Supporting information

Pore Structure Regulation of Biomass-Derived Carbon Materials for Enhanced Supercapacitor Performance

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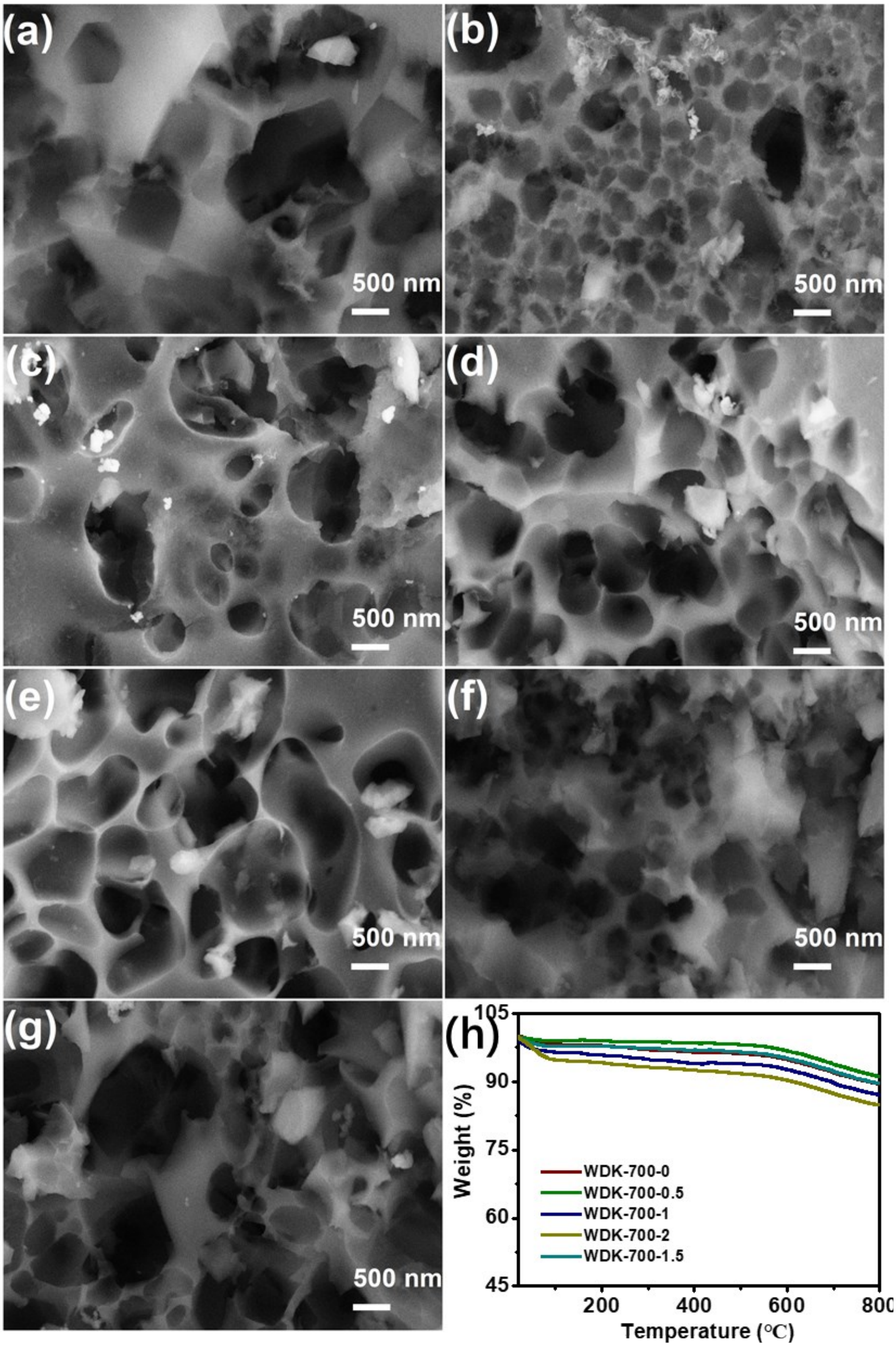

Fig. S1 SEM images of WD-700-1 (a), WDK-700-0 (b), WDK-700-0.5 (c), WDK-700-1.5 (d), WDK-700-2 (e), WDK-600-1 (f), WDK-800-1 (g), and TGA curve of samples in N_2 atmosphere (h).

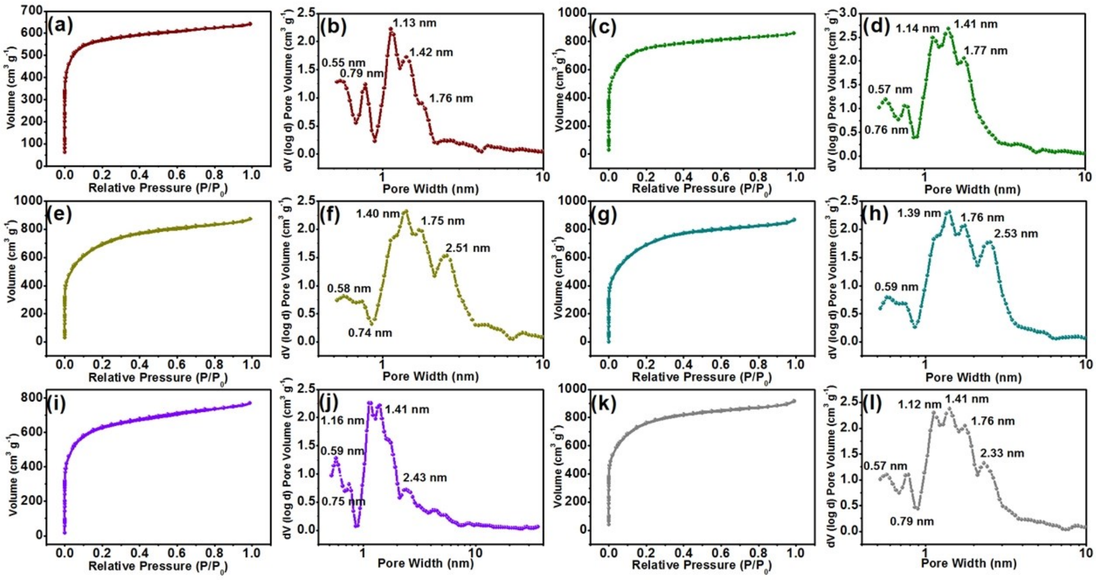

Fig. S2 (a) N_2 adsorption/desorption curve of WDK-700-0, (b) pore size distribution of WDK-700-0, (c) N_2 adsorption/desorption curve of WDK-700-0.5, (d) pore size distribution of WDK-700-0.5, (e) N_2 adsorption/desorption curve of WDK-700-1.5, (f) pore size distribution of WDK-700-1.5, (g) N_2 adsorption/desorption curve of WDK-700-2, (h) pore size distribution of WDK-700-2, (i) N_2 adsorption/desorption curve of WDK-600-1, (j) pore size distribution of WDK-600-1, (k) N_2 adsorption/desorption curve of WDK-800-1, (l) pore size distribution of WDK-800-1.

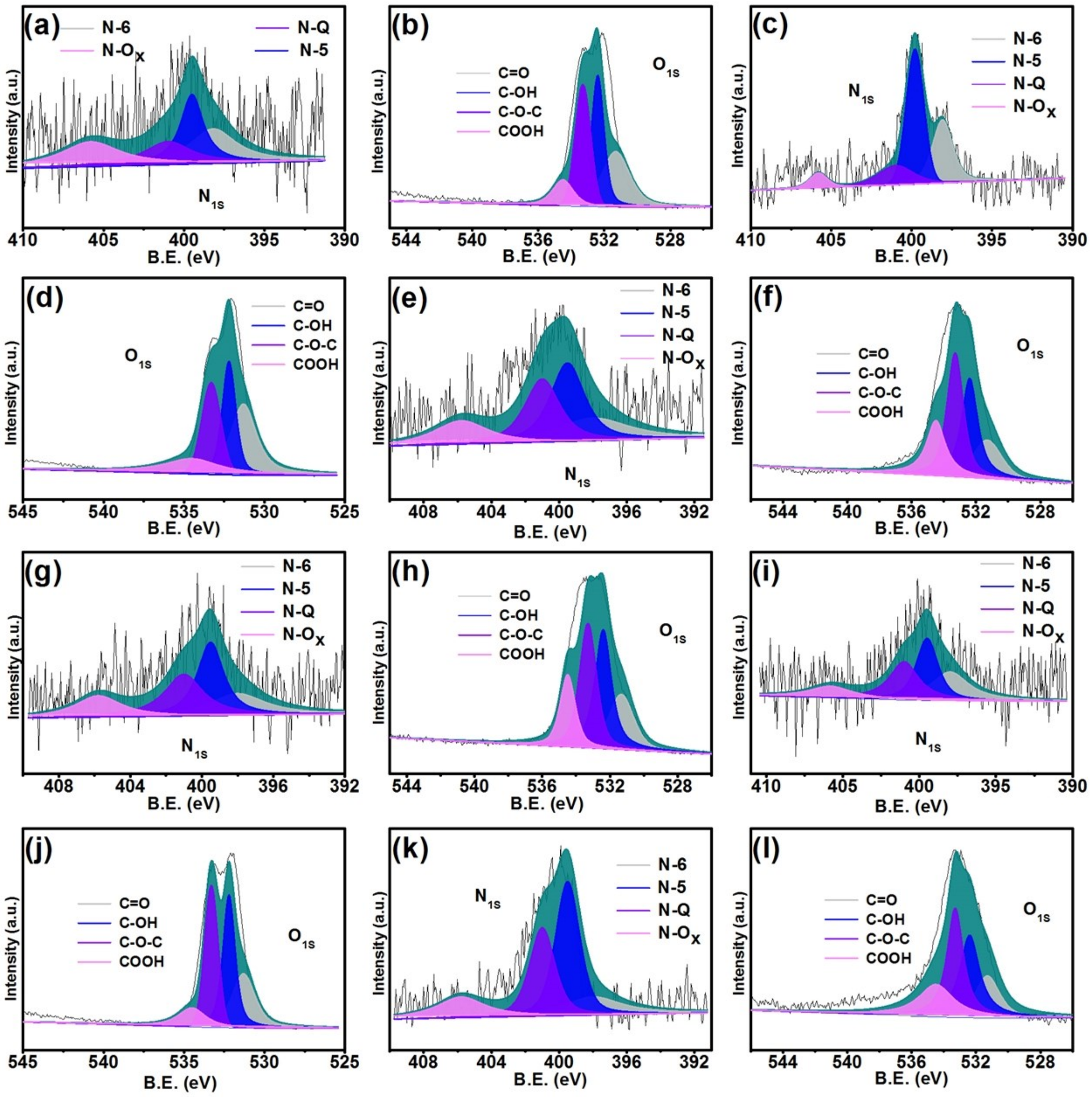

Fig. S3 (a) N_{1s} and (b) O_{1s} high-resolution XPS spectra of WDK-700-0 with deconvoluted peaks, (c) N_{1s} and (d) O_{1s} high-resolution XPS spectra of WDK-700-0.5 with deconvoluted peaks, (e) N_{1s} and (f) O_{1s} high-resolution XPS spectra of WDK-700-1.5 with deconvoluted peaks, (g) N_{1s} and (h) O_{1s} high-resolution XPS spectra of WDK-700-2 with deconvoluted peaks, (i) N_{1s} and (j) O_{1s} high-resolution XPS spectra of WDK-600-1 with deconvoluted peaks, (k) N_{1s} and (l) O_{1s} high-resolution XPS spectra of WDK-800-1 with deconvoluted peaks.

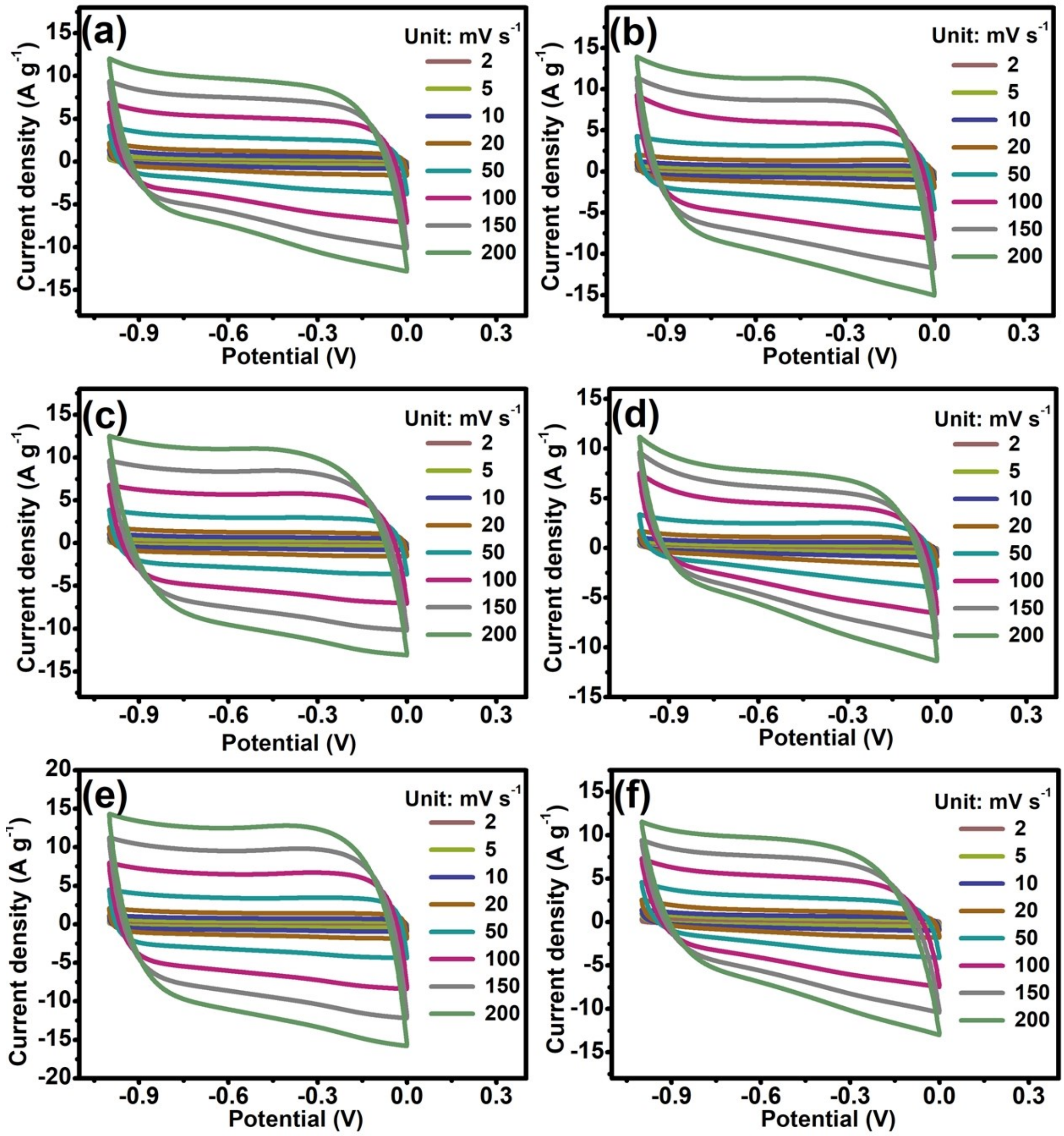

Fig. S4 (a) CV curves of all samples with the different sweep rates: (a) WDK-700-0, (b) WDK-700-0.5, (c) WDK-700-1.5, (d) WDK-700-2, (e) WDK-600-1, (f) WDK-800-1.

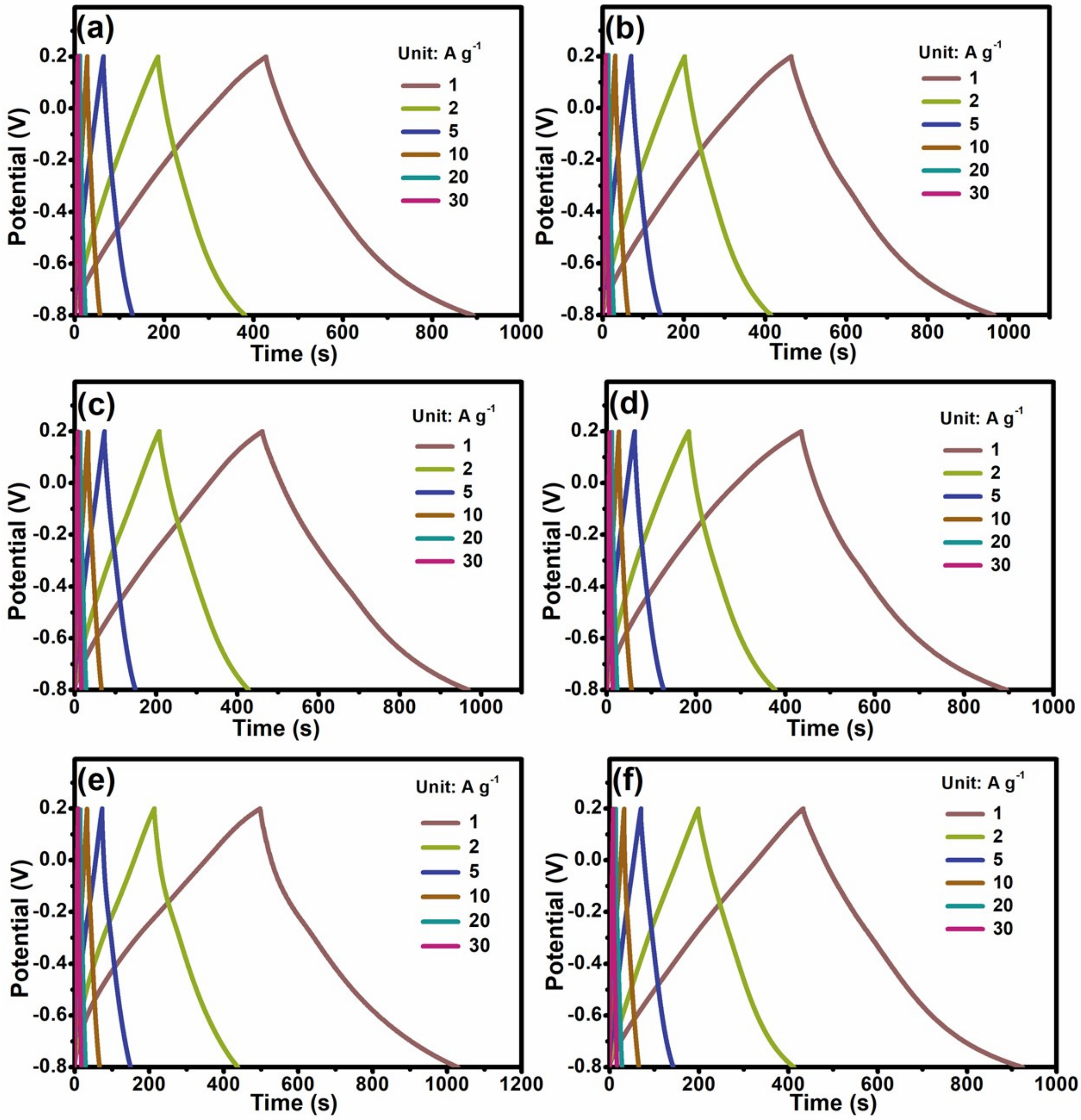

Fig. S5 GCD curves of all samples at various current densities from 1 to 30 A g^{-1} in 1 mol L^{-1} H_2SO_4 electrolyte with the three-electrode system: (a) WDK-700-0, (b) WDK-700-0.5, (c) WDK-700-1.5, (d) WDK-700-2, (e) WDK-600-1, (f) WDK-800-1.

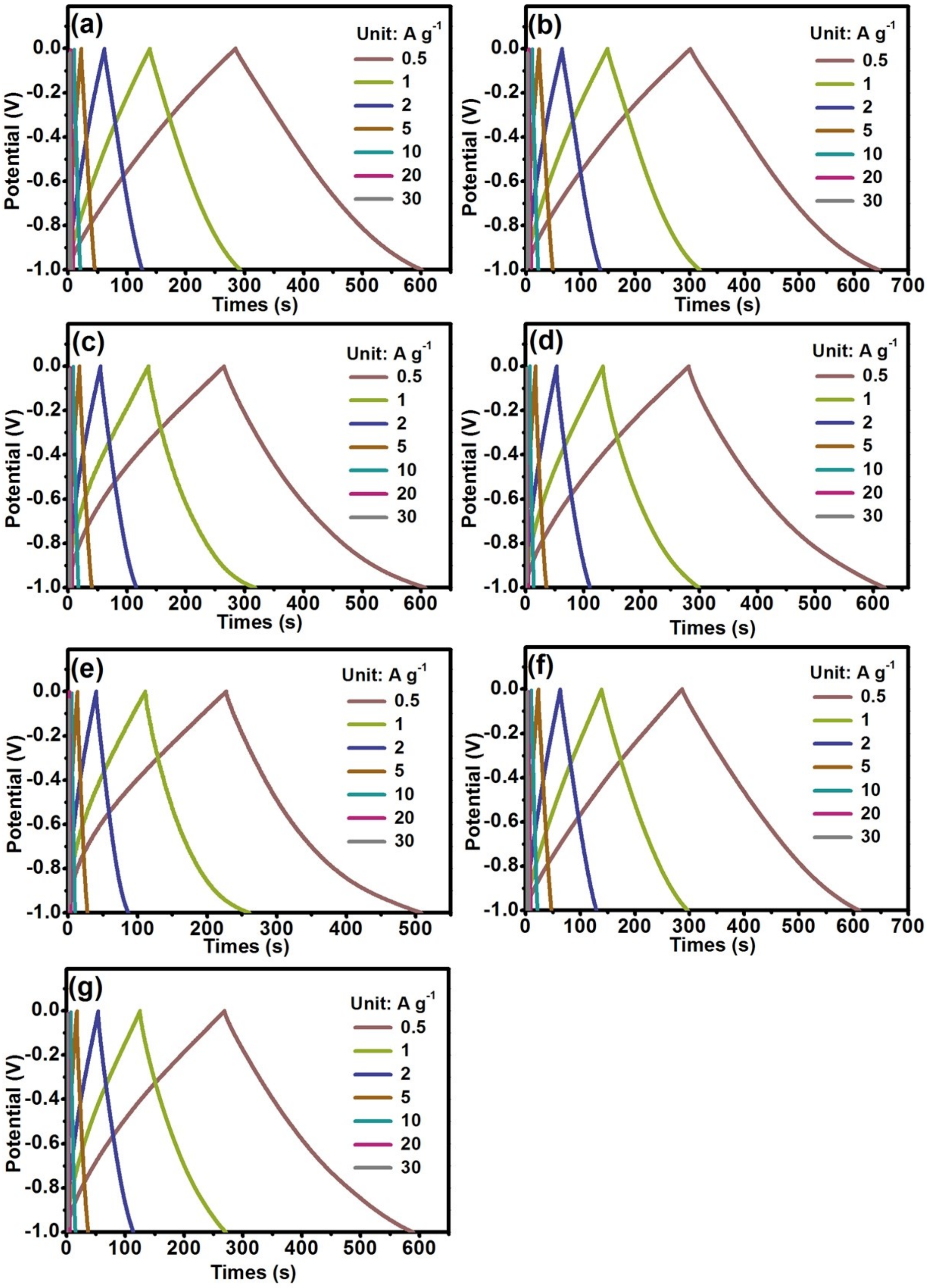

Fig. S6 GCD curves of all samples at various current densities from 1 to 30 A g^{-1} in 1 mol L^{-1} H_2SO_4 electrolyte with the two-electrode system: (a) WDK-700-0, (b) WDK-700-0.5, (c) WDK-700-1, (d) WDK-700-1.5, (e) WDK-700-2, (f) WDK-600-1, (g) WDK-800-1.

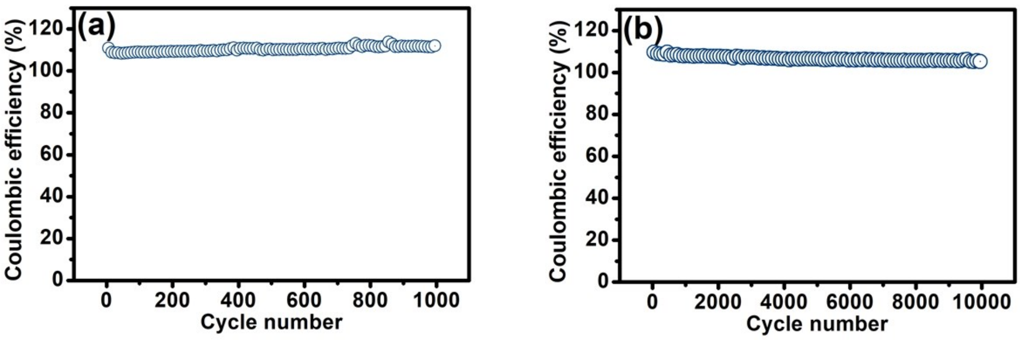

Fig. S7 Coulombic efficiency of WDK-700-1 electrode at 1 A g^{-1} for 1000 cycles (a) and Coulombic efficiency of WDK-700-1 electrode at 30 A g^{-1} for 10000 cycles (b)

The activator mechanism of KOH

Using KOH porogen is one effective way to create the micropores. It is generally believed that the productions in this progress below 700 °C are mainly H_2, H_2O, CO, CO_2, K_2O, and K_2CO_3.[1] This process consists of several simultaneous/continuous reactions as indicated in the following Equations (S1)-(S4). Moreover, at the activation temperature around 400 °C, owing to the dehydration of KOH, K_2O has been produced (Equation (S1)).[2] Then H_2 and CO_2 could be generated as shown in the Equation (S2) and (S3). Hereafter, the K_2O and CO_2 can be converted into K_2CO_3 (Equation (S4)). And the reactions at 570 °C occur by following redox reaction (Equation (S5)):[3]

$$2KOH \rightarrow K_2O + H_2O \quad \text{(S1)}$$

$$C + H_2O \rightarrow H_2 + CO \quad \text{(S2)}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad \text{(S3)}$$

$$CO_2 + K_2O \rightarrow K_2CO_3 \quad \text{(S4)}$$

$$6KOH + 2C \rightarrow 2K + 3H_2 + 2K_2CO_3 \quad \text{(S5)}$$

$$K_2CO_3 \rightarrow K_2O + CO_2 \quad \text{(S6)}$$

$$C + K_2O \rightarrow 2K + CO \quad \text{(S7)}$$

Next, the obtained K_2CO_3 (Equation (4) and (5)) would be transformed into CO_2 and K_2O (Equation (6)) at over than 700 °C, and K_2O could be further reacted with the carbon to produce the metallic K (Equation (7)).[4, 5] Metallic K (Equation (5) and (7)) would intercalate into the carbon structure and expand the lattice leading to the increasing of pore volume. And the escape of H_2, CO_2, CO and H_2O gas from carbon materials as the physical porogens change some micropores into mesopores thus enhancing the porosity.[6] After removing the inserted metallic K and K-containing compounds by the process of hydrochloric acid washing, the expanded carbon lattices cannot be recovered, thus reasonably developing the porosity of the materials.[4, 7]

Table S1 Detailed quantitative element analysis data.

Sample	C_{1s}	O_{1s}	O_{1s}				N_{1s}	N_{1s}			
			C=O	C-OH	C-O-C	COOH		N-6	N-5	N-Q	$N-O_x$
WDK-700-0	80.9	17.34	0.29	0.31	0.29	0.11	1.76	0.28	0.28	0.19	0.26
WDK-700-0.5	78.35	20.09	0.33	0.25	0.24	0.17	1.56	0.31	0.47	0.16	0.06
WDK-700-1	85.3	12.93	0.18	0.34	0.29	0.19	1.77	0.14	0.40	0.32	0.14
WDK-700-1.5	85.95	12.62	0.17	0.29	0.34	0.20	1.43	0.23	0.33	0.27	0.17
WDK-700-2	82.93	15.68	0.20	0.32	0.31	0.17	1.40	0.22	0.32	0.28	0.18
WDK-600-1	79.41	19.1	0.25	0.33	0.31	0.12	1.49	0.28	0.31	0.28	0.13
WDK-800-1	89.9	7.89	0.16	0.30	0.32	0.21	2.21	0.16	0.40	0.28	0.16

Table S2. Comparison of electrochemical performances of the carbon materials synthesized from biomass in supercapacitors.

Materials	Surface area [$m^2\ g^{-1}$]	Electrolyte	Capacitance [$F\ g^{-1}$]	E [$Wh\ kg^{-1}$]	P [$kW\ kg^{-1}$]	Reference
Walnut peel	2495.4	H_2SO_4	557.9 $^{a; b}$	12.4	5.7	This study
Cellulose	859	H_2SO_4	328 $^{a; c}$	–	–	[9]
Cotton	2436	KOH	283 $^{a; b}$	–	–	[10]
Coconut Shell	2440	H_2SO_4	221.4 $^{a; g}$	7.6	4.5	[11]
Chitosan	1582	KOH	252 $^{a; c}$	–	–	[12]
Bagasse	2064	H_2SO_4	142 $^{a; c}$	19.7	0.5	[13]
Human Hair	1306	KOH	340 $^{a; b}$	45.3	2.2	[14]
Rice Husk	1768	KOH	233 $^{a; f}$	8.36	–	[15]
Pomelo Peel	2725	KOH	342 $^{a; e}$	9.4	0.1	[16]
Waste Air-laid Paper	1470	KOH	296 $^{a; c}$	34.3	0.3	[17]
RF Resins	2178	KOH	222 $^{d; c}$	10.1	8.0	[18]
Pomelo Peel	2191	KOH	342 $^{a; b}$	17.1	3.8	[19]
Fungus	1103	KOH	360 $^{a; b}$	22.0	–	[20]
NCAs	1626	KOH	354 $^{a; e}$	–	–	[21]
Duckweeds	1636	KOH	315 $^{a; b}$	8.3	0.1	[22]

$^{(a)}$Capacitance with three-electrode system, $^{(b)}$ the current density of 1 A g^{-1}, $^{(c)}$ the current density of 0.5 A g^{-1}, $^{(d)}$ Capacitance with two-electrode system, $^{(e)}$ the current density of 0.2 A g^{-1}, $^{(f)}$ the current density of 2 A g^{-1}, $^{(g)}$ the current density of 5 A g^{-1}.

Notes and references

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