

Supplementary information

**Development of Strong and High-Barrier Food Packaging Films from
Cyclic-Anhydride Modified Bacterial Cellulose**

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Table S1

Dry and wet TS of the pristine BC film and anhydride modified films at 70 °C for 5 min

Properties	BC	DSA/DMSO (w/w)					OSA/DMSO (w/w)			ODSA/DMSO (w/w)			MA/DMSO (w/w)		
		0.03	0.05	0.1	0.15	0.2	0.03	0.05	0.1	0.1	0.15	0.2	0.01	0.03	0.05
TS (MPa, dry)	28.2 ±1.5	49.5 ±3.3	66.3 ±5.1	83.5 ±4.5	83.3 ±3.5	35.1 ±2.6	3.1 ±0.4	110.7 ±3.5	88.6 ±3.5	45.0 ±2.3	53.6 ±3.2	22.9 ±3.4	43.5 ±1.1	133.4 ±3.3	36.9 ±3.5
TS (MPa, wet)	-	0.5 ±0.2	3.2 ±0.6	15.8 ±1.2	11.5 ±2.1	30.1 ±3.3	0.6 ±0.1	0.5 ±0.1	0.7 ±0.1	5.2 ±0.3	5.6 ±0.2	0.7 ±0.2	13.7 ±1.2	22.5 ±1.9	25.4 ±2.1

Table S2

Chemical compositions of the pristine BC and anhydride modified films at 10 min–3 h

Atom (wt %)	BC	3%C0-BC				5%C8-BC				10%C12-BC				15%C18-BC			
		10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h
C	46.39 ±0.29	49.97 ±0.16	49.68 ±0.18	49.79 ±0.22	50.19 ±0.24	51.07 ±0.20	52.16 ±0.23	52.65 ±0.25	52.75 ±0.23	50.23 ±0.17	50.68 ±0.27	50.81 ±0.19	51.73 ±0.26	49.70 ±0.16	51.88 ±0.23	53.36 ±0.24	54.56 ±0.28
O	53.49 ±0.33	48.93 ±0.21	49.43 ±0.12	49.13 ±0.15	49.18 ±0.19	47.60 ±0.16	45.91 ±0.15	45.85 ±0.18	46.00 ±0.16	48.94 ±0.11	48.30 ±0.13	48.02 ±0.12	46.90 ±0.15	50.12 ±0.20	46.14 ±0.17	45.34 ±0.13	43.69 ±0.12
S	0.12 ±0.02	1.09 ±0.05	0.88 ±0.10	1.08 ±0.04	0.63 ±0.07	1.33 ±0.09	1.93 ±0.10	1.47 ±0.05	1.26 ±0.10	0.83 ±0.07	1.03 ±0.06	1.17 ±0.03	1.37 ±0.07	0.19 ±0.03	1.98 ±0.06	1.30 ±0.07	1.75 ±0.08

Table S3

Mechanical strength of the pristine BC film and anhydride modified films at 10 min–3 h

Properties	BC	3%C0-BC				5%C8-BC				10%C12-BC				15%C18-BC			
		10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h
TS (MPa, dry)	28.2 ±1.5	87.8 ±2.6	89.5 ±2.6	49.9 ±3.8	58.9 ±3.5	88.8 ±3.7	116.6 ±2.3	66.1 ±9.9	66.4 ±3.1	84.6 ±2.8	124.3 ±2.1	93.3 ±2.5	48.1 ±3.1	49.7 ±3.8	110.4 ±2.9	116.3 ±3.5	91.2 ±4.0
EAB (% dry)	13.6 ±0.1	7.7 ±0.6	7.3 ±0.4	3.8 ±0.3	5.3 ±0.4	10.0 ±1.1	13.7 ±2.0	8.6 ±1.5	10.4 ±1.0	12.9 ±0.6	20.1 ±0.5	10.3 ±0.9	5.1 ±1.0	4.8 ±0.5	11.4 ±1.2	12.2 ±0.3	10.1 ±0.6
TS (MPa, wet)	-	16.5 ±1.8	23.0 ±1.5	75.4 ±3.3	48.1 ±2.2	7.4 ±1.4	58.8 ±3.7	53.9 ±4.0	30.9 ±3.1	37.5 ±1.1	81.0 ±1.7	75.7 ±3.1	22.7 ±3.1	15.1 ±1.2	25.3 ±1.9	71.4 ±4.1	73.6 ±3.3
EAB (% wet)	-	2.6 ±0.2	4.6 ±0.3	13.5 ±0.5	8.9 ±0.5	2.8 ±0.3	26.4 ±2.2	16.6 ±1.5	9.6 ±0.5	15.4 ±1.7	15.0 ±0.8	17.5 ±0.9	5.8 ±0.5	7.0 ±0.4	7.9 ±0.4	17.8 ±0.6	13.9 ±1.6

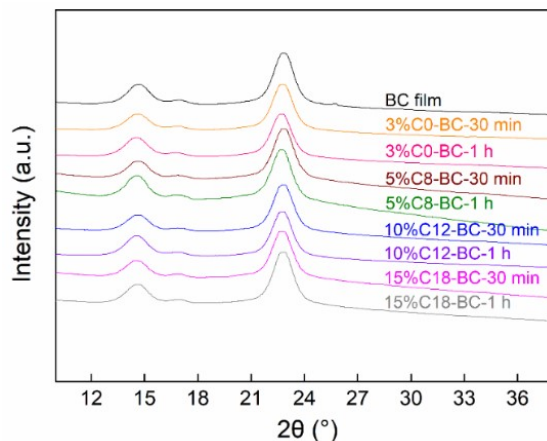


Figure S1. XRD of the pristine BC and 3%C0, 5%C8, 10%C12, 15%C18-30 min, 1 h films.

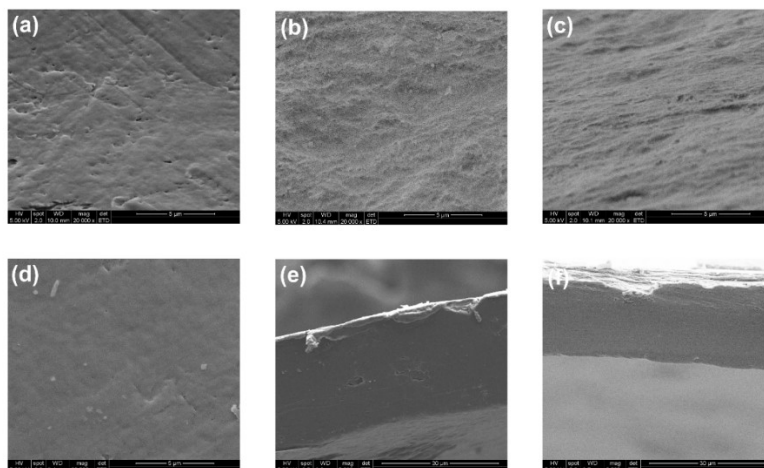


Figure S2. SEM images (cross-section) of (a) 3%C0-BC-1 h, (b) 5%C8-BC-1 h, (c) 10%C12-BC-1 h, (d) C15-BC-1 h at 20,000 \times , and (e) the pristine BC, (f) 5%C8-BC-1 h at 5,000 \times .

Table S4

Water resistance of the pristine BC and anhydride modified BC films at 10 min–3 h

Water resistance	BC	3%C0-BC				5%C8-BC				10%C12-BC				15%C18-BC			
		10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h
WCA, 1 s ($^{\circ}$)	64	73	78	76	81	93	96	88	92	82	96	97	101	93	96	103	104
	± 2	± 3	± 3	± 1	± 2	± 3	± 2	± 1	± 2	± 3	± 2	± 3	± 2	± 3	± 2	± 2	± 2
WCA, 5 min ($^{\circ}$)	18	47	52	54	54	78	83	71	75	52	70	76	78	77	83	90	89
	± 2	± 3	± 2	± 1	± 2	± 3	± 1	± 3	± 3	± 3	± 2	± 3	± 2	± 2	± 3	± 2	± 1
WS (%)	-	18.2	9.5	8.3	4.4	45.8	25.7	21.2	5.7	56.5	40.0	39.1	26.7	27.8	19.2	16.7	15.8
		± 1.3	± 0.7	± 0.5	± 0.5	± 2.2	± 1.9	± 0.7	± 0.3	± 2.3	± 2.1	± 1.2	± 1.3	± 1.2	± 0.4	± 0.8	± 1.3
WVP ($\times 10^{-10}$ g \cdot m $^{-1}$ ·s $^{-1}$ ·pa $^{-1}$)	3.11	2.43	2.48	2.84	2.21	2.93	1.92	1.46	1.26	2.82	2.35	2.47	2.10	2.53	1.89	1.03	1.57
	± 0.08	± 0.07	± 0.06	± 0.07	± 0.06	± 0.11	± 0.06	± 0.05	± 0.09	± 0.07	± 0.11	± 0.16	± 0.09	± 0.10	± 0.17	± 0.10	± 0.15

Table S5

WVP of 10%C8-BC-10 min–3 h and 15%C8-BC-10 min–3 h at 30 °C, 75%

Property	10%C8-BC				15%C8-BC			
	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h
WVP ($\times 10^{-10}$ g·m ⁻¹ ·s ⁻¹ ·pa ⁻¹)	1.16 ±0.03	0.87 ±0.02	0.51 ±0.03	0.92 ±0.01	2.48 ±0.02	2.39 ±0.04	1.77 ±0.06	1.06 ±0.04

Table S6

Mechanical strength of 10%C8-BC-10 min–3 h

Properties	10%C8-BC			
	10 min	30 min	1 h	3 h
TS (MPa, dry)	54.6 ±2.5	95.1 ±1.7	71.4 ±3.3	62.6 ±3.3
EAB (% , dry)	7.8 ±0.5	15.4 ±0.5	11.3 ±0.5	10.7 ±0.8
TS (MPa, wet)	25.2 ±2.1	52.8 ±3.9	37.8 ±3.0	59.8 ±3.6
EAB (% , wet)	9.3 ±0.4	15.6 ±0.5	12.4 ±0.9	10.5 ±0.8

Table S7

Mechanical strength of 15%C8-BC-10 min–3 h

Properties	10%C8-BC			
	10 min	30 min	1 h	3 h
TS (MPa, dry)	46.2 ±2.8	59.0 ±2.8	35.9 ±4.7	48.4 ±3.0
EAB (% , dry)	4.7 ±0.9	8.7 ±0.5	3.4 ±0.4	5.6 ±0.6
TS (MPa, wet)	26.4 ±4.0	35.5 ±3.4	37.6 ±4.9	41.8 ±3.8
EAB (% , wet)	6.8 ±0.5	10.1 ±1.2	9.6 ±0.5	10.3 ±1.1

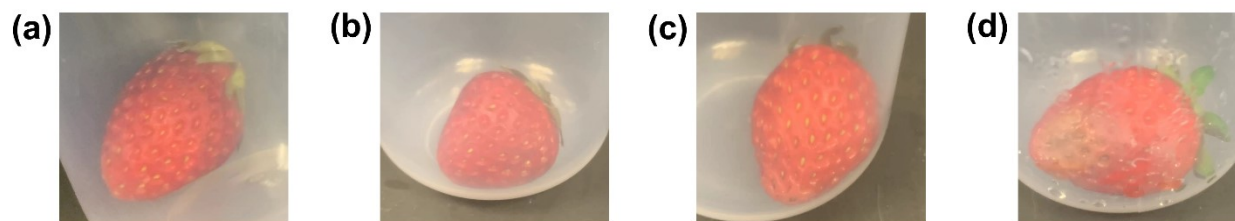
**Figure S3.** The photographs of the strawberries covered by the (a) pristine BC, (b) 3%C0-BC-1 h, (c) 10%C8-BC-1 h, and (d) LDPE films after storing at 4 °C for 7 d.

Table S8

Weight loss (%) of the uncovered, and pristine BC/3%C0-BC-1 h/10%C8-BC-1 h/LDPE covered strawberries during storage in refrigerator for 1–7 d

Samples	Weight loss (%)			
	1 d	3 d	5 d	7 d
uncovered	4.73 ±0.16	12.91 ±0.15	22.05 ±0.21	36.44 ±1.09
BC film covered	2.10 ±0.09	6.65 ±0.10	11.13 ±0.11	20.07 ±0.40
3%C0-BC-1 h covered	2.03 ±0.07	6.33 ±0.18	16.22 ±0.26	16.09 ±0.10
10%C8-BC-1 h covered	1.14 ±0.12	3.59 ±0.18	5.77 ±0.13	9.04 ±0.19
LDPE film	1.01 ±0.04	3.13 ±0.07	4.85 ±0.07	7.88 ±0.26

Table S9

Properties	BC	3%C0-BC				5%C8-BC				10%C12-BC				15%C18-BC			
		10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h	10 min	30 min	1 h	3 h
T _{max} (°C)	338	370	361	364	357	349	371	369	364	360	371	370	362	364	367	369	363

Thermal stability of the pristine BC and 3%C0, 5%C8, 10%C12, 15%C18-BC-10 min–3 h