CRUDE PALM OIL AS A BIOADDITIVE IN POLYPROPYLENE BLOWN FILMS

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Growing public concern about environment and potential risks to health in the polymer and plasticizer industry promises to increase the market for a safer alternative plasticizer such as a vegetable oil-based agent. The purpose of this study was to investigate the potential of crude palm oil as a bio-additive in polypropylene blown films. The polypropylene was blended with 1%, 3%, and 5% dosages of CPO using a twin screw extruder. The extruded samples were blown using the blown thin film technique. Mechanical, physical, and morphological properties were characterized. Modifying polypropylene with CPO showed good enhancement in the mechanical properties of the polypropylene. Tensile strength, elongation at break, impact strength, and tear strength all increased. The scanning electron microscopy photographs of the CPO-modified PP clearly supported the results from the mechanical strength tests. The presence of CPO in the PP matrices decreased the density and increased the melt flow rate. These findings contribute new knowledge to the additives area and give important implications for designing and manufacturing polymer packaging materials.

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INTRODUCTION

An increase in the use of polymeric materials in today's world is observed in the form of various consumer goods. The packaging sector is one of the major consumers of polymeric materials. The properties that make polymers attractive to packaging manufacturers are its lightness, flexibility, chemical resistance, versatility, and a wide range of potential formulations. The word "polymer," or better known as "plastics" refers to materials that are manufactured and designed to resist environmental degradation and are more economical than metal, wood, and glass in terms of manufacturing costs and energy demand (Robertson 2006). Polyolefins, such as polyethylene (PE) and polypropylene (PP), have shown great commercial success in the area of packaging. PE and PP have very low water vapor transmission rates, which are suitable and desired for packaging materials (Roshafima and Aizan 2009).

Polymer additives have a crucial effect on packaging materials. An additive is used in a polymer melt to enhance its processability, performance, and appearance. The ability to modify polymers has allowed the packaging industry to produce better, stronger materials (Murphy 2001) and enhance processability and performance (Soroka

2002). There are several categories of additives such as antistatics, processing aids, lubricants, antioxidants, blowing agents, anti-blocking agents, plasticizers, and coupling agents. Today, in small niche markets the use of additives can provide a cheaper and effective solution to achieving the necessary chemical and physical property improvements (Bart 2005).

Plasticizers account for about one-third of the global additive market, with more than 80% being used in polyvinylchloride (PVC). Recently, plasticizer development has focused on material challenges in improving its resistance to leaching, migration, and health risk upon chronic exposure, according to safety regulations (Pospil and Nesporek 2008). Plasticizers are actually low molecular weight (MW) resins or liquids, which form secondary bonds to polymer chains and spread them apart. Thus, plasticizers reduce polymer-polymer chain secondary bonding and provide more mobility for the macromolecules, resulting in a softer, more easily deformable mass (Rahman and Brazel 2004). This results in a more flexible plastic, but it causes a loss of strength and hardness. Plasticizers can be helpful for production, but they are potentially toxic and should not be used for food packaging applications in which there is a possibility of contamination (Wilson 1995).

Plasticizers from natural products represent a viable alternative as a replacement for traditionally used phthalates in the plastic industry, which are characterized by their toxicity. Vegetable oil plasticizers provide about 15% of the total United States plasticizer market and represent about 8% of the industrial market for vegetable oils (Pryde and Rothfus 1989). Epoxidized oils, especially epoxidized soy bean oil (ESBO), are used extensively as plasticizers and stabilizers for plastics, particularly PVC. A plasticizer increases the workability of a plastic, while a stabilizer reduces the rate of degradation of a plastic by heat or micro-organisms. Epoxidized oils can fulfill both functions, and their compatibility with a plastic increases with the level of epoxide content. There have been several studies conducted on using epoxidized oil as a plasticizer and stabilizer in polymers, replacing di-2-ethylhexy-phthalate (DEHP) (Benaniba et al. 2003; Benaniba et al. 2001; Karmalm et al. 2009a,b; Okieiman 2002; Taghizadeh et al. 2008). A research by Norazlin et al. (2008) on using PP modified with palm oil showed significant effects of palm oil as an additive to PP.

There are many patents registered for using environmentally friendly plasticizers such as ESBO to control the gas permeability in film packaging (Bekele 2000); as the barrier blends for the food packaging application (Fornasiero and Paleari 1998); and to increase the permeability of carbon dioxide in the food packaging film (Paleari and Fornasiero 1996). Epoxidized linseed oil is also used as a plasticizer in antibacterial films suitable for food packaging (Watanabe et al. 1999). Many studies have been done to find substitutes for toxic plasticizers in PVC. The use of natural plasticizers such as epoxidized linseed oil (ELO) (Fenollar et al. 2010) and epoxidized fatty acid ester (EFAE) (Fenollar et al. 2009) have emerged as interesting alternatives for obtaining plastisols with a low toxicity and low environmental impact. Epoxidized safflower oil was also found to be a possible alternative for DEHP, as it exhibits similar plasticizing effects (Sun and Thom, 2010). Other researchers demonstrated the improvement of poly-lactic acid (PLA) flexibility by incorporating epoxidized soybean oil (Ali et al. 2009) or epoxidized palm oil (Al-Mulla et al. 2010).

Malaysia is a huge producer of crude palm oil (CPO), producing 8.4 million tons of CPO per annum, which is 51% of the world's palm oil production and 61% of the

total world export (Yusoff 2006). Palm oil contains 40% oleic acid (monounsaturated fatty acid), 10% linoleic acid (polyunsaturated fatty acid), 45% palmitic acid, and 5% stearic acid (saturated fatty acid). The components obtained from the palm oil, like monoglycerides and triglycerides, are most suitable for use as plasticizers (Wypych 2004). CPO likewise has good potential for addition to polymer as a plasticizer. The presence of crude palm oil in PE has a significant influence on physical properties. Research done by Ratnam et al. (2006) found that the presence of fibrils in the stretch surfaces of HDPE and LLDPE incorporated with 5% CPO provided evidence of orientation strengthening.

The concern that exposure or migration of additives may affect humans and the environment are leading many researchers to vigorously seek for alternative additives, especially plasticizers, to substitute for the prevalent toxic additives. In this study, a vegetable oil base was chosen to facilitate the investigation of the plasticizing effect in polyolefins resins. On top of the additives function described, the most important emphasis is on the plasticizer, which relates to the overall purpose of the study at hand. Clearly underscored is the recent development in the usage and future prospect of crude palm oil as an alternative additive. Also highlighted is the most important advancement in the modified polymer, the identification of physical properties for use in environmentally friendly applications.

EXPERIMENTAL

Materials

The PP resins used in this study were obtained from Polypropylene Malaysia Sdn. Bhd, Gebeng, Malaysia. The grade name was Propelinas I112. The density of the PP was 0.9 g/cm^3. Its melting temperature and melt flow rate were 162ºC and 11 g/ 10 min (at 230°C, 2.16 kg), respectively. The crude palm oil used in this study was obtained in a liquid form directly from the factory Palong Cocoa Palm Oil Mill, Johor, Malaysia. The properties of the CPO are presented in Table 1.

Table 1. Properties of the CPO Used in this Study

Property (unit)	Content
Free fatty acid (%)	3.79
Peroxide value (meq/kg)	2.80
Anisidine value	3.30
Carotenoids (ppm)	>600
Deterioration of Bleachability Index (DOBI)	2.70
Iodine value	52.50
Saponification value	197
Moisture and impurities (%)	0.25
Unsaponifiable matter (%)	0.70
Melting point (^{o}C)	36.50
Copper (ppm)	0.12
Iron (ppm)	4.20
Phosphatides (ppm)	694
Density (g/m^3)	0.899

Methods

The PP modified with CPO granules was obtained by extrusion using a 20 mm co-rotating modulator Laboratory and Pilot Plant twin-screw extruder with counter rotating screws (Lab Tech Engineering Co.). First, the PP was premixed with CPO for 30 minutes to combine the CPO and polyolefins resin before feeding it into the extruder. The premixed PP was fed into the extruder hopper and extricated through a die. The extrudates were placed in a cold-water bath at 25°C, palletized, then dried. The feed, compression, metering zone, and die temperatures used were 125°C, 170°C, 165°C, and 160°C (optimization on the samples and machine were done to determine the best conditions).The screw speed was set to 60 rpm for both resins, which was adopted from Chantara et al. (2006). The PP/CPO granules obtained by extrusion were transformed into films using conventional blowing thin film equipment (Taiking Machinery Factory), which uses the horizontal type. Film specimens were prepared using the sheet extrusion with a round die (single screw extruder, 19/25D).

Preparation of rectangular bar samples

This method was used to prepare samples for Izod impact testing and density measurement. The extruded pallets were compression moulded into 3 mm thick sheets by hot pressing the granules with a hydraulic press at 175°C. The equipment used was a Technopress 40HC-β Hydraulic Compression Moulding. The samples were preheated for 3 minutes and continued with 10 times venting process to melt the compound and remove the air bubbles.   A pressure of 78 bar was then applied for 5 minutes to allow the compound to melt and spread out between the plates. After the final pressing, the sheets were cooled between the two plates of the cold press at 25°C for 5 minutes.

Tensile testing

The tensile strength (Ts) and elongation at break (Eb) were measured using an Instron Universal Testing Machine 3365, with a load of 5kN at 23°C and 50% humidity using a crosshead speed of 50 mm/ min in accordance with ASTM D 882. Altogether, ten samples were used for tensile testing, and averages of six results were recorded as the resultant value. The test specimens were cut to a size of 150 mm in length and 25 mm in width in accordance with ASTM 6287. The tensile tests were performed in both the machine direction (MD) and the transverse direction (TD). The grip separation distance was pneumatic of 100 mm and the strain rate was 50 mm/min.

Izod Impact testing

The Izod impact test was performed using a 2 joule hammer on a Testing Machines Incorporation Monitor Impact Tester machine in accordance with the ASTM D 256. Samples were cut from a 3 mm thickness sheet using an electrical bend saw. Notching was then done in the middle of the samples at about 2.54 mm and an angle of 45°. The energy used to break the samples was recorded in joules and the type of break was also noted.

Tear strength testing

Resistance to tear is a key property of packaging film. It is almost universally measured with the Elmendorf tear test as described by ASTM D 1922. The equipment used for this testing was a HT-8181 Elmendorf Tearing Strength Tester, Hung Ta

Instrument (Co., Ltd). The samples were measured using a pendulum testing device. The sample toughness was measured based on how much the upswing of the pendulum was reduced compared to when no sample was in place. The blown film samples were prepared in the machine direction (MD) and the transverse direction (TD). About ten measurements of each samples of each were recorded, and an average of eight measurements was used as the final result.

Density measurement

Density evaluation was conducted before and after modification, since density affects the flow behavior and process ability. The density measurement was carried out according to ASTM D1505 using an Electronic Densimeter Mettler Toledo's Model XS 800 density determination kit. In total, three rectangular bar-shaped specimens from each composition with a thickness of 3 mm, having a mass of not less than 2 g, and a smooth surface free from crevices and dust was used. Average values were reported.

Fourier Transmission Infra-Red (FTIR)

To understand the connections existing between the polypropylene matrix and CPO, it was necessary to determine the Fourier Transform Infrared (FTIR) spectra corresponding to the samples. The measurements were carried out using a Perkin Elmer Spectrum 2000 FTIR spectrophotometer. The FTIR spectrum of 0%, 1%, 3%, and 5% of the PP modified with CPO were clipped to the film stand and scanned.

Scanning Electron Microscope (SEM)

A Thermo Scientific Scanning Electron Microscope (SEM) was used to obtain an image of the fractured surface, the stretched specimen surface, and the particle agglomerates for film-form specimens. The samples were fractured and coated with gold using a sputter coater. SEM microphotographs of each image were taken at 5,000x and 10,000x magnification. The fractured surfaces of the film specimens were studied after stretching the specimen at an ambient strain rate of 500 mm/min.

RESULTS AND DISCUSSION

Density Determination

Density is a function of chemical composition and dependent on the weight of the individual molecules and the way they are packed together. The effect of CPO loading in PP is summarized in Table 2. It was observed that the density values of modified PP decreased with an increase in CPO. Generally, the introduction of a plasticizer alters the density and causes variations in density across a sample due to non-uniform distribution (Kholodovych and Jwelsh 2007). This trend is in agreement with the findings of Ratnam et al. (2006). The CPO acted as a plasticizer, which increased the free volume available to the polymer chain and thus allowed for greater internal chain rotation and unwinding (Weisfeld 2001). When CPO was incorporated with the PP, the softening action of the plasticizers caused plasticization and was attributed to its ability to reduce the intermolecular attractive forces between the chains in the PP resin system.

Table 2. Effect of CPO Content on the Density of PP

CPO content (% wt)	Density (g/cm^3)
0	0.9056
1	0.9050
3	0.9048
5	0.9032

Fourier Transmission Infra-Red (FTIR)

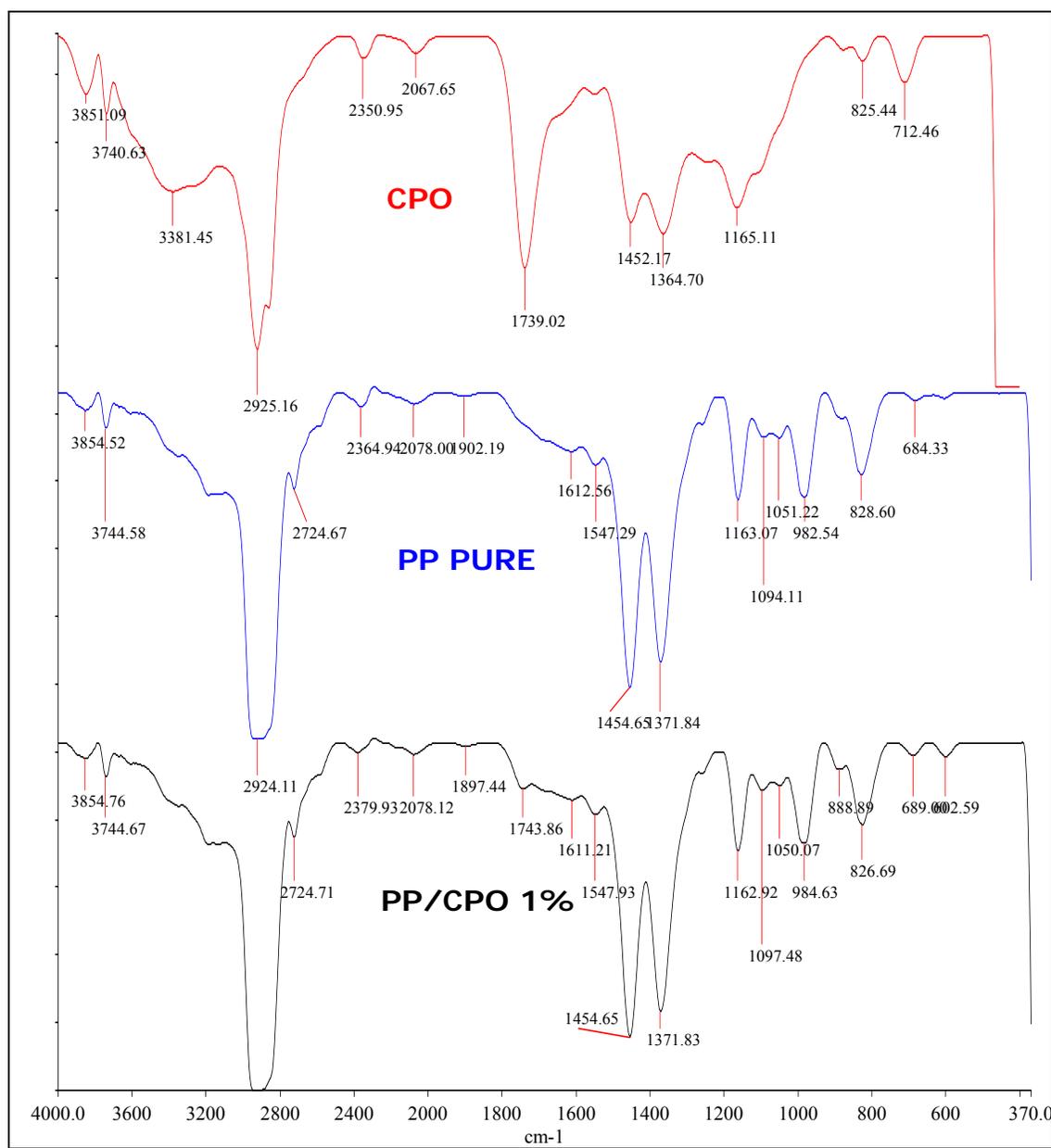The FTIR spectra of the PP blown film and the PP blown film incorporated with CPO are shown in the Fig. 1.

Fig. 1. FTIR spectra of (a) CPO (b) Pure PP and (c) PP incorporation 1% CPO

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Figure 1(a) depicts the CPO spectrum. The FTIR spectra of CPO in Fig. 1(a) show a sharp band at 1739 cm^{-1}, which indicates a triglyceride ester linkage. The bands from 3000 to 2900 cm^{-1} correspond to the CH bond, and bands at 1500 to 1000 cm^{-1} indicates the fingerprint region of oil. This spectrum was also reported in another publication (Man et al. 1999). CPO consists of 50% saturated and 50% unsaturated fatty acids and major triglycerides (Man et al. 1999). From the spectra in Fig. 1(a), the fatty acid content is supported by a large part of the spectrum, such as the bands due to bonded O-H, C= O stretching in the ester bonds, and the C-H olefinic stretching region around 3381 cm^{-1}, 1739 cm^{-1} and 2925 cm^{-1}, respectively.
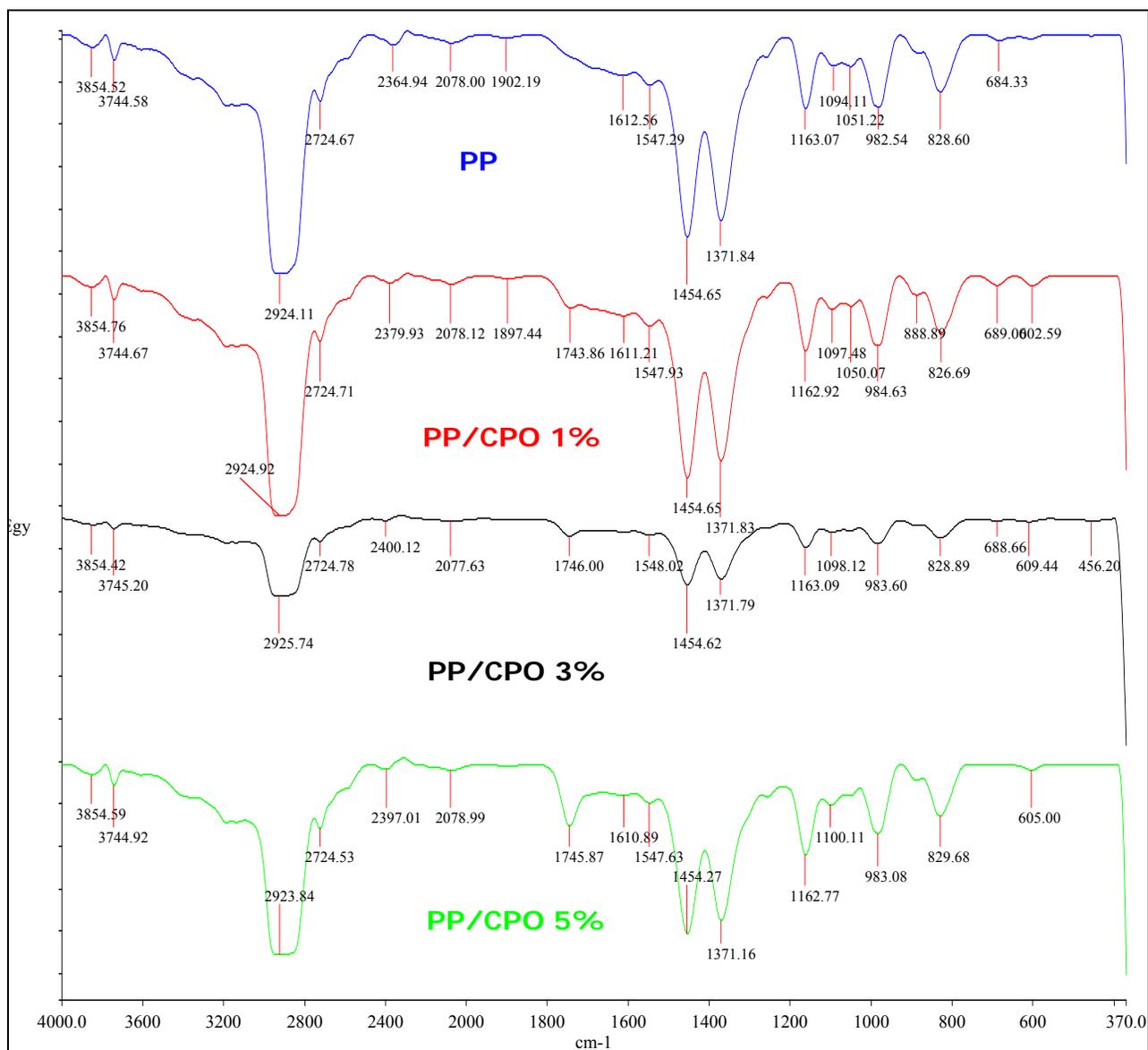

Fig. 2. FTIR spectra of (a) Pure PP, (b) PP incorporation 1 % CPO, (c) PP incorporation 3 % CPO, and (d) PP incorporation 5 % CPO

The spectrum of pure PP in Fig. 1(b) presents wave numbers in the region of 2700 to 2925 cm^{-1} and 1370 to 1455 cm^{-1}, illustrating C-H stretching of aliphatic carbon and CH$_2$ and/or CH$_3$ deformation, respectively. This observation was also reported by other researchers (Prachayayawarakorn and Yaembunying 2005; Chuai et al. 2001; Khali et al. 2001). The FTIR spectrum in Fig. 1(c) clearly shows the vibrational bands of PP modified with the CPO (at 1% wt loading). When the CPO was added to the PP matrix, as indicated in Fig. 1(c), a major change in the FTIR spectra was observed in the 1747 to 1743 cm^{-1} region, indicating that the chemical structure of PP is affected by the modification process. The FTIR results indicate that there are physical molecular interactions between PP and CPO. In addition, it can be seen in Fig. 2 that with increasing content of CPO, the relative strength of the peak at 1743 cm^{-1} increased.

Tensile Strength

The effects of CPO loading on the tensile properties of the PP blown films were investigated and compared. Generally, a plasticizer must plasticize a polymer; the typical expectation is that the tensile strength of a plasticized material decreases with an increased amount of plasticizer (Wypych 2004). Figure 3 shows the tensile strength of the modified PP at various CPO loadings. All tensile properties were measured in both the machine direction (MD) and the transverse direction (TD). It is apparent from Fig. 3 that the tensile strength of the PP showed a higher value in the MD than in the TD. This directionally dependent response is related to the anisotropic properties of individual crystalline lamellar stacks as well as the nature of the non-cystalline phase orientation (Ratnam et al. 2006). The tensile strength of the PP in the MD direction showed a decrease with the addition of CPO. The tensile values of the PP incorporated with CPO in the MD were found to be 28.53 MPa, 27.47 MPa, and 25.89 MPa, compared with the neat PP of 31.24 MPa. The decrement showed about 17% for the 5% CPO content compared to the neat PP. This result supported the initial expectation of the CPO acting like a plasticizer to the PP matrices. Again, the observation was attributed to the inter-molecular interaction and cohesion, which both have an effect on tensile strength (Marcilla and Beltran 2004).

It is believed that the increase in free volume in the PP network with the addition of CPO tends to weaken the interaction between the polymer chains. When the tensile force was applied to the PP samples, the PP molecules were rotating and moving about, and for plasticization it was necessary only to lubricate and to reduce the cohesion forces between them, so that molecules could slip and slide past each other (Marcilla and Beltran 2004). The molecular structure of CPO also tends to affect the tensile strength properties. As mentioned, triglycerides act as a lubricant and cause a decrease in tensile strength of PP. The low molecular weight CPO is believed to be distributed only in the amorphous phase concentration. According to Kirkpatrick (1940), the plasticizer (in this case the CPO) molecule is attached more or less strongly to some portion of the polymer molecule, thereby tending toward solvent action, and the unattached portion acts as a lubricant between the polymer molecules. The plasticizing theory involves filling the large voids in the molecular space lattice, thus leading to the formation of planes of easy glide. The plasticizer fills the voids between the gliding planes and acts as a lubricant, causing the planes to glide smoothly past one another. (Daniels 2009).

The TD direction, however, experienced a gradual increase in tensile strength with a small increment of about 17% for 5% CPO addition to the PP matrix compared to the neat PP. This observation contradicts the expectation of plasticizer action in the polymer and is referred to as antiplasticization. Antiplasticization is generally associated with a reduction in free volume caused by strong interactions between plasticizer molecules and polymer chains (Mascia et al. 1989). Antiplasticization is mechanically characterized by an increase in the PP stiffness upon the incorporation of a small amount of CPO.
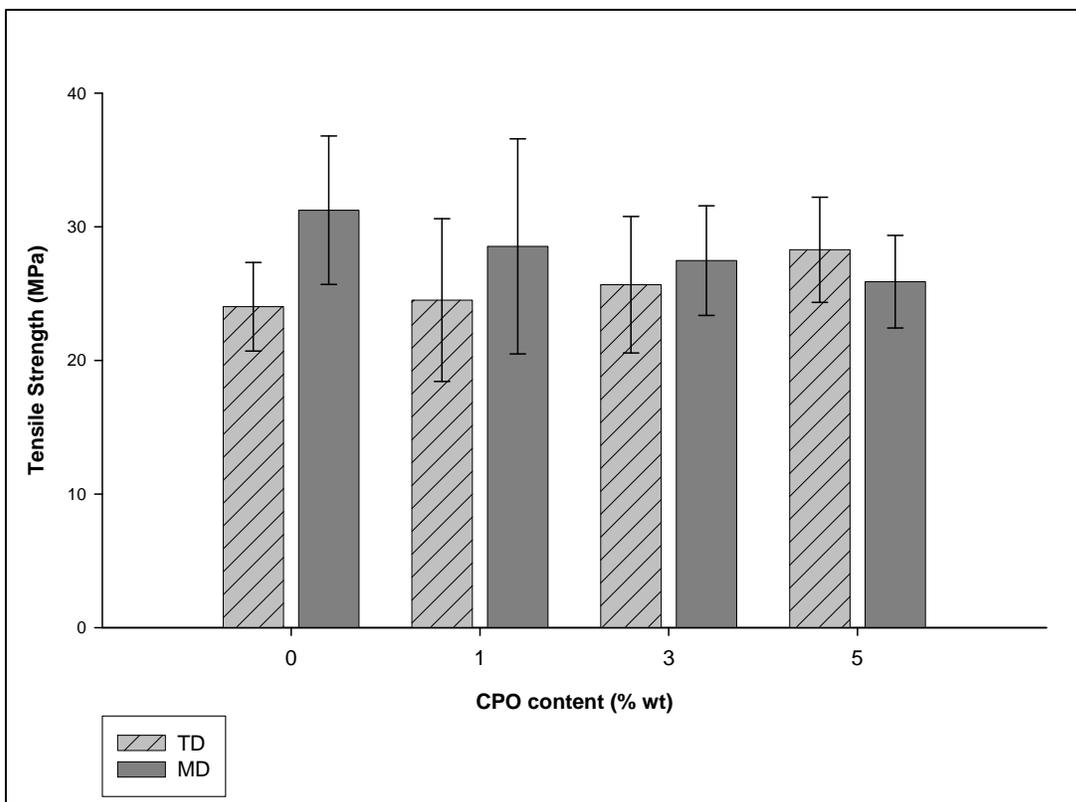

Fig. 3. Effect of CPO loading on the tensile strength of PP blown films

Elongation at Break

Table 3 shows the elongation at break as a function of the neat PP at various amounts of CPO loading in the blown film. The neat PP for the MD and the TD exhibited an elongation at break value of 344% and 30%. It is evident from Table 3 that the PP showed a higher elongation at break in the MD than the TD for the neat PP. The incorporation of CPO in the MD resulted in an increase of elongation at break. The largest elongation at break value was observed at 650% with 5% CPO loading, which reveals a remarkable growth of ductile behavior with an increasing CPO content. The CPO was believed to act as a plasticizer to the PP chains. From the structural point of view, the increase in the quantity of plasticizer addition to the PP acts as an internal lubricant, which facilitates the sliding of the PP chains; therefor, secondary linking forces between the polymer chains were lowered. According to Fenollar et al. (2010), the

plasticizer fills the space between the polymer chains, increasing the separation between them, and causing a decrease in the polar forces of attraction. This structural change explains the change in the mechanical behavior observed when increasing the amount of CPO added to the PP, which provides a more versatile behavior; however, the elongation at break of the PP blown film in the TD with the incorporation the CPO resulted in an opposite trend. The decline in the elongation at break of the TD with the increase of CPO loading was attributed to the increased rigidity of the polymer due to the alignment in the direction of stress during the cold drawing. PP is a relatively rigid polymer compared to LDPE; however, the orientation results of tensile deformation did not impart a significant difference in the elongation at break in the TD of the PP.

Table 3. Effect of CPO Loading on the Elongation at Break of PP Blown Film

CPO content (% wt)	Elongation at Break (%)	
	MD	TD
0	343.52	29.93
1	455.56	16.61
3	629.42	15.35
5	650.30	14.96

Tensile Modulus of PP Blown Film Modified with CPO

Measuring the elastic modulus is a common method used in determining stiffness. Figure 4 shows the tensile modulus of the pure PP and the PP incorporated with the CPO in the MD and the TD.
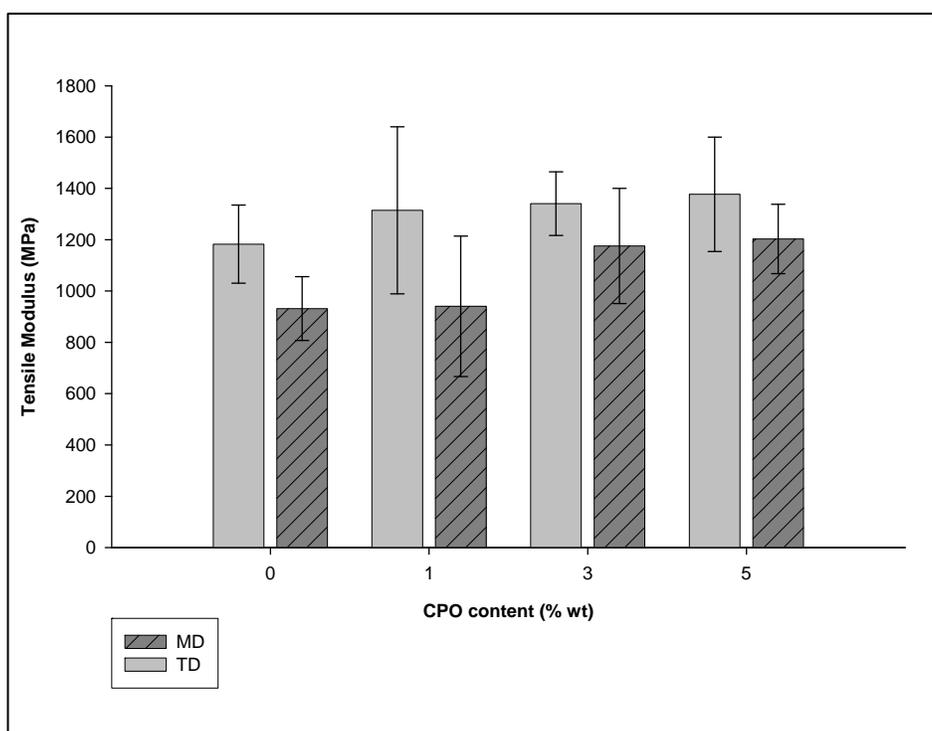

Fig. 4. Effect of CPO content on the tensile modulus of PP blown films

The neat PP in the MD and TD exhibited a modulus value of 931 MPa and 1182 MPa, respectively, and the PP in the TD blown film showed a higher tensile modulus than in the MD. The addition of the CPO significantly increased the stiffness, as the composition modulus value increased by approximately 17% and 30% in the MD and the TD, respectively, compared with that of the neat LDPE resin with the addition of 5% of the CPO. This shows that the PP-modified films were much stiffer. This may partly be due to the introduction of the CPO moieties, resulting in drastic chain flexibility (Srinivasa et al. 2007). Since the CPO consists of polar and non-polar side chains, there are strong intramolecular and intermolecular interactions, such as hydrogen bonding, dipole-dipole, charge-charge, and hydrophobic interactions. The strong charge and polar interaction between the side chains of the CPO molecules restrict the segment rotation and molecular mobility, which lead to an increase in the modulus stiffness (Zhang et al. 2001). This observation was explained in the subtopic of tensile strength, which the antiplasticization mechanism contributed to these observations in the tensile modulus.

Izod Impact Strength

Table 4 depicts the effect of the CPO content on the Izod impact strength of the PP. The impact strength of the PP was found to show a gradual increase with an increase in CPO content; the increase was approximately 30% compared with that of the pure PP. The distribution of the CPO in the PP facilitated the movement rotation of the polymer molecules. The triglycerides contained in the CPO acted as a lubricant which increased the chain mobility of the PP, resulting in the enhancement in the impact strength of the PP (Yusof 2005). This phenomenon increased the ability of the system to absorb energy during the fracture propagation. The increase of impact strength showed that antiplastic-ization occurred in the PP matrix with the addition of the CPO. These observations were also consistent with the results of the tensile strength testing and the elongation at break testing. According to other researchers, it might be inferred that the local mobility in the modified polymer chains allowed them to form a more ordered state or the CPO filled the specific hole free volume of the polymer glass (Tiembo et al. 1994). The molecular structure of PP, which has a higher degree of crystallinity than LDPE, does not give much opportunity for the CPO to distribute in the amorphous phase.

Table 4. Effect of CPO Loading on the Izod Impact Strength of CPO-modified PP with Complete Break

CPO content (% wt)	Izod Impact (J/m^2)
0	1476.94
1	1527.77
3	1706.38
5	1867.04

Tear Strength

The results of the Elmendorf tear strength testing on the pure PP and the PP modified with the CPO are represented in Fig. 5. It is observed that the tear strength in the TD showed a higher value than in the MD. The tear resistance is strongly influenced

by the film morphology consisting stacks of MD and TD lamellae. Godshall et al. (2003) reported that a high degree chain orientation along the MD leads to poor tear resistance along the MD. This is because tear propagation parallel to the chain backbone requires less energy than propagation perpendicular to the chain. The tear strength increased with the amount of the CPO in the TD and the MD, while the neat PP in the TD and MD showed tear propagation strengths of 469 g and 279 g, respectively. It is seen that the plasticized PP films showed a better performance before tear propagation than the neat PP. This is an important factor in food packaging applications.
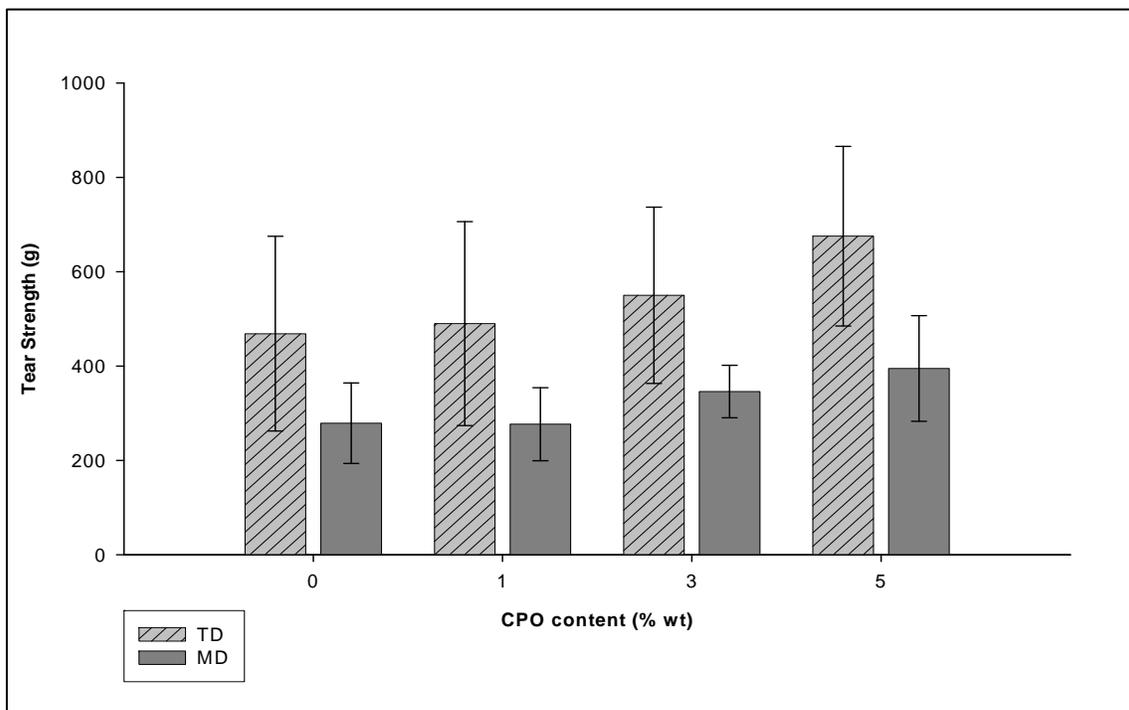

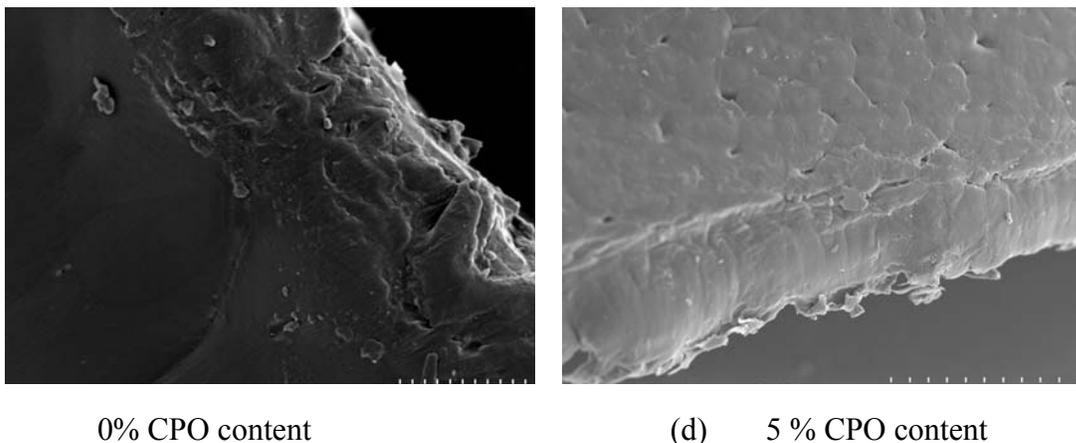**Fig. 5.** The effect of CPO content on the tear strength of PP modified with CPO

0% CPO content   (d)   5 % CPO content

Fig. 6. SEM micrographs of LDPE and PP film fracture part at 500 % elongation (Magnification 10,000x)

Scanning Electron Microcopy (SEM)

Figure 6 shows SEM micrographs of the tensile fracture surfaces of the PP with and without 5% CPO at a strain rate of 500 mm/min and an initial gap distance of 50 mm. The images show the fracture part of the film after stretching at a constant draw ratio of 500%. The same observation was reported by Ratnam et al. (2006). Basically, the CPO addition to the PP does not modify the basic fracture mechanism of the PP matrix.

CONCLUSIONS

1. Polyolefins consisting of PP incorporated with crude palm oil were prepared and characterized. From the characterization, the results obtained from the observation and analysis showed that the CPO used acted as a plasticizer to the polyolefins.
2. The plasticizing effects of the CPO on the mechanical properties of the PP blown film were investigated. The results on the tensile strength and elongation at break of the PP modified with the CPO indicated that the CPO functioned as a plasticizer when the plasticization mechanism occurred; however, the opposite trend of the plasticization effect that occurred to the PP modified with the CPO in the TD was attributed to the anisotropy of the molecular structure and antiplasticization phenomenon. The triglycerides in the CPO acted as a lubricant and increased the free volume in the PP network which tended to weaken the interaction between the polymer chains and resulted in a decrease in tensile strength. The addition of CPO also facilitated the lamellar orientation, which in turn led to a further increase in the elongation at break.
3. The toughness of the PP increased with the addition of the CPO. This observation also could be detected in the tear strength test of the PP modified with the CPO.
4. The SEM morphology confirmed the results indicated in the mechanical properties. The SEM also showed that the CPO was homogenously blended in the PP matrices.
5. The mixing of the PP with the CPO in a variety of ratios showed that the end-products gave a lighter density compared to that of pure PP.
6. The presence of the CPO in polyolefins also was detected with FTIR analysis, which showed that the CPO is not volatile to the environmental and still remains in the polyolefins matrix to react as a plasticizer. The FTIR analysis also showed that there are some changes in the 1745 to 1747 cm^{-1} region of the PP modified with the CPO compared to the neat polyolefins, indicating a physical interaction between the polyolefins and the CPO, which confirms the presence of triglyceride ester linkages of the CPO in the polyolefins matrices.
7. The CPO is capable of being mixed uniformly and homogenously and remains blended when cooled to room temperature and throughout the useful life of the plastic product.
8. This improvement is important to the packaging sector and is fit for use as an environmentally friendly application.

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