

IRSTI 65.65.03

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<https://doi.org/10.55956/MNYP6391>

IRON-INDUCED ASTAXANTHIN ACCUMULATION IN HAEMATOCOCCUS PLUVIALIS AND ANTIOXIDANT ACTIVITY OF ASTAXANTHIN-ENRICHED EXTRA-VIRGIN OLIVE OIL DURING THERMAL STORAGE

Abstract. Lipid oxidation affects the sensory quality, nutritional value, and storage stability of edible oils. This study evaluated the effects of chemical stressors on astaxanthin accumulation in *Haematococcus pluvialis* and the antioxidant activity of astaxanthin-containing extracts incorporated into extra-virgin olive oil (EVOO). Cultures of *H. pluvialis* NIVA-CHL 49 were exposed to hydrogen peroxide, iron(III) citrate, or EDTA-Fe, and astaxanthin was quantified by high-performance thin-layer chromatography. Iron(III) citrate produced the strongest response, increasing astaxanthin to $19.8 \pm 0.7 \text{ mg g}^{-1} \text{ DW}$ versus $10.2 \pm 0.4 \text{ mg g}^{-1} \text{ DW}$ in the control, a 1.94-fold increase ($p < 0.001$). Astaxanthin-containing extracts were added to EVOO, heated at 120°C for 90 min, and stored for 28 days. At the highest oleoresin concentration, DPPH scavenging activity decreased from $88 \pm 4\%$ to $68 \pm 3\%$, compared with $45 \pm 3\%$ to $32 \pm 2\%$ in controls. Oxidation measurements are needed to confirm improved oxidative stability.

Keywords: *Haematococcus pluvialis*, astaxanthin, iron stress, carotenogenesis, HPTLC, extra-virgin olive oil, antioxidant activity.



Kurinnyi D., Kovalenko V., Kovalenko I., Smetanska I. Iron-induced astaxanthin accumulation in *Haematococcus pluvialis* and antioxidant activity of astaxanthin-enriched extra-virgin olive oil during thermal storage // *Mechanics and Technology / Scientific journal*. – 2026. – No.3(93). – P.21-29. <https://doi.org/10.55956/MNYP6391>

Introduction. Lipid oxidation is a major cause of quality loss in edible oils [1,2]. Oxidative reactions can lead to the formation of undesirable volatile compounds, loss of essential fatty acids and bioactive constituents, and deterioration of sensory properties [2-4]. The food industry therefore, seeks effective antioxidant systems that can maintain quality during processing and storage. In this context, naturally derived antioxidants are of increasing interest as alternatives or complements to conventional antioxidant additives.

Astaxanthin is a red ketocarotenoid with a highly conjugated molecular structure and recognized radical-scavenging and singlet-oxygen-quenching activity

[5]. The freshwater green microalga *Haematococcus pluvialis* is one of the richest natural sources of astaxanthin. Under favourable conditions, *H. pluvialis* grows mainly as green, motile vegetative cells. Exposure to stress can promote a transition towards non-motile red cysts, accompanied by accumulation of neutral lipids and secondary carotenoids, particularly astaxanthin [6-10].

Astaxanthin accumulation in *H. pluvialis* is influenced by multiple environmental and nutritional factors, including high irradiance, nutrient limitation, salinity, temperature, and oxidative stress. Iron availability may affect redox balance and carotenoid metabolism, while hydrogen peroxide can act as an oxidative signal at appropriate concentrations. However, responses depend on strain, growth phase, culture density, nutrient status, light regime, stressor concentration, and treatment duration [11-13]. The identification of effective and manageable induction strategies remains important for improving astaxanthin productivity.

In addition to its value as a nutraceutical pigment, astaxanthin may have applications as an antioxidant ingredient in lipid-containing foods [14,15]. However, antioxidant-capacity assays alone cannot establish oil shelf-life extension. The effect of microalgal extracts on food oils should therefore be interpreted cautiously and, ideally, assessed using direct oxidation markers such as peroxide value, *p*-anisidine value, conjugated dienes and trienes, or oxidative induction time.

The objectives of this study were: (i) to compare the effects of hydrogen peroxide, iron(III) citrate, and EDTA–Fe treatments on astaxanthin accumulation in *H. pluvialis*; (ii) to quantify astaxanthin and selected pigment-related indices using HPTLC and spectrophotometric methods; and (iii) to evaluate the DPPH radical-scavenging activity and total phenolic content of EVOO supplemented with astaxanthin-containing extracts after thermal treatment and storage.

Materials and methods. *Microalgal strain and cultivation conditions.* *H. pluvialis* strain NIVA-CHL 9 was cultivated in Bold's Basal Medium (BBM) in 300 mL culture vessels. Cultures were maintained at 28 °C on an orbital shaker at 120 rpm under a 12 h light/12 h dark photoperiod. Irradiance was approximately 100 $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$, provided by sunlight lamps. Growth was monitored spectrophotometrically at 474 nm. The pH level was maintained within 6.5-7.5.

Stress induction treatments. Following the growth phase, *H. pluvialis* cultures were exposed to chemical stress treatments. Untreated cultures were maintained under the same cultivation conditions and served as the control (M1). The treatments were designated H1–H3 for hydrogen peroxide (H_2O_2), Fe1–Fe3 for iron(III) citrate, and E1 for EDTA–Fe, as summarized in Table 1.

Table 1

Chemical stress treatments, nominal treatment levels, and exposure durations used for *Haematococcus pluvialis* cultures

Code	Treatment	Nominal treatment level	Stress duration
M1	Untreated control	-	-
H1	Hydrogen peroxide	20 μL per 250 mL culture per day	6 days
H2	Hydrogen peroxide	40 μL per 250 mL culture per day	6 days
H3	Hydrogen peroxide	80 μL per 250 mL culture per day	6 days
Fe1	Iron(III) citrate	0.009 g L^{-1} Fe	8 weeks
Fe2	Iron(III) citrate	0.020 g L^{-1} Fe	8 weeks
Fe3	Iron(III) citrate	0.030 g L^{-1} Fe	8 weeks
E1	EDTA–Fe	0.0035 g L^{-1}	8 weeks

Hydrogen peroxide was added directly to the cultures once daily for six consecutive days. Treatments H1, H2, and H3 received 20, 40, and 80 μL of H_2O_2 stock solution per 250 mL of culture per day, respectively. Iron(III) citrate treatments were maintained for 8 weeks. Iron(III) citrate was supplied during the stress phase according to the experimental schedule at nominal concentrations of 0.009, 0.020, and 0.030 g L^{-1} for Fe1, Fe2, and Fe3, respectively. These concentrations are reported as specified in the experimental design. The EDTA–Fe treatment (E1) was maintained for 8 weeks at a nominal concentration of 0.0035 g L^{-1} . The concentration is reported as given in the experimental schedule.

All stress treatments were applied under otherwise identical cultivation conditions. The untreated control and chemically stressed cultures were processed using the same sampling and analytical procedures to enable comparison of the effects of H_2O_2 , iron(III) citrate, and EDTA–Fe treatments on *H. pluvialis* growth and pigment accumulation.

Biomass harvesting and extraction. Biomass was harvested by centrifugation at 4,400 rpm for 5 min. The harvested biomass was freeze-dried at $-40\text{ }^\circ\text{C}$ and 0.12 mbar for 72 h. Dried biomass was extracted with methanol. The reported biomass-to-solvent ratio was approximately 0.20–0.28 g DW per 5.0–6.5 mL methanol. Extraction was assisted by ultrasonication and/or mechanical disruption with a mortar. The obtained samples were stored at a temperature of $-20\text{ }^\circ\text{C}$.

HPTLC analysis of astaxanthin and β -carotene. Astaxanthin in *H. pluvialis* biomass was analysed by high-performance thin-layer chromatography (HPTLC). Pigments were extracted from algal biomass using an appropriate organic solvent and the resulting extracts were subjected to HPTLC analysis on precoated silica gel 60 F254 plates.

Samples and astaxanthin reference standards were applied to the plates as narrow bands using a CAMAG Linomat 5 applicator. Chromatographic separation of astaxanthin was performed using n-hexane:acetone (7:3, v/v) as the mobile phase. This solvent system has previously been used for TLC separation of astaxanthin from *H. pluvialis*. [6,8]

The plates were developed in a saturated developing chamber under controlled conditions. After development, the plates were dried and analysed densitometrically using a CAMAG TLC scanner controlled by the visionCATS software. Astaxanthin was identified by comparison of its migration behaviour and spectral characteristics with those of the authentic reference standard. The expected retention factor (Rf) of astaxanthin was approximately 0.49, consistent with the reported range of approximately 0.4–0.6 for *Haematococcus*-derived astaxanthin on silica gel using n-hexane:acetone (7:3). [7]

Quantification was performed using an external calibration curve prepared from the astaxanthin reference standard.

Spectrophotometric pigment analyses. Total chlorophyll and carotenoid contents were determined spectrophotometrically by measuring absorbance at 665, 652, and 470 nm. Pigments were extracted using 80% acetone. Absorbance was measured in a cuvette with a 1-cm optical path length. Pigment concentrations were calculated according to the equations of Lichtenthaler and Wellburn (1983):

$$\text{Chl a} = 12.25 \times A_{665} - 2.79 \times A_{652}$$

$$\text{Chl b} = 21.50 \times A_{652} - 5.10 \times A_{665}$$

$$\text{Chl (a+b)} = 7.15 \times A_{665} + 18.71 \times A_{652}$$

$$\text{Car} = (1000 \times A_{470} - 1.82 \times \text{Chl a} - 85.02 \times \text{Chl b}) / 198$$

The results were corrected for the dilution factor and expressed, for example, as mg g⁻¹ fresh weight. The method of Lichtenthaler and Wellburn (1983) was used as the reference method.

Astaxanthin-containing extracts were added to extra-virgin olive oil (EVOO) at nominal concentrations of 2, 20, and 200 µg mL⁻¹. Samples were heated in a thermos cabinet at 120 °C for 90 min and then stored for 28 days.

DPPH radical-scavenging activity and total phenolic content. Antioxidant activity and total phenolic content. The antioxidant activity of the *Haematococcus pluvialis* oil/extract was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging assay. The assay was based on the reduction of the DPPH radical by antioxidant compounds present in the sample, resulting in a decrease in absorbance. Absorbance was measured at the DPPH absorption maximum of 515–517 nm. The percentage of DPPH radical-scavenging activity was calculated relative to the appropriate reagent control according to:

$$\text{DPPH scavenging activity (\%)} = [(A_0 - A_s) / A_0] \times 100$$

where: A_0 is the absorbance of the control reaction containing DPPH without sample and A_s is the absorbance of the sample reaction after correction for sample background, where applicable.

Total phenolic content (TPC) was determined using the Folin–Ciocalteu colorimetric method. The reaction mixture was incubated under the conditions specified for the assay, and absorbance was measured at 750 nm. Gallic acid was used as the calibration standard, and the results were expressed as mg gallic acid equivalents (GAE) per g of sample.

For both assays, appropriate reagent and sample blanks were used to account for background absorbance originating from the sample matrix. The antioxidant activity and total phenolic content should be interpreted with consideration of the sample matrix and extraction procedure, as both measurements can be affected by the composition of the oil/extract and by the efficiency and selectivity of the extraction step. The DPPH assay was used as an estimate of radical-scavenging capacity, whereas the Folin–Ciocalteu assay was used to estimate total reducing phenolic compounds rather than to identify individual phenolic constituents.

Statistical analysis. Results are presented as mean ± standard deviation. The source document reports triplicate measurements and one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference test for astaxanthin results.

Research results. *Effects of stress treatments on astaxanthin accumulation.* Chemical stress treatments significantly affected astaxanthin concentration in *H. pluvialis* (one-way ANOVA, $F(7,24) = 42.3$, $p < 0.0001$). The untreated control (M1) contained 10.2 ± 0.4 mg g⁻¹ DW astaxanthin. All reported stress treatments increased astaxanthin concentration relative to the control (Table 2).

Table 2

Astaxanthin concentration in *Haematococcus pluvialis* after chemical stress treatments

Sample	Treatment	Astaxanthin (mg g ⁻¹ DW)	Increase relative to control (%)	<i>p</i> value versus M1
1	2	3	4	5
M1	Untreated control	10.2 ± 0.4	-	-
H1	Hydrogen peroxide, 20 µL per 250 mL per day	11.8 ± 0.5	16	0.045

Table 2 (continued)

1	2	3	4	5
H2	Hydrogen peroxide, 40 μL per 250 mL per day	13.2 ± 0.6	29	0.012
H3	Hydrogen peroxide, 80 μL per 250 mL per day	14.5 ± 0.6	42	<0.001
Fe1	Iron(III) citrate, 0.009 g L^{-1} Fe	12.9 ± 0.5	27	0.023
Fe2	Iron(III) citrate, 0.020 g L^{-1} Fe	16.4 ± 0.7	61	<0.001
Fe3	Iron(III) citrate, 0.030 g L^{-1} Fe	19.8 ± 0.7	94	<0.001
E1	EDTA–Fe, concentration to be verified	15.3 ± 0.5	50	<0.001

Hydrogen peroxide produced a concentration-dependent response. Astaxanthin concentration increased from 11.8 ± 0.5 mg g^{-1} DW in H1 to 13.2 ± 0.6 mg g^{-1} DW in H2 and 14.5 ± 0.6 mg g^{-1} DW in H3. These values represented increases of 16%, 29%, and 42%, respectively, relative to the untreated control.

Iron(III) citrate caused the strongest increase in astaxanthin concentration. Fe1, Fe2, and Fe3 reached 12.9 ± 0.5 , 16.4 ± 0.7 , and 19.8 ± 0.7 mg g^{-1} DW, respectively. The Fe3 treatment corresponded to a 94% increase relative to M1 and was reported to differ significantly from the other treatment groups according to Tukey's post-hoc test.

The EDTA–Fe treatment (E1) yielded 15.3 ± 0.5 mg g^{-1} DW astaxanthin, corresponding to a 50% increase relative to the control. The final treatment concentration must be verified before publication.

Values are mean $\pm$ SD. The source document reports one-way ANOVA, $F(7,24) = 42.3$, $p < 0.0001$, followed by Tukey's HSD test. The exact number and nature of replicates must be stated in the final manuscript.

β -Carotene concentration and pigment ratios. The selected stress treatments also increased β -carotene concentration and altered the carotenoid-to-chlorophyll ratio (Table 2). The control culture contained 3.2 ± 0.2 mg g^{-1} DW β -carotene and showed a carotenoid-to-chlorophyll ratio of 0.48:1. In contrast, the Fe3 treatment reached 6.2 ± 0.4 mg g^{-1} DW β -carotene, a 93.8% increase relative to the control, and a carotenoid-to-chlorophyll ratio of 4.2:1.

The observed shift towards higher carotenoid-to-chlorophyll ratios is consistent with a stress-associated pigment response and reduced relative abundance of chlorophyll. However, the present measurements do not directly demonstrate degradation of light-harvesting complexes, alteration of thylakoid ultrastructure, or a specific molecular mechanism.

Table 3

β -Carotene concentration and carotenoid-to-chlorophyll ratio under selected treatments

Sample	Treatment	β -Carotene (mg g^{-1} DW)	Increase relative to M1 (%)	Carotenoid:chlorophyll ratio	p value
M1	Untreated control	3.2 ± 0.2	-	0.48:1	-
H3	Hydrogen peroxide	4.1 ± 0.3	28.1	2.8:1	0.03
E1	EDTA–Fe	4.9 ± 0.2	53.1	3.5:1	0.02
Fe2	Iron(III) citrate, 0.020 g L^{-1} Fe	5.8 ± 0.3	81.3	3.9:1	<0.001
Fe3	Iron(III) citrate, 0.030 g L^{-1} Fe	6.2 ± 0.4	93.8	4.2:1	<0.001

Values are mean $\pm$ SD. The origin and calculation of the carotenoid-to-chlorophyll ratio should be reported explicitly.

Radical-scavenging activity of EVOO supplemented with astaxanthin-containing extracts. Untreated EVOO showed a decrease in DPPH radical-scavenging activity from $45 \pm 3\%$ at baseline to $32 \pm 2\%$ after 28 days of storage following thermal treatment. EVOO supplemented with oleoresin at $200 \mu\text{g mL}^{-1}$ exhibited higher activity, decreasing from $88 \pm 4\%$ at baseline to $68 \pm 3\%$ after 28 days.

A separate sample containing purified astaxanthin at $100 \mu\text{g mL}^{-1}$ was reported to have an initial DPPH activity of 92%, decreasing to 75% after 28 days. Because full methodological and statistical details for this treatment were not provided in the source text, the treatment should be retained only after verification and consistent reporting.

The supplemented EVOO samples maintained greater DPPH radical-scavenging activity than the untreated control under the tested conditions. This result indicates preservation of measurable antioxidant capacity; it does not, by itself, demonstrate inhibition of lipid oxidation or extension of product shelf life.

Total phenolic content. Total phenolic content was reported to range from 15 to 28 mg gallic acid equivalents (GAE). Samples associated with the Fe₃ extract showed the highest values. Because the units and extraction basis are unclear in the source document, these data require methodological clarification before quantitative interpretation.

Discussions. *Iron(III) citrate was the most effective treatment under the tested conditions.* Among the evaluated chemical treatments, iron(III) citrate produced the highest astaxanthin concentration. The Fe₃ treatment yielded 19.8 mg g^{-1} DW, which was approximately 1.94 times the value observed in the untreated control. The increase across Fe₁, Fe₂, and Fe₃ suggests a positive concentration-dependent response within the tested range.

The results are consistent with the general understanding that stress-associated changes in cellular redox status can promote secondary carotenogenesis in *H. pluvialis*. Iron may influence oxidative processes and metabolic regulation, whereas hydrogen peroxide may act as a transient oxidative signal. Nevertheless, the present experiment did not measure reactive oxygen species, iron uptake, cellular redox state, lipid peroxidation, enzyme activity, transcript abundance, or the extent of encystment. Therefore, the mechanisms responsible for the observed treatment differences cannot be established directly from the present data.

The more moderate response to hydrogen peroxide may reflect differences in stress intensity, exposure duration, cellular detoxification capacity, or the stability of hydrogen peroxide in the culture system. The intermediate response to EDTA–Fe may be related to differences in iron speciation and bioavailability. These explanations remain hypotheses and should be tested in future experiments using measurements of growth, viability, intracellular reactive oxygen species, chlorophyll fluorescence, microscopy, and targeted gene-expression or metabolomic analyses.

Pigment changes indicate a stress-associated physiological shift. The increase in β -carotene concentration and the rise in the carotenoid-to-chlorophyll ratio in iron-treated cultures are compatible with a shift from a predominantly vegetative phenotype towards a stress-associated, carotenoid-rich condition. Such changes are expected during secondary carotenogenesis, when astaxanthin and other carotenoids accumulate in lipid-rich cellular compartments.

However, it is important to distinguish between a pigment-ratio observation and a direct structural or molecular conclusion. The data do not demonstrate targeted degradation of photosynthetic complexes, thylakoid disintegration, or activation of specific enzymes such as phytoene synthase, phytoene desaturase, lycopene β -cyclase, β -carotene hydroxylase, or β -carotene ketolase. These potential mechanisms should be discussed as literature-based explanations rather than presented as findings of this study.

Astaxanthin-containing extracts maintained higher DPPH activity in EVOO. EVOO supplemented with astaxanthin-containing oleoresin retained substantially higher DPPH radical-scavenging activity than untreated EVOO after the heating and storage protocol. This result supports the potential of microalgal extracts to increase or preserve measurable antioxidant capacity in a lipid matrix.

Nevertheless, DPPH is an in vitro radical-scavenging assay and does not directly quantify the formation of primary or secondary lipid-oxidation products in oil. The Folin–Ciocalteu assay also has limited specificity and can be influenced by non-phenolic reducing compounds. Accordingly, the present results should be described as evidence of higher antioxidant capacity under the tested conditions, rather than proof of oil stabilization or shelf-life extension.

Future studies should include peroxide value, *p*-anisidine value, conjugated diene and triene measurements, total oxidation (Totox) value, and oxidative induction time. A comparison with a relevant positive control, such as an authorised synthetic antioxidant at an appropriate concentration, would also be necessary before making claims regarding comparative preservative performance.

Practical relevance and limitations. The observed iron-associated increase in astaxanthin concentration indicates that iron(III) citrate may be a useful stressor for laboratory-scale optimisation of *H. pluvialis* cultivation. However, industrial relevance cannot be inferred from the present study alone. Scale-up performance depends on biomass productivity, light distribution, mixing, gas transfer, nutrient management, downstream processing, extraction efficiency, product stability, food-regulatory status, and cost analysis.

Similarly, the oil experiment provides preliminary evidence that astaxanthin-containing extracts can retain radical-scavenging activity in EVOO after thermal treatment and storage. The study does not establish the sensory acceptability, colour impact, regulatory suitability, stability of astaxanthin during food processing, or economic feasibility of a commercial formulation. These aspects should be addressed in future work.

Conclusion. Chemical stress treatments increased astaxanthin accumulation in *Haematococcus pluvialis* under the tested laboratory conditions. Iron(III) citrate at the highest evaluated treatment level produced the strongest response, increasing astaxanthin concentration from 10.2 ± 0.4 mg g⁻¹ DW in the untreated control to 19.8 ± 0.7 mg g⁻¹ DW. Hydrogen peroxide produced a smaller concentration-dependent increase, while EDTA–Fe gave an intermediate response.

Astaxanthin-containing extracts incorporated into extra-virgin olive oil maintained higher DPPH radical-scavenging activity than untreated oil after heating and 28 days of storage. These findings support the potential use of *H. pluvialis*-derived extracts as natural antioxidant ingredients in lipid-rich food systems.

However, the current evidence is limited to pigment quantification, DPPH radical-scavenging activity, and total phenolic-content measurements. Direct measurements of lipid oxidation, comprehensive characterisation of the extract, and detailed validation of the analytical methods are needed before claims

regarding oil stability, shelf-life extension, superiority to synthetic antioxidants, or industrial applicability can be made.

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Received: 21 August 2026

Accepted: 23 September 2026

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НАЕМАТОСОCCUS PLUVIALIS-ДЕГІ ТЕМІР ӘСЕРІНЕН АСТАКСАНТИННІҢ ЖИНАҚТАЛУЫ ЖӘНЕ ТЕРМИЯЛЫҚ САҚТАУ КЕЗІНДЕГІ АСТАКСАНТИНМЕН БАЙЫТЫЛҒАН EXTRA VIRGIN ЗЭЙТҮН МАЙЫНЫҢ АНТИОКСИДАНТТЫҚ БЕЛСЕНДІЛІГІ

Аңдатпа. Липидтердің тотығуы тағамдық майлардың органолептикалық сапасына, тағамдық құндылығына және сақтау тұрақтылығына кері әсер етеді. Бұл зерттеуде химиялық стресс факторларының *Haematococcus pluvialis* жасушаларында атаксантиннің жинақталуына және атаксантин құрамды экстрактілермен байытылған extra virgin зейтүн майының (EVOO) антиоксиданттық белсенділігіне әсері бағаланды. *H. pluvialis* NIVA-CHL 49 культураларына сүтек асқын тотығы, темір(III) цитраты немесе EDTA–Fe әсер еткізіліп, атаксантин мөлшері жоғары тиімді жұқа қабатты хроматография әдісімен анықталды. Ең күшті әсер темір(III) цитратымен өңдеу кезінде байқалды: атаксантин концентрациясы бақылаудағы $10,2 \pm 0,4$ мг/г құрғақ затпен салыстырғанда $19,8 \pm 0,7$ мг/г-ға жетіп, 1,94 есе артты ($p < 0,001$). Атаксантин құрамды экстрактілер EVOO құрамына енгізіліп, 120 °C температурада 90 минут қыздырылды және 28 күн сақталды. Олеорезиннің ең жоғары концентрациясында DPPH бойынша радикалдарды байланыстыру белсенділігі $88 \pm 4\%$ -дан $68 \pm 3\%$ -ға дейін төмендеді, ал бақылауда $45 \pm 3\%$ -дан $32 \pm 2\%$ -ға дейін төмендеді. Тотығу тұрақтылығының жақсарғанын растау үшін тотығу көрсеткіштерін тікелей анықтау қажет.

Тірек сөздер: *Haematococcus pluvialis*, атаксантин, темір стрессі, каротиногенез, ВЭТСХ, extra virgin зейтүн майы, антиоксиданттық белсенділік.

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НАКОПЛЕНИЕ АСТАКСАНТИНА ПОД ВОЗДЕЙСТВИЕМ ЖЕЛЕЗА В НАЕМАТОСОCCUS PLUVIALIS И АНТИОКСИДАНТНАЯ АКТИВНОСТЬ ОБОГАЩЕННОГО АСТАКСАНТИНОМ ОЛИВКОВОГО МАСЛА ЭКСТРА-КЛАССА ПРИ ТЕРМИЧЕСКОМ ХРАНЕНИИ

Аннотация. Окисление липидов отрицательно влияет на органолептические свойства, пищевую ценность и стабильность растительных масел при хранении. В исследовании оценивали влияние химических стрессоров на накопление атаксантина у *Haematococcus pluvialis* и антиоксидантную активность экстрактов, содержащих атаксантин, внесённых в оливковое масло extra virgin (EVOO). Культуры *H. pluvialis* NIVA-CHL 49 подвергали воздействию перекиси водорода, цитрата железа(III) или комплекса EDTA–Fe, а содержание атаксантина определяли методом высокоэффективной тонкослойной хроматографии. Наиболее выраженный эффект наблюдался при использовании цитрата железа(III): концентрация атаксантина достигала $19,8 \pm 0,7$ мг/г сухого вещества по сравнению с $10,2 \pm 0,4$ мг/г в контрольном образце, что соответствовало увеличению в 1,94 раза ($p < 0,001$). Экстракты, содержащие атаксантин, добавляли в EVOO, нагревали при 120 °C в течение 90 мин и хранили 28 дней. При максимальной концентрации олеорезина антирадикальная активность по DPPH снизилась с $88 \pm 4\%$ до $68 \pm 3\%$, тогда как в контроле — с $45 \pm 3\%$ до $32 \pm 2\%$. Для подтверждения повышения окислительной стабильности необходимы прямые измерения процессов окисления.

Ключевые слова: *Haematococcus pluvialis*, атаксантин, стресс вызванный железом, каротиногенез, HPTLC, оливковое масло экстра-вирджин, антиоксидантная активность.