Contribution of electro-optics effect on canola oil as a new alternative method for determination of oil quality using transmission and fluorescence polarization

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Abstract. In this paper we studied contribution of electro-optics effect for evaluation of canola oil quality using transmission and fluorescence polarization. The samples were two different quality of canola oils, i.e. edible canola and expired canola based on the date of expiration at the time of measurement. The physical variable of polarization angle was measured using a pair of polarizers from a 532 nm of green pointer laser. The electro-optics effect was produced by applying high DC voltage 0-9 kV on samples. The result shows that the change of polarization angle of expired oil is greater than the good one for both transmission and fluorescence. The increasing polarization angle is accompanied by increasing saturated FAs and decreasing polyunsaturated FAs simultaneously, in agreement with our previous reports. The fluorescence polarization is dependent on the polarizer’s angle of incoming light and has average angle greater than transmission light. The electro-optic fluorescence is twice as electro-optics transmission due to possibly coupling between pure scattering and fluorescence together, in which large size of TG molecules play an important role into the light scattering and fluorescence perpendicular to the incoming light. This fluorescence light method provides more accurate measurement that transmission light and seems powerful comparison to the other spectroscopy methods.

1. Introduction

In food Industries, the change of transmission polarization angle in linearly polarized light cases is often used to test the active optical properties of sugar-containing samples. In cooking oil for food is also indicated properties of optical activity however with very small specific rotation, which leads to very small change of polarization angle. The angle of polarization in cooking oil sample is in average less than 1° for edible oils dependent on the quality. However by using electro-optics effect, we found that the angle of polarization increases up to several degrees [1-2] through the relation \( \theta = \theta_n + \theta_E \) [3], where \( \theta_n \) and \( \theta_E \) are natural and electro-optics polarization contribution, respectively. An important result indicates that the decreasing quality of cooking oil quality, is accompanied by increasing polarization angle, which provides for future simple oil quality test. Based on our literature studies there has been not much attention of the change of polarization angle for properties of cooking oil quality, both in transmission and fluorescence case. In our previous works [1-8] we have found that this polarization can be used for the quality’s test of cooking oil samples, using both natural polarization and electro-optical polarization. The main cause of such polarization related to the quality
of various vegetable and animal oils is the distribution and composition of saturated and unsaturated fatty acids in cooking oil, and we proved that in case of transmission light the change of polarization is a linear combination of the greatest components of fatty acids content [3]. In case of fluorescence light, there has been many studies and investigations of oil quality using fluorescence spectroscopy system and its derivative instruments [9-13], which is in our consideration as exclusive, intricate, and costly methods. Yet, our method is very different from the fluorescence spectroscopy or other spectroscopy methods. In both of transmission and fluorescence light case we use direct measurement of the change of polarization angle on transmitted or scattered light to characterize the cooking oil quality using the polarization angle, which provides not only a simple tool of measurements but also gives an easy understanding of the related physical phenomenon.

In this paper, we investigate both of transmission and fluorescence polarization on canola oil as a new alternative method for determination of cooking oil quality. The electro-optics effect is applied to the sample to obtain a discrepancy with the natural polarization and to acquire important information of the electro-optics contribution. The profile of canola oil will be described by the change of polarization angle $\theta$ as function of incoming light’s polarization angle ($\phi$), the external electric field $(E=V/d$, where $V$ is potential difference, $d$ the distance between plates), and number of fatty acids $(N)$ assuming that the change of polarization angle is also dependent on the greatest component of fatty acids (FAs) and therefore it is a linear combination of the FAs number in accordance with Firdausi et al [3]. In this present study, the triglycerides (TG) as the most abundant molecules in cooking oil will change the polarization angle due to asymmetry of the three FAs that joined in TG. Based on the experimental information [14-16] of occurring the formation of FAs that joined together in TG molecules, the discussion of $\theta$ as function of a linear combination of the FAs composition combined together in a TG molecule will be based on the following hypothesis. In balanced condition, where the number of most FAs composition is proportional, we propose that the possibilities of the TG formation from three FAs has the following rules: 1) the formation of a TG molecule obeys the nature of lowest energy condition. 2) Consequently, the energy to bind three FAs together become an asymmetric TG molecule is lower than a symmetric TG molecule. In balanced amount of FAs, asymmetric TG molecules will be firstly formed up to certain maximum number and then followed finally by the formation of symmetric TG molecules. 3) If there are three FAs of $F_1$, $F_2$, and $F_3$ that joined together in a TG molecule as $F_1F_2F_3$, where $F_1$, $F_2$, and $F_3$ are the first FA, the second FA centre position, and the third FA, respectively, then the highest priority to form a TG molecule is obtained by subsequent condition: (i) $F_1 \neq F_2 \neq F_3$, (ii) next by $F_1 = F_2 \neq F_3$, (iii) followed by $F_1 = F_3 \neq F_2$, (iv) afterward the lowest priority with $F_1 = F_2 = F_3$. 4) Finally, if there are three different FAs, the middle position should be taken by the most unsaturated FA. If the three FAs are all different saturated FAs, then the middle position should be taken by the second-longest chain of these FAs, i.e. the first and the third should be the shortest and the longest chain of the FA, respectively. The more asymmetry of a TG molecule, the lower energy is needed to become a TG molecule, which can be achieved by joining the more difference between the first and the third FA in a TG molecule.

2. Methods

The sample used was canola oil A that has already expired, and canola oil B that was new edible when taking data. The expiry definition was the expiry date indicated on the oil label that has already exceeded the time the measurement was taken. The light source used was a green laser pointer with $\lambda = 532$ nm. The angle’s variation of incoming light polarization $\phi$ was adjusted using a polarizer from 0˚ to 90˚ with an increment of 10˚. The change of the transmission and fluorescence polarization angle $\theta$ were measured by the analyzer, so as to obtain the relation between $\theta$ and $\phi$, for each of sample A and B. To obtain the best light scattering, the direction of fluorescence light observation was perpendicular to the incoming light. The fluorescence system was calibrated using light scattering on water and sugar solution based on Firdausi et al [17]. The electro-optics effect was obtained by applying potential difference from 0 to 9 kV to the sample in a 5 ml-cuvette between two parallel plates, where the external electric field between the plates can be written as $E=V/d$, with $V$ is potential difference and $d$ is the distance between the plates. The desired electro-optics profile was a
relation between $\theta$ and $V$ for certain value of $d = 2$ cm and certain value of $\varphi = 0^\circ$. The saturated and unsaturated fatty acid composition of the sample that assumed to play a role in the contribution of polarization was measured by the GCMS method. The simple design of the measurement of the polarization angle is shown in Figure 1.

3. Results and discussions
In subsection 3.1, 3.2, and 3.3, respectively, we will discuss the result of natural polarization profile $\theta = \theta_n$, when there is no electro-optics effect (no external electric fields) as a function of the angle $\varphi$ of incoming light, the contribution electro-optics polarization $\theta_E$ as a function of $V$ (instead of $E$), and the relation of $\theta$ and number of FAs composition.

3.1 The natural polarization angle of transmission and fluorescence light
Figure 2 and figure 3 show respectively the change of polarization angle of transmission and fluorescence light without external electric fields on the sample for $0^\circ \leq \varphi \leq 90^\circ$.

**Figure 1.** Simple design of the measurement of the polarization angle of fluorescence and transmission light. The wavelength of the transmitted light is the same as the incoming light. However, the wavelength of the fluorescence light is greater than the incoming light.

**Figure 2.** The change polarization angle of transmitted light of each sample is relative constant.

**Figure 3.** The dependence of polarization angle of fluorescence light $\theta$ on $\varphi$ of each sample.
For both of sample A and B in fig 2, the change of transmission polarization angle can be considered relative constant from $\varphi = 0^\circ$ to $90^\circ$. This can be explained due to symmetric and homogeneous sample in average in the direction of the incoming light. These values are less than $1^\circ$, in agreement with our previous works [5], but our method can still measure the discrepancy of the change of transmission polarization between A and B. The average value of transmission polarization of A more than B and tabulated in table 1.

In case of fluorescence light without external electric fields on the sample, we have the relation of fluorescence polarization angle $\theta$ as a function of $\varphi$ shown in fig 3. Contrary to the transmission case, we found that the average angle of fluorescence is more significant than transmission polarization. The fluorescence polarization angle $\theta$ is not only dependent on $\varphi$, but also provides some characteristics’ values $\theta$ in the interval $0 \leq \varphi \leq 90^\circ$. The fluorescence polarization is very much influenced by the choice of polarizer axis of the incoming light. In fluorescence case, the scattering light or fluorescence light is effectively dependent on the orientation of TG molecules. This explanation is in accordance with our literature studies [9-10] for natural depolarized of fluorescence light. But moreover, we found a left rotation when $\theta$ decreases from $\varphi = 0^\circ$ to $30^\circ$, and then a right rotation when $\theta$ increases from $\varphi = 30^\circ$ to $90^\circ$. The critical value of $\varphi_c = 30^\circ$ in which the angle of rotation $\theta$ is reversed, could be caused by the orientation of TG molecules with most possible composition of saturated and unsaturated FAs. Characteristics values are tabulated in table 1.

### Table 1. The characteristics of transmission and fluorescence polarization angle of each sample.

| Canola oil | Fluorescence | Transmission |
|-----------|--------------|--------------|
|           | $\theta_0$ ($^\circ$) | $\theta_0$ ($^\circ$) | $\theta_{Av}$ ($^\circ$) | $\varphi_c$ ($^\circ$) | $\theta_{Av}$ ($^\circ$) |
| A         | $3.90 \pm 0.16$ | $6.15 \pm 0.08$ | $3.80 \pm 0.04$ | $30$ | $0.73 \pm 0.05$ |
| B         | $2.90 \pm 0.14$ | $6.95 \pm 0.17$ | $3.35 \pm 0.03$ | $30$ | $0.51 \pm 0.04$ |

Both in transmission and fluorescence the average polarization in A is greater than in B indicating different FAs composition related to the different quality between A and B. In addition, the average polarization of fluorescence is higher than polarization of transmission. This could be caused by additional scattering by bigger molecules accumulated at the same time with fluorescence light. This explanation will be detailed discussed in section 3.3 with additional supporting GCMS data of the FAs composition.

#### 3.2 The electro-optics effect

Fig 4 and fig 5 show the total angle $\theta$ as a function of potential difference for transmission and fluorescence light of each sample at $\varphi = 0^\circ$.

![Figure 4](image1.png)  
**Figure 4.** The change of polarization angle of transmitted of each sample as function of potential difference.

![Figure 5](image2.png)  
**Figure 5.** The change of polarization angle of fluorescence light of each sample as function of potential difference.
potential difference.

The total angle $\theta$ is simply written as $\theta = \theta_N + \theta_E$, where $\theta_N$ is natural polarization when $V = 0$, and $\theta_E$ is the contribution of electro-optics polarization when $V \neq 0$. The transmission angle is slightly different between A and B (fig 4), but the fluorescence polarization angle is more significant (fig 5), and more distinguishable than transmission between A and B. The curves in fig 4 and fig 5 show polynomial trend due to electro-optic effect, $\theta_E$, as non-linear polarization on TG molecules in agreement with the previous results [2]. To obtain a pure contribution of electro-optics effect, we subtract the total value of $\theta$ with $\theta_N$ for both cases and of each sample and yields $\theta - \theta_N = \theta_E = f(V)$ shown in figure 6 and figure 7.

**Figure 6.** The contribution of electro-optics effect for transmission as function of potential difference is equal for A and B.

**Figure 7.** The contribution of electro-optics effect for fluorescence as function of potential difference is also equal for A and B.

It is surprisingly found that the contribution of electro-optics effect $\theta_E$ is equal for A and B for transmission (fig 6) and also for fluorescence (fig 7). The same contribution of electro-optics effect for A and B indicates that the formation of electric dipoles is relatively equal for all kind of TG molecules in certain cooking oil. It shows also that the composition of FAs in A and B is almost the same. Comparison between the curves shows that electro-optics effect $\theta_E$ in fluorescence is more significant than in transmission. The discrepancy of electro-optics effect between transmission and fluorescence is shown in figure 8. It is also very surprising that the electro-optics effect of fluorescence is twice as much of transmission. The possible explanation of this reasons can be described as follows.
The difference of electro-optics effect between transmission and fluorescence light

The transmission polarization is simply using light scattering or so-called elastic scattering in the direction of the incoming light whereas the wavelength of polarization is the same as the incoming light. The fluorescence polarization is using the absorption of the incoming light by the TG molecules and results the fluorescence light emission or so-called inelastic scattering perpendicular to the incoming light. The value of contribution of fluorescence electro-optics is twice over transmission that shows the existence of the second harmonic of electro-optics effect of fluorescence from transmission. It could be caused by coupling of pure scattering and fluorescence that perpendicular to the direction of the incoming light simultaneously. However, further investigation using GCMS data in section 3.3 is required to achieve more accurate physical interpretation.

### 3.3 The polarization angle against fatty acids number

To obtain the comprehensive interpretation, the data resulted from GCMS should be included into the contribution of natural $\theta_k$ and electro-optics polarization $\theta_E$ in table 2.

| Table 2 GCMS data of most FAs composition in A and B |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| Canola           | Number of FAs (%) | Electro-optics polarization | Natural polarization |
|                  |                  | $F_1 = 17:0$ | $F_2 = 19:2$ or $F_3 = 19:1$ | Average $\theta_k$ ($^\circ$) | Average $\theta_E$ ($^\circ$) |
|                  |                  | $N_1$ | $N_2$ | $N_3$ | transmission | fluorescence | transmission | fluorescence |
| A                 |                  | 5.48 | 13.65 | 80.87 | 0.74     | 1.47        | 0.73         | 3.90         |
| B                 |                  | 2.97 | 15.07 | 81.96 | 0.75     | 1.47        | 0.51         | 2.90         |

The polarization angle that could have possible linear combination with most FAs composition is considered and calculated using maximum possibility of the production of the TG molecules. According to the hypothesis for various FAs that can join in the most possible formation of TG molecules we predict the presence of TG molecules based on GCMS data as follow. Referring our GCMS data in table 2, the most FAs composition found in A and B is unbalanced condition where the number of monounsaturated $N_1 = (19:1) >> N_2 = (19:2 or 17:2) > N_3 = (17:0)$. Table 3 describes comparison of possible TG formation in balanced condition (where $N_1 > N_2 > N_3$), unbalanced condition (where $N_1 >> N_2 > N_3$), and the A and B condition.

### Table 3 possible TG formation in balanced, unbalanced condition, and in Canola A and B based on previous hypothesis.

| Balanced condition ($N_1 > N_2 > N_3$) | Unbalanced condition ($N_1 >> N_2 > N_3$) | Canola A and B |
|--------------------------------------|------------------------------------------|----------------|
| $F_2F_2F_3$                          | $F_2F_3F_3$                              | $F_2F_3F_3$   |
| $F_2F_2F_3$                          | $F_2F_3F_3$                              | $F_2F_3F_3$   |
| $F_2F_2F_3$                          | $F_2F_3F_3$                              | $F_2F_3F_3$   |
| $F_2F_2F_3$                          | $F_2F_3F_3$                              | $F_2F_3F_3$   |
| $F_2F_2F_3$                          | $F_2F_3F_3$                              | $F_2F_3F_3$   |
| etc.                                 | etc.                                     | other formation is negligible |

With highest composition of monounsaturated FAs of $F_3$ (19:1), the greatest possible TG molecules that can be obtained are $F_2F_2F_3$, $F_2F_3F_2$, and $F_3F_2F_1$ for sample A and B. The asymmetric TG molecules of $F_2F_2F_3$ in A and in B are negligibly small and the symmetric TG molecules of $F_2F_3F_3$ in both of A and B are created due to very large number of $N_1 >> N_2 > N_3$. The $F_3F_2F_1$ its self however will contribute zero polarization because of its symmetrical characteristics. Consequently only the asymmetric TG molecules $F_3F_2F_2$ and $F_3F_2F_1$ contribute to the polarization for sample A and B. The linear combination between natural polarization $\theta_k$ with number $N_i$ of FAs is given for A and B by equation (1)
where $\theta_N$ is natural polarization in transmission or fluorescence without electro-optics effect, $C_i$ is a coefficient that measures the dependence of polarization on the related FAs, and $N_i$ is the number (%) of the $i$-th FA. Solving the equation (1) using maximum and minimum possible condition of the $F_3F_3F_3$, $F_3F_3F_2$ and $F_3F_3F_1$, we obtain the following coefficient related to the FAs type presented in table 4.

### Table 4: the coefficient $C_i$ of the fatty acids for natural polarization $\theta_N$

| Natural polarization | $C_1$ (17:0) | $C_2$ (19:2 or 17:2) | $C_3$ (19:1) |
|----------------------|--------------|----------------------|--------------|
| Transmission         | 2.763        | −0.209               | 0.004        |
| Fluorescence         | 0.404        | −0.007               | 0.022        |

According to the table 4, the natural transmission and fluorescence polarization have similar pattern as a linear combination of most FAs composition. The saturated FAs (17:0) are significantly operative in addition of polarization angle indicated by positive value of the coefficient $C_1$. Increasing the polyunsaturated FAs (19:2 or 17:2) reduces the polarization indicated by negative value of $C_2$. And small positive coefficient $C_3$ of monounsaturated FAs (19:1) indicates slightly influences to the polarization, and this result of course in agreement with the previous studies [3].

The average angle of fluorescence is greater than of transmission, which can be explained as follows. The transmission polarization is very dependent on the existence of saturated FAs and polyunsaturated FAs that joined together in asymmetric TG molecules. In other hand, the fluorescence polarization is not only dependent on the asymmetry, but also significantly influenced by the size of TG molecules. As we can see from table 4, the fluorescence polarization is accompanied in the same direction by pure light scattering, which are both significantly dependent on size of molecules. The greater size of molecules, the higher polarization is. The important result indicated by table 4 is the increasing positive value of $C_3$ in fluorescence (5 times greater than $C_3$ of transmission). The biggest size of monounsaturated FAs (19:1) plays important role in the fluorescence.

In electro-optics effect (table 5) all TG molecules give positive contribution to the polarization because all molecules become electric dipoles, which reflected to all positive values of the coefficient $C_i$, and finally it results to the addition value of $\theta_E$. The contribution of electro-optics effect of fluorescence is twice as transmission (fig 8), which could be caused by coupling the pure scattering and fluorescence light added concurrently to the whole measurement of the polarization angle. Equivalence for electro-optics case, equation (1) where the linear combination between electro-optics polarization and FAs composition is also valid, can also be written as

$$\theta_E = C_1N_1 + C_2N_2 + C_3N_3$$

(2).

Inserting the value $N_i$ for A and B in table 2 for electro-optics polarization, we obtain the linear coefficient $C_i$ tabulated in table 5.

### Table 5: the coefficient $C_i$ of the fatty acids for electro-optics polarization $\theta_E$

| electro-optics polarization | $C_1$ (17:0) | $C_2$ (19:2 or 17:2) | $C_3$ (19:1) |
|-----------------------------|--------------|----------------------|--------------|
| Transmission                | 0.054        | 0.006                | 0.008        |
| Fluorescence                | 0.012        | 0.008                | 0.016        |

The all coefficients $C_i$ is positive and it shows electro-optics effect works to the increasing polarization angle. The electro-optics fluorescence is twice higher than transmission is now clearly understand able. The coupling of light scattering and fluorescence light is simultaneously occurred and the value $\theta_E$ of fluorescence is doubled, because the biggest size and the highest composition in sample is
monounsaturated FAs (19:1) with more than 80%, the created electric dipoles should be the most dominant contribution to the electro-optics. This reflects in table 5 indicated by the positive coefficient \( C_1 \) of fluorescence is two times of transmission.

4. Conclusions
The natural polarization of fluorescence light is dependent on the polarization angle of incoming light and has average polarization angle greater than transmission light. The average change of polarization in canola A is higher than in canola B indicating that the quality of A is relative lower than B at the time of measurement. Combining the GCMS data, polarization angle and the possible TG formation, in natural polarization, gives important results that the increasing saturated FAs is accompanied by increasing polarization angle. And the other hand, the increasing polyunsaturated FAs is accompanied by decreasing polarization angle, in agreement with our previous reports. The electro-optics polarization of transmission and fluorescence gives the same contribution for both sample and it shows that all molecules are similar as shown by dominated FAs (19:1) composition and all FAs molecules give positive contribution to the polarization angle. Besides that, the electro-optics polarization of fluorescence is two times of transmission. This means that high possibility of coupling of two combination between pure light scattering and fluorescence occurs together perpendicular to the incoming light. This method especially for fluorescence light method provides more accurate measurement that transmission light and seems powerful comparison to the spectroscopy methods. It can be further develop for quality evaluation of other various vegetable oils and animal oils.

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