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# Techniques for Detecting Adulteration in Palm Kernel Oil

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## ABSTRACT

*Near infra-red spectroscopy (NIR) is a rapid technique to detect adulteration of crude palm kernel oil (CPKO) by palm oil products and by-products if the level of adulteration is more than 10%. Below this, the technique can detect scavenger, alcohol bottom, ester bottom or soap stock contamination. Determination of solid fat content (SFC) by pulsed nuclear magnetic resonance (PNMR) can be a general technique for detecting adulteration by CPO, refined bleached deodorized (RBD) palm oil, palm olein, RBD stearin, palm residue, scavenger, soap stock, alcohol botom and ester bottom in CPKO at 1% to 10%. Gas chromatography (GC), by measuring the fatty acid composition (FAC), can detect adulteration by CPO, RBDPO, palm olein, RBD stearin, palm residue, scavenger and ester bottom, but is not suitable for soap stock and alcohol bottom. High performance liquid chromatography (HPLC), by measuring the triglycerides content, is not a satisfactory technique for determining adulteration in CPKO. Physical techniques, such as the cloud point, refractive index and slip melting point, and saponification value are also not suitable. GC and PNMR can detect as low as 0.3% adulteration in CPKO. However, due to the large national natural variation of FAC and SFC in CPKO, the limits of determination for nine adulterants were only 4.0% to 7.0% by GC and 3.0% to 9.0% by PNMR. One approach to lower the limit of determination is to reduce the natural variation of FAC and SFC of CPKO by assessing adulteration in individual oleochemical plant. With this approach, the limit of determination can be lowered to < 2.0% by both GC and PNMR.*

## ABSTRAK

*Spektroskopi hampir lembayung merah adalah satu kaedah cepat untuk mengesan pencemaran produk minyak sawit dan sampingannya dalam minyak isirung sawit mentah (CPKO) untuk paras pencemarannya melebihi 10%. Jika paras pencemaran di bawah 10%, teknik ini hanya sesuai mengesan 'scavenger', alkohol bawah dan ester bawah. Penentuan kandungan lemak pejal (SFC) dengan peralatan resonan magnetik nuklear denyut (PNMR) boleh dijadikan satu teknik umum kerana boleh mengesan pada paras 1%-10% CPO, minyak sawit bertapis dinyahwarna dan dinyahbau (RBDPO), olein sawit, stearin bertapis, dinyahwarna dan dinyahbau (RBD), sisa sawit, 'scavenger', stok sabun, alkohol bawah dan ester bawah dalam CPKO. Kaedah kromatogarfi gas (GC) dengan menentukan kandungan asid lemak (FAC) boleh mengesan pencemaran CPO, RBDPO, olein sawit, RBD stearin, residu sawit, 'scavenger' dan ester bawah dalam CPKO; di mana ia tidak sesuai mengesan stok sabun dan alkohol bawah dalam CPKO. Kromatografi cecair bertekanan tinggi (HPLC) dengan menentukan kandungan jenis trigliserida adalah tidak sesuai untuk mengesan pencemaran dalam CPKO. Teknik fizikal seperti takat kabus, indeks refraktif dan takat cair tergelincir, dan nilai pensaponinan juga tidak sesuai untuk penentuan pencemaran dalam CPKO. Teknik GC dan PNMR boleh mengesan serendah 0.3% bahan pencemar dalam CPKO. Memandangkan variasi FAC dan SFC dalam CPKO pada peringkat nasional yang agak tinggi, had penentuan 9 pencemar seperti di atas dengan menggunakan kedua-dua teknik ini adalah dari 4.0% sehingga 7.0% dengan GC, dan 3.0% sehingga 9.0% dengan PNMR. Satu kaedah menurunkan had penentuan ialah dengan mengurangkan variasi FAC dan SFC dari CPKO iaitu dengan menjalankan kajian pencemaran di kilang oleokimia tertentu. Dengan kaedah ini had penentuan pencemaran dalam CPKO adalah kurang dari 2.0% untuk teknik GC dan PNMR.*


**Keywords**: adulteration, palm kernel oil, detection techniques, contamination, oleochemical.

## INTRODUCTION

The adulteration of raw materials is a common problem in trade and industry. Some raw materials present a quality problem but even so, they still have high intrinsic commercial value. Palm oil was reported to have been adulterated with cheaper palm stearin (Rossel, 1983; 1998). Crude palm kernel oil (CPKO) is the main feed stock for the production of oleochemicals in Malaysia. As CPKO is more

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expensive than palm oil products, there is temptation to use palm oil products or oleochemical by-products to adulterate CPKO. Therefore, monitoring for adulteration has become essential to protect the oleochemicals industry.

The adulteration of palm kernel oil (PKO) with palm oil products or by-products leads to:

a. decrease in the quality and purity of this oil;
b. decrease in the quality of oleochemicals produced from it; and
c. increase in the production cost, as in order to maintain the quality of these products, additional treatments or process modifications have to be used or made.

A combination of slip melting point and iodine value had been used to detect for stearin in palm oil (Tan, 1983) and palm oil and palm kernel olein in PKO (Siew *et al*., 1987). This technique is useful for detecting 1% - 20% contamination of palm kernel olein with palm oil.

Marrikar *et al.* (2001) used differential scanning calorimetry to detect adulteration of lard and randomized lard in refined, bleached, deodourized palm oil (RBDPO). The detection limit was 1%. Fourier transformed infra-red (FTIR) spectroscopy was used by Che Man and Mirghani (2001) to detect lard in chicken, lamb and cow body fats. This technique was used for qualitative and semi-quantitative determination of lard in these body fats.

Lee *et al.* (2001) applied high performance liquid chromatography (HPLC) to detect adulteration of perilla oil in sesame oil with the minimum detection limit of 5%. Neff *et al.* (2001) used HPLC and mass spectrometry for specific identification of triacylglycerols of coconut, cocoa, butter, palm and palm olein oils. The detection limit was 0.1%.

Andikpoulos *et al.* (2001) used gas chromatography (GC) to detect adulteration of olive oil with corn, cottonseed, palm, peanut, soyabean and sunflower oils with a limit of detection of 5%. The GC technique was also used by Xia (2001) to detect the adulteration of sesame oil with other vegetable oils.

This article will highlight the techniques, especially rapid methods, for detecting adulteration of CPKO with palm products and by-products, such as crude palm oil (CPO), RBDPO, palm olein, palm stearin, palm residue, soap stock, alcohol bottom, ester bottom and scavenger.

Note:

| | |
|---|---|
| Palm residue | = distillation residue of C8-C18 methyl esters and/or C8-C18 fatty alcohols. |
| Soap stock | = by-product from alkali refining of oils and fats. |
| Alcohol bottom | = distillation residue of C8 – C18 fatty alcohols. |
| Ester bottom | = distillation residue of C8 – C18 methyl esters. |
| Scavenger | = recovery from the production of fatty alcohols. Mixture of methanol and other alcohols. |

The techniques evaluated for detecting adulteration of CPKO with these oils and by-products were FTIR spectroscopy, near infra-red (NIR) spectroscopy, GC, HPLC, pulsed nuclear magnetic resonance (PNMR), refractive index, cloud point, slip melting point and saponification value.

## FTIR AND NIR SPECTROSCOPY

FTIR and NIR were used to correlate the contents of adulterants in CPKO based on the functional groups of the adulterants. FTIR is not a good technique for detecting adulteration in CPKO as there was no satisfactory correlation between the amounts of CPO added to CPKO and those determined by FTIR. This was because of their similar triglyceride functional groups. However, good correlations were obtained using NIR for 10% to 90% CPO added to CPKO, but the correlation was not satisfactory when CPO is less than 10% in CPKO.

NIR can be used as a rapid technique for detecting adulteration by substances that do not have similar functional groups to CPKO. There were good correlations between the amounts of soap stock, alcohol bottom, ester bottom and scavenger added to CPKO and those determined by NIR with correlation coefficients ($r^2$) of 0.985, 0.993, 0.997 and 0.993, respectively. However, there were no satisfactory correlations for RBDPO, RBD palm stearin and palm residue.

The limit of detection for alcohol bottom or ester bottom in CPKO by NIR is 0.5%. The results are shown in *Table 1*.

## GAS CHROMATOGRAPHY

GC was used to correlate the contents of particular fatty acids in CPKO and in adulterated CPKO. There were good correlations between the amounts of CPO, RBDPO, RBD palm stearin, RBD olein, ester bottom, scavenger and palm residue added to CPKO

**TABLE 1. CORRELATIONS BETWEEN THE CONTENTS OF ADULTERANTS IN CRUDE PALM KERNEL OIL (CPKO) TO THOSE DETERMINED BY NEAR INFRA-RED (NIR)**

| 1% to 10% adulterant added to CPKO | Coefficient of correlation ( $r^2$ )[a] n = 10 |
|---|---|
| CPO | No satisfactory correlation |
| RBDPO | No satisfactory correlation |
| RBD stearin | No satisfactory correlation |
| Palm olein | No satisfactory correlation |
| Palm residue | No satisfactory correlation |
| Soap stock | 0.985 |
| Alcohol bottom | 0.993 |
| Ester bottom | 0.997 |
| Scavenger | 0.993 |

Note: [a]Average of two analyses.

Good correlation = $r^2 \geq 0.95$
Satisfactory correlation = $r^2$ 0.90 - 0.94
Not so satisfactory correlation = $r^2$ 0.80 - 0.89
No satisfactory correlation = $r^2 < 0.80$

and the fatty acid compositions of the adulterated CPKOs as determined by GC with $r^2 > 0.95$.

There was no satisfactory correlation between the amounts of soap stock or alcohol bottom added to CPKO and the fatty acid compositions of the adulterated CPKOs. These results are tabulated in *Table 2*.

## LIMITS OF DETECTION AND DETERMINATION

### Definition

For the adulteration of CPKO with palm products, the limit of detection is the minimum sensitivity of the equipment used, while the limit of determination is the minimum sensitivity of the method against the natural variation or characteristics of CPKO produced in Malaysia.

### Limit of Determination by Gas Chromatography (GC)

Adulteration of CPKO with palm products such as CPO, RBDPO, RBDP olein, palm stearin, palm residue, scavenger and ester bottom can be detected by GC as the coefficients of correlation of these adulterants in CPKO to the fatty acid compositions (FAC) of the adulterated CPKOs were > 0.95. GC can detect as low as 0.3% of these adulterants in CPKO. However, a survey carried out in Malaysia in 1998/1999 (Nuzul *et al.*, 2003) indicated that the natural variation of FAC in CPKO was 4.4% for C12:0, 1.4% for C16:0, and 3.3% for C18:1 fatty acids. Since the variations are higher than the detection limit by GC of 0.3%, the limits of determination of these adulterants in CPKO are higher than the detection limit by GC, as shown in *Table 3*. The determination limits of these adulterants in CPKO by GC were about 5%, except for ester bottom, which was slightly higher, *i.e.* 7.0%

### Solid Fat Content (SFC)

Determination of solid fat content (SFC) using PNMR was evaluated for its suitability to detect adulteration of palm products in CPKO.

As the cloud point of CPKO is about 20°C, the SFCs of 1% to 10% adulterated CPKO, *e.g.* with CPO, were determined at 15°C, 20°C and 25°C.

The correlations between the SFC and the level of adulteration in CPKO were satisfactory at 15°C, 20°C and 25°C, although slightly better at 15°C and 25°C than at 20°C as shown in *Figure 1.* Based on these results, the SFCs of CPKO adulterated with each of the other products from 1% to 10% were determined at 15°C and 25°C.

The correlations between the SFCs and amounts of RBD palm olein, RBDPO, RBD palm stearin, soap stock, alcohol bottom, ester bottom, scavenger or palm residue from 1% to 10% in CPKO were good

**TABLE 2. CORRELATION BETWEEN THE AMOUNTS OF ADULTERANTS ADDED IN CRUDE PALM KERNEL OIL (CPKO) AND THE FATTY ACID COMPOSITIONS (by gas chromatography) OF THE ADULTERATED CPKOs**

| 1% to 10% adulterant added to CPKO | Coefficient of correlation ( $r^2$ )[a] n = 10 |
|---|---|
| CPO | 0.982 |
| RBDPO | 0.988 |
| RBD palm stearin | 0.985 |
| RBD palm olein | 0.991 |
| Ester bottom | 0.960 |
| Scavenger | 0.976 |
| Palm residue | 0.956 |
| Soap stock | 0.421 |
| Alcohol bottom | 0.452 |

Note: [a]Average of two analyses.

**TABLE 3. LIMITS OF DETECTION AND DETERMINATION OF ADULTERANTS IN CRUDE PALM KERNEL OIL (CPKO) BY GAS CHROMATOGRAPHY (GC)**

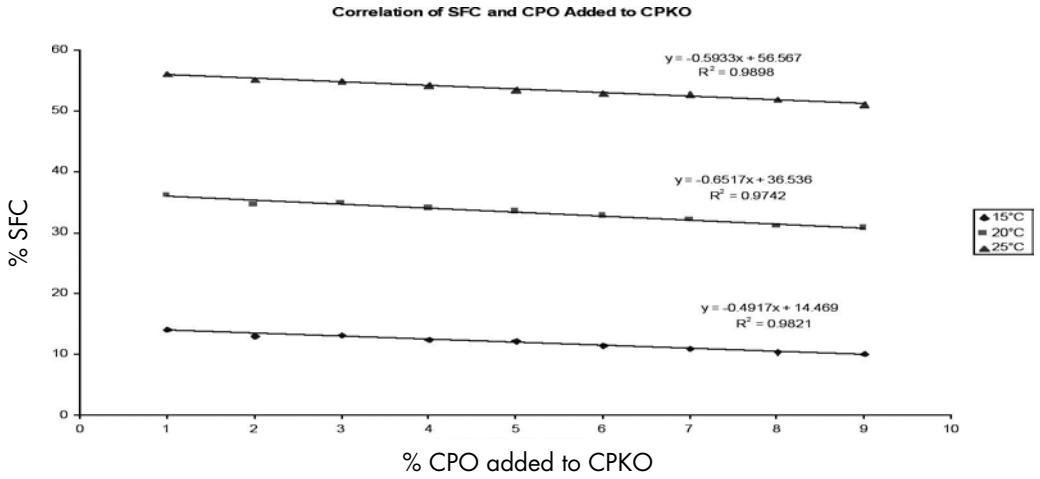
| Adulterant | Limit of determination (%)[a] | Limit of detection | Natural variation (% variation to mean) |
|---|---|---|---|
| CPO | 5.0 | 0.3 % | - |
| Palm olein | 5.0 | | C12 : 0 : 4.4% (9.2%) |
| RBDPO | 5.0 | | - |
| RBD stearin | 5.0 | | C16:0 : 1.4% (16.4%) |
| Palm residue | 6.0 | | - |
| Scavenger | 4.0 | | C18:1: 3.3% (22.1%) |
| Ester bottom | 7.0 | | - |
| Soap stock | NS | | - |
| Alcohol bottom | NS | | - |

Notes: [a]Average of two analyses.
NS = no satisfactory correlation.

- 0.969 to 0.999 at 15°C and 0.981 to 0.998 at 25°C. However, the correlation between SFC and content of alcohol bottom in CPKO was only satisfactory with the coefficient of correlation of 0.923 at 15°C. There was no satisfactory correlation at 25°C with the coefficient of correlation of 0.05 (*Table 4*).

**Limit of Determination by PNMR (solid fat content)**

The determination of adulteration from SFC by PNMR is a versatile technique as 1% to 10% of nine adulterants in CPKO could be detected. The instrument was sensitive, and can detect as low as 0.3 % SFC in CPKO. However, a survey by Siew (1989) indicated that the variation of SFC in Malaysian CPKO is high - 9.5%, 13.1% and 11.3% at 15°C, 20°C and 25°C respectively. Although PNMR is sensitive in detecting SFC, the high variation of SFC in CPKO rendered its limit of determination of adulterants in CPKO quite high, in the range 1.0% to 10%. *Table 5* indicates the sensitivity of the SFC technique for detecting adulteration of CPKO by palm oil products.




Note: [a]Average of two analyses.

*Figure 1. Correlations between solid fat content (SFC) and crude palm oil (CPO) in crude palm kernel oil (CPKO).*

**TABLE 4. CORRELATIONS BETWEEN SOLID FAT CONTENT AND 1% TO 10% ADULTERANT IN CRUDE PALM KERNEL OIL (CPKO)**

| Adulterant | Coefficient of correlation ( $r^2$ )[a] n = 10 | |
|---|---|---|
| | 15°C | 25°C |
| CPO | 0.982 | 0.990 |
| RBD palm olein | 0.987 | 0.993 |
| RBDPO | 0.969 | 0.993 |
| RBD stearin | 0.968 | 0.981 |
| Ester bottom | 0.995 | 0.998 |
| Scavenger | 0.994 | 0.982 |
| Palm residue | 0.999 | 0.994 |
| Soap stock | 0.998 | 0.992 |
| Alcohol bottom | 0.923 | 0.05 |

Note: [a]Average of two analyses.

## IMPROVEMENT OF DETERMINATION LIMIT

GC and PNMR can both detect low levels (0.3%) of adulterants in CPKO. However, their sensitivity can even be better if the natural variations in FAC and SFC of CPKO are lower.

One approach to reduce the natural variation in FAC and SFC of CPKO is to test for adulteration in individual oleochemical plants. An individual plant would have received CPKO with less FAC and SFC variation than at the national level. To verify this approach, CPKO samples were taken from nine mills from Johor (representing a specific area), which would likely have supplied the same oleochemical plant, and their FAC and SFC determined. Johor was chosen for the study because it produced 505 356 t CPKO, about 39.4% of the total CPKO production in Peninsular Malaysia in 2006, and there being three oleochemical plants in the state.

**TABLE 5. LIMITS OF DETECTION AND DETERMINATION OF ADULTERANTS IN CRUDE PALM KERNEL OIL (CPKO) BY THE PULSED NUCLEAR MAGNETIC RESONANCE SPECTROMETER (PNMR) (SFC) TECHNIQUE**

| Adulterant | Limit of determination(%)[a] | Limit of detection | Natural variation (% variation to mean) |
|---|---|---|---|
| CPO | 10.0 | 0.3 % | SFC at: 15°C : 9.5 % (17.1 %) 20°C :13.3% (33.2 %) 25°C :11.3% (66.1 %) |
| Palm olein | 5.0 | | |
| RBDPO | 4.0 | | |
| RBD stearin | 9.0 | | |
| Palm residue | 3.0 | | |
| Scavenger | 1.0 | | |
| Ester bottom | 4.0 | | |
| Soap stock | 3.0 | | |
| Alcohol bottom | 10.0 | | |

Note: [a]Average of two analyses.

As expected, the natural variations in FAC and SFC of the samples were lower than those at the national level. The differences between the highest and the lowest contents of C12:0, C:16 and C18:1 fatty acids were 1.4%, 0.4% and 0.7%, respectively, while the national differences were 4.4%, 1.4% and 3.3%, respectively.

The differences between the highest and the lowest SFC in the Johor CPKO at 15°C and 25°C were 6.2% and 2.9%, respectively, compared with the national figures of 9.5% and 11.3%, respectively. A summary of the natural variation in the FAC and SFC of Johor and national CPKO is given in *Table 6*.

Based on the Johor CKPO variation, the limit of determination for nine adulterants in CPKO by the FAC was improved from ~ 5.0 % to < 2.0 %, and by SFC from an average 5.0% to < 2.0% (*Table 7*).

## HIGH PRESSURE LIQUID CHROMATOGRAPHY

HPLC was evaluated for analysing the triglyceride content in CPKO and adulterated CPKO. The correlation between RBD palm olein added to CPKO and the triglycerides content in adulterated CPKO was satisfactory with $r^2 = 0.929$, while the results for ester bottom added in CPKO was not so satisfactory with $r^2 = 0.833$.

There were no satisfactory correlations between RBDPO, RBD palm stearin, palm residue, soap stock, alcohol bottom or scavenger added to CPKO and the triglycerides content of the adulterated CPKOs. The results are shown in *Table 8*.

**TABLE 6. NATURAL VARIATION IN FATTY ACID COMPOSITION (FAC) AND SOLID FAT CONTENT (SFC) OF CRUDE PALM KERNEL OIL (CPKO) FROM JOHOR AND WHOLE MALAYSIA (% variation/mean)**

| Area | FAC (%) | | | SFC (%) | |
|---|---|---|---|---|---|
| | C 12:0 | C 16:0 | C 18:1 | 15 °C | 25 °C |
| Malaysia, Survey | | | | | |
| - 1989 | - | - | - | 9.5 (17.1) | 11.3 (66.1) |
| - 1999 | 4.4 (9.2) | 1.4 (16.4) | 3.3 (22.1) | - | - |
| Johor | 1.4 (3.0) | 0.4 (4. 8) | 0.7 (4.4) | 6.2 (10.6) | 2.9 (19.2) |

**TABLE 7. LIMITS OF DETERMINATION OF ADULTERANTS IN CRUDE PALM KERNEL OIL (CPKO) BASED ON SAMPLES FROM NINE MILLS IN JOHOR REPRESENTING A SPECIFIC REGION**

| Adulterant | GC (%)[a] | | PNMR (%)[a] | |
|---|---|---|---|---|
| | 1999 (Malaysia) | Johor–specific area | 1999 (Malaysia) | Johor–specific area |
| CPO | 5.0 | 1.0 | 10.0 | 2.0 |
| Palm olein | 5.0 | 1.0 | 5.0 | 1.0 |
| RBDPO | 5.0 | 1.0 | 4.0 | 1.0 |
| RBD stearin | 5.0 | 2.0 | 9.0 | 1.0 |
| Palm residue | 6.0 | 2.0 | 3.0 | 1.0 |
| Scavenger | 4.0 | 2.0 | 1.0 | 1.0 |
| Ester bottom | 7.0 | 1.0 | 4.0 | 1.0 |
| Soap stock | NS | NS | 3.0 | 1.0 |
| Alcohol bottom | NS | NS | 10.0 (estimate) | 1.0 (estimate) |

Notes: [a] Average of two analyses.
NS = no satisfactory correlation.

**TABLE 8. CORRELATIONS BETWEEN ADULTERANTS IN CRUDE PALM KERNEL OIL (CPKO) AND THE TRIGLYCERIDES CONTENT IN ADULTERATED CPKO (by high performance liquid chromatography)**

| 1 % to 10 % adulterant added to CPKO | Coefficient of correlation ($r^2$)[a] n = 10 |
|---|---|
| RBDPO | No satisfactory correlation |
| RBD stearin | No satisfactory correlation |
| Palm olein | 0.929 |
| Ester bottom | 0.833 |
| Scavenger | No satisfactory correlation |
| Palm residue | No satisfactory correlation |
| Soap stock | No satisfactory correlation |
| Alcohol bottom | No satisfactory correlation |

Note : [a] Average of two analyses.

### Refractive Index

The reflective indices of CPKO and adulterated CPKO were used to correlate with the adulteration in CPKO. It was found that the technique was not sensitive enough to detect any contaminant as there was no satisfactory correlation between 1% to 10% CPO added to CPKO and the refractive indices of the adulterated CPKO. The refractive indices of CPKO with 1% to 10% CPO did not vary very much with the standard deviation of 0.0003 unit.

### Cloud Point

The cloud point, one of the physical techniques, was also found not to be sensitive for detecting adulteration of 1% to 10% CPO in CPKO as the cloud points of the adulterated CPKOs were almost similar to that of the non-adulterated CPKO.

### Slip Melting Point

The slip melting point (SMP), a simple physical measure, was used to correlate the amount of

alcohol bottom added in CPKO. The SMPs of these mixtures were determined according to the AOCS Cc 3-25 (1997) method.

The correlation between SMP and 1% to 10% alcohol bottom in CPKO was not so satisfactory with a coefficient of correlation of 0.828. The SMPs of CPKO with 1% to 6% alcohol bottom can be considered similar, as their differences were within the acceptable error of determination, which is 0.5°C. Based on the results, the SMPs of CPKO adulterated with 7% to 10% alcohol bottom were also did not vary very much.

**Saponification Value (SV)**

One of the chemical parameters, saponification value (SV), was evaluated for its suitability in indicating adulteration in CPKO. The SVs of CPKO and CPKO added with adulterants were determined according to the AOCS Cd 3-25 (1997) method.

The saponification method was not a good technique to detect adulteration of CPKO with nine palm products and by-products as the coefficients of correlation between the SV and the amount of adulterants in CPKO were generally poor - < 0.6. This was mainly because of the high SVs of these adulterants, except for that for scavenger of 4.75. However, its correlation coefficient was also not so satisfactory, *i.e.* 0.895.

## SUMMARY

At adulteration of >10%, NIR can be used as a rapid technique for determination of adulteration of CPKO by palm products which have similar functional groups with CPKO. However, at adulteration <10%, SFC by PNMR is a better general method for determination. The GC technique can also be used as it could detect seven out of nine adulterants in CPKO. Other techniques such as HPLC, refractive index, SMP, cloud point and SV were found to be unsuitable. NIR can be used for detecting certain adulterants such as scavenger, ester bottom, soap stock and alcohol bottom at below 10% in CPKO. A summary of the techniques suitable for detecting adulteration in CPKO by palm products is given in *Table 9*.

## CONCLUSION

1. NIR is a rapid technique to detect adulteration of CPKO by palm products and by-products, for levels of contamination of > 10%. However, for contaminants <10%, this technique is only

**TABLE 9. SUITABILITY OF DIFFERENT TECHNIQUES FOR DETECTING ADULTERATION OF CRUDE PALM KRNEL OIL (CPKO) BY PALM PRODUCTS**

| Adulterant | Level in CPKO (%) | Coefficient of correlation[a] ($r^2$) n = 10 | | | | | |
|---|---|---|---|---|---|---|---|
| | | GC | PNMR | NIR | HPLC | Refractive index or cloud point | Saponification value |
| CPO | 10-90 | - | - | 0.929- 0.999 | - | - | - |
| | 1-10 | 0.982 | 0.980 | NSC | - | NSC | - |
| Palm olein | 1-10 | 0.991 | 0.993 | NSC | 0.929 | - | NSC |
| RBDPO | 1-10 | 0.988 | 0.993 | NSC | NSC | - | NSC |
| RBD stearin | 1-10 | 0.985 | 0.981 | NSC | NSC | - | NSC |
| Palm residue | 1-10 | 0.956 | 0.999 | NSC | 0.833 | - | NSC |
| Scavenger | 1-10 | 0.976 | 0.994 | 0.998 | NSC | - | 0.895 |
| Ester bottom | 1-10 | 0.960 | 0.998 | 0.997 | NSC | - | NSC |
| Soap stock | 1-10 | NSC | 0.998 | 0.985 | NSC | - | NSC |
| Alcohol bottom | 1-10 | NSC | 0.923 | 0.993 | NSC | - | NSC |

Notes: [a]Average of two analyses.
NSC = no satisfactory correlation.

suitable for adulterants like scavenger, ester bottom, soap stock and alcohol bottom.

2. Determination of SFC by PNMR can be a general technique for detecting adulteration of CPKO by CPO, RBDPO, palm olein, RBD stearin, palm residue, scavenger, soap stock, alcohol bottom and ester bottom at 1% to 10%.

3. GC, by measuring the FAC, can detect adulteration of CPKO by CPO, RBDPO, palm olein, RBD stearin, palm residue, scavenger and ester bottom. It is not suitable for detecting soap stock and alcohol bottom.

4. Measuring the triglycerides content by HPLC, is not a satisfactory technique for determination of adulteration in CPKO.

5. Physical techniques, such as measurement of the cloud point, refractive index and SMP, are not suitable for detecting adulteration in CPKO.

6. The SV is also not suitable for determination of adulteration in CPKO.

7. GC and PNMR can detect as low as 0.3% adulterant in CPKO. However, due to the wide national natural variation of FAC and SFC in CPKO, the limits of determinations of nine adulterants by these two techniques are only 4.0% to 7.0% by GC and 3.0% to 9.0% by PNMR.

8. If CPKO samples from nine mills from Johor (specific area) are used as the base line for natural variation, the limit of determination for adulteration in CPKO can be less than 2.0% by both GC and PNMR.

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