FUTURE PROSPECTS FOR PALM OIL REFINING AND MODIFICATION

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• Produced at oil mill by **cooking, pressing and clarification.**

• **Quality** of the crude oil affects:
  • **Efficiency** and **yield** of the refining.
  • **Quality** of the fully processed oil.

• Beside triacylglycerols, **multitude of chemical entities**, some with actual or potential value:
  • Free fatty acids (FFA) and partial acylglycerols.
  • Oxidation products and metal traces.
  • Phosphatides and glycolipids.
  • **Tocopherols and tocotrienols.**
  • **Carotenoids.**
  • Sterols, methyl sterols, triterpenes/isoprenoid alcohols, hydrocarbons.
Refining Options

Crude Oil

Chemical Refining

Degumming

Neutralisation

Bleaching

Deodorisation

GUMS

SOAPS

FFA

Physical Refining

Degumming

Bleaching

Steam refining-
Deodorisation

Refined Oil

SPLITTING
Physical refining:

- Higher oil yield.
- Use of less chemicals and water; less effluent.
- Reduction of environmental impact.

Final choice depends on:

- Quality and acidity of the crude oil
  (wide range of undesirable products more easily removed by chemical refining)
- Ability to get rid of soapstocks.
- Local environment legislation.

Crude palm oil with high acidity, low phosphatides, high catotene:

- Physical refining is preferred (operating costs and refining losses).
- The process can be optimized (retention of minor components (tocos)).

Chemical refining still used at a limited capacity.
## Quality Specifications

<table>
<thead>
<tr>
<th></th>
<th>Special quality (SQ) grade</th>
<th>Std quality I</th>
<th>Std quality II</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FFA (% max)</strong></td>
<td>2.5</td>
<td>3.5</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>M and I (% max)</strong></td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>PV (meq O₂/kg max)</strong></td>
<td>2.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>AnV (max)</strong></td>
<td>4.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>DOBI (min)</strong></td>
<td>2.8</td>
<td>2.5</td>
<td>2.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Special grade</th>
<th>Lotox</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FFA (% max)</strong></td>
<td>2.5</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Carotene (ppm max)</strong></td>
<td>-</td>
<td>600-700</td>
<td>-</td>
</tr>
<tr>
<td><strong>Fe (ppm max)</strong></td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Cu (ppm max)</strong></td>
<td>0.02</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
• FFA < 3% guarantee fresh and unbruised fruits, good storage and transportation.
• Freshly expelled crude palm oil allows low hydrolysis and oxidation.
• High FFA is usually combined with high Fe and Cu levels; Fe and Cu have high pro-oxidant potential.
• Low grade crude palm oils suffers auto-oxidation of carotene.

→ **DOBI (Deterioration Of Bleachability Index)** [ISO 7932:2005]:

Good test to assess crude palm oil quality.

\[
\text{DOBI} = \frac{\text{UV absorbance (446nm)}}{\text{UV absorbance at 269 nm}}
\]

- DOBI above 2.5 (easily refined) [above 3: very satisfactory quality].
- DOBI between 2.0 and 2.5 (unpredictable).
- DOBI below 2.0 (difficult to refine).
## DOBI of Crude Palm Oil and Color of the Refined Oil

<table>
<thead>
<tr>
<th>Crude Palm Oil</th>
<th>Bad grade</th>
<th>Poor grade</th>
<th>Poor grade</th>
<th>Poor grade</th>
<th>Fair grade</th>
<th>Good grade</th>
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</thead>
<tbody>
<tr>
<td><strong>FFA (%)</strong></td>
<td>7.21</td>
<td>4.32</td>
<td>3.54</td>
<td>4.91</td>
<td>2.79</td>
<td>1.90</td>
</tr>
<tr>
<td><strong>DOBI</strong></td>
<td>1.34</td>
<td>1.76</td>
<td>2.02</td>
<td>2.23</td>
<td>2.67</td>
<td>3.13</td>
</tr>
<tr>
<td><strong>PV (meq O₂/kg)</strong></td>
<td>2.33</td>
<td>3.79</td>
<td>3.15</td>
<td>3.54</td>
<td>0.36</td>
<td>1.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RBD Palm Oil</th>
<th>Lovibond (5°1/4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.1R/33Y</td>
</tr>
<tr>
<td></td>
<td>3.0R/35Y</td>
</tr>
<tr>
<td></td>
<td>2.2R/20Y</td>
</tr>
<tr>
<td></td>
<td>2.0R/20Y</td>
</tr>
<tr>
<td></td>
<td>1.3R/15Y</td>
</tr>
<tr>
<td></td>
<td>1.4R/15Y</td>
</tr>
</tbody>
</table>

Heat-bleached palm oil with color below 2R can only be produced when crude palm oil has a DOBI above 2.5.
Deodorisation: crucial refining stage, important effect on final oil quality

**Targets:**
- Bland taste and smell
- Low FFA and no hydrolysis
- High oxidative stability
- Light and stable color
- (Removal of contaminants)

**Unwanted side effects:**
- Formation of trans FA
- Polymerisation
- Acyl-migration (intra-esterification)
- Degradation of natural vitamins and anti-oxidants
**Improved Deodorisation**

1) Low “trans” content  
2) Retention of minor components

**Principle of Dual Temperature Deodorizer**

1) Moderate temperature - long time (stage 1)  
   Mild deodorisation and moderate stripping  
   - deodorisation and deacidification -

2) High temperature - short time (stage 2)  
   Final stripping and heat bleaching  
   - controlled stripping of valuable minor components -

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- Qualistock
- deodorizer

High/low or Low/high
**Improved Deodorisation**

Recovery of valuable by-products

**Double Condensing System**

- Increases acidity of the fatty acid distillate
- Recovers valuable by-products

<table>
<thead>
<tr>
<th>PFAD (fatty acid distillate)</th>
<th>Chemical Refining</th>
<th>Physical Refining</th>
<th>DCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFA (%)</td>
<td>33-50</td>
<td>80-85</td>
<td>88.0</td>
</tr>
<tr>
<td>Neutral oil (%)</td>
<td>25-33</td>
<td>5-10</td>
<td>2.0</td>
</tr>
<tr>
<td>MAG (%)</td>
<td>5-10</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>DAG (%)</td>
<td></td>
<td></td>
<td>8.0</td>
</tr>
<tr>
<td>TAG (%)</td>
<td></td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Unsap. (%)</td>
<td>25-33</td>
<td>2-8</td>
<td>2.0</td>
</tr>
<tr>
<td>(tocos, sterols …)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Improved Deodorisation**

1) Low operating pressure
2) Reduction of emission and effluents

**Dry (Ice) Condensing System**

Condensation of steam (into ice) on surface condensers

Low pressure can be reached (< 2 mbar)

Strongly reduced odor emission

10x less waste water

Nearly no motive steam; higher electricity consumption
### Golden Palm Oil (physically refined):

**Dual temperature/low pressure (ice condensing vacuum)**

<table>
<thead>
<tr>
<th></th>
<th>RBD Palm Oil Ref.</th>
<th>Golden Palm Oil A</th>
<th>Golden Palm Oil B</th>
<th>Golden Palm Oil C</th>
<th>Golden Palm Oil D</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFA (%)</td>
<td>0.07</td>
<td>0.20</td>
<td>0.07</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>Lovibond 5”1/4 (R/Y)</td>
<td>2.5/25</td>
<td>11.6/70</td>
<td>6.2/50</td>
<td>4.8/50</td>
<td>4.1/42</td>
</tr>
<tr>
<td>Tocos (ppm)</td>
<td>545</td>
<td>709</td>
<td>671</td>
<td>630</td>
<td>699</td>
</tr>
<tr>
<td>OSI (h at 97.8°C)</td>
<td>70.5</td>
<td>61.5</td>
<td>63.0</td>
<td>50.6</td>
<td>53.4</td>
</tr>
</tbody>
</table>
Specially Refined Palm Oil

High Vitaminic Palm Oil (chemically refined):

<table>
<thead>
<tr>
<th></th>
<th>Crude</th>
<th>Degum. and Neutr.</th>
<th>Degum., Neutr. and Deod.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFA (%)</td>
<td>2.56</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Phosphorus (ppm)</td>
<td>16</td>
<td>3</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>DOBI</td>
<td>3.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carotene (ppm)</td>
<td>580</td>
<td>579</td>
<td>1.0</td>
</tr>
<tr>
<td>Tocos (ppm)</td>
<td>733</td>
<td>679</td>
<td>566</td>
</tr>
</tbody>
</table>

Thermal bleaching at lower temperature (+ Dry fractionation)

Red Cooking Palm Oils: Carotino Cooking Oil, Nutrolein Golden Palm Oil, Sioma Oil, …

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotene (ppm)</td>
<td>600-800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tocos (ppm)</td>
<td>700-900</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total tocoferol (ppm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>α- tocoferol</td>
<td>227</td>
</tr>
<tr>
<td>β- tocoferol</td>
<td>202</td>
</tr>
<tr>
<td>γ-tocoferol</td>
<td>-</td>
</tr>
<tr>
<td>δ-tocoferol</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total tocotrienol (ppm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>α- tocotrienol</td>
<td>656</td>
</tr>
<tr>
<td>γ-tocotrienol</td>
<td>188</td>
</tr>
<tr>
<td>δ-tocotrienol</td>
<td>407</td>
</tr>
<tr>
<td>δ-tocotrienol</td>
<td>61</td>
</tr>
</tbody>
</table>
## Specially Refined Palm Oil

### White Soaps from Physically Refined Palm Oil

High Quality Crude Palm Oil (DOBI > 3) + Optimized Refining Conditions

<table>
<thead>
<tr>
<th>Target:</th>
<th>RBD Oil Color</th>
<th>Saponification Soap Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saponification color &lt; 3R (Lovibond 5°1/4)</td>
<td>Conditions 1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Conditions 2</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Conditions 3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

### Feedstock for Fractionated Products

Specialty Fats

**TAG composition not be affected**  
(optimal SUS/SSU: 8)

**Optimized refining conditions**

- S: saturated; U: unsaturated FA

Deo temperature

- 190°C
- 220°C
- 240°C
- 270°C
Dry Fractionation Of Palm Oil

Where is Fractionation used in Palm Oil processing?

- Food
  - RB(D) PO (Commodity Fats, Special Products)
    - Fractionation
      - Oleins
      - Stearins

- Nonfood
  - FFA
    - Fractionation
      - Oleic Acid
      - Stearic Acid

- Biofuel
  - FAME
    - Fractionation
      - Oleic FAME
      - Stearic FAME
Dry Fractionation Of Palm Oil

Crystallization developments

- two approaches: “slow” crystallisation / long cycle (Tirtiaux)
  “fast” crystallisation / short cycle (De Smet)

- semicontinuous (batch) to continuous

- high shear, low shear (agitation) vs static (block crystallisation)
  eg. PO
  eg. PO/PKO
Any development in press filtration?

- Bigger size → 25m³
- Bigger plates → 2x2m
- Higher pressure → 50 bar
Dry Fractionation Of Palm Oil

Dynamic Concentric Crystallisers

Concentric Cooled Walls
Dry Fractionation Of Palm Oil

Dynamic Tirtiaux Crystallisers

Cooling Fins
Dry Fractionation Of Palm Oil

Low Shear Crystalliser (special cooling surface configuration)

Near static crystallisation

2007/03/14 09:41 pm
Dry Fractionation Of Palm Oil

Static Crystalliser
(for controlled block crystallisation)

Filter press

2005/12/09
Dry Fractionation Of Palm Oil
Multi-step Process

Heterogeneous TAG distribution → separation of compositionally distinct fractions

100% Palm Oil
IV 52

15% Palm Stearin
IV 36

85% Palm Olein
IV 56

Frying Oil

Margarine

45% Soft PMF
IV 46

40% Super Olein
IV >64

Salad Oil

30% Mid Olein
IV 53

20% Mid Olein
IV 60

20% Top Olein
IV >67

Very cold stable salad oil

Commodity Fats

Specialty Fats
**Special products: CBE**  
**High POP Fractions**

**Significative increase of POP in the Hard PMF**

<table>
<thead>
<tr>
<th>%</th>
<th>PO IV 52</th>
<th>POI IV 56</th>
<th>SPMF IV 46</th>
<th>SPMF IV 45</th>
<th>HPMF IV &lt; 35</th>
<th>HPMF IV &lt; 35</th>
<th>CB*</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAG</td>
<td>5.0</td>
<td>5.2</td>
<td>3.8</td>
<td>3.6</td>
<td>2.0</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>PPP</td>
<td>5.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.8</td>
<td>0.9</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>StOSt</td>
<td>0.3</td>
<td>0.2</td>
<td>1.1</td>
<td>0.9</td>
<td>1.3</td>
<td>1.1</td>
<td>26</td>
</tr>
<tr>
<td>POSt</td>
<td>5.0</td>
<td>5.0</td>
<td>9.3</td>
<td>8.5</td>
<td>11.0</td>
<td>12.1</td>
<td>37</td>
</tr>
<tr>
<td>POP</td>
<td>29.3</td>
<td>29.9</td>
<td>48.7</td>
<td>47.8</td>
<td>66.0</td>
<td>64.0</td>
<td>18</td>
</tr>
</tbody>
</table>

* Cocoa Butter
Special products: CBE
High POP Fractions

Solid fat content profile similar to Cocoa Butter
**Special products:**

**Red Palm Fractions**

### Golden Palm Oil
- IV 51-53

### Red Palm Fractions

<table>
<thead>
<tr>
<th></th>
<th>IV</th>
<th>Cloud Point (°C)</th>
<th>Carotene (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Palm Oil</td>
<td>51.9</td>
<td>21.6</td>
<td>382</td>
</tr>
<tr>
<td>Red Olein</td>
<td>56.7</td>
<td>8.1</td>
<td>409</td>
</tr>
<tr>
<td>Red Superolein</td>
<td>63.2</td>
<td>3.3</td>
<td>670</td>
</tr>
<tr>
<td>Red Topolein</td>
<td>71.3</td>
<td>-2.4</td>
<td>854</td>
</tr>
</tbody>
</table>

### Salad Oils
- Cold resistant and high vitatiminic liquid fractions
  - Red solid fractions
    - Stearin
      - 281 ppm Carotene
    - Soft PMF
      - 235 ppm Carotene
    - Hard PMF
      - 80 ppm Carotene
Influence of DAGs on Final Product Quality

Palm Olein IV 56-57
Same TAG distribution

Softness increased when DAGs increased (poor quality crude oil)
Palm Olein IV 56-57
Same TAG distribution

Cloud point increased when DAGs increased (poor quality crude oil)
Enzymatic Interesterification: “low trans” Commodity Fats

EIE = RANDOM re-distribution of FA on the glycerol:

→ improved oxidative stability (iso chemical interesterification)

![Diagram showing chemical structures and oxidative stability graph](image-url)
Enzymatic Interesterification: “low trans” Commodity Fats

- **Continuous process**: less suitable in case of many stock changes.
- **Used in fixed bed** for better process economy.
- **Simple, clean and safe process** (70°C).
- **Limited cross contamination**.
- **Increased stability of the enzyme** → ‘economical’ operating costs.
- **No side reactions, no post-bleaching**.
- **Less oil losses**.
- **Better oxidative stability**.
Enzymatic Interesterification: “low trans” Commodity Fats

- **Base Stocks**
  - SFC 1
  - SFC 2
  - SFC 3

- **Blending**
- **Deodorizing**
- **Enzyme Process**

- **Liquid Oil**
- **Hard Fat (Fractionated or fully hydrogenated)**

- **Finished Margarine/Shortening Fat**
Enzymatic Interesterification
For Special Products

EIE = Regio-selective re-distribution of the FA on the glycerol:
→ sn 1,3 selective enzyme

• Confectionery fats (high SUS: CBE; anti-blooming: BOB)
• Infant formula (high UPU, P in sn 2): readily absorbed by infants
• Easily absorbable and low calory fats (MedUMed)
Strategy: ‘structuring’ POP lipid into StOSt/POST/POP lipid

- POP matrix + Stearic acid or Stearic methyl ester
- sn 1,3 specific EIE
- StOSt/POST/POP matrix + FFA/FAME
- Stripping
- StOSt/POST/POP matrix
- Dry Fractionation
- CBE
## EIE and Dry Fractionation for CBE Production

### Specific EIE

<table>
<thead>
<tr>
<th>%</th>
<th>SPMF</th>
<th>SSS</th>
<th>StOSt</th>
<th>POST</th>
<th>POP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSS</td>
<td>1.0</td>
<td>8.0</td>
<td>15.0</td>
<td>33.0</td>
<td>15.0</td>
</tr>
<tr>
<td>POP</td>
<td>9.0</td>
<td>7.0</td>
<td>22.0</td>
<td>28.0</td>
<td>16.0</td>
</tr>
<tr>
<td>POP</td>
<td>48.0</td>
<td>0</td>
<td>20.0</td>
<td>35.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

### Stripping /Dry Fractionation

<table>
<thead>
<tr>
<th>%</th>
<th>SPMF</th>
<th>SSS</th>
<th>StOSt</th>
<th>POST</th>
<th>POP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSS</td>
<td>1.6</td>
<td>8.0</td>
<td>15.0</td>
<td>33.0</td>
<td>15.0</td>
</tr>
<tr>
<td>POP</td>
<td>9.0</td>
<td>7.0</td>
<td>22.0</td>
<td>28.0</td>
<td>16.0</td>
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</tbody>
</table>

### CBE

<table>
<thead>
<tr>
<th>%</th>
<th>FRAC₁</th>
<th>SSS</th>
<th>StOSt</th>
<th>POST</th>
<th>POP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSS</td>
<td>0</td>
<td>0</td>
<td>16.0</td>
<td>36.0</td>
<td>16.0</td>
</tr>
<tr>
<td>POP</td>
<td>10.0</td>
<td>0</td>
<td>28.0</td>
<td>28.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

### + “S” FFA/FAME

<table>
<thead>
<tr>
<th>%</th>
<th>FRAC₂</th>
<th>SSS</th>
<th>StOSt</th>
<th>POST</th>
<th>POP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSS</td>
<td>0</td>
<td>0</td>
<td>20.0</td>
<td>43.0</td>
<td>20.0</td>
</tr>
<tr>
<td>POP</td>
<td>13.0</td>
<td>0</td>
<td>34.0</td>
<td>34.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
Enzymatic Interesterification Plant

Lab reactor

Pilot unit

Industrial plant
Take home messages:

- Rich in **minor components** (tocopherols and tocotrienols (vitamin E) and carotenoids (alpha and beta carotene)) impart unique nutritional properties that need to be preserved
- Processing duality: target unwanted side effects
  - Improved refining technologies:
    - Dual Temperature, Double Condensing, Ice Condensing
- Crude oil quality
  - Low Acidity, High DOBI, Low partial acylglycerols
- Easily « fractionable » → commodity fats + special products (CBE)
  - New fractionation developments to improve quality and yield
- Feedstock for **enzymatic interesterification**
  - Commodity fats (margarines and shortenings
  - Special products (CBE, infant formula, …)
Science behind Technology

Thank you very much for your attention