Synergistic Effects of Nitrogen Doping in Waste-Fruit Peel–Derived Activated Carbons for Supercapacitors and Water Treatment

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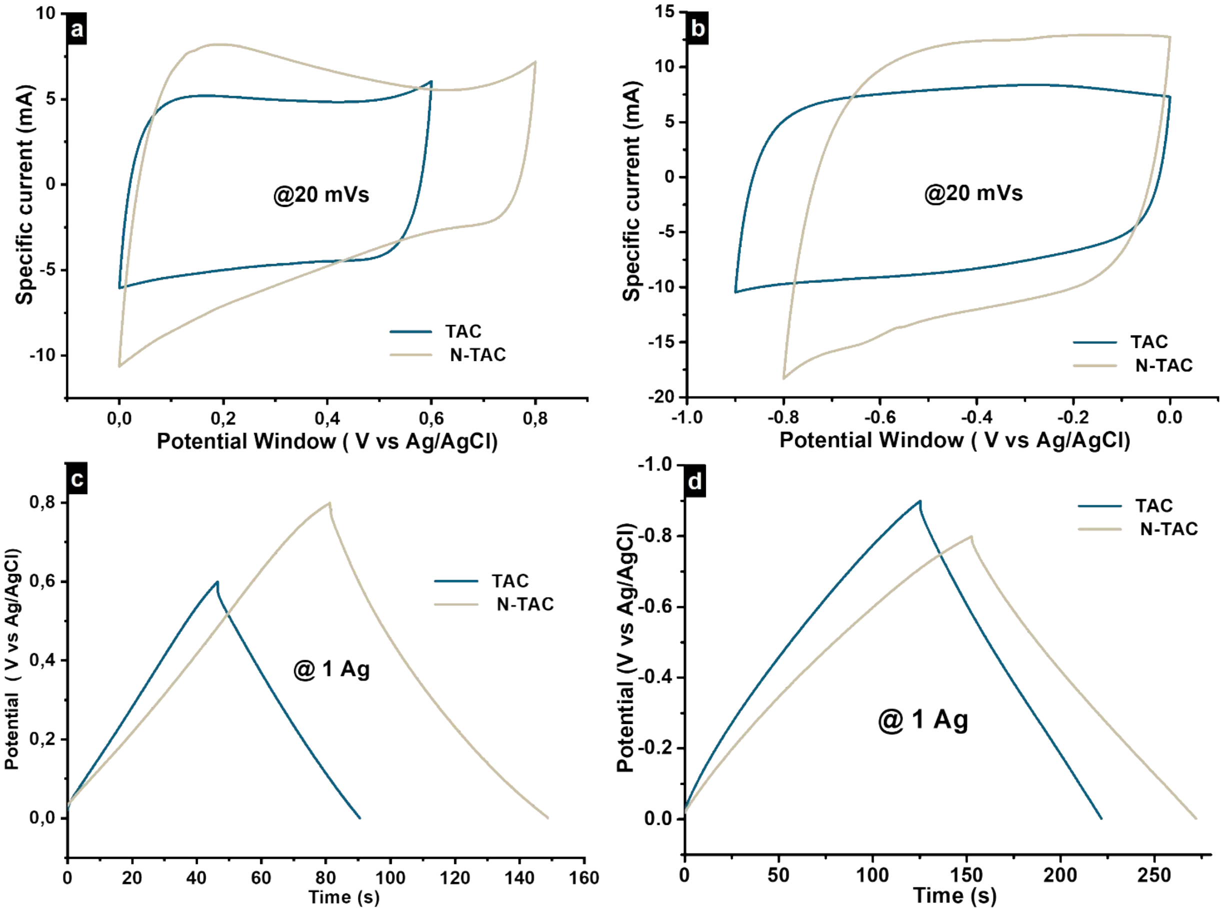


Figure S. 1: Three-electrode electrochemical characterisation of TAC and N-TAC electrodes: cyclic voltammetry (CV) curves recorded at a scan rate of 20 mV s^{-1} within the (a) positive and (b) negative potential windows; galvanostatic charge–discharge (GCD) profiles at a specific current of 0.5 A g^{-1} within the (c) positive and (d) negative potential windows.

Power Law Relationship

The dependence of the current response on scan rate in cyclic voltammetry (CV) follows a power law relationship:

$$I = av^{b} \qquad \text{(S1)}$$

where I is the current (A), v is the scan rate (V s^{-1}), a is a constant, and b is the power-law exponent. For convenient determination of b, Eq. (S1) is expressed in logarithmic form:

$$\log I = \log a + b \log v \qquad \text{(S2)}$$

A plot of log I versus log v yields a linear relationship, where the slope corresponds to b and the intercept to log a. The b-value provides insight into the charge storage mechanism: $b \approx 0.5$ indicates a diffusion-controlled (pseudocapacitive, PC) process, whereas $b \approx 1.0$ suggests a surface-controlled process dominated by electric double-layer capacitance (EDLC). The corresponding plots for N-TAC at selected potentials in both positive and negative windows are presented in Figure S.1.

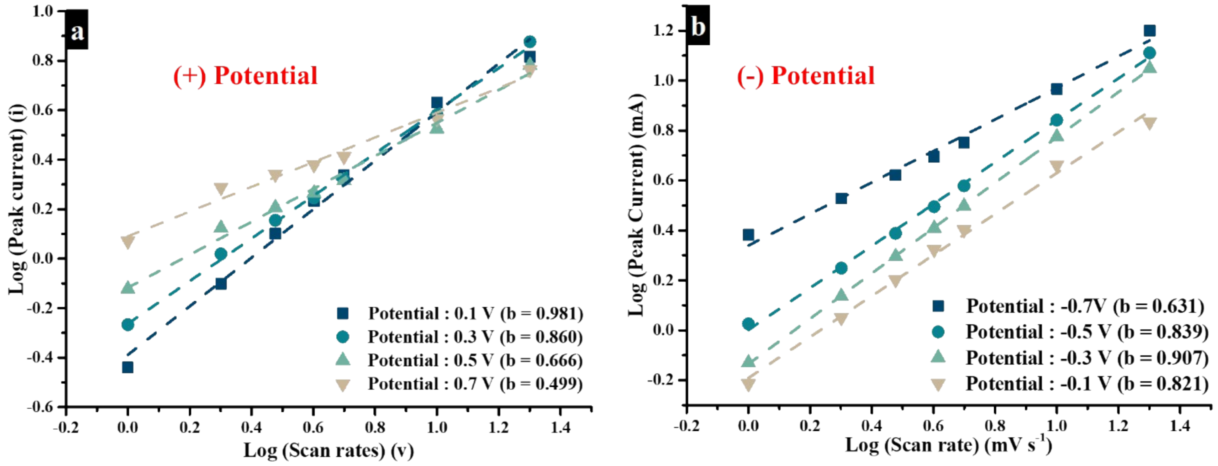


Figure S. 2 : Log(i) versus log(v) plots with linear regression at fixed potentials for the positive (a) (0.1–0.7 V) and negative (b) (−0.1 to −0.7 V) windows across scan rates of 1–20 mV s^{-1}. Slopes yield the b-values in Figure 6(a, b).

Trasatti's Method

The relative contributions of surface-controlled and diffusion-limited processes were further evaluated using Trasatti's method. The total stored charge (Q_T) consists of outer surface charge (Q_o, EDLC) and inner diffusion-controlled charge (Q_i, PC).

The specific capacitance was calculated from CV curves (1–20 mV s^{-1}) using:

$$C_s = \frac{S}{mv\Delta V} \qquad \text{(S3)}$$

where S is the integrated CV area, m is the mass of active material, v is the scan rate, and ΔV is the potential window.

As $v \rightarrow \infty$, ion diffusion into the inner surface becomes negligible, and the intercept of the plot of C_s versus $v^{-1/2}$ gives the electric double-layer capacitance (C_{EDLC}):

$$C_s = kv^{-1/2} + C_{EDLC} \qquad \text{(S4)}$$

Conversely, as $v \rightarrow 0$, ions access both outer and inner surfaces, yielding the total capacitance (C_T), obtained from the intercept of the C_s^{-1} versus $v^{1/2}$ plot:

$$C_s^{-1} = kv^{1/2} + C_T^{-1} \qquad \text{(S5)}$$

The pseudocapacitive contribution is calculated as:

$$C_{PC} = C_T - C_{EDLC}$$

The percentage contributions are determined using:

$$C_{EDLC}(\%) = \frac{C_{EDLC}}{C_T} \times 100 \qquad \text{(S6)}$$

$$C_{PC}(\%) = \frac{C_{PC}}{C_T} \times 100 \qquad \text{(S7)}$$

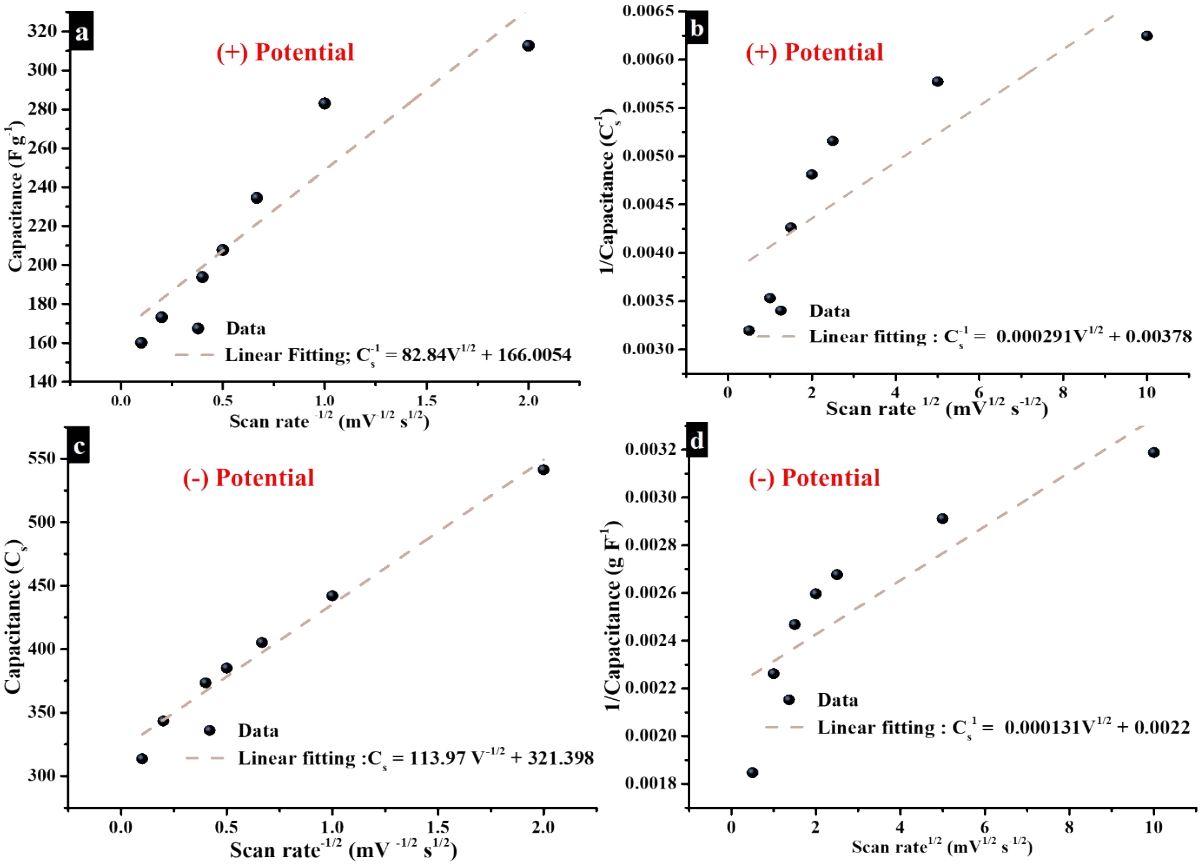


Figure S. 3 : Trasatti deconvolution plots of C_s versus $v^{-1/2}$ for the positive (a) and negative (c) windows, and C_s^{-1} versus $v^{1/2}$ for the positive (b) and negative (d) windows. Y-intercept extrapolations to v → 0 and v → ∞ yield total and outer charge contributions, respectively, reported in Figure 6(c, d).

Dunn's Method

Dunn's method was employed to separate capacitive and diffusion-controlled contributions at a given potential quantitatively. The total current is expressed as:

$$I = k_1 v + k_2 v^{1/2} \qquad \text{(S8)}$$

where $k_1 v$ represents the surface-controlled (EDLC) contribution and $k_2 v^{1/2}$ the diffusion-controlled (PC) contribution.

Dividing by $v^{1/2}$ gives:

$$I v^{-1/2} = k_1 v^{1/2} + k_2 \qquad \text{(S9)}$$

A plot of $I\ v^{-1/2}$ versus $v^{1/2}$ yields a linear relationship, where the slope and intercept correspond to k_1 and k_2, respectively. The obtained constants were used to quantify EDLC and PC contributions across the entire potential window. The potential-dependent separation and scan-rate evolution of the capacitive contributions for N-TAC are presented in Figures S.3 and S. 7.

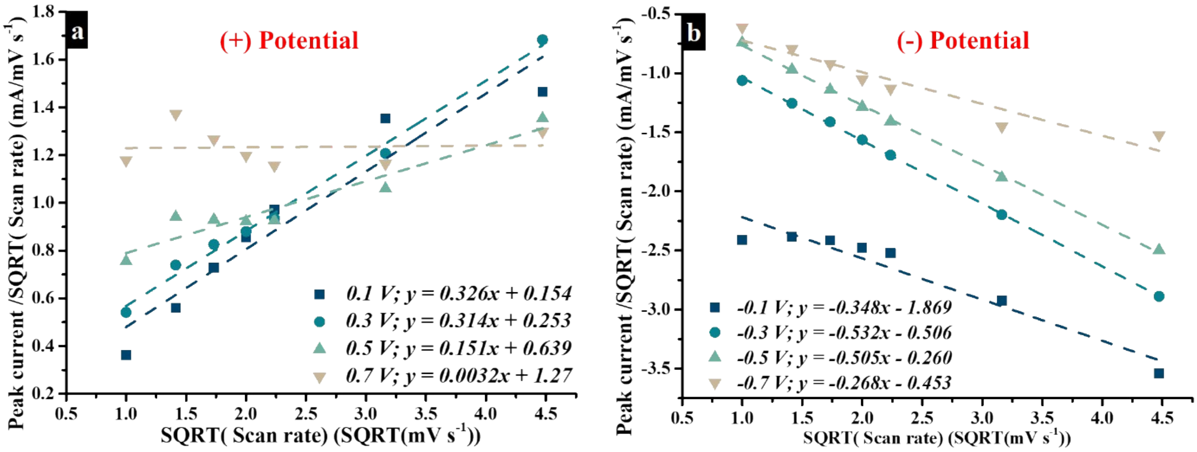


Figure S. 4: Plots of i $v^{-1/2}$ versus $v^{1/2}$ with linear fitting at fixed potentials V for the (a) positive (0.1, 0.3, 0.5, and 0.7) and (b) negative (-0.1, -0.3, -0.5, and -0.7) potential windows, used to extract the k_1 (slope) and k_2 (intercept) coefficients for Dunn's current separation presented in Figure 7.

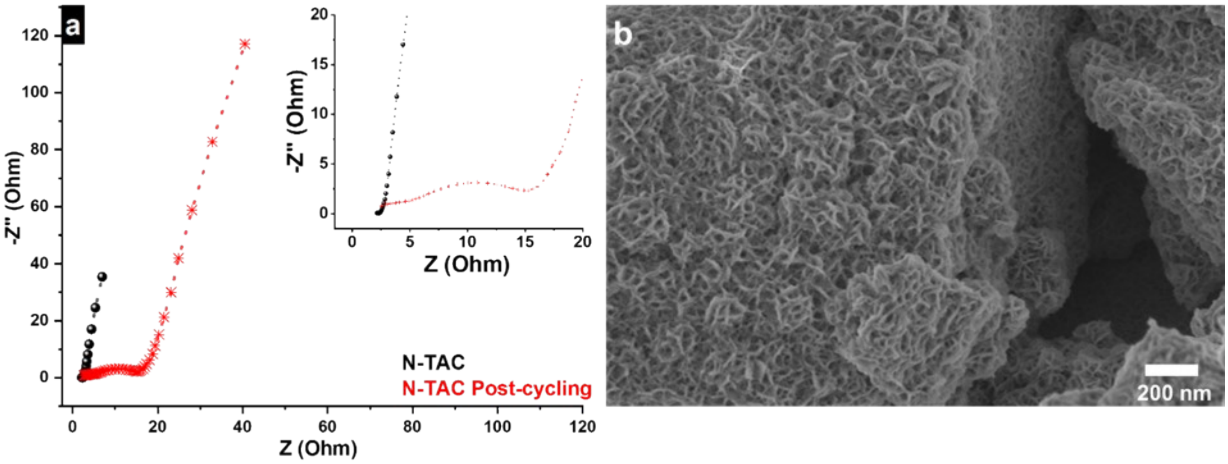
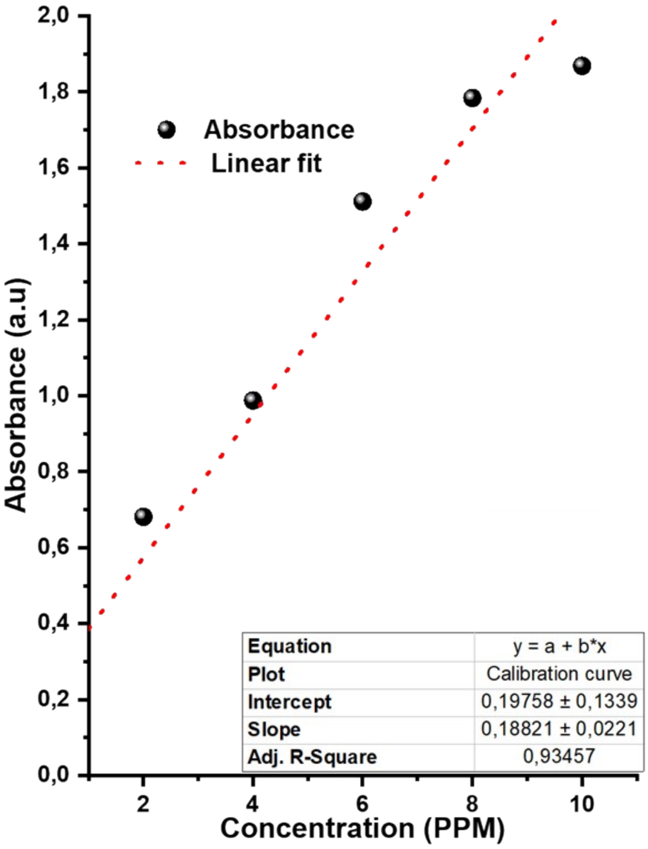


Figure S. 5: Post-cycling EIS and SEM



Equation	y = a + b*x
Plot	Calibration curve
Intercept	0,19758 ± 0,1339
Slope	0,18821 ± 0,0221
Adj. R-Square	0,93457

Figure S. 6: Methylene Blue Calibration curve

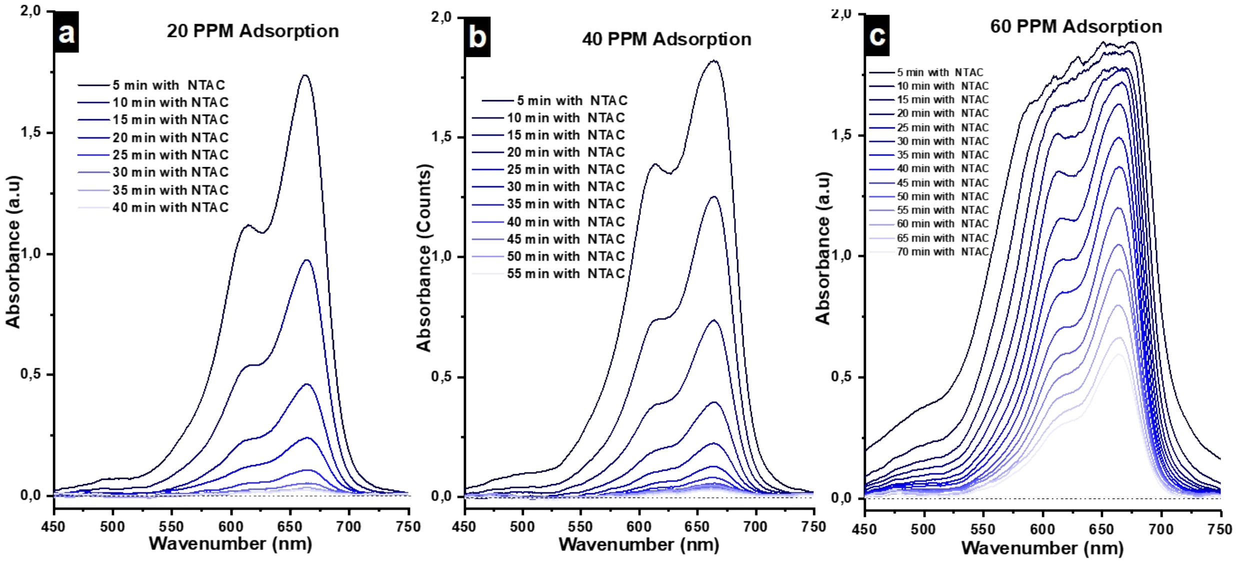


Figure S. 7: UV-Visible absorption spectra demonstrating methylene blue adsorption with 10 mg N-TAC at initial dye concentrations of (a) 20 ppm, (b) 40 ppm, and (c) 60 ppm, measured at various time intervals.