Supporting information

Mathematical modeling of microalgal internal metabolic behaviors under heterotrophic condition and its application

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S1. Assumptions

In the proposed model takes below assumptions into account for established a mathematical model having acceptable complexity:

- Carbon, nitrogen, phosphorus, and sulfur is nutrient for algal growth. Micronutrients such as vitamins and minerals are neglected.
- The proposed model structural and equations are developed based on dominant phenomena.
- Only nitrogen and phosphate contribute to synthesis of nucleotides.
- Amino acid is synthesized by using carbon backbone (C pool), nitrogen (N pool), and sulfur (S pool).
- Chlroin family pigments are grouped as “pigment a”
- Carotenoid family pigments are grouped as “pigment b”
- Pigments, protein, polysaccharide, and membrane lipid are degraded under stress conditions.
- There is no substrate inhibition.

S2. Parameter estimation results

The estimated model parameters of the proposed model and reduced models are enumerated below.

S2.1 Model parameters of the general model

Table S1: Nominal parameter values for the proposed model obtained from experimental data in the literature [1-13]

Index	Parameters	Value	Source	Index	Parameters	Value	Source
1	$q_{C,\max}$	30.54		40	$\pi_{pig1,\max}$	0.505	
2	$q_{N,\max}$	0.515		41	$\pi_{pig2,\max}$	0.861	
3	$q_{P,\max}$	0.345		42	$\pi_{ps,\max}$	2.598	
4	$q_{S,\max}$	0.269		43	$\pi_{ml,\max}$	8.512	
5	$q_{aa,\max}$	4.740	[14]	44	$\pi_{nl,\max}$	6.295	
6	$q_{nt,\max}$	7.110	[14]	45	$\lambda_{aa,\max}$	0.029	
7	$q_{ml,\max}$	5.925	[14]	46	$\lambda_{pro,\max}$	1.398	

8	$q_{nl,\max}$	19.75	[14]	47	$\lambda_{pig1,\max}$	0.094	
9	$q_{pig1,\max}$	1.750	[14]	48	$\lambda_{pig2,\max}$	0.509	
10	$q_{pig2,\max}$	1.750	[14]	49	$\lambda_{ps,\max}$	0.647	
11	$q_{pro,\max}$	25.68	[14]	50	$\lambda_{ml,\max}$	0.349	
12	$q_{ps,\max}$	11.07	[14, 15]	51	$\lambda_{nl,\max}$	0.185	
13	$q_{ms,\max}$	6.701	[14, 15]	52	$Y_{C/ms}$	2.631	
14	$q_{C,\min}$	0	Fixed	53	$Y_{C/pig1}$	6.409	
15	$q_{N,\min}$	0	Fixed	54	$Y_{C/pig2}$	6.185	
16	$q_{P,\min}$	0	Fixed	55	$Y_{C/aa}$	0.098	
17	$q_{S,\min}$	0	Fixed	56	$Y_{C/ml}$	0.158	
18	$q_{aa,\min}$	0	[14]	57	$Y_{aa/C}$	0.236	
19	$q_{nt,\min}$	1.185	[14]	58	$Y_{aa/N}$	1.880	
20	$q_{ml,\min}$	1.975	[14]	59	$Y_{aa/S}$	0.127	
21	$q_{nl,\min}$	3.950	[14]	60	$Y_{aa/pro}$	0.016	
22	$q_{pig1,\min}$	0.079	[14]	61	$Y_{aa/pig2}$	0.044	
23	$q_{pig2,\min}$	0.079	[14]	62	$Y_{nt/P}$	0.548	
24	$q_{pro,\min}$	11.85	[14]	63	$Y_{nt/aa}$	0.890	
25	$q_{ps,\min}$	1.230	[14, 15]	64	$Y_{pro/aa}$	4.601	
26	$q_{ms,\min}$	0.745	[14, 15]	65	$Y_{pig1/C}$	1.360	
27	$\mu_{\max}$	1.700	[16]	66	$Y_{pig2/C}$	1.316	
28	k_d	0.008	[16]	67	$Y_{pig2/aa}$	0.340	
29	$\rho_{C,\max}$	38.00		68	$Y_{ps/C}$	1.111	
30	$\rho_{N,\max}$	26.39		69	$Y_{ms/ps}$	0.177	
31	$\rho_{P,\max}$	5.011		70	$Y_{ml/C}$	0.223	
32	$\rho_{S,\max}$	7.355		71	$Y_{ml/P}$	1.332	
33	K_{s_C}	0.255		72	$Y_{nl/C}$	0.201	
34	K_{s_N}	0.159		73	σ_{nt}	0.657	
35	K_{s_P}	0.108		74	σ_{pro}	0.148	
36	K_{s_S}	0.085		75	σ_{pig1}	0.320	
37	$\pi_{aa,\max}$	9.924		76	σ_{pig2}	0.863	
38	$\pi_{nt,\max}$	1.647		77	σ_{ps}	0.655	
39	$\pi_{pro,\max}$	9.498		78	σ_{ml}	1.785	

S2.2 Model parameters of the example 1

Table S2: Parameter refinement result for the model reduction example 1

Index	Parameters	Initial value	Converged value	95% confidence interval	
1	$q_{car,\max}$	63.60	163.9	147.8	188.1

2	$q_{car,\min}$	2.994	25.98	25.20	26.87
3	$q_{N,\max}$	0.515	1.547	1.519	1.581
4	$q_{N,\min}$	0	0	0	0
5	$q_{lip,\max}$	12.32	246.2	227.1	272.6
6	$q_{lip,\min}$	3.121	3.121	3.121	3.121
7	$q_{pro,\max}$	31.45	494.7	477.0	514.7
8	$q_{pro,\min}$	13.23	145.9	142.5	150.4
9	$\mu_{\max}$	1.700	22.04	21.28	24.93
10	k_d	0.008	0.008	0.004	0.018
11	$\rho_{C,\max}$	38.00	331.0	327.1	338.2
12	$\rho_{N,\max}$	26.39	105.0	82.89	137.2
13	K_{s_C}	0.255	0.192	0.131	0.317
14	K_{s_N}	0.159	0.159	0.159	0.159
15	$\pi_{ml,\max}$	7.795	7.795	7.795	7.795
16	$\pi_{nl,\max}$	7.212	7.212	7.212	7.212
17	$\pi_{pro,\max}$	13.31	78.74	76.62	81.84
18	$\lambda_{ml,\max}$	0.200	0.044	0.026	0.108
19	$\lambda_{pro,\max}$	2.728	3.556	3.091	5.001
20	$Y_{car/C}$	0.534	1.841	1.833	1.855
21	$Y_{car/ml}$	1.686	1.686	1.686	1.686
22	$Y_{car/pro}$	1.401	0.151	0.082	0.306
23	$Y_{ml/car}$	0.256	0.216	0.216	0.216
24	$Y_{nl/car}$	0.349	1.629	1.622	1.673
25	$Y_{pro/N}$	1.965	1.965	1.965	1.965
26	$Y_{pro/car}$	0.853	0.659	0.658	0.663
27	σ_{car}	0.457	0.457	0.457	0.457
28	σ_{lip}	0.186	0.186	0.186	0.186
29	σ_{pro}	0.765	0.765	0.765	0.765
30	k_{nt}	2.265	2.265	2.265	2.265
31	k_{pig}	0.066	0.066	0.066	0.066

S2.3 Model parameters of the example 2

Table S3: Parameter refinement result for the model reduction example 2

Index	Parameters	Initial value	Converged value	95% confidence interval	
1	$q_{C,\max}$	30.54	46.03	35.46	61.83
2	$q_{C,\min}$	0	0	0	0
3	$q_{em,\max}$	19.75	46.87	41.09	58.82

4	$q_{em,\min}$	3.950	3.950	3.950	3.950
5	$q_{sm,\max}$	121.6	47.63	47.63	47.64
6	$q_{sm,\min}$	12.00	0.872	0.833	0.941
7	K_{pH}	0	$10.0^{-8.908}$	$10.0^{-8.908}$	$10.0^{-8.908}$
8	$K_{I,pH}$	$10.0^{-7.0}$	$10.0^{-5.284}$	$10.0^{-5.284}$	$10.0^{-5.284}$
9	$\mu_{\max}$	1.700	1.859	1.426	2.509
10	k_d	0.008	0.034	0.029	0.039
0.11	$\rho_{C,\max}$	38.00	69.21	55.36	98.49
12	K_{s_C}	0.255	4.443	2.924	7.316
13	$\pi_{em,\max}$	6.295	7.867	7.867	7.872
14	$\pi_{sm,\max}$	5.770	0.246	0.163	0.354
15	$\lambda_{sm,\max}$	0.039	28.27	11.83	47.80
16	$Y_{C/sm}$	2.064	0.723	0.723	0.723
17	$Y_{em/C}$	0.028	1.245	1.245	1.245
18	$Y_{sm/C}$	0.593	0.577	0.468	0.743
19	σ_{sm}	1.226	0.032	0.032	0.032
20	k_{lutein}	0.100	0.134	0.134	0.134

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