Supplementary Information (SI) for Journal of Materials Chemistry C.

Supplementary Information

Biomass-derived white light-emitting Carbon Dots for white LEDs

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S1. Experimental Section

S1.1 Materials. The *Epiphyllum oxypetalum* plant was purchased from a local nursery in Sangareddy, Hyderabad, and grown at home under optimal conditions, and used for the experiments. Methanol and hexane were purchased from FINAR, Polyvinylpyrrolidone K90 (PVP) from SRL chemicals, and Polyvinyl alcohol (PVA), Poly(methyl methacrylate) (PMMA) from BLD Pharm. Deionized (DI) water was used for the experiment. All the reagents and chemicals were used directly without further purification.

S1.2 Preparation of the sample for phytochemical analysis. Fifteen grams of the naturally dried leaf powder of *E. oxypetalum* were subjected to Soxhlet extraction using methanol as solvent. The powdered sample was made into a thimble with handmade filter paper. The leaf powder-filled thimble was carefully placed inside the extractor chamber and filled with methanol in a 1:10 ratio. The reservoir round-bottom flask was heated to 50-60 °C in a heating mantle. Twenty refluxes were run to get a good-quality powder extract. The resultant solvent extract was condensed using a rotary evaporator at reduced temperature under vacuum conditions. The resultant crude extract 1.659 g was collected in a container for further analysis and stored at -20 °C.

S1.3 Gas Chromatography-Mass Spectroscopy (GC-MS). The phytochemical compounds present in the methanol extract of the leaves of *E. oxypetalum* were identified through GC-MS analysis. The 50 mg crude extract was dissolved in 1 mL of GC-grade ethyl acetate, vortexed, and filtered through a 0.45 μm filter cartridge. Then, 3 μL of the sample is injected into the GC-MS instrument. The analysis was carried out in spitless mode, with the injector and transfer line temperatures set to 280 °C, and a pressure of 8.2317 psi. The separation was achieved using a DB-5ms column (30 m x 250 μm x 0.25 μm) with Helium as the carrier gas, at a flow rate of 1 mL/min. The oven temperature was programmed to range from 60 °C to 325 °C, with a 1-minute equilibrium time through multiple ramps, resulting in a total run time of approximately 41 minutes. The GC-MS analysis was done by Whizbang Bioresearch Pvt Ltd, and the obtained mass spectra were compared with the NIST (National Institute of Standards and Technology) library for qualitative identification of compounds in the leaf sample.

S1.4 Metal-ion sensing studies. The fluorescence (FL) behavior of the carbon dots (CDs) towards various metal ions (Na^+, K^+, Mg^{2+}, Zn^{2+}, $Cu^{2+,}$ Pb^{2+}, Fe^{3+}, and Hg^{2+}) at 20 µM concentration was investigated. For the blank measurement, the CD solution (synthesized in methanol) was mixed with 20 µL of deionized water. For metal ions, 20 µL of aqueous metal-ion solutions were added separately to the CD solution. The mixture was gently mixed, and the FL spectra were recorded under identical conditions. The relative FL intensity (I/I_O) was calculated from the emission intensity at ~610 nm, where I_O and I correspond to the FL intensity of the blank and metal-ion treated samples, respectively.

S2. Characterization. GC-MS was performed using an Agilent Technologies 7890B GC & 5977B MSD instrument. UV-visible absorbance spectra of the liquid samples were obtained on a Jasco V730 spectrophotometer, at a resolution of 1 nm. FL excitation, emission, and temperature-dependent spectra were measured in a HORIBA FluoroMax-4 spectrofluorometer. The ATR-IR spectra were recorded using the Bruker Alpha P Fourier Transform spectrometer. X-ray photoelectron spectroscopy (XPS) measurements were performed with a Shimadzu AXIS SUPRA monochromator using Al Ka radiation of 1486 eV operated at 75W (40 mA emission current). TEM analysis was recorded with a JEOL JEM 2100FX. The TEM analysis was performed by placing a drop of carbon dot solution on a carbon-coated 200-mesh copper grid and allowing the solvent to evaporate. The PXRD measurements were done using a Rigaku Ultima IV instrument. Litesizer DLS 500 BM10 was used for Zeta potential measurement. Fluorescence quantum yield was calculated using a spectrofluorometer FS5 Edinburgh instrument by the direct method (absolute quantum yield) with an SC-30 integrating sphere.

Time-resolved fluorescence decay studies were performed using the TCSPC technique (Horiba Fluorohub) with an instrumental response function (IRF) of approximately 1 ns. Nano LED (Light-emitting Diode) with an excitation of 371 nm was used. TSCPC data were collected and fitted using DAS6 analysis software. All the parameters, Correlated Color Temperature (CCT), and Color Rendering Index (CRI), were calculated using ColorCalculator v7.71 software. All the fluorescent images were taken under a 365 nm UV LED flashlight.

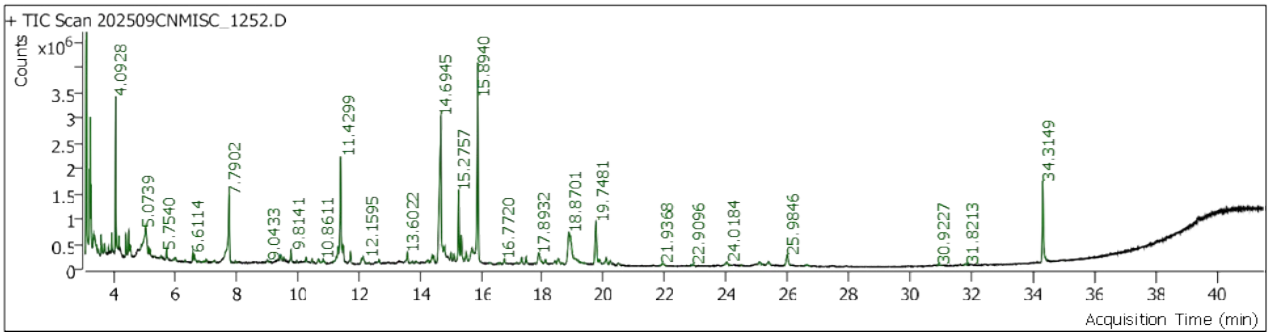


Fig. S1. GC-MS chromatogram of *E. oxypetalum* leaf extract in methanol.

Table S1. GC-MS phytochemical analysis of the methanolic extract of *E. oxypetalum*.

Sno.	RT Min	Compound Name	Molecular formula	Area % of total
1	3.1283	3-Hydroxybenzaldehyde, tert-butyldimethylsilyl ether	$C_{13}H_{20}O_2Si$	4.65
2	3.1489	3-Hydroxybenzaldehyde, tert-butyldimethylsilyl ether	$C_{13}H_{20}O_2Si$	5.14
3	3.2437	3-Hydroxy-4-methoxybenzaldehyde, TBDMS	$C_{14}H_{22}O_3Si$	1.95
4	3.2726	Disiloxane, 1,3-diethoxy-1,1,3,3-tetramethyl-	$C_8H_{22}O_3Si_2$	3.26
5	3.3014	Disiloxane, 1,3-diethoxy-1,1,3,3-tetramethyl-	$C_8H_{22}O_3Si_2$	1.38
6	3.3880	2,6-Dihydroxyacetophenone, 2TMS derivative	$C_{14}H_{24}O_3Si_2$	2.58
7	3.5281	2,4-Dimethoxy-2'-ethoxychalcone (isomer 2)	$C_{19}H_{20}O_4$	0.33
8	3.6270	Diethyl sulfate	$C_4H_{10}O_4S$	0.62
9	3.7383	1-Hexanol, 2-ethyl-	$C_8H_{18}O$	0.29
10	3.8661	Acetic acid, N'-[3-(1-hydroxy-1-phenylethyl)phenyl]hydrazide	$C_{16}H_{18}N_2O_2$	0.10
11	3.9650	Cyclotrisiloxane, hexamethyl-	$C_6H_{18}O_3Si_3$	0.47
12	4.0928	Cyclotrisiloxane, hexamethyl-	$C_6H_{18}O_3Si_3$	4.26
13	4.2082	2,5-Dihydroxybenzaldehyde, 2TMS derivative	$C_{13}H_{22}O_3Si_2$	0.26
14	4.4308	Silicic acid, diethyl bis(trimethylsilyl) ester	$C_{10}H_{28}O_4Si_3$	0.54
15	4.5215	Isophorone	$C_9H_{14}O$	0.61
16	4.5710	Cyclopentasiloxane, decamethyl-	$C_{10}H_{30}O_5Si_5$	0.51
17	4.9296	2-t-Butyl-5-propyl-[1,3]dioxolan-4-one	$C_{10}H_{18}O_3$	0.19
18	5.0739	Dodecane	$C_{12}H_{26}$	2.87
19	5.1687	Naphthalene	$C_{10}H_8$	0.20
20	5.2222	Benzoic acid, 2-(2-methylpropyl)oxy-, methyl ester	$C_{12}H_{16}O_3$	0.16

21	5.3706	5-(p-Aminophenyl)-4-phenyl-2-thiazolamine	$C_{15}H_{13}N_3S$	0.04
22	5.5809	((9-Methoxy-6a,11a-dihydro-6H-benzofuro [3,2-c]chromen-3-yl)trimethylsilane	$C_{19}H_{22}O_4Si$	0.12
23	5.7540	Cyclotetrasiloxane, octamethyl-	$C_8H_{24}O_4Si_4$	0.43
24	6.0508	Eicosane, 10-methyl-	$C_{21}H_{44}$	0.30
25	6.3682	Cyclotetrasiloxane, octamethyl-	$C_8H_{24}O_4Si_4$	0.07
26	6.6114	2,4'-Dimethoxy-2'(tert.-butyldimethylsilyl)oxychalcone	$C_{23}H_{30}O_4Si$	0.29
27	6.6608	4-Hydroxy-2-methylacetophenone	$C_9H_{10}O_2$	0.42
28	6.8010	Benzamide, 4-nitro-N-(4,5,6,7-tetrahydro-3-cyanobenzothien-2-yl)	$C_{16}H_{13}N_3O_3S$	0.07
29	6.9576	Pentane-2,4-dione, 3-amino(1-piperazino)methylene-	$C_{10}H_{17}N_3O_2$	0.09
30	7.0565	Pyrrolizin-1,7-dione-6-carboxylic acid, methyl(ester)	$C_9H_{11}NO_4$	0.17
31	7.3245	Disulfide, di-tert-dodecyl	$C_{24}H_{50}S_2$	0.14
32	7.7902	Tetradecane	$C_{14}H_{30}$	4.99
33	7.9963	3-buten-2-one, 4-(5,5-dimethyl-1- oxaspiro[2.5]oct-4-yl)	$C_{13}H_{20}O_2$	0.07
34	9.0433	2,5,5,8a-Tetramethyl-6,7,8,8a-tetrahydro-5H-chromen-8-ol	$C_{13}H_{20}O_2$	0.16
35	9.4720	Octadecane	$C_{18}H_{38}$	0.24
36	9.5750	Spiro-1-(cyclohex-2-ene)-2'-(5'-oxabicyclo[2.1.0]pentane), 1',4',2,6,6-pentamethyl-	$C_{14}H_{22}O$	0.10
37	9.8141	2,4-Di-tert-butylphenol	$C_{14}H_{22}O$	0.48
38	10.0037	Hexadecanedioic acid, dimethyl ester	$C_{18}H_{34}O_4$	0.04
39	10.3046	Tetradecane, 2,6,10-trimethyl-	$C_{17}H_{36}$	0.22
40	10.5066	Eicosane, 10-methyl-	$C_{21}H_{44}$	0.18
41	10.7045	Dodecanoic acid	$C_{12}H_{24}O_2$	0.31
42	10.8611	Dodecane, 5,8-diethyl-	$C_{16}H_{34}$	0.30
43	11.2857	E-15-Heptadecenal	$C_{17}H_{32}O$	0.39
44	11.3475	2-Hexadecanol	$C_{16}H_{34}O$	0.72
45	11.4299	Diethyl Phthalate	$C_{12}H_{14}O_4$	5.93
46	11.5165	Pentafluoropropionic acid, 4-hexadecyl ester	$C_{19}H_{33}F_5O_2$	0.77
47	11.7514	Pentafluoropropionic acid, 4-hexadecyl ester	$C_{19}H_{33}F_5O_2$	0.41

48	12.1101	2,4-Dimethyl-5,6-dimethoxy-8-aminoquinoline	$C_{13}H_{16}N_2O_2$	0.22
49	12.1595	Benzophenone	$C_{13}H_{10}O$	0.44
50	12.3656	Heptasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13-tetradecamethyl-	$C_{14}H_{44}O_6Si_7$	0.04
51	12.6871	Octane, 1,1'-oxybis-	$C_{16}H_{34}O$	0.19
52	13.6022	Tetradecane, 2,6,10-trimethyl-	$C_{17}H_{36}$	0.47
53	13.7753	Pentadecane, 8-hexyl-	$C_{21}H_{44}$	0.12
54	13.8825	7-Methyl-Z-tetradecen-1-ol acetate	$C_{17}H_{32}O_2$	0.10
55	14.2782	Eicosane	$C_{20}H_{42}$	0.17
56	14.4101	Dodecane, 5,8-diethyl-	$C_{16}H_{34}$	0.33
57	14.4596	Pentadecane, 8-hexyl-	$C_{21}H_{44}$	0.32
58	14.6945	Tetradecanoic acid	$C_{14}H_{28}O_2$	11.36
59	14.8100	Benzyl Benzoate	$C_{14}H_{12}O_2$	0.66
60	15.0284	2-Cyclohexylpiperidine	$C_{11}H_{21}N$	0.33
61	15.1232	tert-Hexadecanethiol	$C_{16}H_{34}S$	0.26
62	15.2757	Tetradecanoic acid, ethyl ester	$C_{16}H_{32}O_2$	3.28
63	15.3623	Octadecane	$C_{18}H_{38}$	1.37
64	15.5231	2-Hexadecanol	$C_{16}H_{34}O$	0.59
65	15.7127	3-Hexadecanol	$C_{16}H_{34}O$	1.88
66	15.8940	Isopropyl myristate	$C_{17}H_{34}O_2$	9.87
67	16.3227	7-Methyl-Z-tetradecen-1-ol acetate	$C_{17}H_{32}O_2$	0.06
68	16.6113	Acetamide, N-methyl-N-[4-[2-acetoxymethyl-1-pyrrolidyl]-2-butynyl]-	$C_{14}H_{22}N_2O_3$	0.10
69	16.7720	1,2-Benzenedicarboxylic acid, butyl octyl ester	$C_{20}H_{30}O_4$	0.25
70	17.1760	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	0.06
71	17.3326	Z-4-Nonadecen-1-ol acetate	$C_{21}H_{40}O_2$	0.35
72	17.4686	Z-4-Nonadecen-1-ol acetate	$C_{21}H_{40}O_2$	0.32
73	17.7489	Phen-1,4-diol, 2,3-dimethyl-5-trifluoromethyl-	$C_9H_9F_3O_2$	0.04
74	17.8932	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	1.10
75	18.1034	Pilocarpine	$C_{11}H_{16}N_2O_2$	0.18

76	18.4167	Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, methyl ester	$C_{18}H_{28}O_3$	0.21
77	18.5238	Malonic acid, 2-methylpentyl undecyl ester	$C_{20}H_{38}O_4$	0.44
78	18.6599	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	0.07
79	18.8701	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	6.13
80	19.7481	Hexadecanoic acid, ethyl ester	$C_{18}H_{36}O_2$	2.67
81	19.8635	Eicosane	$C_{20}H_{42}$	0.18
82	20.0820	Benzenepropanoic acid, 3,5-bis(1,1- dimethylethyl)-4-hydroxy-,methyl ester	$C_{19}H_{30}O_3$	0.55
83	20.2180	2-Hexadecanol	$C_{16}H_{34}O$	0.21
84	20.4900	2-Methoxy-6,10-dimethyl-dodeca- 2E,6Z,10Z-trienoic acid, 12-acetoxy-, methyl ester	$C_{18}H_{28}O_5$	0.11
85	21.9368	E-15-Heptadecenoic acid	$C_{17}H_{32}O_2$	0.28
86	22.9096	Octadecanoic acid, 4-hydroxy-, methyl ester	$C_{19}H_{38}O_3$	0.11
87	24.0184	Heptacosane	$C_{27}H_{56}$	0.33
88	24.4925	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	0.05
89	25.0654	trans-9-Octadecenoic acid, pentyl ester	$C_{23}H_{44}O_2$	0.23
90	25.3746	Hexadecane, 2,6,10,14-tetramethyl-	$C_{20}H_{42}$	0.27
91	25.9846	Octadecanoic acid, ethyl ester	$C_{20}H_{40}O_2$	0.95
92	26.6194	7-Methyl-Z-tetradecen-1-ol acetate	$C_{17}H_{32}O_2$	0.16
93	30.9227	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	0.10
94	31.8213	Octadecane, 3-ethyl-5-(2-ethylbutyl)-	$C_{26}H_{54}$	0.08
95	34.3149	Bis(2-ethylhexyl) phthalate	$C_{24}H_{38}O_4$	4.29

*3.9238 (0.03%), 5.6344 (0.06%), 39.3893 (0.25%) RT peaks library match not found.

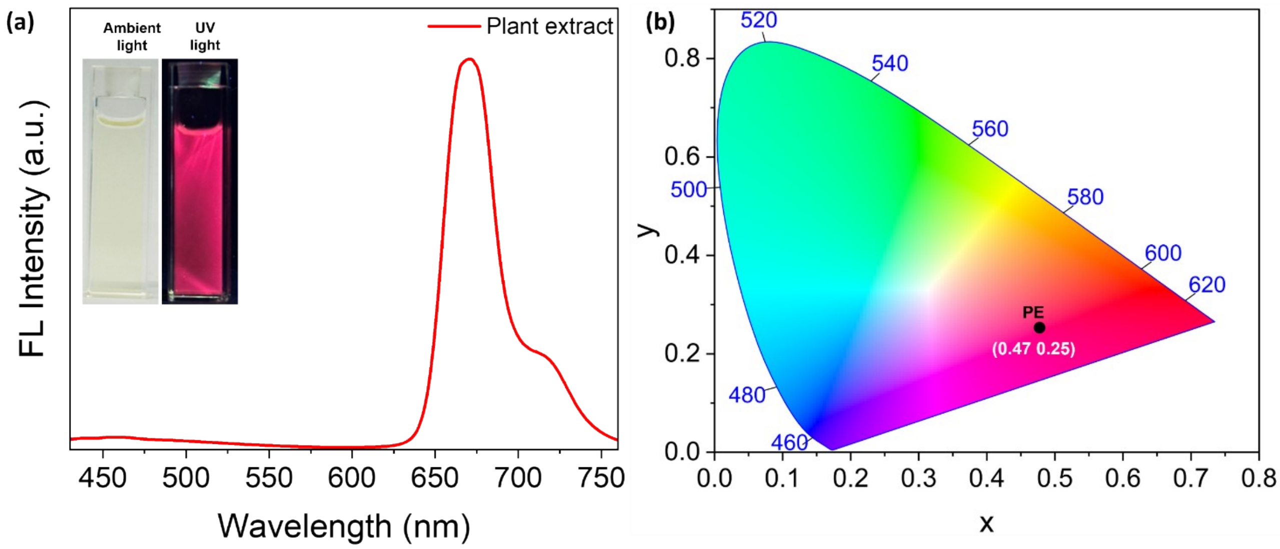


Fig. S2. (a) Fluorescence (FL) of the methanolic plant extract before synthesis. Insets show the extract under ambient and UV light, and (b) the corresponding CIE plot.

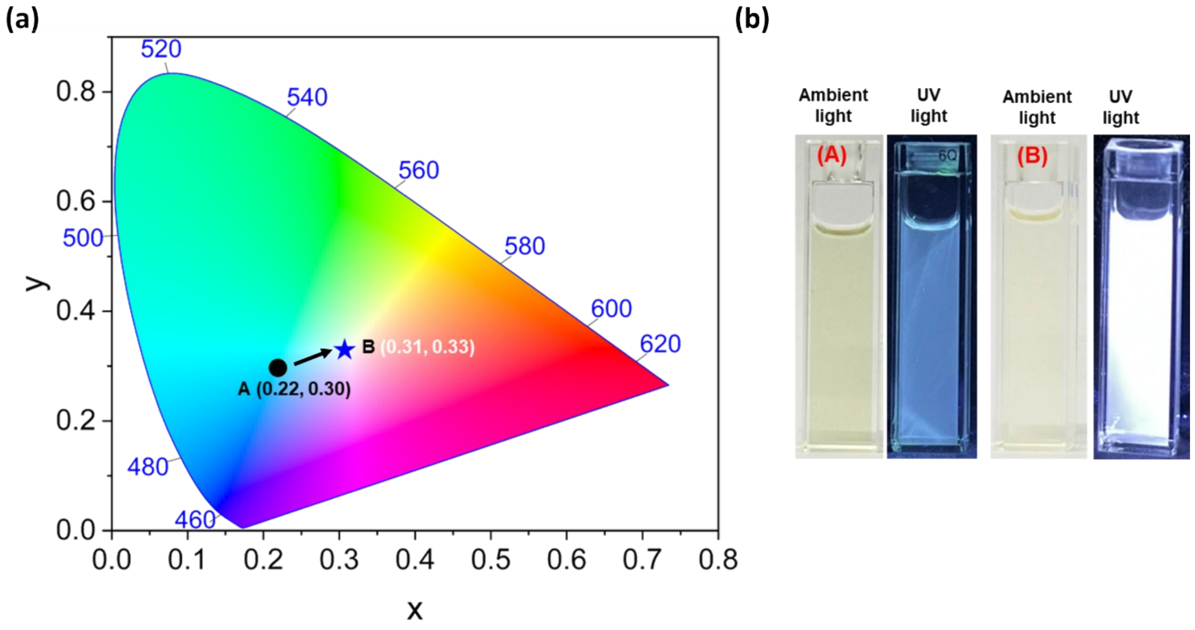


Fig. S3. (a) CIE plot of fresh (A) and extracted leaf (B), (b) the corresponding images under ambient and UV light.

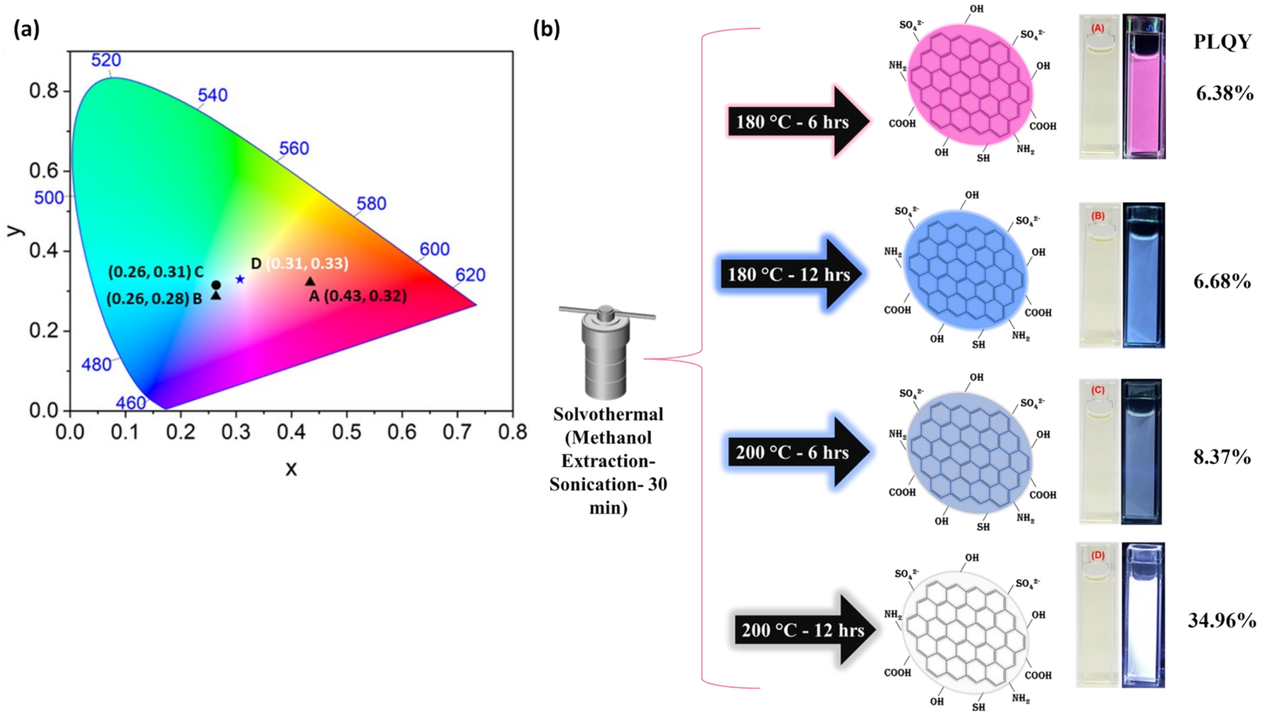


Fig. S4. (a) CIE plot of the CDs synthesized under different reaction conditions. (b) The Corresponding ambient and 365 nm UV light irradiation photographs.

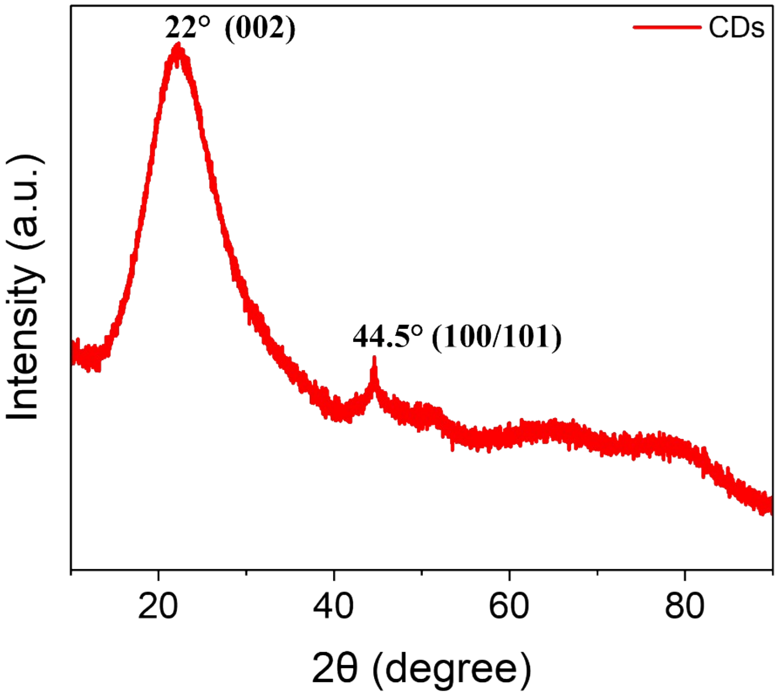


Fig. S5. PXRD of the CDs.

Table S2. Elemental composition of the CDs.

	C	O	N	O/C	N/C
CDs	**78.4%**	**16.3%**	**1.9%**	**0.21**	**0.02**

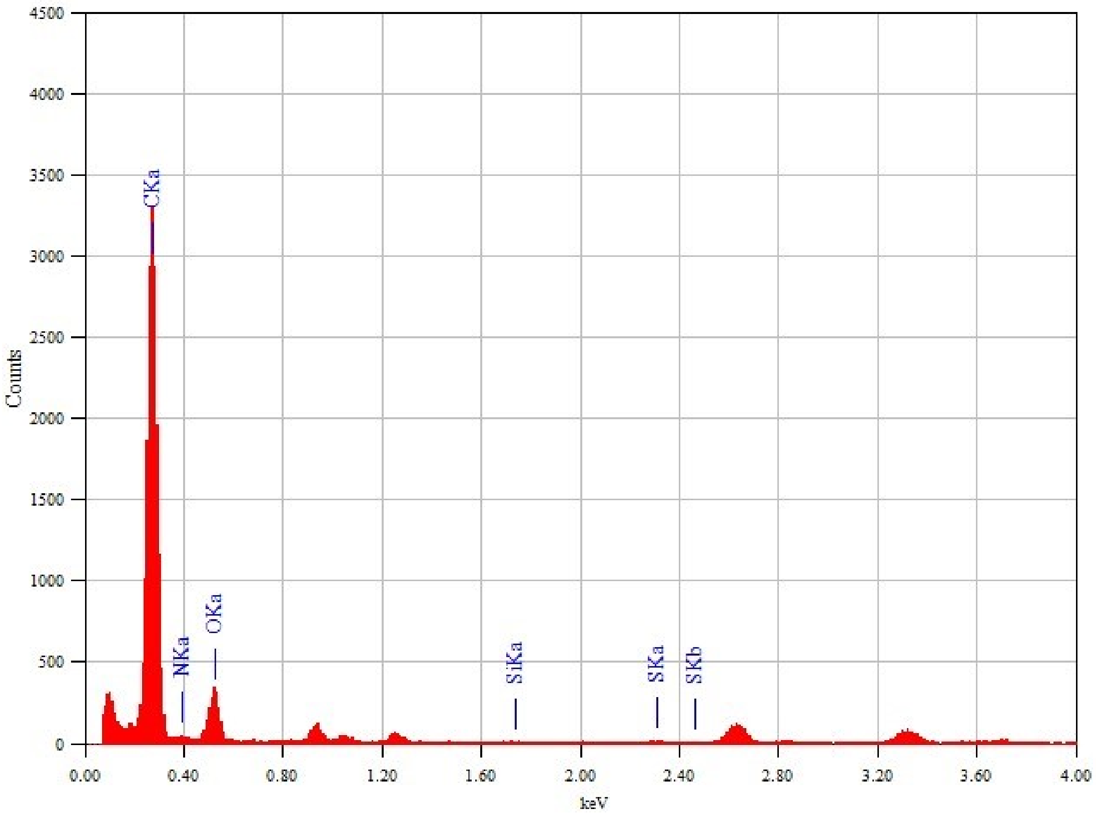


Fig. S6. EDAX elemental analysis of the CDs from TEM.

Table S3. Comparison between biomass-derived CDs in WLED fabrication.

S. No	Source	Method and Conditions	Dopants	PLQY	Emission strategy	CIE	Ref
1.	Lemon peel	Hydrothermal, 180 °C-10 hrs	Ethylenediamine, m-phenylenediamine, glutathione	35.58%	RGB Mixing	(0.37, 0.32)	[1]
2.	Areca nut husk	Hydrothermal, 120 °C- 3 hrs	-	63%	Mixing Areca nut extract + Areca nut CDs	(0.28, 0.34)	[2]
3.	Carrot	Solvothermal, 200 °C-10 hrs	-	10%	Mixing Crt-CDs, S-CDs, and P-CDs	(0.34, 0.32)	[3]
4.	Curry leaves	Microwave, 650 W, 8 min	-	23.1%	RGB Mixing	(0.30, 0.35)	[4]
5.	*Trachelospermum jasminoides* leaves	Solvothermal, 190 °C- 8 hrs	Zinc metal	19.8%	RGB Mixing	(0.36, 0.32)	[5]
6.	Mango leaves	Solvothermal, 200 °C-35 min	Ethylenediamine (EDA)	-	CDs+ EDA	(0.32, 0.32)	[6]
7.	Neem and Fenugreek leaves	Hydrothermal, 300 °C- 8 hrs	-	41.2% & 38.9%	RGB Mixing	(0.31, 0.31)	[7]
8.	Sichuan pepper seeds	Solvothermal, 180 °C-10 hrs, & 200 °C-12 hrs	1,4-dihydroxynaphthalene	85%	RGB Mixing	(0.40, 0.39)	[8]
9.	Tea residue	Microwave, 500 W,12 min	-	13.42%	Using R- CDs	(0.33, 0.37)	[9]
10.	*Momordica monadelpha* leaves	Solvothermal, 200 °C- 8 hrs	-	11% & 14%	RGB Mixing	(0.32, 0.34)	[10]
11.	Pulmeria leaves	Solvothermal, 160 °C- 8 hrs	Terbium acetate	39.49%	CDs+ Tb^{3+}	(0.33, 0.34)	[11]
12.	*Epiphyllum oxypetalum* leaves	Solvothermal, 200 °C-12 hrs	-	34.96%	One-pot synthesis	(0.31, 0.34)	**This work**

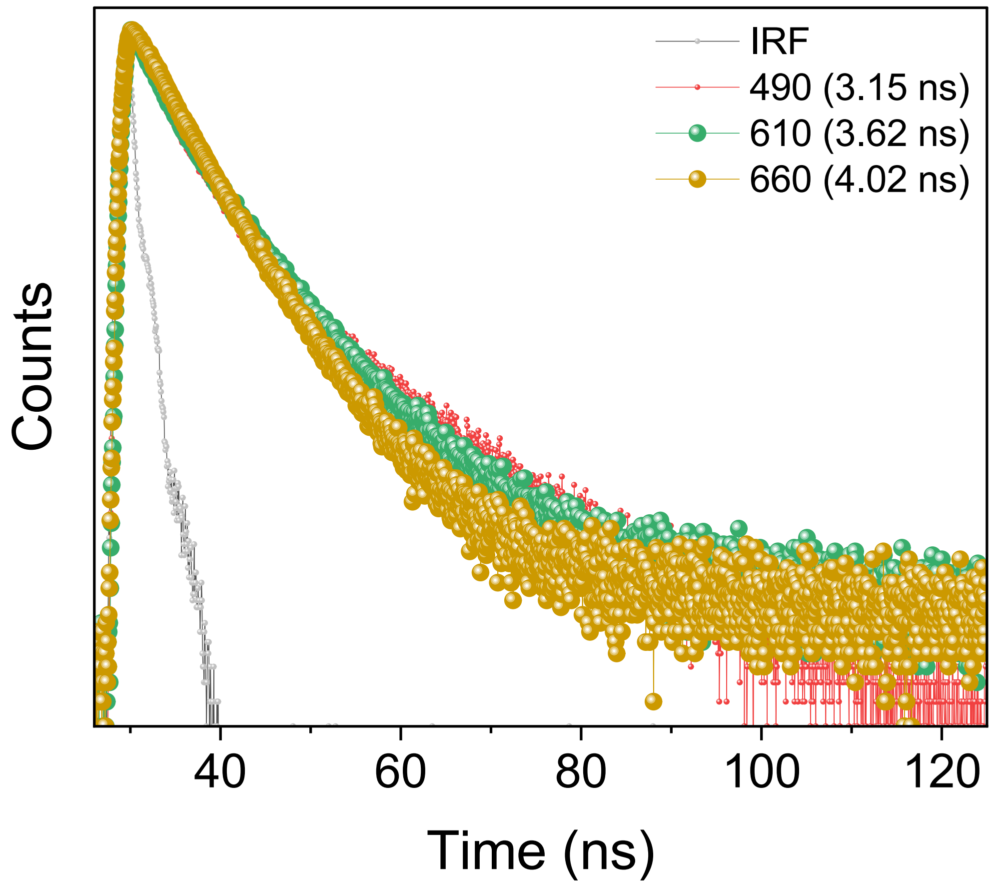
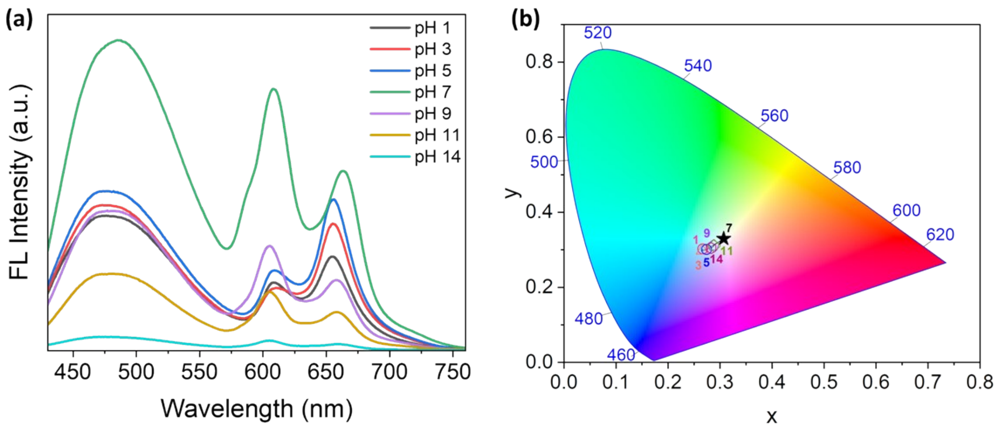


Fig. S7. Lifetime spectra of the CDs.

Table S4. Time-resolved FL data of the CDs.

S. No	λ_{em} (nm)	τ_1 (ns)	α_1	τ_2 (ns)	α_2	τ_3 (ns)	α_3	τ_{av} (ns)
1.	490	0.96 (54%)	0.54	4.15 (37%)	0.37	12.02 (9%)	0.09	3.15
2.	610	1.29 (53%)	0.53	5.64 (42%)	0.42	12.02 (5%)	0.05	3.62
3.	660	1.15 (26%)	0.26	4.70 (71%)	0.71	12.02 (3%)	0.03	4.02



(c)

Sample	pH	CIE coordinates	
		x	y
1	1	0.26	0.30
2	3	0.26	0.30
3	5	0.27	0.30
4	7	0.31	0.33
5	9	0.29	0.31
6	11	0.29	0.31
7	14	0.29	0.30

Fig. S8. (a) FL spectra of CDs at different pH values (pH 1-14). (b) It's corresponding CIE plot. (c) Table representing their corresponding CIE chromaticity coordinates values.

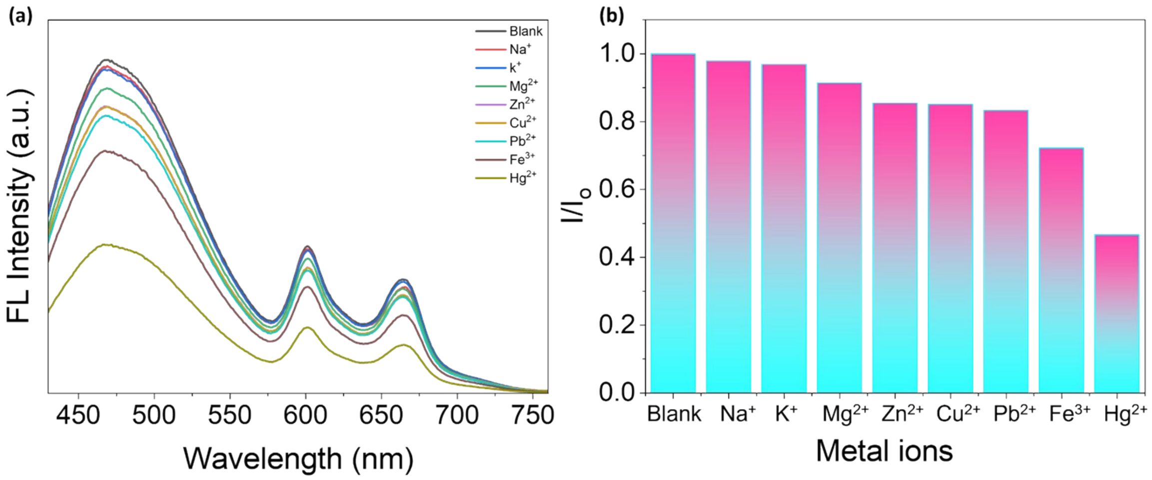


Fig. S9. (a) FL spectra of CDs in the presence of different metal ions. (b) Bar graph representing the relative FL intensity (I/I_o) of the CDs towards various metal ions.

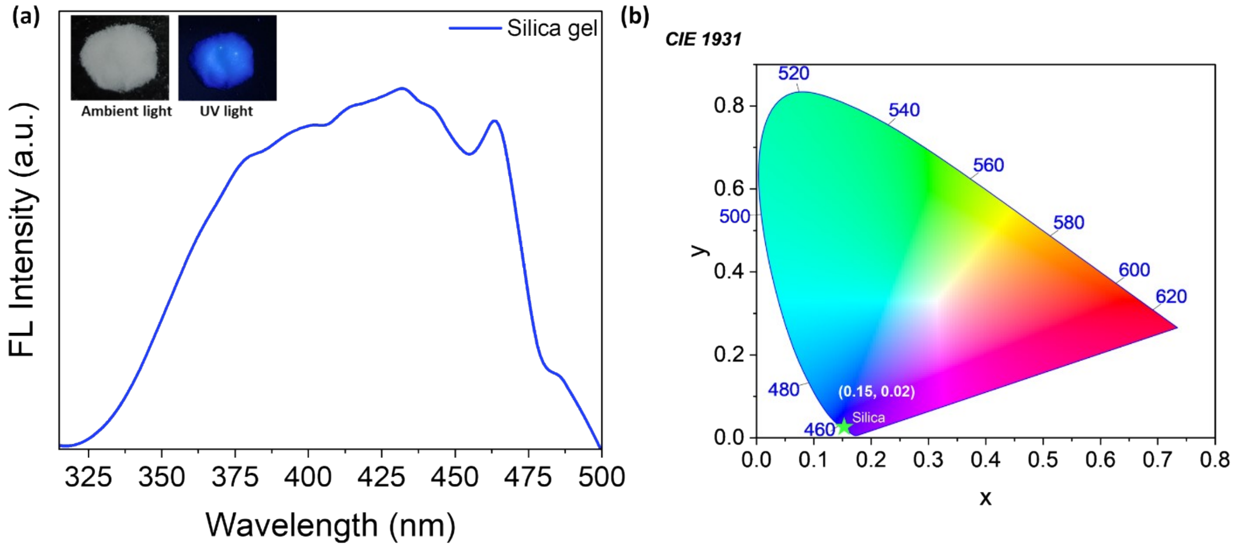


Fig. S10. (a) FL spectrum of Silica gel (insets photographs taken under ambient and UV light) and (b) the corresponding CIE plot.

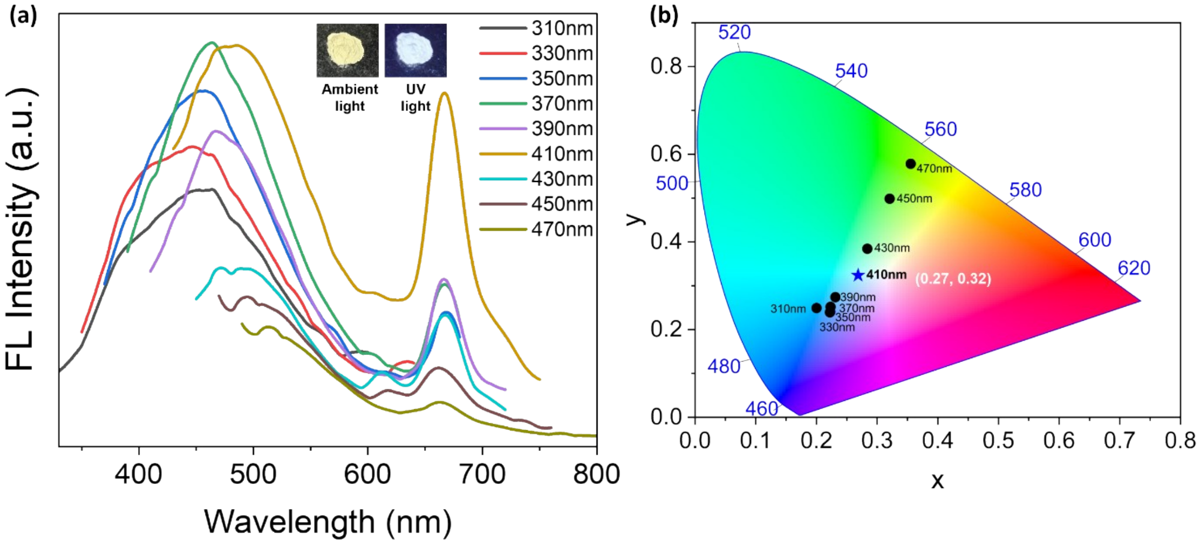


Fig. S11. (a) FL spectra of S-CDs (insets photographs taken under ambient and UV light) and (b) the corresponding CIE plot.

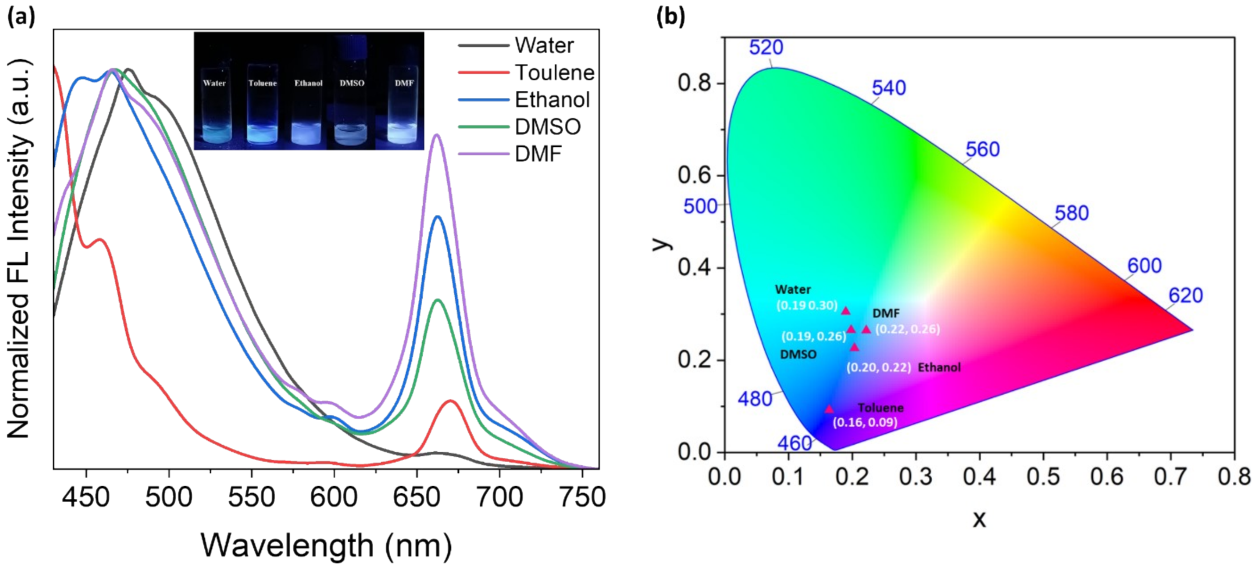


Fig. S12. (a) FL spectra of S-CDs dispersed in various solvents (insets photographs taken under ambient and UV light) and (b) the corresponding CIE plot.

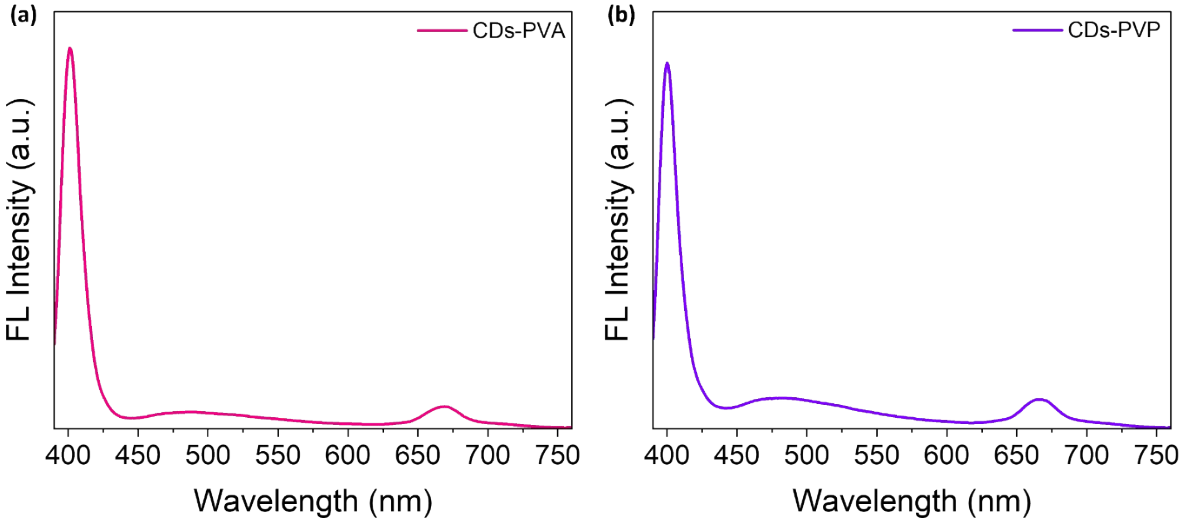


Fig. S13. FL spectra of CDs-polymer composites coated on 410 nm LED (a) PVA (b) PVP.

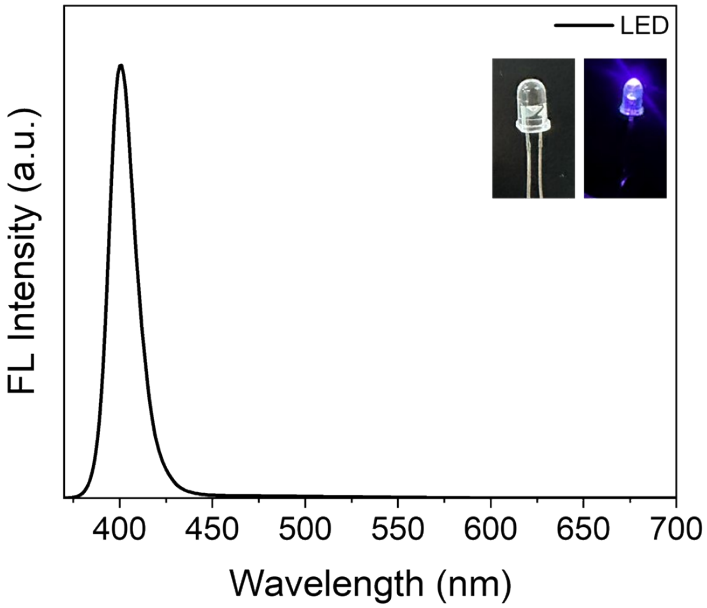


Fig. S14. FL spectrum of bare LED with insets showing photographs of bare LED under ambient light and UV light.

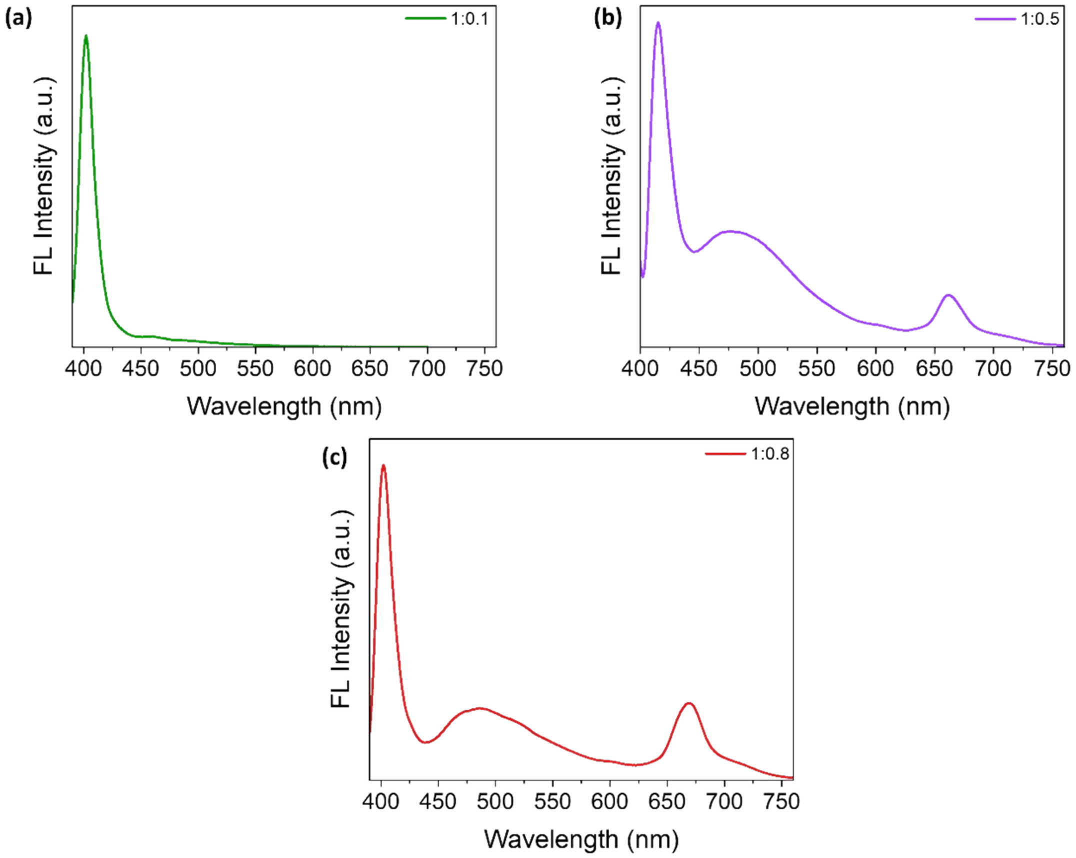
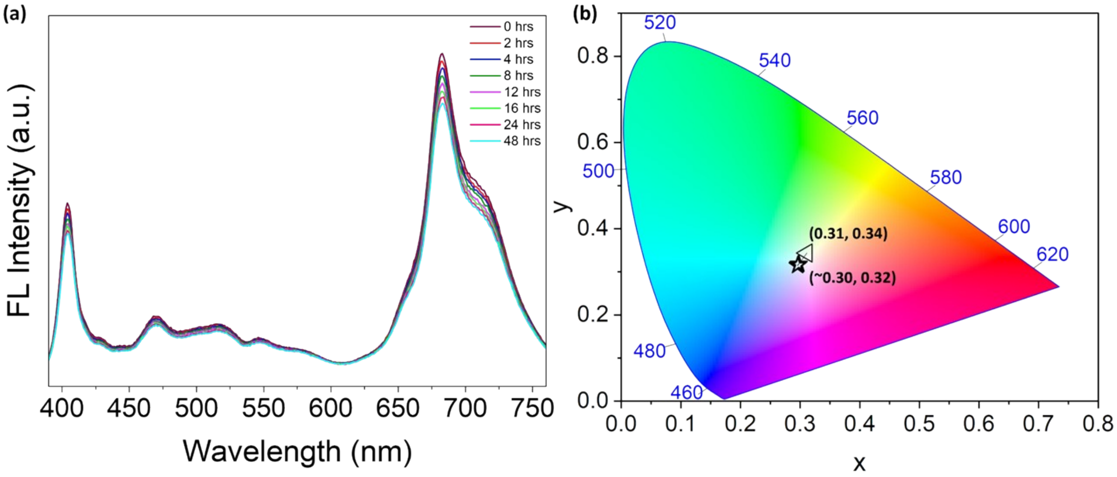
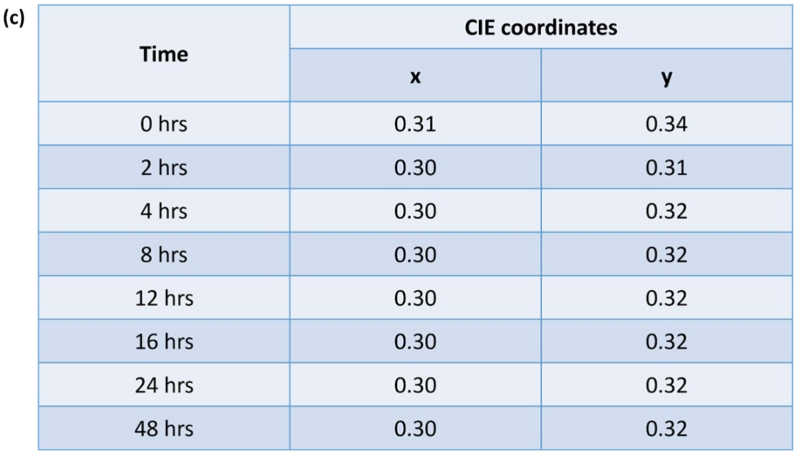


Fig. S15. FL spectra of CD-PMMA with (a) 1:0.1, (b) 1:0.5, and (c) 1:0.8 ratios.




(c)

Time	CIE coordinates	
	x	y
0 hrs	0.31	0.34
2 hrs	0.30	0.31
4 hrs	0.30	0.32
8 hrs	0.30	0.32
12 hrs	0.30	0.32
16 hrs	0.30	0.32
24 hrs	0.30	0.32
48 hrs	0.30	0.32

Fig. S16. (a) Emission spectra of WLED under continuous operation. (b) the corresponding CIE plot. (c) Table representing their corresponding CIE chromaticity coordinates values.

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