

Supplementary Table 1. Type and family of selected CBMs and primers used for PCR amplification. Underlining indicates *EcoRI*, *ApaI* or *MluI* restriction sites.

Name	Type	Family	Forward primer (5'-3')	Reverse primer (5'-3')
Chit46 (C)	-	-	CTGCGAATTCAGCCCCCTGGCCACAG	ACTTACGCGTAACTGGGCCCGTT CAGACCGTTCCTGATGTT
CBM3	A	CBM3	AACTGGGCCCCAGGAATCATCCTCAGCT	ACTTACGCGTATTTGGTTCTGTT CCCCA
CBM6	B	CBM6	AACTGGGCCCATTTCCAATTTAAACCCAT	ACTTACGCGTTTTGCGTAAACTGC CAGTAA
CBM26	B	CBM26	AACTGGGCCCGCAAAGCGCCTCATGTT	ACTTACGCGTATTCTGACCGGGC ACTTG
Chit46 (N)	-	-	CTGCGAATTCAACTGGGCCCGAGCCCC TGGCCACAG	ACTTACGCGTTTCAGACCGTTCC TGATGTT
CBM48	B	CBM48	CTGCGAATTCCTCCCTCGGCGCGCATTAC	AACTGGGCCCGCGCAAGGATC AATCAA
CBM25	B	CBM25	CTGCGAATTCGGAAATACTGTGGAGCTG	AACTGGGCCCATTGACATTCATG TATCC
CBM48-P	B	CBM48	CTGCGAATTCGAGCTGGGCGCCGTTTAT	AACTGGGCCCGGCATACTGGTC AACTGT
LysM1	-	CBM50	CTGCGAATTCCTTTATCCATATCGTCGGG	AACTGGGCCCGGAATCGTTAT TTTTGC
LysM2	-	CBM50	CTGCGAATTCATGGTAAACAAGGCGAC	AACTGGGCCCGATGTATAAACG GAAACC
LysM3	-	CBM50	CTGCGAATTCCAAAGCATTAAAGGTGAAA	AACTGGGCCCTTTCACCTTCAAT ACTTG
LysM4	-	CBM50	CTGCGAATTCGAAGCAAAAACGATAAAA	AACTGGGCCCGAAATAGTCAG AACCTG

Supplementary Table 2. Concentration of chitin oligomers products of colloidal chitin hydrolyzed by chitinases.

Chitinase	Time (h)	DP1 (g/l)	DP2 (g/l)	DP3 (g/l)	DP4 (g/l)	DP5 (g/l)	DP6* (g/l)	DP6 (g/l)	DP7# (g/l)	Total (g/l)
rChit46	1	0.03	0.42	0.07	0.10	2.19	1.16	0.20	0.74	4.91
	2	0.04	1.50	0.09	0.11	2.12	1.17	0.25	0.31	5.59
	3	0.04	1.92	0.09	0.11	2.12	1.12	0.28	1.66	7.34
	4	0.04	1.94	0.07	0.12	2.31	1.24	0.32	1.74	7.79
	5	0.04	2.13	0.05	0.10	1.80	1.23	0.43	3.67	9.46
	6	0.05	2.41	0.05	0.10	1.80	1.23	0.66	4.60	10.91
Chit46-CBM3	1	0.06	2.78	0.10	0.17	1.08	0.84	0	2.68	7.70
	2	0.17	4.48	0.05	0.16	0.86	0.76	0	2.37	8.85
	3	0.26	6.51	0.09	0.17	1.07	0.93	0	0.91	9.93
	4	0.28	7.19	0.08	0.16	1.00	0.89	0	1.31	10.92
	5	0.31	7.73	0.08	0.16	0.92	0.85	0	2.14	12.19
	6	0.33	8.28	0.08	0.16	0.95	0.90	0	2.68	13.38
Chit46-CBM6	1	0.04	1.73	0.12	0.17	0.50	0.48	0	2.23	5.28
	2	0.07	2.22	0.05	0.15	0.31	0.53	0	2.57	5.90
	3	0.10	3.14	0.07	0.15	0.36	0.54	0	2.00	6.36
	4	0.12	3.43	0.00	0.12	0.32	0.70	0.01	2.23	6.93
	5	0.18	4.95	0.11	0.17	0.53	0.79	0.02	2.69	9.44
	6	0.28	7.96	0.12	0.17	0.72	0.88	0.05	2.07	12.26
Chit46-CBM26	1	0.07	2.06	0.15	0.17	2.84	1.11	0.04	3.09	9.52
	2	0.08	3.61	0.12	0.17	2.39	1.12	0.25	2.43	10.17
	3	0.14	4.21	0.11	0.17	2.33	1.30	1.45	1.68	11.40
	4	0.18	4.68	0.10	0.18	2.54	1.40	2.07	1.05	12.20
	5	0.22	5.52	0.08	0.20	2.40	1.69	2.88	0.93	13.91
	6	0.24	6.06	0.06	0.19	2.18	1.68	2.93	1.29	14.63

Supplementary Table 3. Concentration of chitin oligomers products of shrimp shell powders hydrolyzed by chitinases.

Chitinase	Time (h)	DP1 (g/l)	DP2 (g/l)	DP3 (g/l)	DP4 (g/l)	DP5 (g/l)	DP6* (g/l)	DP6 (g/l)	DP7#(g/l)	Total (g/l)
rChit46	1	0.03	0.02	0.02	0.02	0.36	0.34	0.31	0.14	1.09
	2	0.04	0.02	0.02	0.02	0.37	0.35	0.40	0.17	1.17
	3	0.06	0.04	0.02	0.03	0.38	0.39	0.47	0.19	1.29
	4	0.06	0.05	0.01	0.03	0.24	0.47	0.48	0.22	1.30
	5	0.04	0.02	0.01	0.03	0.21	0.62	0.56	0.19	1.66
	6	0.06	0	0	0.04	0.21	0.12	0.74	0.54	1.71
Chit46-CBM3	1	0.11	0.22	0.08	0.14	2.33	1.20	3.03	0	7.12
	2	0.13	0.31	0.09	0.14	2.73	1.27	3.46	0	8.14
	3	0.13	0.37	0.13	0.14	2.65	1.26	3.37	0.19	8.24
	4	0.14	0.40	0.13	0.13	2.66	1.26	3.37	0.69	8.78
	5	0.07	0.38	0.13	0.13	2.64	1.25	3.36	0.82	8.77
	6	0.15	0.41	0.13	0.14	2.82	1.29	3.56	1.55	10.05
Chit46-CBM6	1	0.20	0	0.05	0.04	0.86	1.04	1.90	0	4.09
	2	0.21	0.28	0.05	0.04	0.89	1.14	1.88	0.41	4.90
	3	0.26	0.37	0.02	0.06	1.00	1.65	2.25	0.43	6.04
	4	0.25	0.51	0.01	0.06	0.99	1.67	2.18	1.33	7.00
	5	0.26	0.51	0.01	0.07	1.12	1.85	2.26	1.80	7.88
	6	0.58	0.84	0	0.07	1.08	1.81	3.31	0.92	8.61
Chit46-CBM26	1	0.07	0.11	0.03	0.04	1.38	0.94	1.59	0.90	5.16
	2	0.08	0.12	0.04	0.04	1.41	1.02	1.60	1.03	5.44
	3	0.14	0.07	0.01	0.03	1.44	1.50	1.62	0.76	5.64
	4	0.18	0.12	0.02	0.04	1.57	1.60	1.80	1.12	6.49
	5	0.22	0.08	0.02	0.04	1.75	1.98	1.97	0.98	7.06
	6	0.24	0	0	0.06	1.30	3.31	2.73	0.73	8.41

Supplementary Table 4. Inventory of the traditional, enzymatic and one-step processes (per year in Guangzhou).

Process	Agent	Deproteinization	Demineralization	Deacetylation	Polymer hydrolysis	Astaxanthin extraction
Traditional process	Chemicals/enzymes	10,000 tonnes NaOH (9,000,000 USD)	5000 tonnes HCl (460,000 USD)	40,000 tonnes NaOH (36,000,000 USD)	Chitosanase (2,000,000 USD)	–
	Reaction conditions	20,000 m ³ Water; 90°C/1 atm/2 h	100,000 m ³ Water; 25°C/1 atm/2 h	100,000 m ³ Water; 90°C/1 atm/6 h	–	–
	Energy exhausted	45,500,000 kWh	20,000 kWh	68,250,000 kWh		
	Waste water	214,800 tonnes with protein	106,800 tonnes with minerals	140,400 tonnes with NaAc	–	–
	CO ₂ emissions	6,806,800 kg	2,992 kg	10,210,200 kg		
	Valuable products	Protein and astaxanthin lost	Minerals lost; 2000 tonnes chitin (30,000,000 USD)	1500 tonnes chitosan (40,000,000 USD)	1640 tonnes chitosan oligomers (136,120,000 USD)	–
Enzymatic process with three enzymes	Chemicals/enzymes	Proteases (2,000,000 USD)	–	–	Chitinase (2,000,000 USD)	36,000 tonnes ethyl acetate
	Reaction conditions	300,000 m ³ Water; 40°C/1 atm/4 h	–	–	100,000 m ³ water; 45°C/1 atm/6 h	30°C/1 atm/2 h
	Energy exhausted	7,875,000 kWh			3,500,000 kWh	120,000 kWh
	Waste water	–	–	–	–	36,000 tonnes ethyl acetate recovered by distillation
	CO ₂ emissions	1,178,100 kg			523,600 kg	17,950 kg
	Valuable products	4600 tonnes protein (6,800,000 USD)	–	–	2000 tonnes chitin oligomers (166,000,000 USD)	1 tonne Astaxanthin (4,800,000 USD) and 3300 tonnes minerals
One-step chitinase process	Chemicals/enzymes			Chitinase (4,000,000 USD)		
	Reaction conditions			100,000 m ³ Water at 40°C/1 atm/12 h		
	Energy exhausted			2,625,000 kWh		
	Waste water			–		
	CO ₂ emissions			392,700 kg		
	Valuable products	950 tonnes chitin oligomers (78,850,000 USD), 1130 tonnes protein (1,670,000 USD) and 7690 tonnes residue (11,000,000 USD)				

Supplementary Table 5. Resource parameters used in ecological footprint calculation^a.

Resources	Energy intensity (GJ/units)	Productivity	
		Natural (Units/ha/y)	Energy (GJ/ha/y)
Water	-	1500	-
NaOH	40	-	71
HCl	40	-	71
Enzymes	1.64	28.05	71

^a C. Lopes, L. T. Antelo, A. Franco-Uria, A. A. Alonso and R. Perez-Martin, *J Clean Prod*, 2018, **172**, 4140-4151.