

Absorption and photoluminescence of Buriti oil/polystyrene and Buriti oil/poly(methyl methacrylate) blends

J.A. Durães ^a, A.L. Drummond ^a, T.A.P.F. Pimentel ^a, M.M. Murta ^b,
F.da S. Bicalho ^c, S.G.C. Moreira ^c, M.J.A. Sales ^{a,*}

^a Laboratório de Pesquisa em Físico-Química de Polímeros, Instituto de Química, Universidade de Brasília, Caixa Postal 4478, Brasília-DF 70904-970, Brazil

^b Laboratório de Isolamento e Transformação de Moléculas Orgânicas, Instituto de Química, Universidade de Brasília, Caixa Postal 4478, Brasília-DF 70904-970, Brazil

^c Departamento de Física, Universidade Federal do Pará, CEP 66075-900, Belém-PA, Brazil

Received 24 April 2006; received in revised form 1 August 2006; accepted 19 September 2006

Available online 31 October 2006

Abstract

This work reports the preparation and characterization of Buriti (*Mauritia flexuosa* L.) oil/polystyrene (PS) and Buriti oil/poly(methyl methacrylate) blends. The Buriti is an abundant palm tree of the Amazon region. This oil was used because of its chemical composition (high concentrations of oleic acid, tocopherols and carotenoids, especially β -carotene) and interesting optical properties, such as absorption and photoluminescence. The incorporation of the vegetable oil in the PS and PMMA matrices renders orange-colored blends, which were verified to absorb UV–Vis radiation and emit light in the green region. The intensity of these properties is proportional to the oil content in the samples. Micrographs of the blends showed that the oil is located in cavities distributed in the polymeric matrices. This work shows that it is possible to employ the Buriti oil, a cheaper and abundant natural resource, to improve absorption and light emission properties of PS and PMMA polymers.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Poly(methyl methacrylate); Polystyrene; Buriti oil; Optical properties

1. Introduction

The wide variety of polymer applications in several environments makes the polymers more susceptible to several degradative processes. Photodeg-

radation is particularly important and threatens mainly polymeric materials exposed to external environments. Pigmentation, used in most cases, works as a good indicator of the stabilization against this type of degradation and can further reduce the radiation penetration in the interior of the polymer matrix. However, the use of pigmentation or coating cannot always be employed successfully, and thus photostabilizers have gained attention because they act as UV absorbers and

* Corresponding author. Tel.: +55 61 3307 2179; fax: +55 61 3273 4149.

E-mail address: mjsales@unb.br (M.J.A. Sales).

traps for radicals [1]. Al-Malaika et al. [2–4] investigated the use of vitamin E (α -tocopherol) as an alternative to the phenolic antioxidants, concluding that the tocopherol has an excellent melt stabilizing activity in polyolefin.

Currently, there is a high demand for polymeric materials with special properties such as absorption and emission of light. Light emission is one of the most important optical properties of polymers because it allows its use in several technological areas, especially in the construction of light emitting diodes (LEDs) [5–9]. Luminescent organic materials, mainly fluorescent polymers, show many benefits in comparison to luminescent inorganic materials such as low cost, easy manufacture, and color synchrony [10]. There are several studies involving the synthesis, characterization, investigation of optical properties, and application of luminescent conjugated polymers, especially with the derivatives of poly(phenylenevinylene) (PPV) [11–17]. However, conjugate polymers are known to be unstable to photooxidation, especially when exposed to radiation with photon energy much higher than its electron gap energy [18].

Few studies exist on the use of vegetable oil in polymer technology, but these studies have intensified in recent years. Besides the studies of epoxidized oils as plasticizers and thermal stabilizers, new themes such as oil transesterification catalysed by enzymes, fatty acids sorption by polymer films and polymer production from seed, palm and soybean oil are described in the literature [19–27].

The Buriti (*Mauritia flexuosa* L.), an abundant palm in the Amazonian region of Brazil, supplies raw material for a variety of applications such as roots for medicinal use, fruit and trunks to produce wine, liqueur and canoe manufacture, standing out as an important resource. The oil extracted from the Buriti fruit is of great interest because of its physical and chemical characteristics [28–33]. The average composition of fruit is 20% of shell and pulp, 30% of white cellulose layer and 50% seed (wt/wt of fruit) [29]. The Buriti oil extracted with hexane presents a remarkable chemical composition and nutritional properties, and it was thus proposed that the oil could be used to combat the lack of lipids in nourishment [28]. When the Buriti oil is extracted with supercritical CO_2 , it shows a chemical composition with high concentrations of oleic acid, tocopherols and carotenoids, especially β -carotene, which is responsible for the oil's red–orange

color [29,31]. Some of characteristics of Buriti oil are: density of 0.86 g cm^{-3} , refractive index of 1.46 at 22°C , iodine index of 77.2 cg I_2 per 100 g, saponification index of 169.9 mg KOH/g and melting point at 12°C [31–33].

The π -conjugated structures, which the tocopherols and carotenoids exhibit, are of special interest in the research of optical devices. However, it is known that the carotenoids have poor photo and thermostability *in vitro*, which makes it unsuitable for the construction of photofunctional materials [34].

Studies of Buriti oil's thermal diffusivity, using the thermal-lens technique, were performed [30]. Garcia-Quiroz et al. [31] investigated its dielectric properties by determining the dielectric constant (dc), which was related to the dc of its main constituents. They also reported that the oleic acid's phase transition, which was present in the differential scanning calorimetry (DSC) curves of Buriti oil, is a consequence of the acid's high concentration in the oil [31]. Albuquerque et al. [32] observed that the infrared spectrum of Buriti oil is very similar to that of triolein, a triglyceride of oleic acid.

With the aim to introduce these notable Buriti oil properties in a polymeric material, we decided to incorporate this oil into polystyrene (PS) and poly(methyl methacrylate) (PMMA) matrices, which are typical polymers for multiple and common uses. Besides, Buriti oil has a favorable chemical composition in that it provides a medium with a higher stability of β -carotene. In this work we investigated the absorption and photoluminescence properties of Buriti oil, PS and PMMA polymers blends in the UV–Vis region.

2. Experimental

2.1. Materials

Buriti oil ($\rho = 0.86 \text{ g mL}^{-1}$) was extracted with supercritical CO_2 from the shell and the pulp of ripe Buriti fruits. Table 1 presents the oil composition used in this work. Low molecular weight PMMA ($\overline{M}_w = 120,000$; $\rho = 1.188 \text{ g mL}^{-1}$; $T_g = 114^\circ\text{C}$) and PS ($\overline{M}_w = 280,000$; $\rho = 1.047 \text{ g mL}^{-1}$; $T_g = 100^\circ\text{C}$) purchased from Aldrich Chemical Co. were chosen to be the matrices because they are widely employed polymers and are soluble in the same solvent as Buriti oil. Analytical reagent grade chloroform was used in all preparations.

Table 1

Composition of the oil from the shell and pulp of Buriti extracted with CO₂ at 20 MPa and 313 K [33]

Substance	Amount
Carotenoids (ppm)	1707
Tocopherols (ppm)	800
Free fatty acid composition (%)	
Saturated fatty acid:	
Miristic	0.10
Palmitic	17.34–19.20
Stearic	2.00
Unsaturated fatty acid:	
Oleic	73.30–78.73
Linoleic	2.40–3.93
Linolenic	2.20
Some carotenoids (ppm)	
<i>trans</i> - β -Carotene	672 $\pm$ 10
13- <i>cis</i> - β -Carotene	359 $\pm$ 27
9- <i>cis</i> - β -Carotene	150 $\pm$ 18
α -Carotene	61 $\pm$ 7

2.2. Preparation of Buriti oil/PS and Buriti oil/PMMA blends

The Buriti oil/PS and Buriti oil/PMMA blends were prepared by adding different amounts of Buriti oil (8; 15; 35 and 47 wt%) to polymer in chloroform at room temperature under continuous stirring for 4 h. The resultant mixture was submitted to solvent casting technique using TeflonTM dishes for at least 24 h at room temperature and vacuum (between 5 and 10 Torr) for 4 h. The casting surfaces were in an environment free from light to avoid the oil's decomposition and the thickness of the material obtained was between 200 μ m and 300 μ m.

2.3. Absorption and photoluminescence measurements

Buriti oil solution in chloroform (0.5% (vol/vol)) were prepared and exposed at ambient with different lighting conditions: laboratory environment, dark, UV light (254 nm) and sunlight, under atmospheric conditions. Samples of solutions were analyzed after the following time intervals: 0, 1, 2, 4 and 8 h of exposure. UV–Vis absorption spectra of the Buriti oil solutions were recorded on a DU650 Beckman UV–Vis spectrophotometer.

Measurements of electromagnetic radiation absorption and photoluminescence of Buriti oil, Buriti oil/PS and Buriti oil/PMMA were obtained in equipment built in the Physics Department of

Universidade Federal do Pará (UFPA) for this application. The equipment consisted of a silicon photodetector, an Acton 308i monochromator with a sample chamber, a Xenon lamp (75 W), a filter (350 nm) and a computer to control the experiments and data acquisition.

2.4. Scanning electron microscopy

Surface structures of the samples were studied through scanning electron microscopy, SEM (Zeiss, model DSM 962). The samples were fractured in liquid nitrogen, fixed on aluminum supports using silver adhesive and covered with gold (Sputter Coater Balzers SCD050). The SEM images were obtained at 15 kV and 60 μ A.

3. Results and discussion

The UV–Vis absorption spectrum of Buriti oil is displayed in Fig. 1. It can be observed that the Buriti oil shows a strong absorption of radiation between 300 nm and 550 nm due to the presence of β -carotene. Keinonen [34] observed an absorption band between 350 and 550 nm for a β -carotene–polystyrene film, while Kakegawa and Ogawa [35] reported absorption bands close to 463 nm and 488 nm for an inorganic system containing β -carotene. It is important to emphasize that even though the oil's fatty acids also present UV absorption as a result from the forbidden $n \rightarrow \pi^*$ (carbonyl groups) and the $\pi \rightarrow \pi^*$ (not-conjugated double bond) transitions, these absorptions take place near 200 nm [36–39]. On the other hand, β -carotene consists of a conjugated system where the $\pi \rightarrow \pi^*$ transitions shift towards longer wavelengths as a

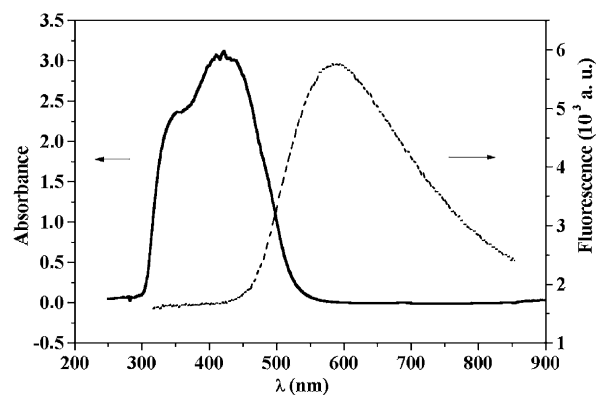


Fig. 1. UV–Vis absorption and fluorescence spectra of Buriti oil.

consequence of the proximity of the molecular orbital energy levels [40,41]. Therefore, it is clear that the oil's absorption between 300 nm and 550 nm is due to the β -carotene content. Furthermore the Buriti oil exhibits an intense and well-resolved photoluminescence band centered around 540 nm (Fig. 1), corresponding to the green range of the spectrum.

The evaluation of the oil's capacity to act as a radiation capturer was carried out by exposure of the Buriti oil solution to different radiation conditions. In all investigated situations a discoloration of the solution as a function of exposure time was verified. This is probably an effect of the deactivation of chromophore groups present in the oil, caused by the absorption–relaxation process. The loss of color was of greater intensity in the solution exposed to sunlight because of the nature and intensity of the incident radiation in addition to the heat generated by the UV radiation absorbed.

It is appropriate to mention that all the solutions, as well as the oil, were handled under atmospheric air. It was reported by Arudi et al. [38] that the unsaturated fatty acids have a significant lability toward dioxygen and light and this leads to the formation of hydroperoxide impurities. Furthermore, these impurities can absorb UV radiation in the 240–290 nm range. The absorption of solutions of Buriti oil was evaluated at 245 nm, 248 nm and 276 nm, which corresponded to the maximum absorption wavelengths registered. Variation of the solutions absorbance with time is showed in Figs. 2 and 3. The absorption changes more pronounced in the first two hours of exposure. After this time, in spite of the absorption being reduced, the solutions still absorbed at a high percentage in relation to the initial absorption (Table 2).

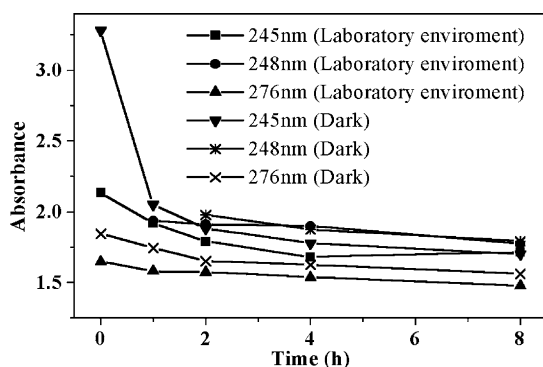


Fig. 2. Absorbance variation in UV–Vis with the time of exposition of the solutions of Buriti oil: in the laboratory environment and in the dark.

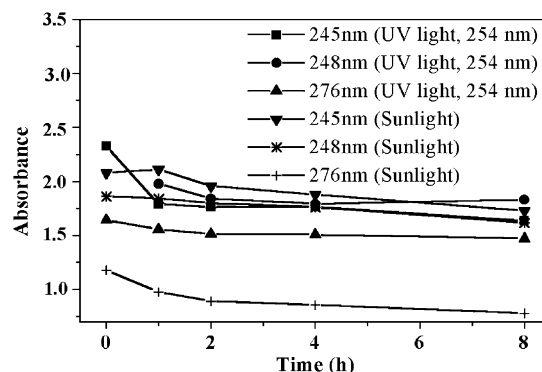


Fig. 3. Absorbance variation in UV–Vis with the time of exposition of the solutions of Buriti oil: in the UV light (254 nm) and in the sunlight.

The mixtures of PS and PMMA with Buriti oil resulted in materials with an orange color and whose intensity varied with the oil concentration in the matrix (8; 15; 35 and 47 wt%). It was also observed that an increase in oil content provides an increase in the apparent material flexibility.

Absorption spectra in the UV region of the PS and the Buriti oil/PS blends (Fig. 4) shows that the oil caused a very significant increase in the absorption of UV radiation by blends. While pure PS is almost transparent to UV radiation the Buriti oil/PS blends exhibits a strong/intense band of absorption between 275 nm and 375 nm. This suggests that the Buriti oil was incorporated in the PS matrix, although the absorption region is shorter than that exhibited by the oil itself (300–550 nm), probably due to the oil aggregation in the matrix interlayer. It is important to notice the displacement of the maximum absorption towards longer wavelengths that occurs following the addition of the Buriti oil content in the blends. This gradual change is associated with the β -carotene contained in the Buriti oil, and consequently, in the matrix interlayer.

Mixtures of PS with the Buriti oil also promoted an impressive enhancement in the visible radiation absorption of the resulted material. Fig. 5 shows that while pure PS was 80% transparent to visible light the Buriti oil/PS blends absorb around 70% of radiation in the range of 550–700 nm. By analyzing Fig. 5, we can also conclude that the wavelength limit of permitted light crossing the sample is determined by the oil concentration in the blends. Therefore, it is possible to make a variety of capturer with different cutoff point. Furthermore these blends can

Table 2

Percentage absorption of the Buriti oil solutions, after exposure for 8 h to different conditions

λ (nm)	Laboratory environment	Dark	UV light (254 nm)	Sunlight
245	80.22	51.84	70.37	82.92
248	91.59	90.61	92.61	86.77
276	89.64	84.65	89.49	66.04

Original absorption = 100%.

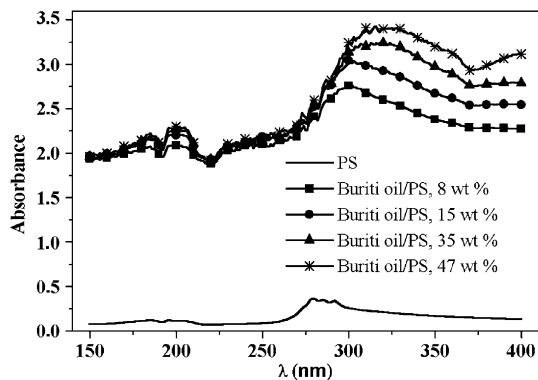


Fig. 4. UV absorption spectra of PS and Buriti oil/PS blends.

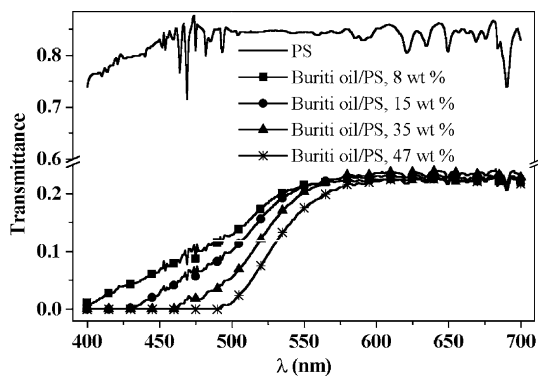


Fig. 5. Visible transmittance spectra of PS and Buriti oil/PS blends.

emit visible light exhibiting the photo-luminescent phenomena when it is properly UV excited. In Fig. 6, we can see that the PS mixed with Buriti oil presents a large band (around 510 nm) of emitted light when the samples are illuminated at 350 nm. We also observed a red shift in the emission band as a function of oil concentration.

Absorption spectroscopy in the UV region shows that the Buriti oil provides an increase of radiation absorption (up to 400%) by Buriti oil/PMMA blends, as indicated in Fig. 7. Absorption spectra of these blends reveal intense bands between 260

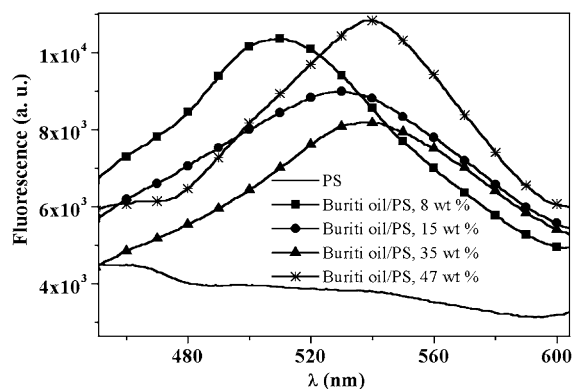


Fig. 6. Fluorescence spectra of PS and Buriti oil/PS blends.

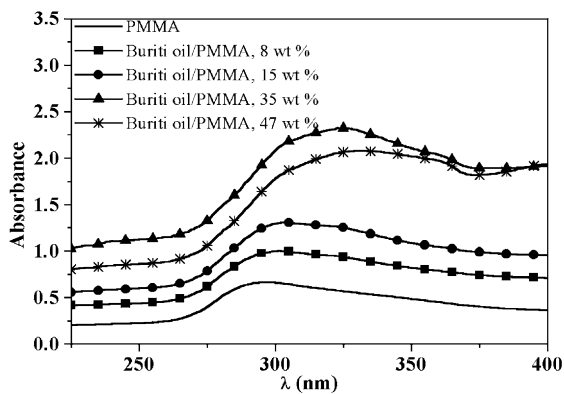


Fig. 7. UV absorption spectra of PMMA and Buriti oil/PMMA blends.

and 380 nm, with relative intensities proportional to the oil content, except for the blend with the major grade of Buriti oil. Even though exudation has not been observed, it is possible at higher oil concentrations that the Buriti oil has not been fully incorporated into the polymer matrix, and the most superficial coating undergoes the degradation reactions caused by light or atmospheric oxygen.

Transmission spectra in the visible region (Fig. 8) reveal that the PMMA mixed with Buriti oil presents one of the most notable properties of Buriti oil: light absorption in visible region (400 and

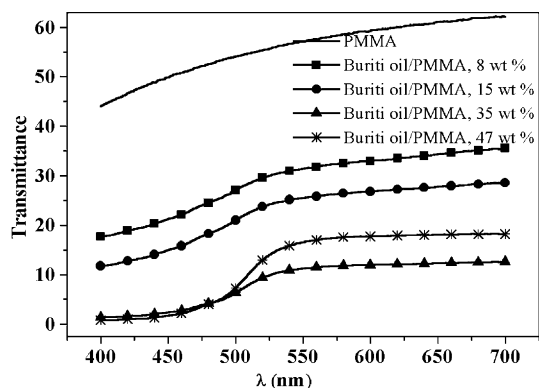


Fig. 8. Visible transmittance spectra of PMMA and Buriti oil/PMMA blends.

500 nm). Pure PMMA exhibits 60% transparency, while the mixed material underwent a transparency reduction with increasing oil content in the polymeric matrix. PMMA mixed with Buriti oil also presents photoluminescence related to the oil incorporated into the matrix (Fig. 9). The emission spectra of the blends exhibit a large band in the green region (530 to 580 nm) when the material is UV irradiated (350 nm).

The morphology of the samples was analyzed by SEM. In the micrographs of the fractured surfaces of the pure PS and Buriti oil/PS blends (Fig. 10) it can be observed that while pure PS presents a homogeneous surface, the Buriti oil/PS exhibit a lot of spherical cavities where the oil is located and immobilized. These cavities are regularly dispersed throughout the PS matrix, which may act as protection for the oil from degradation reactions generated by exposed to sunlight and atmospheric oxygen. The fractured surface of the pure PMMA

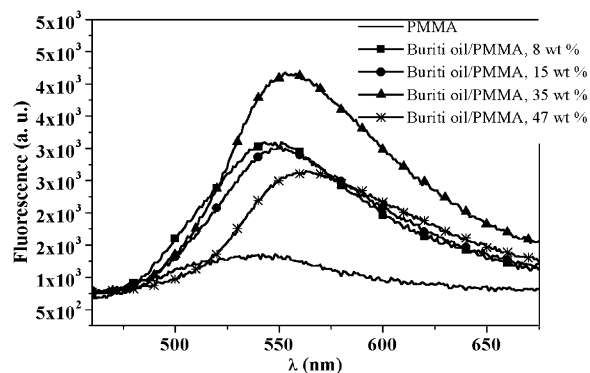


Fig. 9. Fluorescence spectra of PMMA and Buriti oil/PMMA blends.

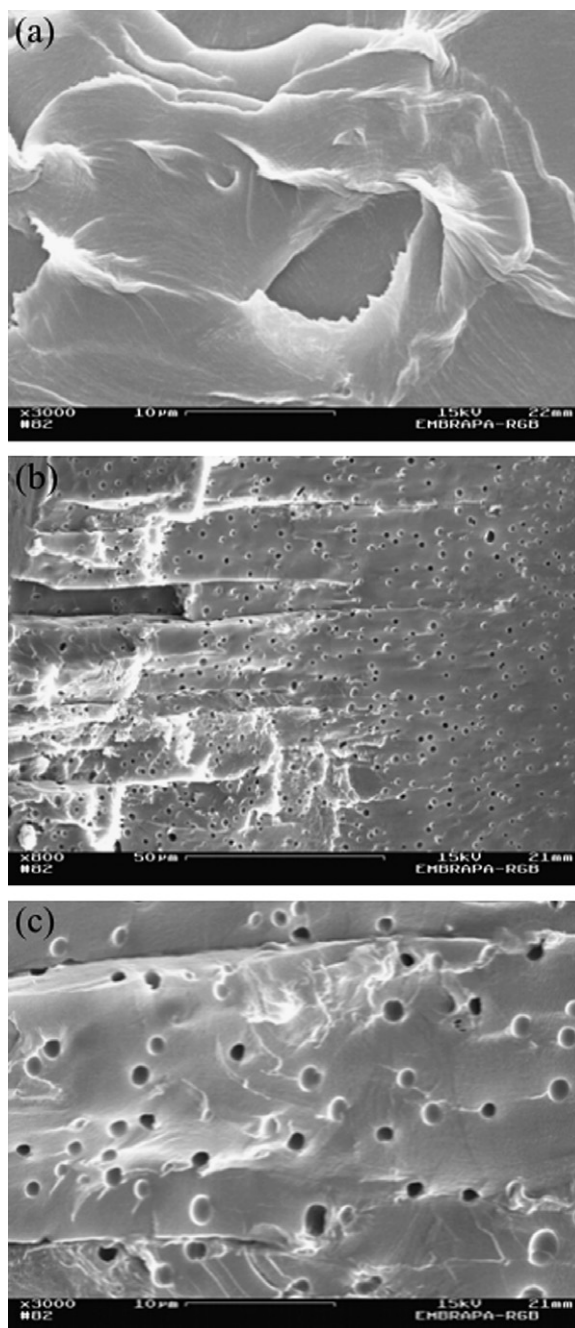


Fig. 10. SEM micrographs of the (a) pure PS ($\times 3000$) and Buriti oil/PS, 8 wt%, (b) $\times 800$ and (c) $\times 3000$.

(Fig. 11) shows layers and globules spread irregularly. In the Buriti oil/PMMA blends (Fig. 11) the oil is also located into cavities concentrated in one of the extremities of the longitudinal fracture of the sample. It can be noted that these cavities present an oval shape that may be linked to the

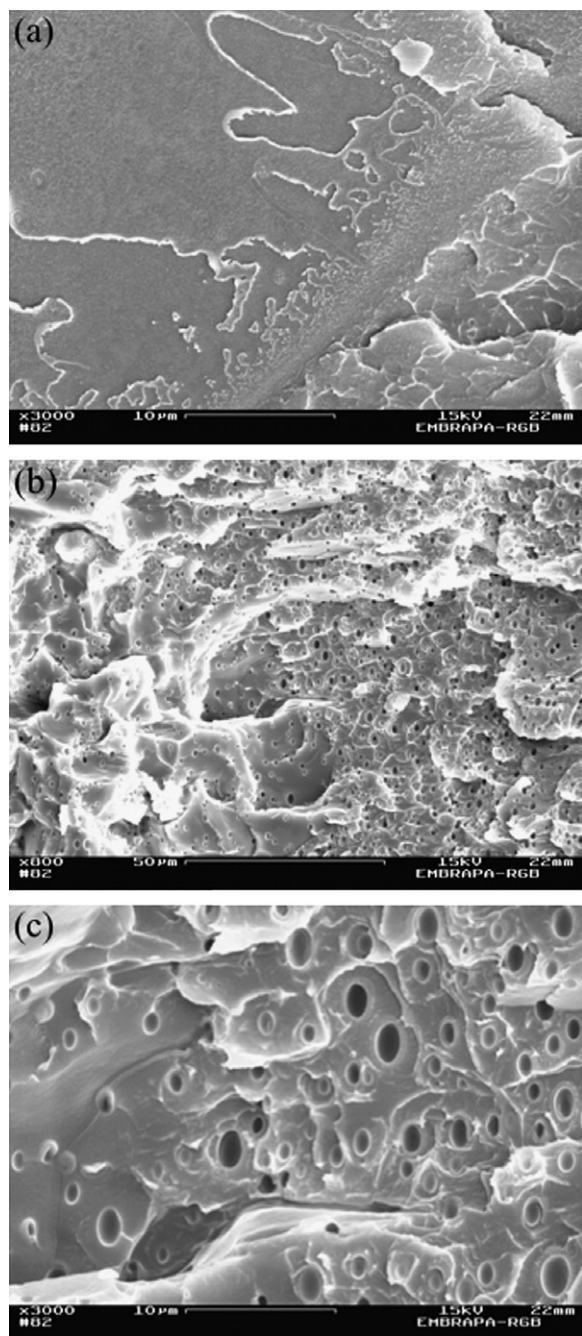


Fig. 11. SEM micrographs of (a) pure PMMA ($\times 3000$) and Buriti oil/PMMA, 8 wt%, (b) $\times 800$ and (c) $\times 3000$.

intermolecular interactions between the carboxylate groups of PMMA and the oil. Although these interactions have low energy they are present in vast quantities leading to a very good dispersion of Buriti oil in the matrix. The dispersed oil drops have diameters varying between $0.5\ \mu\text{m}$ and $1.5\ \mu\text{m}$. We

can conclude that the oil's properties were not modified and consequently, as observed for the PS, it is protected from the damages caused by exposure to sunlight and atmospheric oxygen.

Based on the observed absorption and photoluminescence properties it is possible to predict different applications for this type of polymeric material. Our results show that the typical Buriti oil absorption as well as its photoluminescence properties can be incorporated in PS and PMMA polymer matrices getting it in a stable solid material with important optical properties with a variety of powerful applications such as electromagnetic wave filters, UV radiation detectors, photo-luminescent plastics, LED devices, etc.

4. Conclusions

This study presents new materials composed by a polymer [polystyrene or poly(methyl methacrylate)] that incorporated Buriti oil micro drops at different concentrations. This study contributes towards the initial characterization of the optical properties of the Buriti oil/PS and Buriti oil/PMMA blends. Preliminary results showed that the Buriti oil presents intense absorption (300–550 nm). Its absorption bands are related to the β -carotene presence. This interesting oil has a strong emission band (500–650 nm). The diluted Buriti oil's solutions, even after 8 h of exposition at ambient temperature and pressure with different conditions of lighting, continue exhibiting a considerable percentual absorbance of the initial oil. The results also revealed two important physical properties of Buriti oil when added to PS and PMMA matrices: absorption and emission of light. It was observed that both Buriti oil/PS and Buriti oil/PMMA present a strong radiation absorption in visible and ultraviolet regions. Furthermore, the maximum of absorption displaced itself towards longer wavelengths as a consequence of an increase in the oil content. A similar behavior was noted regarding to photoluminescence phenomena. All the studied blends, when irradiated at 350 nm, showed light emission in the visible region (from 508 nm to 539 nm and from 530 nm to 580 nm, respectively). The maximum light emission, which occurs around the green light region, undergoes a displacement to longer wavelengths following an increase in the oil's concentration in the matrices. The Buriti oil displays itself as a good alternative to produce polymeric materials that absorbs visible and ultraviolet radiation, and exhibits

photoluminescence. It is worthwhile to notice that the wavelength of maximum emission is related to the oil content in the matrices. In this sense, the importance of this work is to encourage the use of the Buriti oil as polymeric additive, since this oil is cheaper and more abundant natural resource of Amazonian region. Moreover, the use of this oil mixed with PS and PMMA matrices allows one to obtain polymeric blends that absorb UV and visible radiation and emits light.

Acknowledgements

The authors are grateful for financial support from UnB-IQ, CNPq, FUNTEC/SECTAM, CAPES, FAP-DF and FINATEC and to Dr. J.A. Dias (IQ-UnB) for useful discussions.

References

- [1] Hawkins WL. Polymer degradation and stabilization. Polymer: properties and applications, vol. 8. Berlin: Springer-Verlag; 1984.
- [2] Al-Malaika S, Ashley H, Issenhuth S. The antioxidant role of α -tocopherol in polymers I. The nature of transformation products of α -tocopherol formed during melt processing of LDPE. *J Polym Sci, Part A: Polym Chem* 1994;32(16): 3099–113.
- [3] Al-Malaika S, Goodwin C, Issenhuth S, Burdick D. The antioxidant role of α -tocopherol in polymers II. Melt stabilising effect in polypropylene. *Polym Degrad Stab* 1999;64:145–56.
- [4] Al-Malaika S, Issenhuth S. The antioxidant role of α -tocopherol in polymers III. Nature of transformation products during polyolefins extrusion. *Polym Degrad Stab* 1999;65:143–51.
- [5] Huang H, He Q, Lin H, Bai F, Cao Y. Properties of an alternating copolymer and its applications in LEDs and photovoltaic cells. *Thin Solid Films* 2005;477:7–13.
- [6] Suzuki H. Organic light-emitting materials and devices for optical communication technology. *J Photochem Photobiol A* 2004;166:155–61.
- [7] Cuppoletti CM, Rothberg LJ. Persistent photoluminescence in conjugated polymers. *Synth Met* 2003;139:867–71.
- [8] Miozzo L, Papagni A, Cerminara M, Meinardi F, Tubino R, Botta C. Sensitized green emission in an electrically active polymer doped with a fluorinated acridine. *Chem Phys Lett* 2004;399:152–6.
- [9] Sales MJA, Serra OA, de Barros GG. Energy transfer to Eu (III) in the solid-state low-density polyethylene-poly(acrylic acid) and low-density polyethylene- Fe_2O_3 -poly(acrylic acid) matrices. *J Appl Polym Sci* 2000;78:919–31.
- [10] Uthirakumar P, Suh E-K, Hong C-H, Lee Y-S. Synthesis and characterization of polyesters containing fluorescein dye units. *Polymer* 2005;46:4640–6.
- [11] Huang Y, Lu Z, Peng Q, Jiang Q, Xie R-G, Han S-H, Dong L, Peng J-B, Cao Y, Xie M-G. Luminescent properties of coumarin-doped MEH-PPV and novel coumarin-terminated MEH-PPV. *Mater Chem Phys* 2005;93:95–9.
- [12] Liao L, Pang Y, Ding L, Karasz FE. Optical properties of poly[(1,4-phenylenevinylene)-alt-(1,3-phenylenevinylene)]s with *cis*-vinylene structure and short side chain. *Thin Solid Films* 2005;479:249–53.
- [13] Yoon BN, Chang I-H, Choi S-H, Choi DH, Cho MJ, Kim J-H. Unusual behaviours of photoluminescence by long-term illumination in alkoxy-substituted phenylene vinylene polymer. *Synth Met* 2005;150:213–6.
- [14] Yang S-H, Chen J-T, Li A-K, Huang C-H, Chen K-B, Hsieh B-R, Hsu C-S. New soluble poly(2,3-diphenylphenylene vinylene) derivatives for light-emitting diodes. *Thin Solid Films* 2005;477:73–80.
- [15] Tang R, Xu X, Cheng C, Yu G, Liu Y, Xi F. Synthesis and luminescence properties of novel phenyl-substituted poly(*p*-phenylene vinylene) derivatives. *Synth Met* 2005;150:63–71.
- [16] Marletta A, Gonçalves VC, Balogh DT. Effect of temperature on emission of MEH-PPV/PS solid-state solution. *J Lumin* 2005;116:8793.
- [17] Nguyen TP, Yang SH, Le Rendu P, Khan H. Optical properties of poly(2-methoxy-5-(2'-ethyl-hexyloxy)-phenylene vinylene) deposited on porous alumina substrates. *Composites Part A* 2005;36:515–9.
- [18] Cumpston BH, Jensen KF. Photo-oxidation of polymers used in electroluminescent devices. *Synth Met* 1995;73: 195–9.
- [19] Arora AP, Halek GW. Structure and cohesive energy density of fats and their sorption by polymer films. *J Food Sci* 1994;56:1325–7.
- [20] Li F, Hanson MV, Larock RC. Soybean oil-divinylbenzene thermosetting polymers: synthesis, structure, properties and their relationships. *Polymer* 2001;42:1567–79.
- [21] Okieimen FE. Studies in the utilisation of epoxidised vegetable oils as thermal stabiliser for polyvinyl chloride. *Indus Crops Prod* 2002;15:71–5.
- [22] Okieimen FE, Eromonsele OC. Stabilising effect of derivatives of Khaya seed oil on the thermal degradation of poly(vinyl chloride). *Eur Polym J* 2000;36:525–37.
- [23] Aigbodion AI, Okieimen FE. Kinetics of the preparation of rubber seed oil alkyls. *Eur Polym J* 1996;32:1105–8.
- [24] Okieimen FE, Sogbaiké CE. Stabilising effect of derivatives of jatropa seed oil on the thermal degradation of poly(vinyl chloride). *Eur Polym J* 1996;32:1457–62.
- [25] Schuchardt U, Sercheli R, Vargas RM. Transesterification of vegetable oils: a review. *J Braz Chem Soc* 1998;9:199–210.
- [26] Barret LW, Sperling LH, Murphy CJ. Naturally functionalized triglyceride oils in interpenetrating polymer networks. *J Am Oil Chem Soc* 1993;70:523–34.
- [27] Schuchardt U, Vargas RM, Gelbard G. Transesterification of soybean oil catalyzed by alkylguanidines heterogenized on different substituted polystyrenes. *J Mol Catal A: Chem* 1996;109:37–44.
- [28] Lognay G, Trebejo E, Jordan E, Marlier M, Severin M, de Zárate IO. Investigaciones sobre el aceite de *Mauritia flexuosa* L. *Grasas y Aceites* 1987;38:303–7.
- [29] França LF, Reber G, Meireles MAA, Machado NT, Brunner G. Supercritical extraction of carotenoids and lipids from Buriti (*Mauritia flexuosa*): a fruit of the Amazon region. *J Supercrit Fluids* 1999;14:247–56.

- [30] Bernal-Alvarado J, Mansanares AM, da Silva EC, Moreira SGC. Thermal diffusivity measurements in vegetable oils with thermal lens technique. *Rev Sci Instrum* 2003;74:697–9.
- [31] Garcia-Quiroz A, Moreira SGC, de Moraes AV, Silva AS, Rocha GN, Alcântara P. Physical and chemical analysis of dielectric properties and differential scanning calorimetry techniques on Buriti oil. *Instrum Sci Technol* 2003;31:93–101.
- [32] Albuquerque MLS, Guedes I, Alcântara P, Moreira SGC. Infrared absorption spectra of Buriti (*Mauritia flexuosa* L.) oil. *Vib Spectrosc* 2003;33:127–31.
- [33] Albuquerque MLS, Guedes I, Alcântara P, Moreira SGC, Neto NMB, Correa DS, et al. Characterization of Buriti (*Mauritia flexuosa* L.) oil by absorption and emission spectroscopies. *J Braz Chem Soc* 2005;16:1113–7.
- [34] Keinonen T. Investigation of grating recording in betacarotene–polystyrene film. *J Mod Opt* 1997;44:555–62.
- [35] Kakegawa N, Ogawa M. The intercalation of β -carotene into the organophilic interlayer space of dialkyldimethylammonium-montmorillonites. *Appl Clay Sci* 2002;22:137–44.
- [36] Silverstein RM, Bassler GC, Morrill TC. Spectrometric identification of organic compounds. New York: John Wiley & Sons; 1991.
- [37] van den Berg JDJ, Vermist ND, Carlyle L, Holcapek M, Boon JJ. Effects of traditional processing methods of linseed oil on the composition of its triacylglycerols. *J Sep Sci* 2004;27:181–99.
- [38] Arudi RL, Sutherland MW, Bielski BHJ. Purification of oleic acid and linoleic acid. *J Lipid Res* 1983;24:485–8.
- [39] Kapoor R, Reaney M, Westcott ND. Conjugated linoleic acid oils. In: Fereidoon S, editor. Canada: John Wiley & Sons Inc.; 2005. p. 1–35.
- [40] Renge I, van Grondelle R, Dekker JP. Matrix and temperature effects on absorption spectra of β -carotene and pheophytin a in solution and in green plant photosystem II. *J Photochem Photobiol A* 1996;96:109–21.
- [41] Atkins PW. Physical chemistry. Oxford: Oxford University Press; 1997.