Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 27(3): 19 – 34 (2023)
www.ejabf.journals.ekb.eg

Chemical and Biochemical Properties of Marine Algae *Ulva lactuca* and *Nannocholoropsis oculata*

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ARTICLE INFO

Article History:
Received: April 10, 2023
Accepted: May 7, 2023
Online: May 12, 2023

Keywords:
Nannochloropsis oculate,
Ulva lactuca,
Biochemical properties,
Amino acids,
Fatty acids

ABSTRACT

Marine algae are considered a source of different bioactive constituents including protein, oil, fiber, vitamins, pigments and dietary minerals. To evaluate the fine chemical and biochemical properties of the marine microalga *Nannochloropsis oculata* and macroalga *Ulva lactuca*, the present study was carried out. The cultivated *N. oculate* and the collected *U. lactuca* were washed, oven-dried, ground and subjected to analysis of moisture, protein, fats, carbohydrates and ash. In addition, macro and micro-nutrients, amino acids profile, fatty acids methyl ester and pigments were assessed. The moisture content of *U. lactuca* was higher (13.25 %) than *N. oculata* (3.5 %). Protein, oil and fiber contents were significantly higher (P<0.05) in *N. oculata* than in *U. lactuca* and ranged between 32.19 % and 20.44 %, 10.29 % and 0.65 %, 11.91 % and 8.61 %, respectively, based on dry weight. Total phytochemical chlorophyll in *U. lactuca* (5.97µg/ml) was more than in *N. oculata* (1.18µg/ml). The dominant dietary element in *N. oculata* was P (24000 mg/kg), while Ca (48300 mg/kg) was dominant in *U. lactuca*. The trace dietary minerals (Fe, Mn and Cu) were significantly higher in *U. lactuca* than in *N. oculata*. Both algae proteins had 17 (*N. oculata*) and 16 (*U. lactuca*) amino acids, seven of them being non-essential amino acids, which accounted for 40.01 and 48.75 g/100g, respectively. **S**aturated and unsaturated fatty acids represented 45.13 and 54.87%; 68.95 and 31.05% of the fat of *N. oculata* and *U. lactuca*, respectively. Polyunsaturated fatty acids were more evident in *N. oculata* (31.36%) than in *U. lactuca* (3.81%).

INTRODUCTION

The search for new sustainable sources of food has become necessary, especially with the continued increase in the number of populations around the world. Marine algae (macro or microalgae) can be considered one of the sustainable sources of food. In general, algae can be grown and produced in brackish or freshwater systems utilizing a wide range of water type, carbon source and nutrient concentrations (**El-Sayed *et al.*, 2008, 2010, 2011, 2012, 2015; Battah *et al.*, 2013; El-Kassas *et al.*, 2017; Kamal *et al.*, 2017; Almutairi *et al.*, 2020; El-Awady *et al.*, 2020; El-Sayed *et al.*, 2020; Marwa Red *et al.*, 2020; Almutairi *et al.*, 2021; El-Sayed *et al.*, 2022; Abo El-Khair *et al.*, 2023**).

Currently, there are about 200 algae species that are consumed, of which 22 types seaweeds such as *Ulva* sp. have been allowed to be eaten through the European regulation (**Abreu *et al*., 2014**). Also, *Nannochloropsis* sp. is one of the microalgae that tend to be applied in healthy foods because it contains some components that the human body needs, such as fats, vitamins and minerals (**Andrés *et al*., 1992; Bishop & Zubeck, 2012**). It is worthily used not only as a food additive (**Mohamed *et al*., 2013; Hassan *et al*., 2015**), but also as a source of long chain matrix of biologically active ingredients (**Kamal *et al*., 2017; Abo El-Khair *et al*., 2022a**).

Increasing interest in algae requires increasing attention in controlling its production systems to obtain it with the highest quality and safety (**Pereira *et al*., 2021**). With the end of the wild or farmed algae production processes, it is harvested, washed and packaged in various forms, the most important of which is the powder form that is directed to the food market. Therefore, post-harvest operations are of great importance in preserving the vital components of algae to benefit from them, as well as reducing storage, shipping and transportation costs (**Abreu *et al*., 2014**).

Some algae are eaten fresh due to their chemical composition and the nature of their active bio-components. Due to the distinctive characteristics of micro or micro algae and their high levels of protein, low fat and salt, and the presence of fiber, pigments and vitamins, all of which have made algae an essential element in the composition of healthy foods today (**Baik *et al*., 2013; Mithril *et al*., 2013**). The use of algae biomass in many industries has caused widespread acceptance of these products across the world. It was found that the addition of algae or their extracts such as alginate and carrageenan as food additives has important technological effects (**Priyadarshani & Rath, 2012; Enzing *et al*., 2014; Kim & Chojnacka, 2015; Bux & Chisti, 2016; Ruiz *et al.*, 2016**). It was found that these hydrocolloids have many applications in the field of food, pharmaceutical and other fields of biotechnology since they improve the gelling and thickening of the products texture and their stability (**Ścieszka & Klewicka, 2019**).

Egypt is currently seeking to take advantage of its natural resources of algae, expanding its cultivation to provide cheap protein needed for nutrition to cope with the population growth. Egypt also seeks to keep pace with the development in the field of food health and safety by focusing on natural food products and functional ingredients that improve human health and well-being. Therefore, the interest in algae cultivation in Egypt and other countries suffering from an increasing population will make it preserve the natural resources of water and arable land while providing protein and functional ingredients that can support the quality of food that currently required by the market (**Greene, 2020**). Thus, the objective of this study was to evaluate the composition and properties of two species of algae powder; namely, *Ulva lactuca* and *Nannochloropsis oculata* which further incorporated in food chain.

MATERIALS AND METHODS

1. Macro and micro-algae

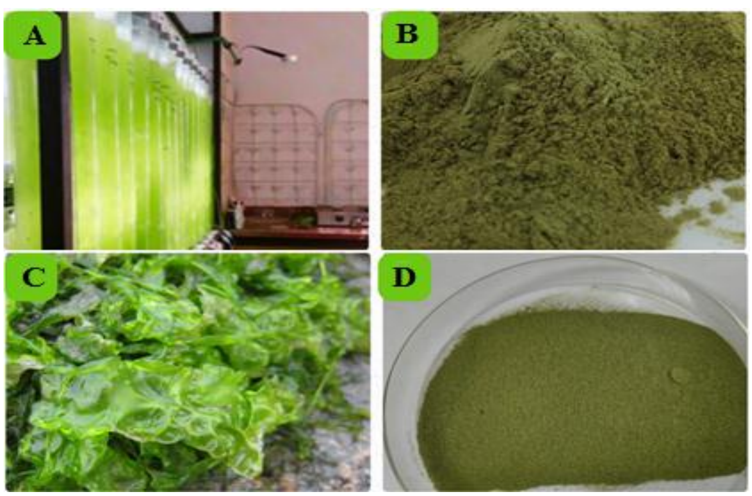
During winter 2021, fresh seaweed *(Ulva lactuca*) was collected from El-Attaka port, (Red Sea, Gulf of Suez, 29˚ 54' 0.76" N 32˚ 28' 00.4" E). The *Chrythophyta* alga *Nannochloropsis oculata* (NNO-1 UTEX Culture LB 2164) was produced and collected from the Algal Biotechnology Unit, Biological and Agricultural Research Institute, National Research Centre, Dokki, Giza, Egypt.

1.1. Growth medium and conditions of N. oculate

For *N. oculata*, F2 medium (**Guillard, 1975**) was used for indoor inoculation, while commercial formula was used for outdoor production. F2 was composed of (g.l^{-1}) 0.075 $NaNO_3$, 0.005 $NaH_2PO_4.$ H_2O and 0.030 $Na_2SiO_3.9H_2O$ with A5 micronutrients solution (1.0 ml.l^{-1}). During indoor growth (inoculum preparation); artificial sea water (pH 8.2) was prepared from crystal sea salt (35 g.l^{-1}). Columns containing *N. oculata* broth (15 x 7 L) were exposed to continuous light provided from a bank of white fluorescent lamps (5×40 W), and continuously aerated from gentle air stream by air left technique. All of the grown cultures were transferred to outdoor growth (1200 L Zigzag-shape photobioreactor), using artificial formula of nutrients (**El-Sayed *et al*., 2020**). Three weeks later, alga was harvested by centrifugation at 3588g. The collected biomass (Pic. 1-A) was powdered by freeze-drying (Pic. 1-B), packed in air tight dark packs and stored at ambient temperature until use.

1.2. Seaweed powder

Fresh *U. lactuca* (Pic. 1-C) was washed then dried at 50˚C for 10 - 12 h in oven dryer (Pic. 1-D). The dried sample was grinned in electrical grinder then packed in air tight dark packs and stored at 23±2˚C.



Pic.1. Appearance of macro and micro marine algae

A: Culture of *N. oculata,* **B:** Dried *N. oculata,* **C:** Fresh *U. lactuca,* **D:** Dried *U. lactuca*

2. Chemical analysis

2.1. Proximate composition

It (Moisture, protein, and ash constituents) was determined according to **AOAC (2000)**. Fats were extracted by a mixture of n-hexane: isopropanol (3:2/ v:v) after water washing and drying; weight differences represented the oil content (%) (**Zuta *et al*., 2003**). Carbohydrates were determined by phenol sulphuric method (**Dubois *et al*., 1956**) using glucose as a standard.

2.2. Macro and micro minerals

They were measured after ashing materials and resuspended in 2.0N HCl (**Chapman & Pratt, 1974**). Iron, zinc, copper, manganese and magnesium were detected by atomic absorption, while calcium, sodium and potassium were detected by flame emission. Phosphorous was spectrophotometrically determined (**Murphy & Rilley, 1962**), and nitrogen was digested, distilled and determined based on Microkjeldahl technique (**Ma & Zauzag, 1942**).

2.3. Amino acids composition

It was determined after protein hydrolysis with 6N HCl at 110°C for 24 hrs, and the hydrolysate was neutralized with 6N NaOH then derivatized using a kit (AccQ-Fluor Reagent, WAT052880, Waters) (**Mohanty *et al*., 2012**). The prepared hydrolysate samples were injected in High-Performance Liquid Chromatography (HPLC, 1525, Waters), equipped with a C18 RP column and a fluorescence detector (2475, Waters). The composition of amino acids was identified and quantified according the retention times and peak areas of amino acid standards (WAT088122, Waters).

2.4. Fatty acids methyl esters

They were identified and quantified by methyl esterifying to the extracted oil and injected in Gas Chromatography (Hewlett Packard model 5890), equipped with FID detector (300 °C, with 30mL/ min H_2 and 300mL/ min air) (**AOAC, 2000**).

2.5. Total Chlorophyll and carotenoid contents

They were spectrophotometrically determined (**Mackinney, 1941**) after centrifuging 5ml of algae culture at 6000rpm for 10min and re-suspending the pellet with equal amount of methanol into a glass tube rested at 55°C in a water bath for about 15min to extract the pigments. The supernatant was diluted with methanol to a concentration sufficient for measuring. The absorbance (E) of the samples against blank was read at 650, 665 and 452nm.

3. Statistics analysis

Results were expressed as mean ± standard deviation. Paired comparison t-test analysis was performed to estimate the amount of variation of a set of values, using IBM SPSS Statistics version 22. All data represent the mean of three replicate experiments (n = 3).

RESULTS AND DISCUSSION

1. Proximate composition and minerals

The compositions of dried seaweed *Ulva lactuca* and microalga *Nannochloropsis oculata* are presented in Table (1). The moisture content of *U. lactuca* was higher (13.25 %) than *N. oculata* (3.5 %). The increase in moisture content might return to relatively carbohydrates content of *Ulva* on the expense of oils. Polysaccharides of marine algae increase the water holding capacity within cells, which in turn, increases the initial moisture content, where the extrinsic moisturization is mainly formed via the formation of hydrogen bonds between polysaccharides and the intrinsic moisturizing is mainly performed by regulating the production of some tight junction proteins (**Zhang *et al*., 2022**). Furthermore, **Schmid *et al.* (2022)** stated that the single cell algae (*Tetraselmis chui* and *Nannochloropsis oceanica*) differed in moisture content within the same drying method.

Table 1. Biochemical composition of *N. oculata and U. lactuca*.

Component	***N. oculata***	***U. lactuca***
Moisture %	3.50 ± 0.10^{b}	13.25 ± 0.24^{a}
Crude protein (%)	32.19 ± 0.2^{a}	20.44 ± 0.15^{b}
Crude oil (%)	10.29 ± 0.23^{a}	0.65 ± 0.02^{b}
Crude ash (%)	19.41 ± 1.02^{b}	30.88 ± 0.39^{a}
Crude Fiber (%)	11.91 ± 0.09^{a}	8.61 ± 0.12^{b}
Carbohydrates (%)	26.2 ± 0.66^{b}	39.42 ± 0.15^{a}
Total Chlorophyll (µg/ml)	1.18 ± 0.16^{b}	5.97 ± 0.07^{a}
Total carotenoid (µg/ml)	0.34 ± 0.04^{b}	3.34 ± 0.02^{a}

$^{a,\,b}$ Letters denote significant difference in each raw (P<0.05; Paired t-test)

Protein, oil and fiber contents were significantly higher (P<0.05) in *N. oculata* than in *U. lactuca*. Based on dry weight, values were recorded as 32.19 - 20.44 % of total protein, 10.29 - d 0.65 % of oil content and 11.91 - 8.61 % of fibers, respectively. The results of *U. lactuca* in this study are consistent with those of **Yaich *et al.* (2011)** for the moisture content (14.94%), while they differed in protein and oil (8.46% and 7.87%, respectively). Moreover, **Fleurence (1999)** added that the protein content in *Ulva* species ranged between 10 & 26% according to the season and species. **Salehi *et al.* (2019**) stated that green seaweeds had higher protein content than others. According to **Paes *et al.* (2016)**, proteins, lipids and carbohydrates of *N. oculata* ranged between 17.9 and 30.8%, 17.8 and 33.7%, 23.3 and 29.3%, respectively, depending on the conditions and growth phase. In this context, nutritional status also defines the fine composition of the grown algae, where *N. oculata* grown under different organic carbon sources and fixed other growth conditions resulted in maximum dry weight with all okara concentrations used and lower okara concentration (25%) enhanced, while higher concentration (100%) reached the maximum chlorophyll content with a completely opposite pattern, observed with total carotene (**Kamal *et al*., 2017**). Furthermore, the high protein content of *N. oculata* grown in bagasse waste might be attributed to the high organic carbon nutrition (**El-Sayed *et al*., 2020**).

Following protein, carbohydrates represented the second potent figure. In fact, algal cells contain about 50% of their dry weight of carbon; however, protein revealed the maximum constituent; both carbohydrate and oils served as storage metabolites. In the case of un-favorable conditions (environmental or nutritional), protein content tended to markedly decrease vice the rise of carbohydrates and/or oils. With respect to the result of carbohydrates, oil ratio is widely differed based on algae species and stress conditions. Macroalgae normally contain lower content of oils, compared to microalgae and vise-versa concerning carbohydrates, where macroalgae showed the highest one.

In the present study, oil content was maximized with *N. oculata* (10.29%); while *U. lactuca* resulted in 0.65% of oil content. For carbohydrate content, the opposite manner was found, where *U. lactuca* (39.42 % surpasses *N. oculata* considering carbohydrate content (26.2 %).

The *U. lactuca* contained 8.6% of crude fiber, which was higher than the finding (5.6%) of **Tabarsa *et al*. (2012)**. On the other hand, crude fiber was 11.91% in *N. oculata* which was lower than those obtained by **Matos *et al*. (2016)** who recorded a value of 13.0%. According to **Øverland *et al*. (2019)**, green algae had 10 to 69% crude fibers. These fibers could improve human health by controlling the digestive tract, blood sugar and cholesterol levels, and preventing serious diseases like diabetes, obesity and cancer **(Cardoso *et al*., 2015; Catarino *et al*., 2018)**.

The familiar Egyptian macroalga *Enteromorpha* sp. contains the neighbor chemical composition of those found in *U. lactuca*, where 7.06% of total protein, 51.37% of total carbohydrates and 6.3% of total oils were detected (**El-Sayed *et al*., 2017**).

The total phytochemical chlorophyll in *U. lactuca* (5.97µg/ml) was more than in *N. oculata* (1.18µg/ml), which may be due to the differences in light source (nature or artificial) during growth and genotype. Chlorophyll plays an important role against oxidants and mutagens and appears in green.

Major important dietary minerals determined in *N. oculata and U. lactuca* were P, Ca, K and Mg (Table 2). The dominant element in *N. oculata* was P (24000 mg/kg); while Ca (48300 mg/kg) was dominant in *U. lactuca.* Significant differences (P<0.05) in Ca, K and Mg quantity were detected between *N. oculata* and *U. lactuca*. The order of trace dietary minerals in *N. oculata* and *U. lactuca* were Fe, Mn, Zn and Cu, respectively. Fe was the dominant element in both micro and macro algae (100 and 108 mg/kg). Fe, Mn and Cu were significantly higher in *U. lactuca* than in *N. oculata*. The Fe contents in *N. oculata and U. lactuca* were reached and slightly exceeded the maximum permissible limits according to **FAO (1983)**, **FAO/WHO limit (1989)**, **WHO (1998)** and **Mokhtar**

***et al*. (2009)**. In contrast to our findings, **Kim *et al*. (2001)** reported that the main elements in *N. oculata* were Ca, Mg, K and Fe (8820.57, 10390.15, 129060.86 and 7470.20 mg/kg, respectively). **Debbarma *et al*. (2016)** reported that *U. lactuca* was possessed macro nutrients, Ca (180.67 mg %), K (209.00 mg %) and Na (351.67 mg %) content which were lower than those determined in our study. Additionally, micro nutrients, Fe, Zn, Cu and Mn contents were 34.47, 1.78, 1.83 and 4.8 mg %, respectively, which are higher than those recorded in the current study, except for Zn. Here, the high initial content of some nutrients (macro and micro) could be ascribed to the traditional method used for *N. oculata* production, concerning the added chemicals, while for *U. lactuca,* the case might refer to the environmental status of alga grown site. Significant effects on human health are caused by high levels of inorganic macro minerals and trace levels of micro minerals, which are vital for numerous physiological processes (**Debbarma *et al*., 2016**). The biological adsorption and accumulation of minerals in algae resulted in a higher mineral content compared to other plants (**Yadav *et al*., 2021**).

Table 2. Mineral fraction of *N. oculata* and *U. lactuca*

	N. oculata	***U. lactuca***
Macro mineral (%)		
P	2.4±0.05	2.56±0.08
K	1.27±0.02[a]	1.2±0.01[b]
Ca	1.68±0.3[b]	4.83±0.2[a]
Mg	0.23±0.01[b]	0.34±0.02[a]
Micro mineral (ppm)		
Fe	100±0.57[b]	108±0.87[a]
Mn	35±0.25[b]	41±0.05[a]
Zn	33±0.07[a]	19.5±076[b]
Cu	6 ± 0.5[b]	7.01±0.29[a]

[a, b] Letters denote significant difference in each raw (P<0.05; Paired t-test)

2. Amino acids profile

Becker and Richmond (2004) stated that almost all algae have an amino acid composition comparable to other dietary proteins, with slight shortages in the sulfur-containing amino acids cysteine and methionine. Table (3) displays the amino acids profiles of *N. oculata* and *U. lactuca*. Micro and macro marine algae proteins had 17 and 16 amino acids, respectively; seven of them being non-essential amino acids (NEAA) which accounted for 40.01 and 48.75g/ 100g, respectively. Total essential amino acids (EAA) was less than total NEAA in both *N. oculata* and *U. lactuca*. Most levels of amino acids in *U. lactuca* were higher than in *N. oculata*. In descending order, the dominant essential amino acids in *N. oculata* were threonine (4.28%), Lysine (4.22%) and isoleucine (4.1%); while leucine (7.1%), phenylalanine (5.81%), valine (5.3%), threonine (4.87%) and lysine (4.1%) in *U. lactuca*. Alanine, glutamic acid and aspartic acid were dominant non-essential amino acids in both marine algae. Many algae species contain extremely high quantities of aspartic acid and glutamic acid, which are largely responsible for algae's distinct umami flavor (**Mac Artain *et al*., 2007**).

In this study, *U. lactuca* had amounts of the various amino acids ranging from 0.75 to 11.52 g/100 g protein, a result which agrees with that of **Yaich *et al*. (2011)** who recorded their values ranging from 1.39 to 12.94g/ 100g protein. Furthermore, the levels of amino acids in *N. oculata* ranged from 0.53 to 9.18g/ 100g protein, which coincides with the findings of **Brown *et al*. (1993)** where they ranged from 0.29 to 11.9 g/100 g protein, depending on the growth phase.

Table 3. Amino acids profile (g/100g protein) and nutritional value of *N. oculata* and *U. lactuca*

Component	**Alga**		**FAO/ WHO Provisional Pattern***
	N. oculata	***U. lactuca***	
Essential amino acids			
Threonine (THR)	4.28±0.01[b]	4.87±0.04[a]	4
Valine (VAL)	3.39±0.02[b]	5.3± 0.01[a]	4.98
Isoleucine (ILE)	4.1±0.14	3.8±0.02	4
Leucine (LEU)	3.95±0.01[b]	7.1±0.01[a]	7
Phenylalanine (PHE)	3.69±0.05[b]	5.81±0.02[a]	6
Tyrosine (TYR)	3.23±0.02[a]	2.7± 0.03[b]	
Histidine (HIS)	2.43±0.02[a]	1.08±0.01[b]	
Lysine (LYS)	4.22±0.03[a]	4.1±0.02[b]	5.4
Methionine (MET)	2.68±0.04[a]	2.3±0.1[b]	3.25
Cysteine (CYS)	0.53±0.1[a]	ND [b]	3.25
Σ EAA	**32.50**	**37.06**	
Non-essential amino acids			
Arginine (ARG)	4.26±0.03[b]	6.87±0.02[a]	
Aspartic (ASP)	5.56±0.03[b]	9.69±0.15[a]	
Serine (SER)	4.91±0.02[b]	4.06±0.03[a]	
Glutamic (GLU)	9.18±0.02[b]	10.32±0.01[a]	
Glycine (GLY)	4.32±0.09[b]	5.54±0.02[a]	
Alanine (ALA)	7.32±0.1[b]	11.52±0.04[a]	
Proline (PRO)	4.46±0.03[a]	0.75±0.01[b]	
Σ NEAA	**40.01**	**48.75**	
Nutritional value (Kcal/100g)	**326.17**	**245.29**	
C-PER**	**2.43**	**7.97**	
C-BV***	**77.07**	**75.99**	

ND not detected; Tryptophan not determined

FAO/WHO/UNU (1985) Energy and protein requirement. Technical Report Series No.724.

** C-PER Calculated Protein Efficiency Ratio

*** C-BV Computed Biological Value

[a, b] Letters denote significant difference in each raw (P<0.05; Paired t-test)

3. Nutritional value

As shown in Table (3), the caloric value of *N. oculata* was higher than that of *U. lactuca* (326.17 and 245.29 Kcal/ 100g) due to the variation in chemical composition, especially in fat content. From the results, both marine algae are good source of high caloric values and required micro and macro minerals.

Protein quality is assessed using the protein efficiency ratio (PER) and biological value (BV). As presented in Table (3), calculated C-PER and C-BV were 2.43 and 77.07; 7.97 and 75.99, respectively, of *N. oculata* and *U. lactuca*. PER denotes weight increase per unit of protein during food studies; whereas, BV denotes nitrogen maintained for growth or maintenance (**Becker, 2007**). **Becker and Richmond (2004)** reported that PER and BV of differently processed algae which ranged between 0.84 and 2.10; 52.9 and 77.6, respectively. The results of EAA, C-PER and C-BV in this study indicate that *N. oculata* and *U. lactuca* had good protein quality, compared to casein protein (**Becker, 2007; Bleakley & Hayes, 2017**).

4. Fatty acids profile

Results in Table (4) show that saturated and unsaturated fatty acids represented 45.13 and 54.87%; 68.95 and 31.05% of the fat of *N. oculata* and *U. lactuca*, respectively. Palmitic acid (C16:0) was the dominant saturated fatty acid in both *N. oculata* (28.23%) and *U. lactuca* (52.93%). The prevalent unsaturated fatty acid was Oleic acid (25.08%) in *U. lactuca*, while it was linoleic acid (15.66%) and oleic acid (15.07%) in *N. oculata*. These results of *U. lactuca* correspond with the data found by **Ortiz *et al*. (2006)** and **Yaich *et al*. (2011)**.

Media composition widely affected the results; where control cultures of *N. oculata* compared to those grown under organic carbon or stressed one resulted in 10.2, 9.11 and 6.94 % of MUSFA vice 40.44, 36.3 and 11.69% of PUSFA (**Abo El-Khair *et al*., 2022b**).

Nutritionally, *N. oculata* seems to be rich as a source of oil fraction load, where the sum of saturated fatty acids (SFA) was lower (45.13%), compared to those obtained by *U. lactuca* (68.95%). In addition, polyunsaturated fatty acids were more evident in *N. oculata* (31.36%) than in *U. lactuca* (3.81%), which consisted of important fatty acids in human nutrition, especially linoleic acid, linolenic acid, arachidonic acid, eicosatetraenoic acid (EPA) and docosahexaenoic acid (DHA). According to **WHO (2005)**, SFA/PUFA ratio of *N. oculata* was in the healthful limits of lipid quality (less than 2.22), while *U. lactuca* exceeded this limit. ω-3 and ω-6 PUFA were higher in *N. oculata* than in *U. lactuca*, and both ω-3/ ω-6 ratios were consistent with the ratio (>0.1) advised by **WHO (2005)**.

Table 4. The fatty acids composition of *N. oculata* and *U. lactuca* oil

Fatty acid %	Alga	
	N. oculata	***U. lactuca***
Saturated		
Myristic acid (C14:0)	0.59±0.01[b]	1.86±0.05[a]
Palmitic acid (C16:0)	28.23±0.03[b]	52.93±0.01[a]
Heptadecanoic acid (C17:0)	5.12±0.01[a]	0.0±0.0[b]
Stearic acid (C18:0)	7.07±0.01[a]	5.28±0.03[b]
Arachidic acid (C20:0)	4.12±0.03[b]	8.88±0.02[a]
Σ (SFA)	**45.13**	**68.95**
Unsaturated		
Myristoleic acid (C14:1 ω5)	0.29±0.01[b]	2.16±0.01[a]
Pentadecenoic acid (C15:1 ω5)	0.94±0.02[a]	0.0 ±0.0[b]
Palmitoleic acid (C16:1 ω7)	1.64±0.02[a]	0.0±0.0[b]
Heptadecenoic acid (C17:1 ω7)	5.57±0.01[a]	0.0±0.0[b]
Oleic acid (C18:1 ω9)	15.07±0.0[b]	25.08±0.0[a]
Σ (MUFA)	**23.51**	**27.24**
Linoleic acid (C18:2 ω6)	15.66±0.02[a]	1.14±0.02[b]
Linolenic acid (C18:3 ω3)	7.3±0.02[a]	2.62±0.03[b]
Arachidonic acid (C20:4 ω6)	4.36±0.01[a]	0.0±0.0[b]
Eicosapentaenoic acid (EPA) (C20:5 ω3)	3.05±0.03[a]	0.05±0.01[b]
Docosahexaenoic (DHA) C22:6 ω3	0.99±0.02[a]	0.0±0.0[b]
Σ (PUFA)	**31.36**	**3.81**
Σ (USFA)	**54.87**	**31.05**
SFA/MUFA	**1.92**	**2.53**
SFA/PUFA	**1.44**	**18.10**
SFA/USFA	**0.82**	**2.22**
ω3	**11.34**	**2.67**
ω6	**20.02**	**1.14**
ω3/ ω6	**0.57**	**2.34**

[a, b] Letters denote significant difference in each raw (P<0.05; Paired t-test).

CONCLUSION

The important nutritional components make both types of *N. oculata* (microalgae) and *U. lactuca* (seaweed) distinct sources of nutritional value, fiber, protein and essential amino acids, especially threonine, lysine and isoleucine in addition to both glutamic and aspartic acid, which are responsible for the distinctive umami flavor, and the presence of chlorophyll and carotenoid pigments (nature bioactive substances), which are responsible for the appearance of the green color. Furthermore, C-PER and C-BV in addition to the ω3/ω6 ratio indicated the protein and lipid quality of these algae. According to the previous results, both *N. oculata* and *U. lactuca* can be used to support the quality of food currently required by the market.

REFERENCES

Abo El-Khair B. E.; Nashwa, A. F., Fatma. M. I. and Sadik, M.W. (2022b). Biomass Fatty acids profile and fuel properties prediction of bagasse wastes grown *Nannochloropsis oculata*. Agriculture, 12: 1201.

Abo El-Khair, B. E.; El-Feky, A. M.; Mounier, M. M. and Reda, M. M. (2022a). C-Phycocyanin, Anticancer Activity and Nutritional Value of Mass-Produced *Spirulina platensis*. Egyptian Journal of Chemistry, 65(11): 611 – 625.

Abo El-Khair, B. E.; Marwa, M. R.; Adel, W. A. and Charalampos, M. (2023). Productivity and biochemical constituents of *Chlorella vulgaris* grown in Net-House Photobioreactor. Journal of Taibah University for Science. 17(1): 2194843.

Abreu, M. H.; Pereira, R. and Sassi, J. F. (2014). Marine algae and the global food industry. Marine algae, biodiversity, taxonomy, environmental assessment, and biotechnology. CRC Press, Bocca Raton, FL, 300-319.

Almutairi, A. W.; El-Sayed, A. B. and Reda. M. M. (2020). Combined effect of salinity and pH on lipoid content and fatty acids composition of *Tisochrysis lutea*. Saudi Journal of Biological Sciences. 27: 3553-3558.

Almutairi, A. W.; El-Sayed, A. E. K. B. and Reda, M. M. (2021). Evaluation of high salinity adaptation for lipid bio-accumulation in the green microalga *Chlorella* vulgaris. Saudi Journal of Biological Sciences, 28(7): 3981-3988.

Andrés, M.; Raúl, C.; Luis, L. and Mariane, L. (1992). Evaluation of marine microalga *Nannochloropsis* sp. as a potential dietary supplement. Chemical, nutritional and short term toxicological evaluation in rats. Nutrition Research, 12(10): 1273-1284.

AOAC (Official Method of Analysis). (2000). Association of Official Analytical Chemists, Gaithersburg, Md, USA, 17th. ed. 969.3 and 991.39 Fatty acids in oils and fats preparation of methyl esters. Boron trifluorid AOAC-IUPAC method codex-Adopted-AOAC method, 41: 19-20.

Baik, I.; Lee, M.; Jun, N. R.; Lee, J. Y. and Shin, C. (2013). A healthy dietary pattern consisting of a variety of food choices is inversely associated with the development of metabolic syndrome. Nutrition Research and Practice, 7(3): 233-241.

Battah, M. G.; El-Sayed, A. B. and El-Sayed, E. W. (2013). Growth of the green alga *Chlorella vulgaris* as affected by different carbon sources. Life Science Journal 2013; 10(1):2075-2081.

Becker, E. W. (2007). Micro-algae as a source of protein. Biotechnology Advances, 25(2): 207-210.

Becker, W. and Richmond, A. (2004). Handbook of microalgal culture. Microalgae in Human and Animal Nutrition, 312-351.

Bishop, W. M. and Zubeck, H. M. (2012). Evaluation of microalgae for use as nutraceuticals and nutritional supplements. Journal Nutrition Food Science, 2(5): 1-6.

Bleakley, S., & Hayes, M. (2017). Algal proteins: extraction, application, and challenges concerning production. Foods, 6(5): 33.

Brown, M. R.; Garland, C. D.; Jeffrey, S. W.; Jameson, I. D. and Leroi, J. M. (1993). The gross and amino acid compositions of batch and semi-continuous cultures of *Isochrysis* sp. (clone T. ISO), *Pavlova lutheri* and *Nannochloropsis oculata*. Journal of Applied Phycology, 5: 285-296.

Bux, F. and Chisti, Y. (Eds.). (2016). Algae biotechnology: products and processes**.** Springer. DOI 10.1007/978-3-319-12334-9

Cardoso, S. M.; Pereira, O. R.; Seca, A. M.; Pinto, D. C. and Silva, A. M. (2015). Seaweeds as preventive agents for cardiovascular diseases: From nutrients to functional foods. Marine Drugs, 13(11): 6838-6865.

Catarino, M. D.; Silva, A. M. and Cardoso, S. M. (2018). Phycochemical constituents and biological activities of *Fucus* spp. Marine Drugs, 16(8): 249.

Chapman, H. D. and Pratt, P. F. (1974). Methods for Soils, Plants and Waters. Berkeley: university of California, Division of Agricultural Sciences, USA.

Debbarma, J.; Rao, B. M.; Murthy, L. N.; Mathew, S.; Venkateshwarlu, G. and Ravishankar, C. N. (2016). Nutritional profiling of the edible seaweeds *Gracilaria edulis, Ulva lactuca* and *Sargassum* sp. Indian Journal Fish, 63(3): 81-87.

Dubois, M.; Gilles, K. A; Hamilton, J. K.; Rebers, P. A. and Smith, F. (1956). Calorimetric methods for determination of sugars and related substances. Analytical Chemical, 28: 350–356

El-Awady, R. M.; El-Sayed, A. B.; El-Zabalawy, K. M. and El-Mohandes, M. A. (2020). Bio-mass Production of *Chlorella vulgaris* grown on date wastes under different stress conditions. Al-Azhar Journal of Agricultural Research, 45(2): 62-75.

El-Kassas, H. I.; El-Sayed, A. B.; Maryam, M. M. and Marwa, M. R. (2017). Algal growth and nutrient removal as affected by nitrogen sources. Journal of Environmental Science. 39(3): 117-135.

El-Sayed, A. B. (2010). Circulation of Quaron Lake Wastes. I- Solidification of magnesium salts and the complementary demineralization by the green alga *Scenedesmus* sp. Journal of American Science, 6(9): 870-875.

El-Sayed, A. B.; Abdel-Maguid, A. A. and Hoballah, E. M. (2011). Growth response of *Chlorella vulgaris* to acetate carbon and nitrogen forms. Nature and Science, 9(9): 53-58.

El-Sayed, A. B.; Battah M. G. and El-Sayed, E. W. (2015). Utilization efficiency of artificial carbon dioxide and corn steam liquor by *Chlorella vulgaris*. Biolife, 3(2): 391-403.

El-Sayed, A. B.; El-Fouly, M. M. and El-Sayed, A. A. (2008). Utilization efficiency of elevated nitrogen, phosphorous and potassium concentrations by the green alga *Scenedesmus* sp. In The 17th International Symposium of CIEC "Plant Nutrient Management under Stress Conditions". NRC, Cairo.

El-Sayed, A. B.; Fetyan, N. A.; Ibrahim, F.; Fayed, S. and Sadik, M. W. (2020). Application of bagasse extract in economic *Nannochloropsis oculata* mass production. Egyptian Journal of Chemistry, 63(12): 5183-5192.

El-Sayed, A. B.; Fetyan, N. A.; Moghanm, F. S.; Elbagory, M.; Ibrahim, F. M.; Sadik, M. W. and Shokr, M. S. (2022). Biomass fatty acid profile and fuel property prediction of bagasse waste grown *Nannochloropsis oculata*. Agriculture, 12(8): 1201.

El-Sayed, A. B.; Hoballah, E. M. and Khalafallah, M. A. (2012). Utilization of citrate wastes by *Scenedesmus* sp. i- enhancement of vegetative growth. Journal of Applied Sciences Research, 8(2): 739-745.

El-Sayed, A. B.; Nashwa, A. H. F. and El-Fakharany, M. K. (2017). Bioethanol production from Egyptian alga *Enteromorpha* sp. Middle East Journal of Applied Sciences, 1: 216-25.

Enzing, C.; Ploeg, M.; Barbosa, M. and Sijtsma, L. (2014). Microalgae-based products for the food and feed sector: an outlook for Europe. JRC Scientific and Policy Reports, 19-37.

FAO. (1983). Compilation of legal limits for hazardous substances in fish and fishery products. FAO Fish Circ, 464:5–100.

FAO/WHO (Joint FAO/WHO Expert Committee on Food Additives, Food and Agriculture Organization of the United Nations and World Health Organization). (1989). Evaluation of certain food additives and contaminants: thirty-third report of the Joint FAO/WHO Expert Committee on Food Additives [meeting held in Geneva from 21 to 30 March 1988] . World Health Organization. https://apps.who.int/iris/handle/10665/39252

Fleurence, J. (1999). Seaweed proteins: biochemical, nutritional aspects and potential uses. Trends in Food Science and Technology, 10(1): 25-28.

Greene, C. H. (2020). The Green New Deal: Algal Solutions to Reversing Climate Change and Ending World Hunger. In Ocean Sciences Meeting 2020. AGU.

Guillard, R. R. (1975). Culture of phytoplankton for feeding marine invertebrates. In Culture of marine invertebrate animals: proceedings—1st conference on culture of marine invertebrate animals greenport. Springer US, 29-60.

Hassan S.; Nadra, Y.; Zahrat, E. M. and Abo El Khair, B. E. (2015). Production and evaluation of pasta supplemented with Spirulina platensis biomass. Advances in Food Sciences. 37(4);153-162.

Kamal, S.; El-Sayed, A. B.; Hassan, A. A.; El-Shazly, H. A. and Ibrahim, M. T. (2017). Use of okara waste for algae nutrition. Arab Universities Journal of Agricultural Sciences, 25(2): 271-279.

Kim, S. K. and Chojnacka, K. (Eds.). (2015). Marine algae extracts: processes, products, and applications. John Wiley and Sons.

Kim, S. K.; Baek, H. C.; Byun, H. G.; Kang, O. J. and Kim, J. B. (2001). Biochemical composition and antioxidative activity of marine microalgae. Korean Journal of Fisheries and Aquatic Sciences, 34(3): 260-267.

Ma, T.S. and Zauzage, C. (1942). Micro-kjeldahl determination of nitrogen, a new indicator and improved rapid method. Industrial Engineering Chemical Analysis, 14: 280-286.

MacArtain, P.; Gill, C. I.; Brooks, M.; Campbell, R. and Rowland, I. R. (2007). Nutritional value of edible seaweeds. Nutrition reviews, 65(12): 535-543.

Mackinney, G. (1941). Absorption of light by chlorophyll solutions. Journal of Biological Chemistry, 140(2): 315-322.

Marwa, R.; Abo El-Khair, E.; Adel, A. and Hassoub, A. (2020). Fatty Acid Profiles and Fuel Properties of Oils from Castor Oil Plants Irrigated by Microalga-treated Wastewater. Egyptian Journal of Botany. 60 (3): 797-804.

Matos, Â. P.; Feller, R.; Moecke, E. H. S.; de Oliveira, J. V.; Junior, A. F.; Derner, R. B. and Sant'Anna, E. S. (2016). Chemical characterization of six microalgae with potential utility for food application. Journal of the American Oil Chemists' Society, 93: 963-972.

Mithril, C.; Dragsted, L. O.; Meyer, C.; Tetens, I.; Biltoft-Jensen, A. and Astrup, A. (2013). Dietary composition and nutrient content of the New Nordic Diet. Public health nutrition, 16(5): 777-785.

Mohamed, A. G.; Abo-El-Khair, B. E. and Samah M. Shalaby. (2013). Quality of novel healthy processed cheese analogue enhanced with marine microalgae *Chlorella vulgaris* biomass, World Applied Sciences Journal, 23 (7): 914-925, 2.

Mohanty, B. P.; Paria, P., Das, D.; Ganguly, S.; Mitra, P.; Verma, A.; Sahoo, A.; Mahanty, A.; Aftabuddin, Md.; Behera, B. K.; Sankar, T. V. and Sharma, A. P. (2012). Nutrient profile of giant river-catfish *Sperata seenghala* (Sykes). National Academy Science Letters, 35: 155-161.

Mokhtar, M.; Aris, Z. A. and Munusamy, V. (2009). Assessment level of heavy metals in *Penaeus Monodon* and *Oreochromis* Spp in Selected aquaculture ponds of high densities development area. European Journal of Science Research, 30: 348-360.

Murphy, J. A. M. E. S. and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta, 27: 31-36.

Ortiz, J.; Romero, N.; Robert, P.; Araya, J.; Lopez-Hernández, J.; Bozzo, C.; Navarrete, E.; Osorio, A. and Rios, A. (2006). Dietary fiber, amino acid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea antarctica*. Food Chemistry, 99(1): 98-104.

Øverland, M.; Mydland, L. T. and Skrede, A. (2019). Marine macroalgae as sources of protein and bioactive compounds in feed for monogastric animals. Journal of the Science of Food and Agriculture, 99(1): 13-24.

Paes, C. R.; Faria, G. R.; Tinoco, N. A.; Castro, D. J.; Barbarino, E. and Lourenço, S. O. (2016). Growth, nutrient uptake and chemical composition of *Chlorella* sp. and *Nannochloropsis oculata* under nitrogen starvation. Latin American Journal of Aquatic Research, 44(2): 275-292.

Pereira, S. A.; Kimpara, J. M. and Valenti, W. C. (2021). Sustainability of the seaweed *Hypnea pseudomusciformis* farming in the tropical Southwestern Atlantic. Ecological Indicators, 121: 107101

Priyadarshani, I. and Rath, B. (2012). Commercial and industrial applications of micro algae–A review. Journal of Algal Biomass Utilization, 3(4): 89-100.

Ruiz, J.; Olivieri, G.; De Vree, J.; Bosma, R.; Willems, P.; Reith, J. H.; Eppink, H. M. M.; Kleinegris, M. M. D.; Wijffels, H. R. and Barbosa, M. J. (2016). Towards industrial products from microalgae. Energy and Environmental Science, 9(10): 3036-3043.

Salehi, B.; Sharifi-Rad, J.; Seca, A. M.; Pinto, D. C.; Michalak, I.; Trincone, A.; Mishra, A.P.; Nigam, M.; Zam, W. and Martins, N. (2019). Current trends on seaweeds: Looking at chemical composition, phytopharmacology, and cosmetic applications. Molecules, 24(22): 4182.

Schmid, B.; Navalho, S.; Schulze, P.S.C.; Walle, S. V. D.; Royen, G. V.; Schüler, L. M.; Maia, L. B.; Bastos, C. R. V.; Baune, M-C.; Januschewski, E.; Coelho, A.; Pereira, H.; Varela, J.; Navalho, J. and Rodrigues, A.M.C. (2022). Drying Microalgae Using an Industrial Solar Dryer: A Biomass Quality Assessment. Foods, 11: 1873.

Ścieszka, S. and Klewicka, E. (2019). Algae in food: A general review. Critical reviews in Food Science and Nutrition, 59(21): 3538-3547.

Tabarsa, M.; Rezaei, M.; Ramezanpour, Z. and Waaland, J. R. (2012). Chemical compositions of the marine algae *Gracilaria salicornia* (Rhodophyta) and *Ulva lactuca* (Chlorophyta) as a potential food source. Journal of the Science of Food and Agriculture, 92(12): 2500-2506.

WHO (World Health Organization). (2005). Department of Health. Nutritional Aspects of Cardiovascular Disease. London: WHO.

World Health Organization. (1998). The World Health Report 1998: Life in the 21st century a vision for all. In The world health report 1998: life in the 21st century A vision for all, 241-241.

Yadav, D. K.; Singh, A.; Agrawal, V. and Yadav, N. (2021). Algal Biomass: A Natural Resource of High Value Biomolecules. Bioprospecting of Plant Biodiversity for Industrial Molecules, 303-334.

Yaich, H.; Garna, H.; Besbes, S.; Paquot, M., Blecker, C. and Attia, H. (2011). Chemical composition and functional properties of *Ulva lactuca* seaweed collected in Tunisia. Food chemistry, 128(4): 895-901.

Zhang, T.; Guo, Q.; Xin, Y. and Liu, Y. (2022). Comprehensive review in moisture retention mechanism of polysaccharides from algae, plants, bacteria and fungus. Arabian Journal of Chemistry, King Saud University; 15: 104163.

Zuta, C. P.; Simpson, B. K.; Chan, H. M., and Phillips, L. (2003). Concentrating PUFA from mackerel processing waste. Journal of the American Oil Chemists' Society, 80(9): 933-936.