

Supplementary Material

Table S1. D-optimal experiment design matrix for extraction with pressurized liquid (PLE)

Run	Pressure	Temperature	Cosolvent	Anthocyanins (mg C3GE/g coat)	Total phenolic compounds (mg GAE/g coat)
1	250	40	EtOH-H ₂ O 70%	1.14±0.01 ^j	3.86±0.35 ^k
2	250	40	EtOH-H ₂ O 70%	0.53±0.006 ^l	1.79±0.05 ^l
3	100	40	EtOH-H ₂ O 70%	0.65±0.005 ^k	1.89±0.008 ^l
4	250	60	EtOH-H ₂ O 70%	2.61±0.06 ^a	11.89±0.14 ^a
5	100	40	EtOH-H ₂ O 70%	0.73±0.008 ^k	2.13±0.04 ^l
6	100	60	EtOH-H ₂ O 70%	2.13±0.03 ^{ef}	7.45±0.14 ^f
7	100	60	EtOH-H ₂ O 70%	2.19±0.02 ^{de}	7.39±0.07 ^{fg}
8	200	60	EtOH-H ₂ O 50%	2.23±0.04 ^d	8.77±0.15 ^d
9	100	40	EtOH-H ₂ O 50%	1.28±0.02 ⁱ	4.02±0.05 ^k
10	200	40	EtOH-H ₂ O 50%	1.90±0.008 ^g	6.29±0.05 ^{hi}
11	100	60	Acidified H ₂ O	1.86±0.05 ^g	8.85±0.14 ^d
12	100	50	Acidified H ₂ O	1.32±0.03 ⁱ	5.84±0.11 ^{ij}
13	250	60	Acidified H ₂ O	1.85±0.04 ^g	8.38±0.14 ^{de}
14	100	40	Acidified H ₂ O	0.67±0.005 ^k	3.59±0.08 ^k
15	200	40	Acidified H ₂ O	1.08±0.01 ^j	5.63±0.18 ^j
16	200	50	Acidified H ₂ O	1.61±0.02 ^h	6.82±0.09 ^{gh}
17	100	50	EtOH-H ₂ O 50%	2.14±0.06 ^{def}	7.91±0.59 ^{ef}
18	250	40	Acidified H ₂ O	0.75±0.01 ^k	4.05±0.09 ^k
19	250	50	EtOH-H ₂ O 50%	2.08±0.02 ^f	7.44±0.21 ^f
20	200	60	EtOH-H ₂ O 50%	2.33±0.03 ^c	9.72±0.11 ^c
21	250	50	Acidified H ₂ O	1.30±0.007 ⁱ	5.59±0.22 ^j
22	250	60	EtOH-H ₂ O 70%	2.48±0.001 ^b	10.43±0.2 ^b

EtOH: Ethanol, H₂O: Water, C3GE: Cyanidin 3-glucoside equivalents, GAE: Gallic acid equivalents. Different letters indicate significant differences within a column at $p < 0.05$ (Tukey HSD post hoc analysis).

Table S2. D-optimal experiment design matrix for extraction with supercritical CO₂ (SFE)

Run	Pressure	Temperature	Cosolvent	Anthocyanins (mg C3GE/g coat)	Total phenolic compounds (mg GAE/g coat)
1	300	60	Acidified H ₂ O	3.15±0.02 ^a	8.81±0.26 ^b
2	200	40	Acidified H ₂ O	2.48±0.05 ^g	5.56±0.01 ^{jk}
3	160	40	EtOH-H ₂ O 50%	2.72±0.03 ^{de}	7.54±0.16 ^e
4	160	60	EtOH-H ₂ O 10%	2.29±0.07 ^h	6.00±0.18 ^{hi}
5	300	60	EtOH-H ₂ O 50%	2.73±0.04 ^{de}	8.63±0.16 ^{bc}
6	200	60	Acidified H ₂ O	2.63±0.009 ^{efg}	6.67±0.02 ^{fg}
7	300	40	EtOH-H ₂ O 10%	1.98±0.02 ^{jk}	5.21±0.03 ^{kl}
8	160	40	EtOH-H ₂ O 50%	2.78±0.006 ^{de}	6.93±0.13 ^f
9	160	60	EtOH-H ₂ O 50%	2.84±0.01 ^{cd}	9.00±0.04 ^b
10	160	50	Acidified H ₂ O	2.76±0.08 ^{de}	6.11±0.07 ^h
11	300	50	Acidified H ₂ O	2.26±0.05 ^{hi}	5.49±0.04 ^{jk}
12	300	40	EtOH-H ₂ O 50%	2.81±0.06 ^{cd}	8.33±0.05 ^{cd}
13	160	40	EtOH-H ₂ O 10%	2.11±0.02 ^{ij}	5.48±0.15 ^{jk}
14	300	60	EtOH-H ₂ O 10%	3.00±0.02 ^{ab}	9.67±0.07 ^a
15	300	50	EtOH-H ₂ O 10%	2.25±0.01 ^{hi}	6.99±0.12 ^f
16	160	60	EtOH-H ₂ O 50%	2.95±0.12 ^{bc}	8.06±0.12 ^d
17	160	60	EtOH-H ₂ O 10%	2.08±0.04 ⁱ	6.32±0.05 ^{gh}
18	160	50	Acidified H ₂ O	2.30±0.03 ^h	5.67±0.08 ^{ij}
19	300	40	Acidified H ₂ O	1.79±0.04 ^l	4.32±0.13 ^m
20	200	50	EtOH-H ₂ O 10%	2.56±0.05 ^{fg}	6.77±0.14 ^f
21	160	40	EtOH-H ₂ O 10%	1.91±0.04 ^{kl}	5.04±0.07 ^l
22	300	50	EtOH-H ₂ O 50%	2.65±0.01 ^{ef}	8.24±0.04 ^d

EtOH: Ethanol, H₂O: Water, C3GE: Cyanidin 3-glucoside equivalents, GAE: Gallic acid equivalents. Different letters indicate significant differences within a column at $p < 0.05$ (Tukey HSD post hoc analysis).

Table S3. Comparative table of the recovery of bioactive compounds from common bean by conventional and alternative extraction methods

Method	Time required to process 50 grams of common bean		
	Conventional (Leaching)	Alternative (SFE)	Alternative (PLE)
Husking	8 h		
Grinding	30 min	Does not require	Does not require
Sieving	30 min	sample processing	sample processing
Extraction	15 min	1 h	15 min
Centrifugation	15 min	Does not apply	Does not apply
Other advantages			
Solvent amount	High (212 mL)	Low (95 mL)	High (212 mL)
Solvent type	Ethanol and hydrochloric acid	Ethanol and water	Ethanol and water
Cotyledon recovery	Yes	Yes	Yes

SFE: Supercritical fluid extraction, PLE: Pressurized liquid extraction, h: hour(s), min: minute(s).

Table S4. First-order reaction kinetics for (A) total phenolic compounds and (B) color a* parameters degradation of extracts under light and dark conditions after 10 days.

(A)	Total phenolic compounds			
	Parameter	Light condition	By LEA-M	By SFE
	Rate (k, d ⁻¹)	Light	0.0162±0.002 ^{aA}	0.0210±0.0002 ^{aA}
		Dark	0.0090±0.002 ^{aA}	0.0167±1·10 ^{-4bA}
	Half-life (t _{1/2} , d)	Light	44.09±5.587 ^{aA}	33.01±0.455 ^{bA}
		Dark	89.37±24.073 ^{aA}	41.31±0.353 ^{aA}
	Regression coefficient, R ²	Light	0.99	0.95
		Dark	0.98	0.93

(B)	Color a*			
	Parameter	Light condition	By LEA-M	By SFE
	Rate (k, d ⁻¹)	Light	0.0349±5·10 ⁻⁴ ^{aB}	0.0866±2·10 ^{-4aA}
		Dark	0.0202±7·10 ⁻⁵ ^{bB}	0.0487±4·10 ^{-4bA}
	Half-life (t _{1/2} , d)	Light	19.82±0.322 ^{bA}	7.99±0.024 ^{bB}
		Dark	34.25±0.118 ^{aA}	14.22±0.141 ^{aB}
	Regression coefficient, R ²	Light	0.99	0.99
		Dark	0.99	0.99

LEA-M: Leaching extraction of manually husked bean coat, SFE: Supercritical fluid extraction, D: days. Different lowercase letters show significant differences within the same sample under distinct light condition, while different uppercase letters show significant differences among samples under the same light condition (p-level < 0.05, two-sample t-test). The results are shown in mean ± standard error.

Table S5. First-order reaction kinetics and Arrhenius parameters for (A) total phenolic compounds and (B) color a* parameters degradation of extracts at 4°C, 25°C and 32°C after six weeks.

(A)	Total phenolic compounds			
	Parameter	Temperature	By LEA-M	By SFE
	Rate (k, d ⁻¹)	4°C	0.0031±1·10 ⁻⁴ bB	0.0061±2·10 ⁻⁴ aA
		25°C	0.0051±6·10 ⁻⁵ aB	0.0060±1·10 ⁻⁴ aA
		32°C	0.0061±1·10 ⁻⁴ aA	0.0110±0.0015 ^{aA}
	Half-life (t _{1/2} , d)	4°C	224.71±12.92 ^{aB}	113.80±3.90 ^{aA}
		25°C	133.82±1.52 ^{bB}	114.09±2.11 ^{aA}
		32°C	113.72±2.87 ^{bA}	65.07±8.96 ^{bA}
	Q ₁₀	(4 – 25°C)	1.2817±0.039 ^{aA}	1.2398±0.078 ^{aA}
		(25 – 32°C)	1.2527±0.035 ^{aA}	1.2151±0.070 ^{aA}
	Energy of activation, Ea (kJ/mol)		16.63±2.12 ^A	14.47±4.36 ^A
	Regression coefficient, R ²		0.99	0.99

(B)	Color a*			
	Parameter	Temperature	By LEA-M	By SFE
	Rate (k, d ⁻¹)	4°C	0.0011±3·10 ⁻⁵ cB	0.0053±5·10 ⁻⁵ cA
		25°C	0.0094±1·10 ⁻⁵ bB	0.0222±7·10 ⁻⁵ bA
		32°C	0.0194±5·10 ⁻⁵ aB	0.0369±1·10 ⁻⁴ aA
	Half-life (t _{1/2} , d)	4°C	580.68±16.28 ^{aA}	128.99±1.20 ^{aB}
		25°C	73.55±1.52 ^{bA}	31.13±0.094 ^{bB}
		32°C	35.69±0.094 ^{bA}	18.77±0.095 ^{cB}
	Q ₁₀	(4 – 25°C)	2.74±0.031 ^{aA}	2.09±0.010 ^{aB}
		(25 – 32°C)	2.50±0.026 ^{aA}	1.88±0.009 ^{bB}
	Energy of activation, Ea (kJ/mol)		69.33±0.795 ^A	47.87±0.371 ^B
	Regression coefficient, R ²		0.99	0.99

LEA-M: Leaching extraction of manually husked bean coat, SFE: Supercritical fluid extraction, D: days, Q₁₀: change in the reaction rate constant for 10°C. Different lowercase letters show significant differences within the same sample at distinct storage temperature (p-level < 0.05, Tukey HSD post hoc analysis), while different uppercase letters show significant differences among samples under the same storage temperature (p-level < 0.05, two-sample t-test). The results are shown in mean ± standard error.

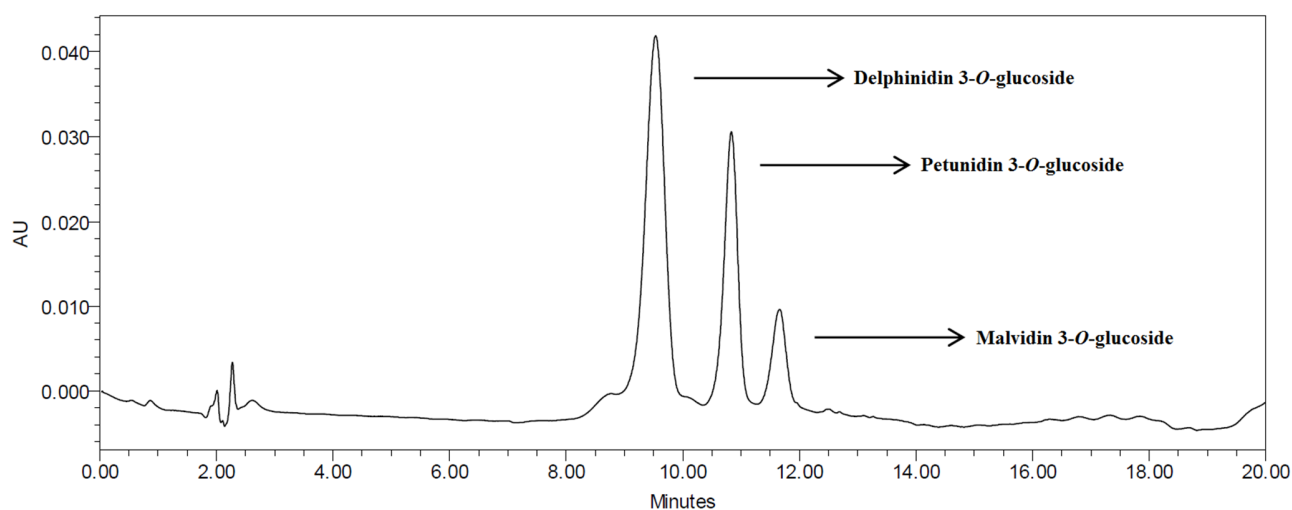


Figure S1. Representative UHPLC chromatogram of the anthocyanin extracts and the % relative area (absorbance at 520 nm). The results are shown in mean $\pm$ standard deviation.

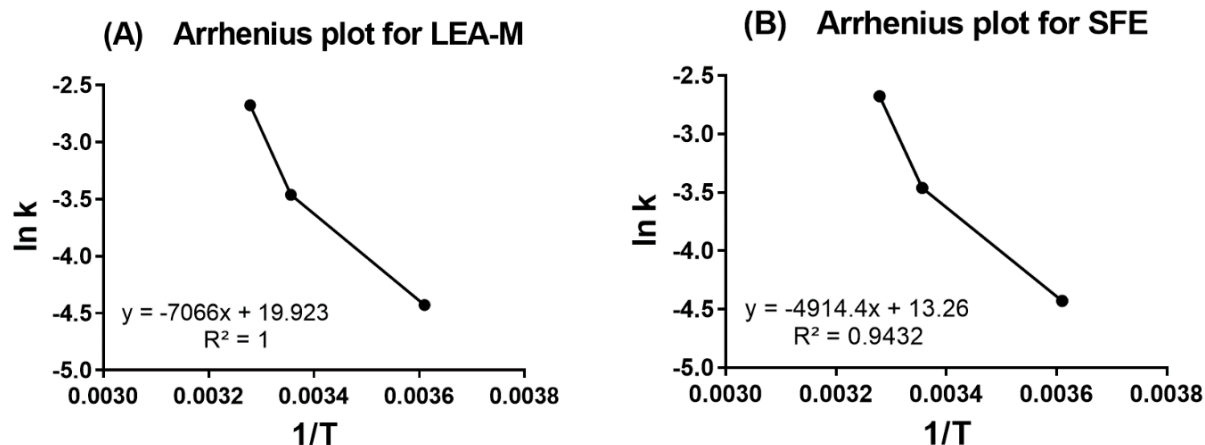


Figure S2. Arrhenius plot of anthocyanins at different temperatures for Leaching extraction of manually husked bean coat LEA-M (A) and Supercritical fluid extraction – SFE (B). k : Rate, T : Temperature, R^2 : Regression coefficient.

Effect of light exposure on color difference

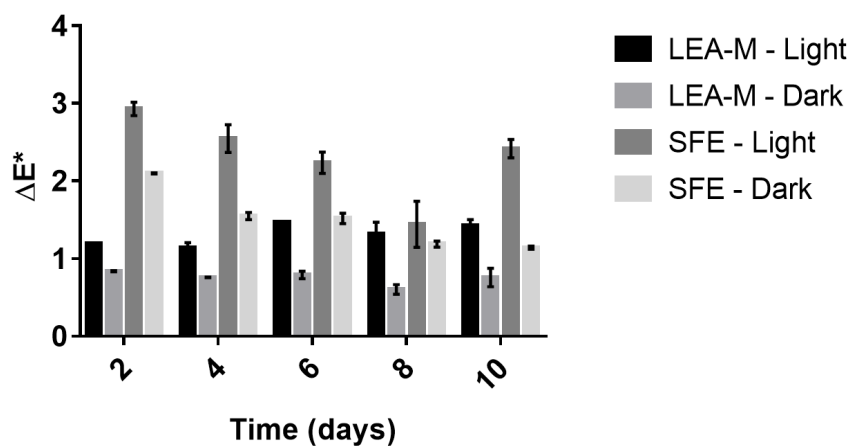
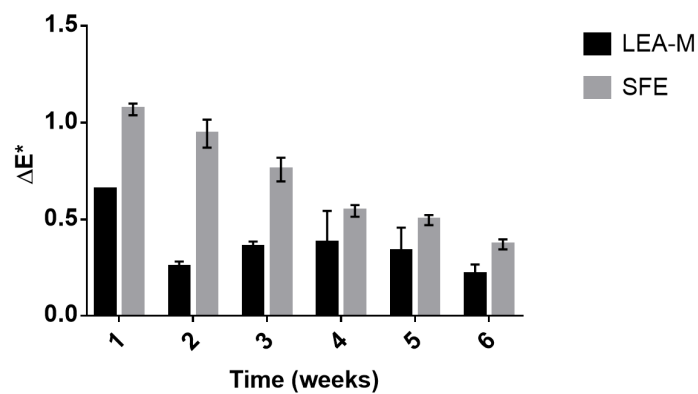
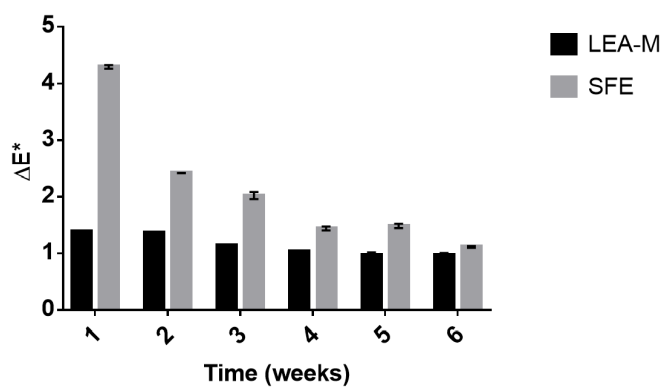


Figure S3. Effect of light exposure on the color difference (ΔE^*) of anthocyanin-rich extract from LEA-M and SFE. LEA-M: Leaching extraction of manually husked bean coat, SFE: Supercritical fluid extraction. The results are shown in mean $\pm$ standard error.

(A) Effect of storage at 4°C on color difference



(B) Effect of storage at 25°C on color difference



(C) Effect of storage at 32°C on color difference

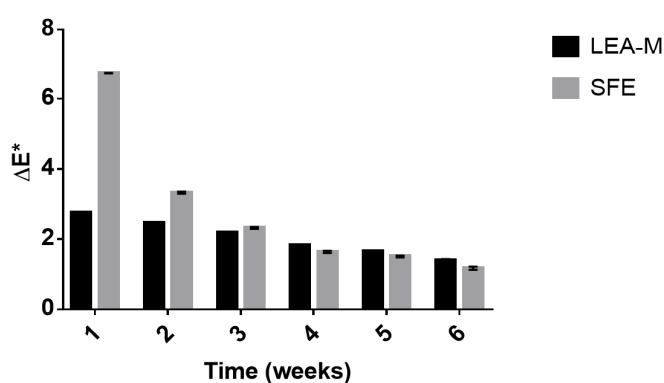


Figure 4. Effect of temperature storage on the color difference (ΔE^*) of anthocyanin-rich extract from LEA-M and SFE. (A): 4°C. (B): 25°C, (C): 32°C. LEA-M: Leaching extraction of manually husked bean coat, SFE: Supercritical fluid extraction. The results are shown in mean $\pm$ standard error.