The contribution of fatty acids composition of soybean oil on natural and electro-optics polarization

A Rahmawati, K S Firdausi, H Sugito, M Azzam, V Richardina and Q M B Susanto

Departement of Physics, Faculty of Science and Mathematics, Diponegoro University Semarang, Indonesia

Corresponding author: aidahrahmawati@st.fisika.undip.ac.id, firdausi@fisika.undip.ac.id

Abstract. A study of light polarization as a new alternative test of cooking oil quality today provides an advantage in biophysics and other fields. In this research, we determined the relation between polarization and fatty acids composition of soybean oil. The light source was a green pointer laser with $\lambda = 532$ nm, and the electro-optics polarization was produced through high DC voltage 0-9 kV across the sample. The results show that natural polarization and electro-optics polarization give different physical meanings in relation to oil fatty acid composition. The natural polarization informed that the increasing polarization was caused by increasing polyunsaturated acids and saturated acids in asymmetric triglyceride molecules. It was accompanied by the decreasing polarization due to the increasing monounsaturated in symmetric triglyceride molecules. While the electro-optics polarization described that all fatty acids contribute to the increasing polarization due to increased induced dipole from all acids.

1. Introduction
The studies on changing the polarization of light when interacting with cooking oil are very interesting. This not only provides new information relating to various oil quality levels and polarization as an alternative powerful method for testing oil quality but also enables polarization for the study of the interaction between light and matter in the development of biophysics and other relevant fields [1-10]. So far the optically active properties of cooking oil are caused by the presence of asymmetric triglyceride (TG) molecules so that they are able to rotate the direction of the electric field of the light passing through it. If the oil quality is reduced, it can be estimated that the asymmetric TG molecule has increased, and this results in an increase in the optical activity of the oil.

Based on the hypotheses in previous studies [6] and experimental results [11], it was shown that the asymmetric and symmetric TG molecular composition depends on the distribution of dominant fatty acid composition in cooking oil. In the existence of three most dominant fatty acids such as polyunsaturated, monounsaturated and unsaturated fatty acids, if one fatty acid is the most dominant number from the others, as a result, the formation of symmetric TG molecules is quite dominant compared to the asymmetric TG molecules. Then the polarization changes that occur are usually very small. This is due to the significant number of symmetric TG molecules that are developed from the highest number of the dominant fatty acids. Different types of cooking oil, each of which has a unique composition of the number of fatty acids. Cooking oils like olives and canola oil, which have the highest composition of monounsaturated fatty acids around 75%-80% compared to saturated fatty acids and
polyunsaturated fatty acids which both are only 20%-25%, usually have small optical activity and therefore produce relatively small changes in the polarization of light [6, 9]. Palm oil for example, on average has a composition of the three dominant fatty acids in almost equal amounts and so that we estimate that under the same conditions the number of asymmetric TG molecules is sufficiently dominant and usually has an average optical activity than olive or canola oil. In this paper, we discuss the role of most dominant fatty acids in asymmetric and symmetric TG molecules by measuring changes in the polarization of light with the composition of fatty acids in soybean oil.

Considering polarization as response due to an external fields $E$ on the sample, the induced dipole from the polarization can be expressed as

$$ p = \alpha E $$

where $\alpha$ is the polarisability of the molecule. In additional strong external field $E$, the non-linear response of polarisability can be written as

$$ \alpha = \alpha_0 + \alpha_1 E + \alpha_2 E^2 + \cdots $$

In equation (2), $\alpha_0$ is the polarisability in the absence of $E$. The coefficient parameters of $\alpha_1$, $\alpha_2$... and $\alpha_i$ in general are tensors. In our research, we did not measure $\alpha$ directly but rather changes in the polarization of light $\theta$ passing through the sample in a polynomial function of $E$. The polarization of light $\theta$ increases due to non-linear polarization respond of oil, or so-called electro-optics effect, can be written as follows [2]

$$ \theta = \theta_0 + \theta_1 E + \theta_2 E^2 + \cdots $$

The polarization changes now can be described by a combination of natural polarization $\theta_0$ due to natural optical activity and electro-optics polarization $\theta_E = \theta_1 E + \theta_2 E^2 + \cdots$ due to the strong external field as follows [6],

$$ \theta = \theta_0 + \theta_E $$

For the number of three dominant fatty acids $N_1$ (saturated fatty acids), $N_2$ (monounsaturated fatty acids), and $N_3$ (polyunsaturated fatty acids), we proposed that both of the natural and electro-optics polarization are a linear combination of the fatty acids number, and can be written as [6]

$$ \theta_0 = a_{01} N_1 + a_{02} N_2 + a_{03} N_3 $$

$$ \theta_E = a_{E1} N_1 + a_{E2} N_2 + a_{E3} N_3 $$

The coefficients $a_{0i}$ and $a_{Ei}$ indicate the strength of polarization dependence on each fatty acid. The coefficient $a_{0i}$ supposedly describes the contribution of each fatty acid in symmetric or asymmetric TG molecules resulting in natural polarization, whereas the coefficient $a_{Ei}$ states the electro-optical contribution of each fatty acid in the response due to the existence of external fields.

2. Methods

The sample used was soybean oil which had different expiration dates shown in table 1. The sample A1 had the relatively best quality from A2 and A3 according to the date of expiration during the time of measurement.

| sample | date of expiration | remark* |
|--------|--------------------|---------|
| A1     | 28-2-2019          | not yet expired |
| A2     | 6-9-2018           | expired   |
| A3     | 25-5-2018          | expired   |

*$The measurement was taken in December 2018 – January 2019
The experimental procedures were referred to as Afiefah et al [6] using transmission electro-optics polarization with $\lambda=532$ nm. GCMS was used for the validation of fatty acid composition.

3. Results and discussion

Figure 1 shows the polarization light as a function of the external field for all samples. The Exchange of the $E$ field variable to a potential difference of $V$ is possible because the electric fields in parallel plates are considered homogeneous and is satisfied by the equation $E = V/D$ where $D$ is the distance between the plates. For the curves in fig 1, we obtain that for all samples polarization changes increase quadratically to potential differences according to equation (7).

$$\theta = \theta_0 + \theta_1 \frac{V}{D} + \theta_2 \frac{V^2}{D^2}$$  \hspace{1cm} (7)

![Figure 1](image)

**Figure 1** The polarization changes $\theta$ as a function of potential difference $V$ since the field $E$ is considered to be homogeneous between parallel plates then $E = V/D$.

By using equation (4) we can obtain the electro-optics contribution only in polarization so-called electro-optics polarization $\theta_i = \theta_0 V/D + \theta_2 V^2/D^2$. Changes in electro-optics polarization in all samples show an increase in polynomials of the second order of $V$ shown in figure 2, in accordance also with the previous results [2, 6, 9].
The electro-optics polarization $\theta_E$ as a function of potential difference $V$ for all samples.

In contrast to natural polarization (figure 1), electro-optics polarization (figure 2) shows almost the same value for the three samples. In table 2 the sample quality is shown by a significantly different natural polarization value. The best quality A1 samples from A2 and A3 according to the expiration date is shown by the smallest average natural polarization, in accordance also with the results of previous studies.

Table 2. The natural and electro-optics polarization

| sample | Polarization changes |
|--------|----------------------|
|        | $\theta_0$ (°) | $\theta_E$ (°)* |
| A1     | 0.40±0.02 | 1.25±0.06 |
| A2     | 0.75±0.04 | 1.25±0.06 |
| A3     | 0.60±0.03 | 1.20±0.06 |

*Electro-optics polarization at maximum value $V = 9$ kV

While the contribution of electro-optics polarization of $\theta_E$ for all three samples showed relatively similar values. Because the amount of the composition of the three fatty acids is not too much different, it seems that the development of induced dipoles relatively gives similar polarization strength. This shows that the contribution of electro-optics polarization is dominated only by the formation of TG-induced dipoles induced by external fields. To ensure natural polarization values that depend on asymmetric TG molecules and electro-optical polarizations that depend on the induced dipole-dipole response, the examination using GCMS is needed. Table 3 shows the result of the GCMS test of the three dominant fatty acids of samples.

Table 3. The three dominant fatty acid composition of soybean oil after the GCMS test

| sample | Fatty acid composition |
|--------|------------------------|
|        | $N_1$ (%) | $N_2$ (%) | $N_3$ (%) |
| A1     | 11.89    | 26.24    | 61.88    |
| A2     | 11.97    | 23.44    | 64.58    |
| A3     | 9.21     | 25.47    | 65.32    |
In table 3 the parameters $N_1$, $N_2$, and $N_3$ are the amount of saturated, monounsaturated, and polyunsaturated fatty acids, respectively. All samples contained the highest and most dominant polyunsaturated fatty acids from the other two fatty acids. The relationship between these parameters and the polarization is assumed to be fulfilled by equations (5) and (6) to obtain the natural polarization coefficients $a_0$ and $a_E$ listed in table 4.

| Natural coefficient | Electro-optics coefficient |
|---------------------|---------------------------|
| $a_{01}$ 0.003       | $a_{E1}$ 0.01             |
| $a_{02}$ -0.08       | $a_{E2}$ 0.01             |
| $a_{03}$ 0.04        | $a_{E3}$ 0.01             |

For the case of natural polarization, positive coefficient values indicate that saturated and polyunsaturated fatty acids play a role in the asymmetric in TG molecules. The ratio $a_{03}/a_{01} = 40/3$ means that the contribution of polyunsaturated fatty acids plays a greater role in asymmetric TG molecules than saturated fatty acids. While negative coefficients indicate that monounsaturated fatty acids play a role as the dominant symmetric fatty acids in TG molecules. However, this needs to be clarified with the results of the TG molecular composition test on the sample, which we have not been able to do comprehensively. In our previous study [6, 9], canola oil and olive oil with the highest composition of more than 75% of monounsaturated fatty acids show the strongest contribution in asymmetric TG molecules due to saturated fatty acids. On the other hand, polyunsaturated acids show many contributions in symmetric TG molecules.

Whereas in the case of electro-optics polarization, all coefficients are positive, which indicates that all symmetric and asymmetric TG molecules become induced dipoles as a consequence of the polarization response by external fields in accordance with previous results. The contribution of saturated fatty acids is three times higher than mono- and polyunsaturated acids which could be due to its longest size of the molecular chain. The longer chain of the molecule, then the higher induced dipole that can be produced through external fields.

4. Conclusions
In this paper, light polarization is able to distinguish the various qualities of soybean oil. The contribution of natural polarization which plays an important role in symmetric and asymmetric TG molecules can significantly differentiate oil quality based on the expiry date. In this case, the monounsaturated acids play in symmetric TG molecules resulting in reducing natural polarization and whereas the polyunsaturated and saturated acids play more active in asymmetric TG molecules resulting in increasing natural polarization.

While the contribution of electro-optics polarization plays an important role in the formation of electric dipoles of all fatty acids due to external fields, especially fatty acids with the longest molecular chains. With almost the same fatty acid composition for the three samples, this gives almost the same electro-optical polarization values for all samples.

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