63</td>
<td>1.46 ± 0.40</td>
</tr>
<tr>
<td>PPO</td>
<td>1982 ± 117</td>
<td>8.12 ± 2.28</td>
<td>1.83 ± 0.87</td>
</tr>
</tbody>
</table>

*After Kritchevsky *et. al* Lipids 2000;35:p 621
Necropsy data: Rabbits fed atherogenic diets containing TGs for 20 weeks*

<table>
<thead>
<tr>
<th></th>
<th>Aortic arch</th>
<th>Thoracic aorta</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOS</td>
<td>1.60 ± 0.10</td>
<td>1.10 ± 0.33</td>
</tr>
<tr>
<td>SSO</td>
<td>1.36 ± 0.34</td>
<td>0.57 ± 0.28</td>
</tr>
<tr>
<td>POP</td>
<td>1.36 ± 0.26</td>
<td>0.29 ± 0.18</td>
</tr>
<tr>
<td>PPO</td>
<td>2.42 ± 0.51</td>
<td>1.17 ± 0.21</td>
</tr>
</tbody>
</table>

*After Kritchevsky et. al Lipids 2000;35:p 621
In human adults:

- Modest intake of IE fat blend with 16:0 in \textit{sn}-2 position did not affect plasma lipids

- 18:0-rich IE blend of FHSBO and soybean oil (SBO) resulted in increased plasma \text{LDL}:\text{HDL-C} ratio and elevated blood glucose levels compared to palm olein (Sundram \textit{et al})
Palm Oil has a non-significant effect on plasma TC from the meta-analysis of 37 dietary trials.
Palm Oil has a non-significant effect on plasma LDL-C from the meta-analysis of 37 dietary trials.
Fasting Plasma Glucose Concentrations (mmol/L) in Response to Dietary Treatment
Comparison between PO, Hydrogenated & Interesterified Fats Postprandial Effect on Plasma Glucose (n=20)

*\(p = .000\)
Comparison of PO, Stearate & Interesterified Fats

Postprandial Effect on Plasma Glucose (n=14)

*\(p = 0.001\)
Comparison between PO, Hydrogenated & Interesterified Fats

Postprandial Effect on Plasma Glucose (n=20)

*\(p = .000\)
Comparison of PO, Stearate & Interesterified Fats
Postprandial Effect on Plasma Triglycerides (n=14)

Plasma TG (mmol/L)

Comparison of PO, Stearate & Interesterified Fats
Postprandial Effect on Plasma Triglycerides (n=14)
Comparison of PO, Stearate & Interesterified Fats

Postprandial Effect on Plasma Total Cholesterol (n=14)

*ns*
Comparison of PO, Stearate & Interesterified Fats

Postprandial Effect on Plasma Glucose (n=14)

*\(p=0.001\)
Conclusion

1. TGs structure has an impact on postprandial effects on intestinal absorption and affects the profile of absorbed fatty acids

Fatty acids in $sn1$ and $sn3$ are absorbed as free fatty acid and metabolized in the lumen. Fatty acids in $sn2$ are absorbed intact as monoglyceride and enters the blood circulation. Therefore the type of fatty acid in the $sn2$ position could determine blood lipid profile and cholesterol level.
Conclusion

2. The composition and position of FAs in TGs affect
   - Bioavailability
   - Digestibility of fats and oils in both infants and adults

The type of fatty acids in sn2 position appears important for overall digestibility and fat absorption. In human milk, palmitic acid is largely in the sn2 position and this is preferred for optimum absorption of fats in infants. Infant formula lacking the placement of palmitic acid in the sn2 position are thus poorly absorbed compared to human milk.
3. Stereospecificity of most native vegetable oils and fats favour polyunsaturates or monounsaturates in the \textit{sn}-2 position whilst saturates are distributed at the \textit{sn}-1/3 positions.

Chemical Interesterification has the capacity to invert this distribution by placing saturated fatty acids in the \textit{sn}-2 position.

Displacing PUFA or MUFA from the critical \textit{sn}-2 position by substitution with SFA is hypothesized to cause lipid and lipoprotein abnormalities.
Conclusion

4. Studies comparing the chain length of saturated fatty acids are limited but indicate that C16:0 is most detrimental in the \textit{sn}-2 position. The amount of C16:0 in the \textit{sn}-2 position maybe critical in affecting TC and TG levels. Research is currently being undertaken in many centres worldwide to determine the effect of palmitic acid in the \textit{sn}-2 position on cardiovascular health.

In the rabbit model \textit{sn}-2 16:0 appears to contribute to the development of atherogenicity in a dose-dependent manner but other animal models do not show this effect.
Conclusion

5. The current concept of saturation and unsaturation may not be the only consideration in determining nutritional effects.

The sn2 hypothesis could pave a new perspective to health and nutrition especially in coronary Heart Disease.
“POSITION COUNTS”

THANK YOU