

Table S1. Regression equation of carotenoid standards separated by LC-MSMS analysis.

| Carotenoid standards | Regression Equation | Coefficient of Determination (R2) |
|------------------------|-------------------------------|-----------------------------------|
| Phytofluene | $y = 1.01893 x + 0.01762$ | 0.99156 |
| Phytoene | $y = 0.31801 x + 0.06991$ | 0.99427 |
| ϵ -Carotene | $y = 7.39225 x - 0.00101$ | 0.99104 |
| α -Carotene | $y = 1.88950 x - 9.95177e-4$ | 0.99427 |
| β -Carotene | $y = 3.88371 x - 0.00451$ | 0.99691 |
| Lycopene | $y = 0.64511 x - 6.81716e-4$ | 0.99854 |
| Violaxanthin | $y = 19.21851 x + 0.01079$ | 0.99066 |
| Neoxanthin | $y = 9.58998 x + 0.00231$ | 0.99263 |
| β -citraurin | $y = 26.97911 x + 0.00743$ | 0.99015 |
| Antheraxanthin | $y = 3.08713 x + 0.00587$ | 0.99127 |
| Lutein | $y = 4.09580 x + 0.00722$ | 0.99114 |
| Apocarotenal | $y = 12.62865 x - 3.96567e-4$ | 0.99048 |
| Zeaxanthin | $y = 1.55523 x + 0.02137$ | 0.99831 |
| β -Cryptoxanthin | $y = 2.86672 x + 0.01271$ | 0.99189 |
| γ -Carotene | $y = 2.63151 x - 0.00395$ | 0.99632 |

Table S2. Regression equation of organic acids separated by HPLC analysis.

| Organic Acids | Regression Equation | Coefficient of Determination (R ²) |
|---------------|---------------------|------------------------------------------------|
| Oxalic acid | $y=7229.7x+166423$ | 0.9958 |
| Tartaric acid | $y=1161.6+145350$ | 0.9921 |
| Malic acid | $y=811.19x+14469$ | 0.9930 |
| Lactic acid | $y=369.06+7309.7$ | 0.9989 |
| Acetic acid | $y=284.49+33801$ | 0.9939 |
| Citric acid | $y=1007.2+30824$ | 0.9917 |
| Succinic acid | $y=639.55+17248$ | 0.9966 |

Table S3. Carotenoid contents of the yellow lantern pepper sauce during fermentation.

| No . | Compounds | Ionization model | Parent Ion (Da) | Daughter Ion (Da) | Contents of carotenoids and carotenoid esters (ug/g DW) | | | | | |
|---------|-------------------------------|------------------------|--------------------|----------------------|---------------------------------------------------------|----------------|----------------|---------------|---------------|----------------|
| | | | | | 0 d | 7 d | 14 d | 21 d | 28 d | 35 d |
| 1 | α -Carotene | [M+H] ⁺ | 537.5 | 123.2 | 50.90±0.50 | 32.40±1.50 | 34.55±2.75 | 34.25±1.15 | 30.00±0.80 | 22.85±0.35 |
| 2 | β -Carotene | [M+H] ⁺ | 537.6 | 177.1 | 61.30±1.40 | 34.70±3.20 | 33.55±2.15 | 39.15±2.55 | 34.00±2.30 | 21.60±1.40 |
| 3 | γ -Carotene | [M+H] ⁺ | 537.4 | 177.3 | 3.83±0.19 | 2.19±0.17 | 2.35±0.30 | 2.44±0.09 | 2.05±0.04 | 1.321±0.14 |
| 4 | ε -Carotene | [M+H] ⁺ | 537.6 | 123.2 | 1.14±0.05 | 0.81±0.03 | 0.71±0.02 | 0.72±0.07 | 0.59±0.04 | 0.52±0.02 |
| 5 | Lycopene | [M+H] ⁺ | 537.4 | 81 | 5.42±0.28 | 3.21±0.14 | 2.94±0.24 | 2.28±0.14 | 2.21±0.14 | 1.67±0.04 |
| 6 | (E/Z)-Phytoene | [M+H] ⁺ | 545.3 | 81 | 2940.00±30.00 | 2155.00±125.00 | 2090.00±100.00 | 1860.00±30.00 | 1765.00±25.00 | 1300.00±150.00 |
| 7 | Antheraxanthin | [M+H] ⁺ | 585.5 | 175.4 | 0.34±0.00 | 0.17±0.00 | 0.15±0.01 | 0.15±0.01 | 0.11±0.01 | 0.11±0.01 |
| 8 | Violaxanthin | [M+H] ⁺ | 601.4 | 565.4 | 2.32±0.24 | 2.62±0.09 | 2.32±0.13 | 1.98±0.02 | 1.26±0.07 | 1.80±0.15 |
| 9 | Zeaxanthin | [M+H] ⁺ | 569.4 | 477.5 | 5.68±0.02 | 7.54±0.37 | 6.77±0.93 | 5.01±0.30 | 5.64±0.22 | 4.07±0.32 |
| 10 | Lutein | [M+H-18] ⁺ | 551.5 | 175.4 | 69.55±0.05 | 54.97±2.95 | 55.95±4.85 | 42.00±1.50 | 38.70±0.00 | 33.90±1.60 |
| 11 | β -Cryptoxanthin | [M+H] ⁺ | 553.5 | 177.4 | 6.02±0.06 | 4.41±0.03 | 4.01±0.35 | 4.52±0.01 | 4.51±0.22 | 3.07±0.09 |
| 12 | α -Cryptoxanthin | [M+H] ⁺ | 597.3 | 147.1 | 3.26±0.00 | 2.13±0.10 | 2.34±0.21 | 1.84±0.09 | 2.13±0.14 | 1.46±0.01 |
| 13 | Apocarotenal | [M+H] ⁺ | 417.3 | 325.3 | 0.02±0.00 | 0.03±0.00 | 0.02±0.00 | 0.03±0.00 | 0.03±0.00 | 0.02±0.00 |
| 14 | Neoxanthin | [M+H] ⁺ | 601.4 | 565.5 | 0.34±0.01 | 0.06±0.00 | 0.06±0.01 | 0.06±0.01 | 0.04±0.00 | 0.04±0.00 |
| 15 | Antheraxanthin dipalmitate | [M+H] ⁺ | 1061 | 805 | 0.51±0.00 | N.D. | N.D. | N.D. | N.D. | N.D. |
| 16 | Lutein caprate | [M+H-18] ⁺ | 705.7 | 533.5 | 0.32±0.05 | 0.21±0.01 | 0.50±0.10 | 0.23±0.01 | 0.13±0.02 | 0.29±0.06 |
| 17 | Lutein palmitate | [M+H-18] ⁺ | 789.8 | 533.5 | 4.98±0.14 | 3.08±0.29 | 3.49±0.13 | 2.69±0.16 | 2.17±0.06 | 2.54±0.04 |
| 18 | 5,6epoxy-Lutein dilaurate | [M+H-200] ⁺ | 749.6 | 549.5 | 0.81±0.10 | 0.59±0.04 | 0.58±0.08 | 0.52±0.02 | 0.49±0.07 | 0.35±0.04 |
| 19 | Lutein dilaurate | [M+H-201] ⁺ | 733.5 | 533.3 | 7.66±0.23 | 7.81±0.04 | 6.82±0.44 | 5.70±0.21 | 6.08±0.04 | 5.40±0.44 |
| 20 | Lutein dimyristate | [M+H-228] ⁺ | 761.8 | 533.5 | 39.50±2.40 | 30.70±1.00 | 32.85±1.65 | 28.55±0.05 | 30.85±0.65 | 23.45±2.15 |
| 21 | Lutein dipalmitate | [M+H-256] ⁺ | 789.8 | 533.5 | 1.84±0.27 | 1.43±0.18 | 1.57±0.06 | 1.41±0.16 | 1.43±0.28 | 1.14±0.13 |
| 22 | Violaxanthin dibutyrate | [M+H] ⁺ | 741.6 | 653.5 | 0.38±0.00 | 0.34±0.01 | 0.28±0.02 | 0.28±0.02 | 0.24±0.00 | 0.25±0.02 |
| 23 | Violaxanthin laurate | [M+H-18] ⁺ | 783.7 | 583.4 | N.D. | 2.60±0.35 | 1.99±0.26 | 2.20±0.42 | 1.34±0.03 | 1.25±0.04 |

| | | | | | | | | | | |
|----|--------------------------------------|------------------------|--------|-------|------------|------------|------------|------------|------------|------------|
| 24 | Violaxanthin myristate | [M+H] ⁺ | 811.8 | 793.7 | 63.60±3.90 | 55.25±4.95 | 51.20±0.40 | 45.70±2.00 | 36.25±2.45 | 32.20±0.70 |
| 25 | Violaxanthin palmitoleate | [M+H] ⁺ | 837.7 | 745.6 | 0.20±0.04 | 0.17±0.01 | 0.20±0.02 | 0.13±0.03 | 0.14±0.00 | 0.14±0.01 |
| 26 | Violaxanthin dilaurate | [M+H] ⁺ | 966.7 | 948.8 | 4.25±0.46 | 2.71±0.18 | 2.52±0.07 | 3.41±0.63 | 1.26±0.08 | 1.78±0.06 |
| 27 | Violaxanthin- myristate-caprate | [M+H] ⁺ | 965.7 | 947.8 | 3.05±0.13 | 11.45±1.25 | 12.50±2.30 | 6.10±0.14 | 10.45±0.15 | 9.07±0.18 |
| 28 | Violaxanthin- myristate-laurate | [M+H] ⁺ | 993.8 | 975.7 | 39.10±2.00 | 24.20±1.50 | 21.80±2.90 | 30.35±3.35 | 13.30±0.80 | 15.80±0.00 |
| 29 | Violaxanthin dimyristate | [M+H] ⁺ | 1021.8 | 793.7 | 9.11±0.56 | 4.50±0.02 | 4.40±0.34 | 6.77±0.54 | 2.61±0.04 | 3.14±0.07 |
| 30 | Violaxanthin- myristate-palmitate | [M+H] ⁺ | 1050 | 793.8 | 1.93±0.02 | 0.80±0.04 | 0.87±0.05 | 1.33±0.01 | 0.39±0.06 | 0.51±0.05 |
| 31 | Violaxanthin dipalmitate | [M+H] ⁺ | 1077.9 | 821.7 | 2.44±0.06 | 0.43±0.03 | 0.59±0.04 | 1.13±0.03 | 0.28±0.03 | 0.28±0.00 |
| 32 | Zeaxanthin palmitate | [M+H] ⁺ | 807.8 | 551.5 | 3.92±0.13 | 3.97±0.24 | 3.49±0.35 | 3.03±0.13 | 2.94±0.12 | 2.24±0.20 |
| 33 | Zeaxanthin dilaurate | [M+H] ⁺ | 933.9 | 533.2 | 1.31±0.02 | 1.44±0.05 | 1.29±0.05 | 1.10±0.05 | 1.14±0.09 | 0.87±0.05 |
| 34 | Zeaxanthin-laurate- myristate | [M+H] ⁺ | 962.7 | 733.5 | 2.03±0.06 | 2.17±0.017 | 2.12±0.14 | 1.76±0.01 | 1.96±0.14 | 1.32±0.09 |
| 35 | Zeaxanthin dimyristate | [M+H] ⁺ | 990 | 761.8 | 53.05±0.45 | 53.35±1.15 | 53.25±4.75 | 44.40±1.50 | 49.50±1.30 | 36.25±2.25 |
| 36 | Zeaxanthin-laurate- palmitate | [M+H] ⁺ | 989.9 | 533.4 | 12.15±0.35 | 12.10±0.00 | 11.20±0.70 | 10.29±0.52 | 11.50±0.60 | 8.79±0.71 |
| 37 | Zeaxanthin- myristate-palmitate | [M+H] ⁺ | 1018.1 | 533.6 | 2.91±0.04 | 2.55±0.02 | 2.38±0.21 | 2.30±0.16 | 2.11±0.08 | 1.63±0.16 |
| 38 | Zeaxanthin dipalmitate | [M+H-256] ⁺ | 789.5 | 533.5 | 2.47±0.20 | 1.550.09± | 1.64±0.29 | 1.81±0.13 | 1.33±0.07 | 1.01±0.01 |
| 39 | zeaxanthin- palmitate-stearate | [M+H] ⁺ | 1074.1 | 789.8 | 0.01±0.00 | 0.01±0.00 | 0.01±0.00 | 0.01±0.00 | 0.01±0.00 | N.D. |

| | | | | | | | | | | |
|--------------------------|---------------------------------|-----------------------|--------|-------|-----------------|------------------|------------------|-----------------|-----------------|------------------|
| 40 | zeaxanthin-oleate- palmitate | [M+H] ⁺ | 1071.9 | 789.8 | 0.02±0.00 | 0.02±0.00 | 0.01±0.00 | 0.02±0.00 | 0.02±0.00 | N.D. |
| 41 | β-cryptoxanthin laurate | [M+H] ⁺ | 735.8 | 535.5 | 7.65±0.15 | 5.74±0.36 | 4.47±0.26 | 5.40±0.13 | 5.04±0.04 | 3.78±0.54 |
| 42 | β-cryptoxanthin myristate | [M+H] ⁺ | 763.9 | 535.5 | 12.50±0.00 | 7.92±0.17 | 7.88±0.19 | 8.24±0.11 | 7.52±0.19 | 6.15±0.34 |
| 43 | β-cryptoxanthin palmitate | [M+H] ⁺ | 791.9 | 535.5 | 4.20±0.12 | 2.28±0.22 | 2.64±0.10 | 2.42±0.10 | 2.07±0.14 | 1.51±0.06 |
| 44 | Rubixanthin caprate | [M+H] ⁺ | 707.7 | 535.6 | 0.19±0.03 | 0.14±0.01 | 0.14±0.02 | 0.15±0.01 | 0.11±0.01 | 0.11±0.01 |
| 45 | Rubixanthin laurate | [M+H] ⁺ | 735.6 | 535.4 | 7.31±0.53 | 5.10±0.52 | 6.09±0.36 | 5.31±0.09 | 5.15±0.13 | 3.80±0.07 |
| 46 | Rubixanthin palmitate | [M+H] ⁺ | 791.7 | 535.4 | 4.92±0.02 | 2.65±0.00 | 2.81±0.15 | 3.08±0.08 | 2.55±0.13 | 2.05±0.15 |
| 47 | Neochrome palmitate | [M+H-18] ⁺ | 821.7 | 565.5 | 1.99±0.02 | 2.30±0.02 | 2.44±0.11 | 2.16±0.09 | 1.57±0.06 | 1.61±0.01 |
| Total Carotene | | | | | 3065.59±32.32 a | 2228.31±129.36 b | 2164.10±105.46 b | 1938.83±34.00 c | 1833.85±28.24 c | 1347.95±151.87 d |
| Total Xanthophylls | | | | | 87.52±0.17 a | 71.69±3.82 b | 71.62±6.49 b | 55.57±1.90 c | 52.41±0.66 c | 44.46±2.16 d |
| Total Xanthophyll esters | | | | | 296.25±1.07 a | 294.52±1.43 b | 243.97±15.13 b | 227.92±2.70 c | 201.88±4.43 d | 168.64±7.91 e |
| Total Carotenoids | | | | | 3446.36±31.42 a | 2542.96±134.19 b | 2473.32±126.51 b | 2222.33±42.59 c | 2081.47±32.92 c | 1556.50±161.85 d |
| Degradation rate (%) | | | | | - | 26.21 | 28.23 | 35.52 | 39.60 | 54.84 |

Values are expressed as means ± SD of 3 replicate; values followed by different letters in the same column are significantly different by Duncan's multiple range test ($P < 0.05$); N.D. represent not detected.

Table S4. The results of Spearman correlation analysis.

| | Oxalic acid | Tartaric acid | Malic acid | Lactic acid | Acetic Acid | Citric Acid | Succinic Acid | pH | Crude fat | FFAs |
|--------------------------------|-------------|---------------|------------|-------------|-------------|-------------|---------------|---------|-----------|----------|
| α -Carotene | 0.6 | 0.319 | -0.143 | -0.829* | -0.820* | 0.829* | -0.429 | 0.829* | 0.829* | -0.829* |
| Lycopene | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| γ -Carotene | 0.486 | 0.116 | -0.257 | -0.771 | -0.698 | 0.771 | -0.543 | 0.771 | 0.771 | -0.771 |
| β -Carotene | 0.371 | -0.029 | -0.543 | -0.714 | -0.516 | 0.714 | -0.829* | 0.714 | 0.714 | -0.714 |
| ϵ -Carotene | 0.714 | 0.435 | -0.6 | -0.943** | -0.820* | 0.943** | -0.886* | 0.943** | 0.943** | -0.943** |
| Antheraxanthin | 0.714 | 0.435 | -0.6 | -0.943** | -0.820* | 0.943** | -0.886* | 0.943** | 0.943** | -0.943** |
| Zeaxanthin | 0.6 | 0.812* | -0.086 | -0.771 | -0.880* | 0.771 | -0.6 | 0.771 | 0.771 | -0.771 |
| Violaxanthin | 0.841* | 0.882* | -0.406 | -0.841* | -0.893* | 0.841* | -0.638 | 0.841* | 0.841* | -0.841* |
| Neoxanthin | 0.714 | 0.406 | -0.257 | -0.771 | -0.759 | 0.771 | -0.314 | 0.771 | 0.771 | -0.771 |
| Lutein | 0.771 | 0.58 | -0.257 | -0.943** | -0.941** | 0.943** | -0.543 | 0.943** | 0.943** | -0.943** |
| β -Cryptoxanthin | 0.143 | -0.29 | -0.371 | -0.543 | -0.334 | 0.543 | -0.657 | 0.543 | 0.543 | -0.543 |
| Apocarotenal | -0.314 | -0.145 | 0.2 | -0.143 | -0.213 | 0.143 | -0.543 | 0.143 | 0.143 | -0.143 |
| α -Cryptoxanthin | 0.486 | 0.319 | -0.029 | -0.714 | -0.698 | 0.714 | -0.314 | 0.714 | 0.714 | -0.714 |
| (E/Z)-Phytoene | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| Antheraxanthin dipalmitate | 0.655 | 0.133 | -0.655 | -0.655 | -0.417 | 0.655 | -0.393 | 0.655 | 0.655 | -0.655 |
| Lutein caprate | 0.543 | 0.377 | 0.029 | -0.314 | -0.395 | 0.314 | 0.314 | 0.314 | 0.314 | -0.314 |
| Lutein palmitate | 0.886* | 0.667 | -0.371 | -0.886* | -0.880* | 0.886* | -0.429 | 0.886* | 0.886* | -0.886* |
| 5,6epoxy-lutein dilaurate | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| Lutein dilaurate | 0.714 | 0.754 | -0.371 | -0.886* | -0.880* | 0.886* | -0.771 | 0.886* | 0.886* | -0.886* |
| Lutein dimyristate | 0.486 | 0.319 | -0.029 | -0.714 | -0.698 | 0.714 | -0.314 | 0.714 | 0.714 | -0.714 |
| Lutein dipalmitate | 0.486 | 0.319 | -0.029 | -0.714 | -0.698 | 0.714 | -0.314 | 0.714 | 0.714 | -0.714 |
| Neochrome palmitate | 0.486 | 0.696 | 0.143 | -0.543 | -0.759 | 0.543 | -0.257 | 0.543 | 0.543 | -0.543 |
| Rubixanthin caprate | 0.486 | 0.116 | -0.257 | -0.771 | -0.698 | 0.771 | -0.543 | 0.771 | 0.771 | -0.771 |
| Rubixanthin laurate | 0.371 | 0.058 | 0.029 | -0.657 | -0.638 | 0.657 | -0.257 | 0.657 | 0.657 | -0.657 |
| Rubixanthin palmitate | 0.486 | 0.116 | -0.257 | -0.771 | -0.698 | 0.771 | -0.543 | 0.771 | 0.771 | -0.771 |
| Violaxanthin dibutyrate | 0.829* | 0.522 | -0.714 | -0.886* | -0.759 | 0.886* | -0.771 | 0.886* | 0.886* | -0.886* |
| Violaxanthin laurate | -0.143 | 0.261 | 0.257 | -0.086 | -0.273 | 0.086 | -0.371 | 0.086 | 0.086 | -0.086 |
| Violaxanthin myristate | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| Violaxanthin palmitoleate | 0.886* | 0.754 | -0.371 | -0.714 | -0.698 | 0.714 | -0.2 | 0.714 | 0.714 | -0.714 |
| Violaxanthin dilaurate | 0.657 | 0.261 | -0.6 | -0.771 | -0.638 | 0.771 | -0.657 | 0.771 | 0.771 | -0.771 |
| Violaxanthin-myristate-caprate | -0.086 | 0.493 | 0.6 | 0.086 | -0.213 | -0.086 | 0.2 | -0.086 | -0.086 | 0.086 |
| Violaxanthin-myristate-laurate | 0.657 | 0.261 | -0.6 | -0.771 | -0.638 | 0.771 | -0.657 | 0.771 | 0.771 | -0.771 |
| Violaxanthin dimyristate | 0.657 | 0.261 | -0.6 | -0.771 | -0.638 | 0.771 | -0.657 | 0.771 | 0.771 | -0.771 |

| | | | | | | | | | | |
|----------------------------------|--------|--------|--------|----------|----------|---------|----------|---------|---------|----------|
| Violaxanthin-myristate-palmitate | 0.6 | 0.203 | -0.371 | -0.714 | -0.638 | 0.714 | -0.429 | 0.714 | 0.714 | -0.714 |
| Violaxanthin dipalmitate | 0.6 | 0.203 | -0.371 | -0.714 | -0.638 | 0.714 | -0.429 | 0.714 | 0.714 | -0.714 |
| Zeaxanthin palmitate | 0.771 | 0.754 | -0.429 | -0.943** | -0.941** | 0.943** | -0.829* | 0.943** | 0.943** | -0.943** |
| Zeaxanthin dilaurate | 0.714 | 0.754 | -0.371 | -0.886* | -0.880* | 0.886* | -0.771 | 0.886* | 0.886* | -0.886* |
| Zeaxanthin-laurate-myristate | 0.6 | 0.812* | -0.086 | -0.771 | -0.880* | 0.771 | -0.6 | 0.771 | 0.771 | -0.771 |
| Zeaxanthin dimyristate | 0.6 | 0.812* | -0.086 | -0.771 | -0.880* | 0.771 | -0.6 | 0.771 | 0.771 | -0.771 |
| Zeaxanthin-laurate-palmitate | 0.6 | 0.435 | -0.486 | -0.829* | -0.698 | 0.829* | -0.771 | 0.829* | 0.829* | -0.829* |
| Zeaxanthin-myristate-palmitate | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| Zeaxanthin dipalmitate | 0.486 | 0.116 | -0.257 | -0.771 | -0.698 | 0.771 | -0.543 | 0.771 | 0.771 | -0.771 |
| Zeaxanthin-palmitate-stearate | 0.829* | 0.638 | -0.486 | -1.000** | -0.941** | 1.000** | -0.771 | 1.000** | 1.000** | -1.000** |
| Zeaxanthin-oleate-palmitate | -0.2 | -0.435 | -0.086 | -0.257 | -0.091 | 0.257 | -0.486 | 0.257 | 0.257 | -0.257 |
| β -cryptoxanthin laurate | 0.543 | 0.232 | -0.657 | -0.829* | -0.638 | 0.829* | -0.943** | 0.829* | 0.829* | -0.829* |
| β -cryptoxanthin myristate | 0.543 | 0.174 | -0.486 | -0.829* | -0.698 | 0.829* | -0.771 | 0.829* | 0.829* | -0.829* |
| β -cryptoxanthin palmitate | 0.6 | 0.319 | -0.143 | -0.829* | -0.820* | 0.829* | -0.429 | 0.829* | 0.829* | -0.829* |

* $p<0.05$; ** $p<0.01$