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The composition and oxidative stability of vegetarian omega-3 algal oil nanoemulsions suitable for functional food enrichment

Table 1. Fatty acid composition of DHA-S™ bulk algae oil by GC

Fatty acid	DHA-S™ algal oil (g/100g)
14:0 (Myristic acid)	6.00
16:0 (Palmitic acid)	15.80
18:0 (Stearic acid)	0.90
18:1*n*-9 (Oleic acid)	14.8
18:2*n*-6 (Linoleic acid)	1.00
20:4*n*-6 (Arachidonic acid)	0.90
20:5*n*-3 (EPA)	<0.10
22:5*n*-6 (Docosapentaenoic acid)	16.70
22:6*n*-3 (DHA)	39.40
Total LCn3PUFA	39.40

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Table 2. Composition of main fatty acids (% of total fatty acids) of algal oil and nanoemulsions stabilized with emulsifiers Lecithin (LN), Tween 40 (TN) and lecithin/Tween 40 (LTN) storage at 4°C, 20 °C and 40 °C for weeks 1 and 5 determined via gas chromatography

% FA	14:0	16:0	18:1n-9	18:2n-6	22:5n-6	22:6n-3
4°C			Week 1			
Oil	6.62±0.60	16.80±1.58	15.28±1.48	0.60±0.52	17.94±0.82	42.76±4.19
LN	5.99±0.91	17.53±2.71	16.15±2.65	6.68±1.10	16.42±2.82	37.24±7.81
LTN	5.23±0.20	17.26±1.13	16.59±1.29	5.09±0.39	16.59±1.03	39.03±2.43
TN	5.60±0.72	18.42±2.46	16.14±2.26	1.99±0.30	17.02±2.49	40.83±5.99
20°C			Week 1			
Oil	6.46±0.48	16.67±0.75	15.38±0.63	0.90±0.05	17.84±1.35	42.76±3.26
LN	5.88±0.39	17.19±1.12	15.94±1.08	6.61±0.45	16.28±1.22	38.10±2.71
LTN	5.39±0.68	17.12±2.33	16.37±2.14	4.98±0.71	16.74±1.89	39.40±4.15
TN	5.60±0.49	18.40±1.63	16.16±1.48	2.00±0.19	17.05±1.63	40.80±3.81
40°C			Week 1			
Oil	-	-	-	-	-	-
LN	5.91±0.41	17.21±1.21	15.96±1.14	6.66±0.48	16.27±1.20	37.99±2.72
LTN	5.40±0.47	17.27±1.51	16.53±1.53	5.00±0.48	16.63±1.63	39.18±4.15
TN	5.47±0.47	17.95±1.52	15.75±1.40	1.96±0.19	16.54±1.63	39.81±3.91
4°C			Week 5			
Oil	6.59±0.002	16.39±0.014	14.88±0.046	0.83±0.01	18.05±0.18	43.25±0.02
LN	5.91±0.50	17.36±1.53	16.24±1.48	6.81±0.62	16.66±1.56	37.03±5.77
LTN	5.27±0.03	16.92±0.05	16.34±0.11	4.97±0.03	16.82±0.56	39.67±1.21
TN	5.47±0.09	18.02±0.30	15.91±0.26	1.95±0.03	17.27±0.28	41.37±0.70
20°C			Week 5			
Oil	6.58±0.35	16.45±0.88	15.03±0.83	0.84±0.06	17.56±0.27	43.54±2.38
LN	5.82±0.51	17.09±1.36	15.97±1.28	6.72±0.54	16.38±1.34	38.06±3.03
LTN	5.31±0.6	16.87±1.96	16.17±1.96	4.90±0.62	16.84±1.90	39.91±4.91
TN	5.52±0.26	18.17±0.94	15.98±0.89	1.95±0.11	17.25±1.04	41.12.±2.75
40°C			Week 5			
Oil	6.71±0.10	17.70±0.12	14.07±0.10	1.39±0.05	17.66±0.09	42.47±0.07
LN	5.85±0.24	17.01±0.75	15.90±0.79	6.73±0.33	16.37±0.99	38.14±2.01
LTN	5.35±0.27	17.17±0.86	16.52±0.86	4.98±0.25	16.77±1.03	39.21±2.42
TN	5.42±0.34	18.03±1.05	15.95±0.92	1.94±0.14	17.27±1.15	41.38±2.93

- Indicates unsuccessful test

Table 3. Gas chromatography headspace analysis on oxidised compounds produced by bulk algal oil during storage at 4, 20 and 40°C

Compound	Propanal	2-ethylfuran	Propan-3-ol	Valeraldehyde	Hexanal
4°C					
Baseline	24842.84±12532.9	1387.75±275.74	2568.99±1056.64	1283.49±359.95	4955.02±1715.53
Week 2	46504.11±32846.38	2829.28±2162.36	4592.7±2528.86	1994.81±1379.312	8622.653±5598.343
Week 5	7065±5153.3	1175.82±294.53	1138.81±315.74	1405.71±510.57	4293.56±1535.67
20°C					
Baseline	24842.84±12532.9	1387.75±275.74	2568.99±1056.64	1283.49±359.95	4955.02±1715.53
Week 2	153570.1±57352.66[a, A]	4389.26±471.73[a]	46596.07±55108.23	9985.07±630.02[a,A]	15970.01±3777.689[a,A]
Week 5	87246.28±3926.33	3612.65±1356.67	10392.83±341.148	49968.2±143.44A	7888.1±546.86
40°C					
Baseline	24842.84±12532.9	1387.75±275.74	2568.99±1056.64	1283.49±359.95	4955.02±1715.53
Week 2	119512.5±27131.02	2849.01±426.81	9660.44±2168.67	2067.2±249.78	11488.65±2193.952
Week 5	266506.2±98586[a, A]	4477.76±1780.1[a,A]	23729.58±8216.07	6799.61±2606.54[a,A]	22117.46±7463.08[a,A]

[a]: Indicates significant differences between storage times [A]: Indicates significant differences between storage temperatures.

Table 4. Gas chromatography headspace analysis on oxidised compounds produced by algal oil nanoemulsion stabilized by 6% lecithin (LN) during storage at 4, 20 and 40°C

Compound	Propanal	2-ethylfuran	Propan-3-ol	Valeraldehyde	Hexanal
4°C					
Baseline	44913.43±2201.79	5633.02±109.91	8219.32±739.1	16252.44±542	23936±1272.58
Week 1	102757.8±38255.58	13122.01±5034.23	16120.97±5264.99	19647.8±7193.4	36710.01±12734.02
Week 2	150174.5±6087.08	17934.31±999.31	22880.2±500.76[a]	21413.66±325.61	38513.04±1049.41
Week 5	110398.2±38228.17	13326.27±4708.24	17943.34±6589.57	18147.43±5840.73	22969.34±11116.63
20°C					
Baseline	44913.43±2201.79	5633.02±109.91	8219.32±739.1	16252.44±542	23936±1272.58
Week 1	165865.9±489.95[a]	21705.4±2.1a	28419.67±14.04	25701.33±537.31	48808.01±913.16
Week 2	125430.1±44876.62	18629.73±5691.22[a]	20820.27±5797.19[a]	8800.83±2097.04[A]	23410.08±5567.83
Week 5	175276±46031.18[a]	25898.45±4130.9[a]	33016.13±3168.46[a,A]	13792.41±940.38	27012±6351.09
40°C					
Baseline	44913.43±2201.79	5633.02±109.91	8219.32±739.1	16252.44±542	23936±1272.58
Week 1	306664.2±9482.03[a,A]	42303.26±1913.36[a,A]	50754.29±646.5482[a,A,]	26405.99±409.49	57320.96±10437.13[a]
Week 2	203925.4±90123.4[a]	25053.8±7071.18[a]	29800.22±8537.95[a]	17485.64±5151.8	45195.6±12571.16
Week 5	263618±67145.2[a, A]	37470.81±9492.57[a,A]	31608.97±7707.56[a,A]	23443.53±5826.38	64734.87±19100.06[a,A]

[a]: Indicates significant differences between storage times [A]: Indicates significant differences between storage temperatures.

Table 5. Gas chromatography headspace analysis on oxidised compounds produced by algal oil nanoemulsion stabilized by 6% Tween 40 (TN) during storage at 4, 20 and 40°C

Compound	Propanal	2-ethylfuran	Propan-3-ol	Valeraldehyde	Hexanal
4°C					
Baseline	13628.6±7430.75	3118.48±973.47	4041.46±1087.57	656.81±428.92	2806.53±341.86
Week 1	59698.09±5399.7	7086.56±912.67	7747.4±457.77	827.05±84.79	6972.97±2531.56
Week 2	161155.8±135887.8	10647.44±8348.11	24406.21±18926.6[a]	2903.84±2446.11	25234.2±20374.05
Week 5	161859.1±12819.23	21292.68±5622.96[a]	25182.85±2471.92[a]	2258.34±801.39	23734.18±2404.15
20°C					
Baseline	13628.6±7430.75	3118.48±973.47	4041.46±1087.57	656.81±428.92	2806.53±341.86
Week 1	56054.94±33169.79	10958.07±4205.52	13996.41±5059.66	19418.58±6348.1[a,A]	31413.39±15573.24[a,A]
Week 2	226867.4±3241.5[a]	11095.24±1653.5	30264.8±4331.22[a]	5808.2±454.22	29578.12±3682.37[a]
Week 5	196127.3±32536.75[a]	21587.94±5484.66[a]	30095.91±3173.1[a]	7689.15±7150.04[a]	26600.65±3809.5[a]
40°C					
Baseline	13628.6±7430.75	3118.48±973.47	4041.46±1087.57	656.81±428.92	2806.53±341.86
Week 1	107139.4±46935.58	10529.16±0	13292.6±0	1546.61±0	12863.85±0
Week 2	357994.4±85487.8[a]	13651.26±1502.88	48171.1±8224.61[a,A]	6445.38±1437.94	46258.49±10216.66[a]
Week 5	299928.4±16948.06[a,A]	11081.96±1008.79	40114.84±1651.08[a]	6603.94±6392.84	42513.74±996.14[a]

[a]: Indicates significant differences between storage times [A]: Indicates significant differences between storage temperatures.

Table 6. Gas chromatography headspace analysis on oxidised compounds produced by algal oil nanoemulsion stabilised by 3% lecithin and 3% tween 40 (LTN) during storage at 4, 20 and 40°C

Compound	Propanal	2-ethylfuran	Propan-3-ol	Valeraldehyde	Hexanal
4°C					
Baseline	32084.01±0	5788.86±0	6687.58±0	3987.43±0	17492.75±0
Week 1	59321.16±773.90	11090.92±946.22	12285.23±213.153	6675.55±209.16	30493.1±1120.35
Week 2	140201.2±14239.99	18776.48±911.05	20814.22±2225.27	12078.74±8493.48	42121.75±2734.76[a]
Week 5	130062.9±11497.58	22397.19±2709.64[a]	21114.93±1305.01	6196.08±310.59	42650.72±1211.56[a]
20°C					
Baseline	32084.01±0	5788.86±0	6687.58±0	3987.43±0	17492.75±0
Week 1	57090.97±2770.84	11088.26±1736.78	12718.25±796.93	7098.87±284.421	30280.06±1323.57
Week 2	67144.3±77958.1	24211.04±1348.41[a]	32967.4±6969.69[a]	10207.16±66.25	47101.22±17107.54[a]
Week 5	209987.2±123433.36[a]	11319.99±6417.16	23787.33±12829.2[a]	4477.93±2468.12	19532.97±10698.34[A]
40°C					
Baseline	32084.01±0	5788.86±0	6687.58±0	3987.43±0	17492.75±0
Week 1	71597.26±9864.61	213078.73±564.13	16354.94±549.44	7472.367±147.57	38350.93±461.43[a]
Week 2	271886.1±42527.65[a]	19464.7±13876.99[a]	41249.95±10907.88[a,A]	9696.11±5875.53	80247.73±10421.71[a,A]
Week 5	458613.7±17751.51[a, A]	41125.13±2800.66[a,A]	47851.73±2209.94[a,A]	18549.4±450.41[a,A]	109196.8±3445.581[a,A]

[a]: Indicates significant differences between storage times [A]: Indicates significant differences between storage temperatures.