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The Effect of The Wavelength of the LED used to Pump Phosphor Produced from Curcuminoids Dye Extracted from Turmeric (Curcuma Longa L.) to Produce White Light

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Abstract. Previous studies have investigated the use of curcuminoids dye extracted from turmeric (*Curcuma longa L.*) for light down-conversion of UV light (390 nm) for application as white light emitting diode (WLED) as well as the three methods used to extract curcuminoids dye (the normal method, use of Soxhlet apparatus and by combining the normal method with the Soxhlet extraction). This paper goes a step further to analyze the effect of the wavelengths of LED sources (365, 390 and 445nm) used to pump phosphor in the conversion of white light. The chromaticity coordinates (CIE), color rendering index (CRI) and color temperature (CCT) were measured for different applied currents (20, 60 and 100mA) and weights of curcuminoids (5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 55mg). With optimum CRI, CIE and CCT values of 73.9, 0.3304;0.3501, and 5579K, respectively, the samples pumped with LED source of 365 nm wavelength produced better white light compared to 390 and 445 nm, in terms of the amount of phosphor used. Thus, the wavelength of the LED source used to pump phosphor is inversely related to the amount of yellow light produced into the blue light when the concentration of phosphor is constant. The stress test showed that the degradation time of the dye could be improved by reducing the wavelength used to pump the sample or selecting a weak thermal conductivity material.

1- Introduction

In recent times, LEDs have become extensively utilized in different applications, beginning from their use as alarm signals in traffic signals and other similar devices to parts in television and telephone screens such as OLED screens that have recently garnered a global trend. This attention can be attributed to their exceptional properties, which include long life and energy efficiency. LED lamps can be produced in various colors using different techniques, with the white LEDs being the most important color. The white LED industry has transformed into one of the most recognized and significant LED field due to its application in majority of public and private facilities in preference to traditional light sources, such as incandescent and fluorescent lamps, which consume significant amounts of energy and negatively affect the environment [1, 2].

A set of methods and materials have been applied to acquire white light emission, which comprises the three essential components: red, green and blue components like excited state intramolecular proton transfer (ESIPT) [3], FRET [4], the mixing of monomer and excimer fluorescence [5] and Inter- and intra- molecular charge transfer [6]. Organic and inorganic materials that are capable of emitting white light when photoexcited at near UV wavelengths are also used to produce white light, although organic materials is a preferred option because of its low-toxicity, cost effectiveness and ease of modification [7]. Examples of such organic materials are [BODFluTh]2FB [8], BODIPY, (TPA-Flu)2BT and (TPA-Flu)2BTBT [9] and Lumogen® [10].

However, there is a dearth of research on the use of dyes extracted from nature despite the numerous existing natural plants rich in fluorescent pigments such as Turmeric (*Curcuma longa L.*). Turmeric is a member of the gingerbread plant family (Zingiberbis family), frequently appears in yellow color and is exploited as a food additive, spice and color agent [11, 12]. It has also been incorporated into traditional medicines such as Ayurveda, Siddha, and Unani [13]. There are several solvents for extracting dye from turmeric such as methanol [14] , dichloromethane (DCM), acetonitrile, dimethylsulfoxide (DMSO) [11], ethanol, acetone and ethyl acetate [15]. The dye extracted from Turmeric consists of numerous compounds called curcuminoids. Curcuminoids is essentially composed of Curcumin, Demethoxycurcumin and Bis-demethoxycurcumin [16].

This study investigates the effect of three different values of LED wavelength (365, 390 and 445 nm) used to pump phosphors produced from the curcuminoids extracted from Turmeric (*Curcuma longa L.*) to yield white light. The curcuminoid dye was extracted using methanol. Silica gel was used to absorb the curcuminoids extracted from turmeric and to resolve its intrinsic sticky feature. Phosphor was produced by mixing the extracted curcuminoids with silica gel. Different extracting techniques and different weights of phosphor were used in this study. The electroluminescence spectra (EL), color temperature (CCT), color rendering index (CRI) and chromaticity coordinates (CIE) were measured.

2-Experimental

2.1 Materials
CHANZON UV-LED ultraviolet chips (wavelengths of 365 and 390nm, and 10 watts power) and blue LED (wavelength 445nm, power 10 watts) were procured from AliExpress. Natural Turmeric was obtained from the Indian market (Little India) in Penang, Malaysia. Methanol was used as the extracting solvent. Silica gel (particle size: 0.040-0.063mm) is a German product. The silicon (model BM800-H001) was purchased online and comes in two containers (A and B), which were subsequently mixed at a ratio of 1:1. 10 samples of circular shaped aluminum molds with diameter size of 2 cm each, were fabricated in the laboratory workshop.

2.2 Preparation of curcuminoids dye (phosphor)
Natural Turmeric was crushed to obtain *Curcuma longa L.* powder. The curcuminoids were extracted from Turmeric (*Curcuma longa L.*) via three approaches: normal method (M1), use of the Soxhlet apparatus (M2) and by combining the normal way with the Soxhlet extractor (M3). The difference between these three methods and the results of each method were explained in another research paper.

2.3 Preparation of samples
The two-part silicone material was doped with curcuminoid dye (phosphor) for encapsulation. The silicone was prepared by mixing part A with part B at a ratio of 1:1. Approximately 0.7 ml silicone volume was mixed with a different weights (concentrations) of phosphor (5,10, 15, 20, 25, 30, 35, 40, 45 ,50 and 55 mg) for M1, M2 and M3. The mixtures were then poured into molds, which were then oven dried at 50 °C for 20min. The samples were removed from the mold and subsequently characterized.

3- Results and discussions

3.1 Absorption

Following the mixing of phosphor with silicone rubber, its absorption and fluorescence were measured using Cary Series 5000 UV–Vis-NIR spectrophotometer, which is depicted in figure 1. For fluorescence spectra, the excitation UV LED wavelength was fixed at 390 nm. The absorption spectra shows a high intensity band in the region of 300 to 500 nm with maximum value at 410nm, which is in line with prior studies [17]. Because of the wide absorption range, a comparative analysis was carried out using three wavelengths of LED pumped sources (365, 390 and 445 nm).

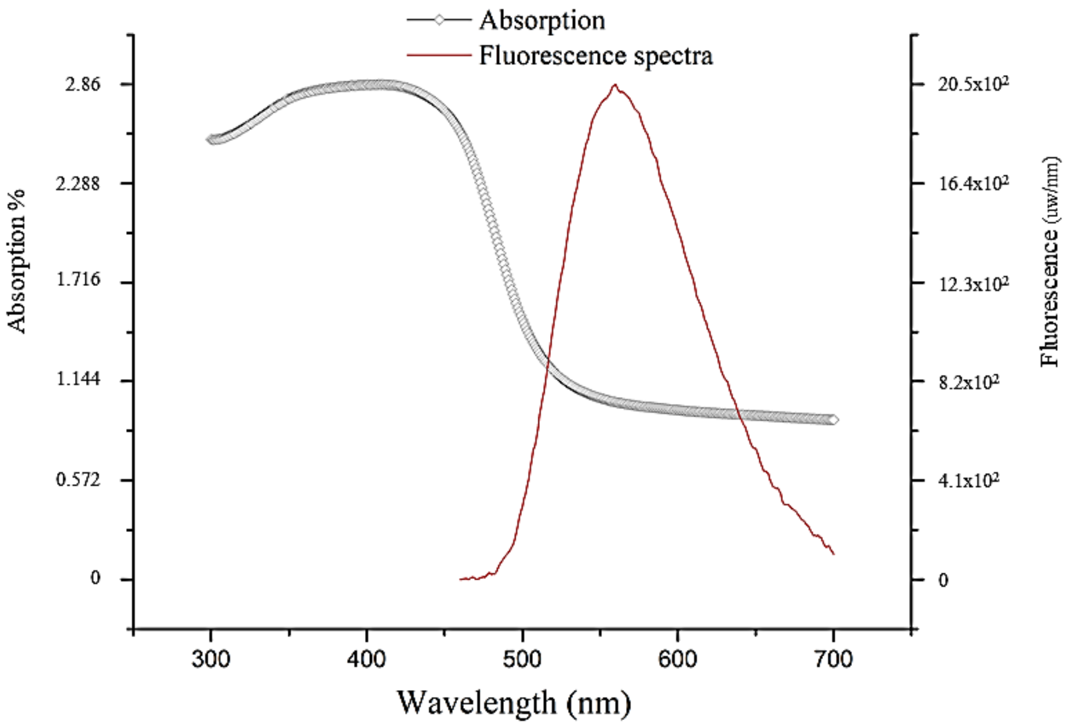


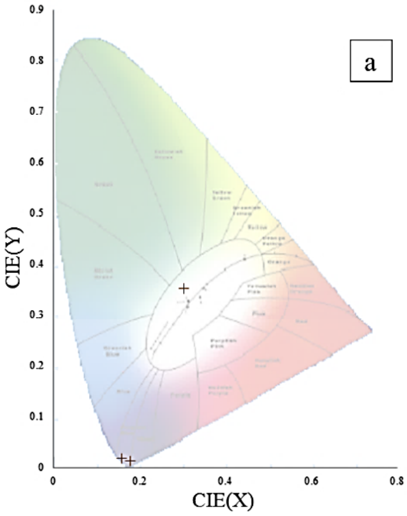
Figure 1. Absorption and Fluorescence for sample weight 40mg with current 60mA extracting by M3 method

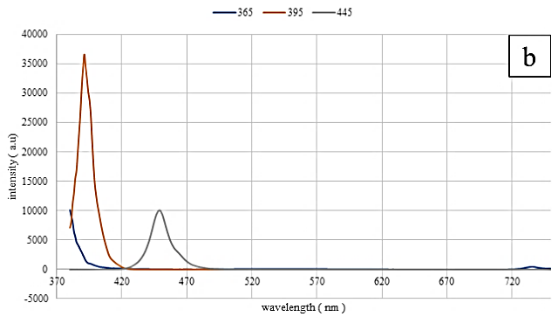
The absorption is attributable to the electronic dipole allowed π - π* type excitation of its extended π-conjugation system. When light is absorbed, a π electron is excited from the ground state to the first excited state and oscillates from one end of the chromophore to the other [16, 17], which leads to light absorption in the ultraviolet to blue range, wherein a yellow color is produced, as observed in figure 1 (red line). A broad band of emission for yellow color is discernible in the region of 500 to 700 nm with a peak value of 560nm.

3.2 Down-conversion light using remote phosphor

Three types of LED sources (365 nm, 390 nm and 445 nm) were utilized for light down-conversion. The UV and blue light from a LED were used for phosphor excitation to enable the emission of yellow light, which blends with the blue light from the source to produce a luminous flux appearance of white light. When three samples of phosphors with similar weights (10mg) were pumped with at wavelengths, it was observed that the best white light was produced at 365 nm with CIE of 0.298;0.355, which is comparably lower than 0.175;0.0165 and 0.1539;0.0219 for 390nm and 445 nm, respectively, as observed in figure 2. This indicates that the amount or intensity of yellow light produced by phosphor when pumped by wavelength of 365 nm is sufficient to match the blue light generated by the source to form the white light.

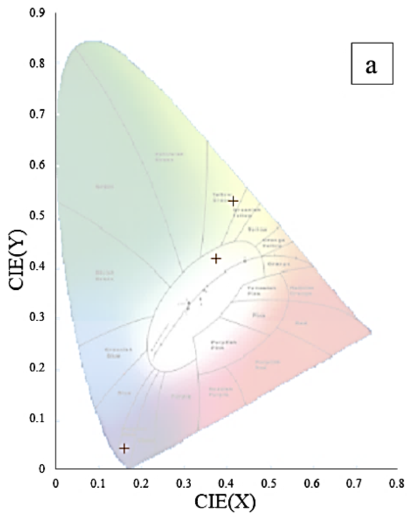
By increasing the weight of phosphor from 10 mg to 30 mg, the light CIE coordinates of the sample pumped at 365 nm in the range of yellow light increased to 0.4118;0.5323 (figure 3). This indicates a higher increase in the amount of yellow light produced by the sample compared to the blue light output from the source. It is also observed that the sample pumped at a wavelength of 390 nm entered the white light range, whereas the 445nm sample remained in the range of blue light.

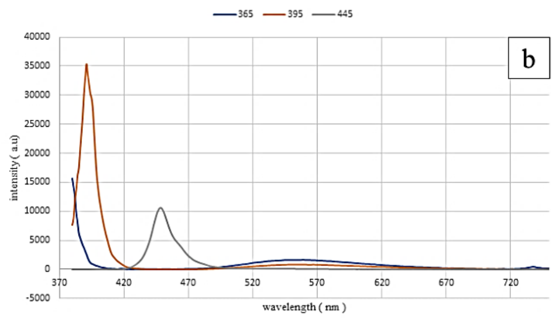




wavelength (nm)	CIE(X)	CIE(Y)	CCT(K)	CRI(%)
365	0.2983	0.3549	6955	63
395	0.175	0.0165	25000	-67.4
445	0.1539	0.0219	25000	-53.4

Figure 2. CIE chromaticity coordinates (a) and Electroluminescence spectra (EL) (b) for M3 phosphor (10mg) at I=20mA pumped by wavelength (365,390 and 445nm).

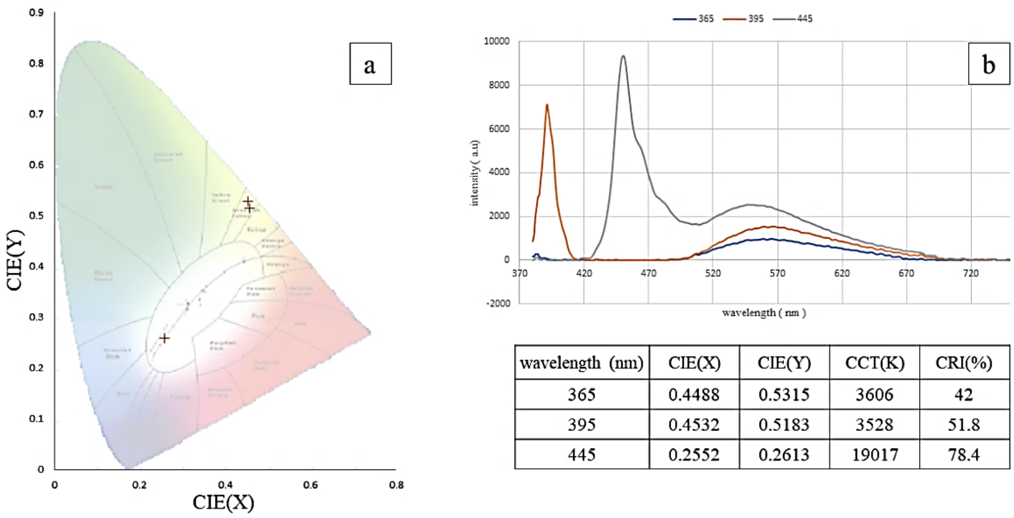




wavelength (nm)	CIE(X)	CIE(Y)	CCT(K)	CRI(%)
365	0.4118	0.5323	4138	49.7
395	0.3714	0.4184	4482	55.1
445	0.1567	0.0443	25000	-28.5

Figure 3. CIE chromaticity coordinates (a) and Electroluminescence spectra (EL) (b) for M3 phosphor (30mg) at I=100mA pumped by wavelength (365,390 and 445nm).

As the weight (concentration) of samples is increased to 50 mg, the 365 nm and 390 nm samples moved to yellow light as expected and at the same time the 445-nm sample shifted to the range of white light, as observed in figure 4. As shown in figures 3 and 4, the electroluminescence spectra range of yellow light produced from samples is similar, although there is a difference in the concentration and sources used, where the period ranged from 500 to 700nm, which is consistent with previously shown in the absorption part.



wavelength (nm)	CIE(X)	CIE(Y)	CCT(K)	CRI(%)
365	0.4488	0.5315	3606	42
395	0.4532	0.5183	3528	51.8
445	0.2552	0.2613	19017	78.4

Figure 4. CIE chromaticity coordinates (a) and Electroluminescence spectra (EL) (b) for M3 phosphor (50mg) at I=20mA pumped by wavelength (365,390 and 445nm).

The results of M1 and M2 samples are comparable with M3, where it is generally observed that the amount of yellow light produced by the sample compared with the blue light produced by the source increases as the wavelength of the source decreases. Therefore, LED sources with relatively smaller wavelength are preferred to produce white light because they require less phosphor. Table 1 shows the optimum results for each wavelength, where the concentration (weight) of phosphor is observed to increase with wavelength. The color rendering index (CRI) was better when using a wavelength of 365 nm followed by 445 nm (73.9 and 70.7, respectively), but in terms of chromaticity coordinates (CIE), the 390nm wavelength exhibited the best result (0.3304;0.3501).

Table 1. Summary of the optimum results of the wavelengths used to pump samples

Wavelength (nm)	Weight (mg)	Current (mA)	CIE(X)	CIE(Y)	CCT(K)	CRI(%)
365	5	100	0.3116	0.3465	6428	73.9
390	35	60	0.3304	0.3501	5579	54.5
445	55	20	0.3122	0.3412	6432	70.7

3.3 Stress testing

As the LED continues to work, the optical transmission of the samples tends to increase. The chromatic co-ordinates (CIE) of three LED sources (365, 390 and 445 nm) were measured every minute for 10 minutes at a constant current of 60 mA for same phosphor concentration (40 mg). As observed in figure 5, the top point represents CIE of the 365-nm source, where there is no evident change in the coordinates with time. This indicates that the degradation of phosphor for 365 nm LED source is very low over time. The same stress test was repeated to show the CIE of light emitted over time, using 390 nm wavelength source. With time, the top point visibly and gradually shifted towards the direction of the blue zone. When the same test was performed using the 445-nm source, the light CIE shifted rapidly towards the blue zone at the bottom-left of the CIE diagram, which denotes the wavelength of the blue color produced from the source. The key reason for this observed change in light is the degradation of the organic dye since it is affected by the heat from the source. This problem can be resolved by selecting a weak thermal conductivity material or using a low wavelength source, as reported in earlier research papers.

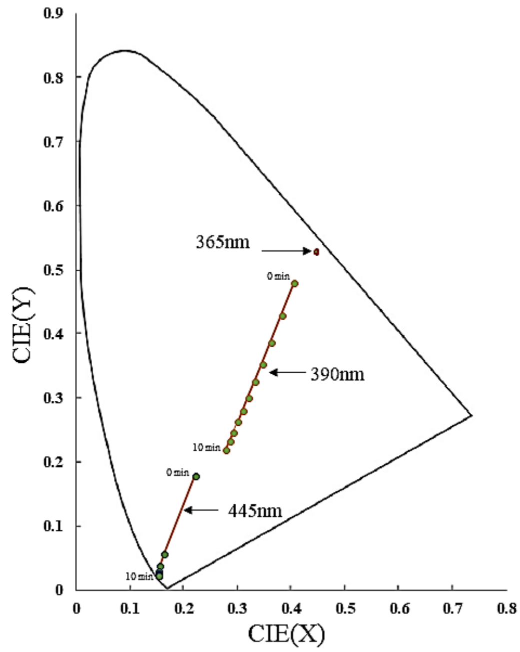


Figure 5. Light Emitting Coordination in CIE chromaticity diagram during stress test comparison between three types of wavelength pumped (365,390 and 445nm) during 10 min.

4. Conclusion
In summary, this study was able to produce white light emission from natural dye extract of Turmeric (*Curcuma Longa. L.*). The samples pumped with LED source of 365 nm wavelength produced better white light compared to 390 and 445 nm, in terms of the amount of phosphor used in the production of samples. Thus, the wavelength of the LED source used to pump phosphor is inversely related to the amount of yellow light produced into the blue light when the concentration of phosphor is constant.
Based on the chromatic co-ordinates (CIE) results, dye degradation is lower in samples where phosphor is pumped at relatively lower wavelengths. The stress test showed that the degradation time of the dye could be improved by reducing the wavelength used to pump the sample or selecting a weak thermal conductivity material.

5. Acknowledgment
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