## Supplementary information

Waste materials, including oil palm leaves, sesbania, and filter cake, were preliminarily studied their composition using Thermogravimetric Analysis (TGA). It was found that oil palm leaves, sesbania, and filter cake consisted of approximately 7%, 0.727%, and 67% of ash, respectively (Table S1). When the carbons derived from these waste materials were activated with potassium hydroxide, their morphology was analyzed using a scanning electron microscope (SEM) (Fig. S1). The resulting materials displayed distinctive structures: oil palm leaves exhibited an irregular and porous structure, sesbania showed a layered sheet-like surface, and filter cake had a lumpy appearance. Energy dispersive X-ray spectroscopy (EDX) revealed that the carbon material derived from oil palm leaves was composed of carbon, along with other elements such as oxygen, silicon, and iron. These elements may be primarily silica, a major dietary component found in plants. The AC material from sesbania consisted of carbon, with similar additional elements like oxygen, silicon, and iron, akin to other plant-based biomass materials. For the filter cake, the as-prepared material mainly contained carbon and other elements such as oxygen, silicon, potassium, and iron. The high silicon content indicates the presence of silica, which has low electrical conductivity and may affect the material's charge storage capacity[1,2]. When the surface area and porosity of the material were analyzed using nitrogen gas adsorption analysis (Fig. S2A), the carbon material derived from oil palm leaves exhibited a type IV isotherm with type I characteristics. This indicates that the resulting carbon contains both mesopores and micropores. The synthesis of carbon materials via activation with potassium hydroxide can produce a range of pore sizes. The Brunauer-Emmett-Teller (BET) surface area of the carbon material from oil palm leaves was 877.63 $m^2/g$, with a pore volume of 0.56 $cm^3/g$ and an average pore diameter of 4.42 nm (Table S2). X-ray diffraction (XRD) analysis of this carbon material showed a peak at 26° in the pattern, indicating the presence of stacked graphene layers. The peak at 43° corresponded to $sp^2$ carbon, consistent with the 002 and 100 planes of graphite or carbon materials[3,4] (Fig. S2B). Raman spectroscopy analysis supported these findings, showing a D band peak at 1345 $cm^{-1}$, indicative of defects in the carbon, and a G band peak at 1586 $cm^{-1}$, indicative of $sp^2$ carbon[5] (Fig. S2C). The $I_D/I_G$ ratio, representing the quality of the carbon material, was 0.84 (Table S3). For the sesbania, the BET-specific surface area was 1,140 $m^2/g$, with a pore volume of 0.62 $cm^3/g$ and an average pore diameter of 2.18 nm. The XRD analysis of the carbon material from sesbania showed peaks at 26.5°, 42.9°, 44°, 49° and 54°, corresponding to the (002) (020) (111) (022) and (004) planes of graphite, indicating high crystallinity[6]. Similar to the AC derived from oil palm leaves, Raman spectroscopy analysis confirmed the presence of a D band peak and a G band peak[7] and the $I_D/I_G$ ratio was 0.85. For the filter cake, the carbon material had a BET-specific surface area of 246.79 $m^2/g$, a pore volume of 0.37 $cm^3/g$, and an average pore diameter of 6.01 nm. X-ray diffraction analysis confirmed the carbon character of the material, showing peaks at 20° and 26° [8]. The $I_D/I_G$ ratio of this material is 0.88.

**Table S1 TGA analysis of waste materials (oil palm leaves, sesbania, and filter cake)**

| Waste material | % Ash | % Moisture content |
|---|---|---|
| Oil palm leaves | 7 | 9.69 |
| Sesbania | 0.7 | 17.99 |
| Filter cake | 67 | 1.76 |

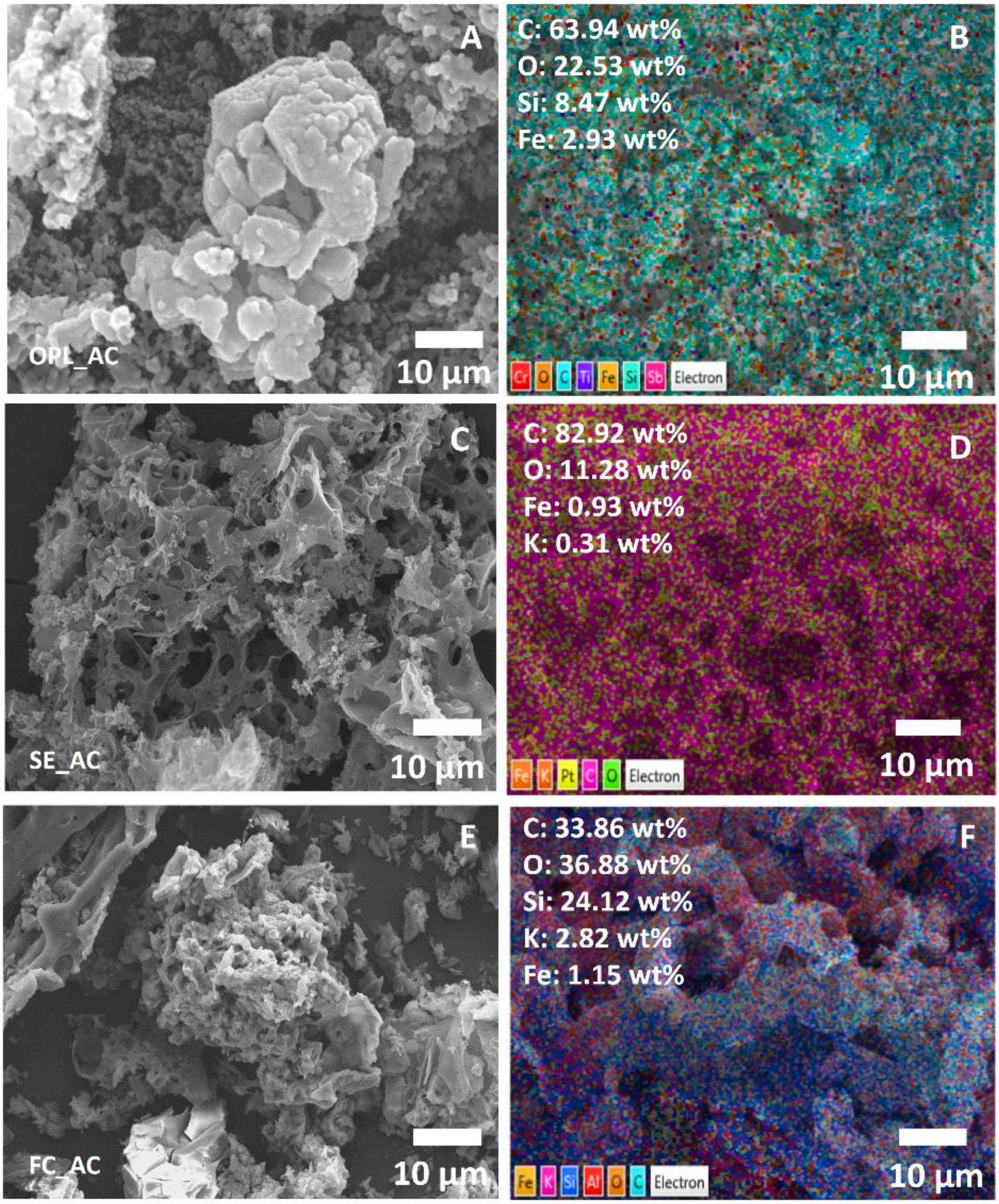


**Fig. S1 SEM images of as-prepared activated carbon (AC) derived from oil palm leaves (A), sesbania (C), and filter cake (E), along with EDX analysis of AC derived from oil palm leaves (B), sesbania (D), and filter cake (F).**

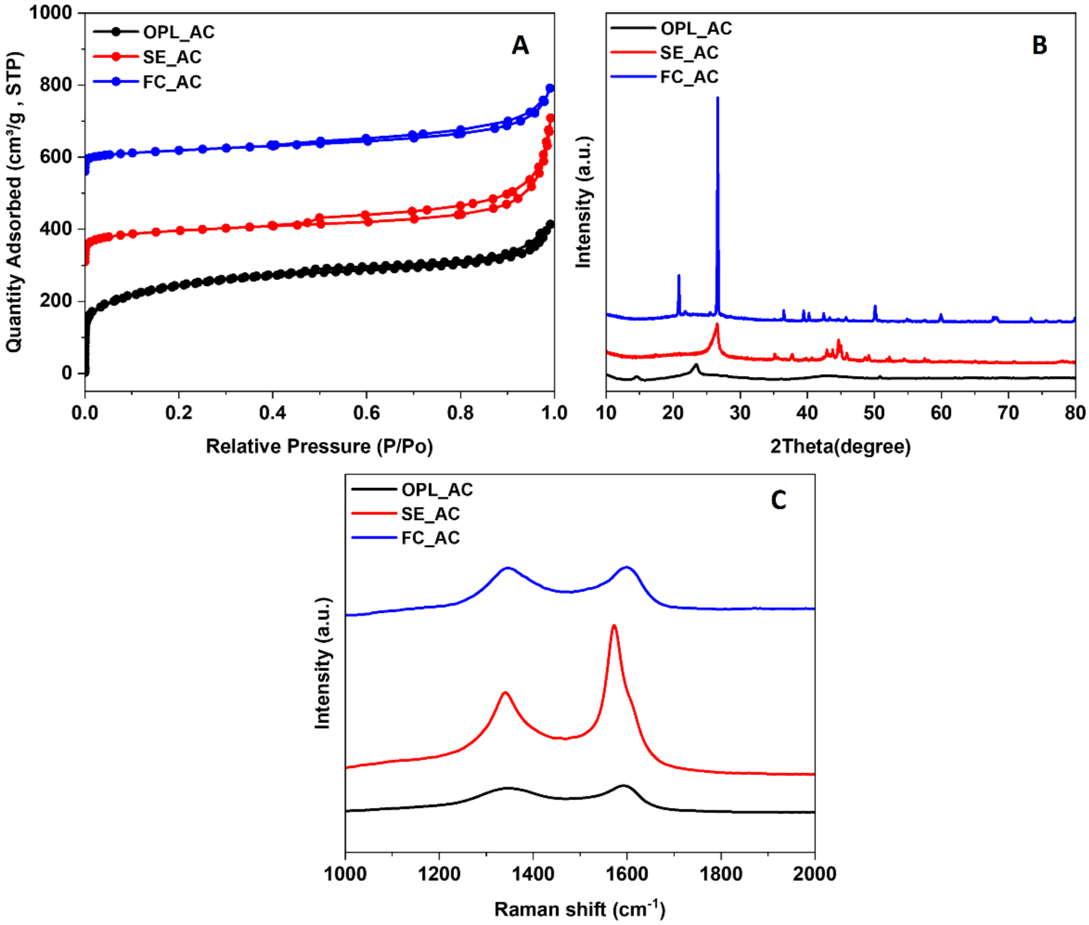


**Fig. S2 $N_2$ adsorption-desorption isotherms (A), XRD patterns (B), and Raman spectra (C) of the AC derived from oil palm leaves (black line), sesbania (red line), and filter cake (blue line).**

**Table S2 The BET surface area and pore size of the AC derived from oil palm leaves, sesbania, and filter cake.**

| **Material** | **Surface area ($m^2 \cdot g^{-1}$)** | **Total pore volume ($cm^3 \cdot g^{-1}$)** | **Average pore diameter (nm)** |
|---|---|---|---|
| Oil palm leaves | 877.63 | 0.56 | 4.42 |
| Sesbania | 1,140 | 0.62 | 2.18 |
| Filter cake | 246.79 | 0.37 | 6.01 |

**Table S3 The $I_D/I_G$ ratios from Raman spectra for AC samples derived from oil palm leaves, sesbania, and filter cake**

| **Material** | **$I_D/I_G$** |
|---|---|
| Oil palm leaves | 0.84 |
| Sesbania | 0.85 |
| Filter cake | 0.88 |

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