Biomass Nutrient Profiles of Three Microalgae: *Spirulina platensis, Chlorella vulgaris,* and *Isochrisis galbana*

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ABSTRACT: Nutritional composition was determined for *Spirulina platensis, Chlorella vulgaris,* and *Isochrisis galbana* cultures. Data include the proximate composition, energy value, mineral elements, and fatty acid composition. Sixteen strains of these microalgae were obtained as a percentage of total fat. Total PUFA, SFA contents, *n*-3/*n*-6 ratios, and eicosapentaenoic acid (EPA)/docosahexaenoic acid (DHA) ratios were obtained. Protein content was high in *Spirulina* samples, whereas *Isochrisis* had the highest ash content. *Spirulina* is a rich source of γ-linolenic acid (GLA); *Chlorella* was an important source of PUFAs. *Spirulina* is a rich source of K, *Chlorella* is rich in P, and *Isochrisis* is a good source of Ca and Mg. Se content of *Isochrisis* is higher than in the other microalgae.

Keywords: microalgae, proximate composition, fatty acid, mineral content

Introduction

THE BIOCHEMISTRY AND PHYSIOLOGY OF microalgae have been studied extensively, and microalgae cultures have been developed as a food supplement (Schwartz and others 1991; Brown and others 1997; Jany 1997; Miranda and others 1998; Nitzan and others 1999).

Microalgal biomass is a rich source of some nutrients, such as *n*-3 and *n*-6 fatty acids, proteins, minerals, and other essential nutrients (Becker 1994; Tokuşoglu and Ünal 2001). Epidemiological and clinical investigations have shown a strong relationship between CHD and consumption of foods rich in omega-3 fatty acids (Ricardo and Valenzula 2000). *N*-3 fatty acids from microalgae into the food supply have resulted in w-3 FAs- enriched foods in the agrifood industry (Simopoulos 1999, 2000).

Bioavailable protein and mineral element contents are important for the recommended daily intakes for an adult and could be used for nutritional purposes (Becker 1994).

The objective of this research is to determine the proximate composition, fatty acid profiles (FAs), and mineral contents of *Spirulina platensis, Chlorella vulgaris,* and *Isochrisis galbana,* and to compare the abovementioned microalgae as potential food supplements and food additives.

Materials and Methods

Cultivation and preparation of microalgae samples

Three starter cultures of *Spirulina platensis* and 1 each starter culture of *Chlorella vulgaris* and *Isochrisis galbana* were obtained from the Culture Collection of Algae and Protozoa, Dunstaffnage Marine Laboratory, OBAN, Argyll, Scotland, U.K. The isolation of microalgae from cultures was done in the solid state via the agar method (Belcher and Swale 1982) at Pínar Deniz A.S¸., Ízmir, Turkey.

The microalgae cultures were developed using the semicontinuous culture system in duplicate runs (Richmond 1986), then massive productions were done in duplicate flasks. Inoculation density of cultures in production were (1.5 to 1.8) × 10^6 cell/mL. These cultures were continuously aerated by using an air pump without additional carbon dioxide. The laboratory temperature was kept at 20 ± 2 °C, and 16 fluorescent lamps of 36 W each were provided for continual light. The light reaching the surfaces of cultures was measured as μE m^{-2} s^{-1}. In all microalgae cultivations, Conwey culture medium (Pinar Deniz A.S., Izmir, Turkey) was used and the pH and salinity of cultures was routinely measured.

Biomasses of *Spirulina platensis, Chlorella vulgaris,* and *Isochrisis galbana* were collected directly from the bioreactor to a Pyrex glass container and centrifuged at 4000 rpm for 4 min. The harvested biomass had a high moisture content. The harvested biomass of *Spirulina , Chlorella,* and *Isochrisis* were centrifuged with the same procedure, biomass cakes of samples were washed with 0.5 M NaCl and bidistilled water in order to eliminate nonbiological material such as mineral salt precipitates. Then the biomass was freeze-dried and stored in Eppendorf vials at –28 °C to analyze for nutrient profiles. These biomasses were sampled in triplicate (n = 3).

Proximate analysis

The moisture content was determined by drying a representative 2 g sample at 100 to 105 °C for 40 h by the procedure described by Rebolloso Fuentes and others (2000). Total ash was determined by incineration of a representative 0.5 g sample at 450 °C for 48 h (Rebolloso Fuentes and others 2000).

Total lipids of samples were determined by a modified version of the Bligh and Dyer (1959) method. In this method, 0.16 mg of dry microalgae (2 g of the wet sample) was placed into a 15 mL test tube and 1.6 mL water, 4mL chloroform, and 2 mL methanol were added. The solution was mixed in a vortex for 5 min. This reaction mixture, including an additional 2 mL of chloroform and 1 mL of methanol, was placed in an ultrasonic bath at 25 °C for 10 min, then the test tube contents were mixed using a vortex for 30 s. The test tubes were centrifuged at 3500 rpm for 15 min. The upper (water + methanol) phase was withdrawn by using a Pasteur pipette. The lower chloroform phase containing the extracted lipids was transferred to a 20 mL test tube. The remaining solid material at the bottom of the extraction tube was extracted with the same procedure 3 more times and then filtered through filter paper wetted with chloroform. The filtrate was concentrated in a rotary evaporator at 50 °C under reduced pressure and evaporated to dryness using nitrogen.

Crude protein was determined by

Kjeldahl protein units ("Gerhardt" incineration apparatus and "Gerhardt Vapodest 20" distillation apparatus). The protein was calculated as nitrogen (%) × 6.25 (AOAC 1990). Available carbohydrate was determined by the anthrone spectrophotometric method (Osborne 1986).

All proximate determinations were done in triplicate. Total energy content of the microalgae was determined by multiplying the values obtained for crude protein, total carbohydrate, and total lipid by 4.00, 3.75, and 9.00, respectively, and summing the results (Rebolloso Fuentes and others 2000).

FAME of microalgae samples

The fatty acid methyl esters (FAMEs) were prepared from extracted lipids from each species by esterification reaction with 14% Boron trifluoride (BF_3) - methanol complex (AOAC 1990).

Gas chromatography(GC)

FAMES were prepared from microalgae lipids according to Joseph and Ackman (1992) and from subsequent FA profiles obtained by gas-liquid chromatography (GC). The fatty acid methyl esters were analyzed using a 100-m (with 0.20 μm film thickness), 0.25-mm-inside dia WCOT fused-silica SP-2560 capillary column installed on a Hewlett-Packard 5890 gas-liquid chromatograph (Albertville, Minn., U.S.A.) with a flame ionization detector (FID). The gas chromatograph was temperature-programmed to start at 170 °C and to increase at 1 °C/min to 205 °C. Injector and detector temperatures were set to 250 °C and 270 °C, respectively. Carrier gas was hydrogen at a flow rate of 1.5 mL/min and split ratio was 33:1. The samples were injected as 2 μL. Fatty acid determinations were performed from 3 separate lipid extractions and esterification operations. Each was injected in triplicate (n = 3). Retention times were compared with FAMEs of known standards. FA standards had linear calibration curves through the origin (R^2 = 0.9999). The GC method used was validated for fatty acid determination of 3 microalgae within the 95% confidence limits. Mean analytical recoveries determined from individual fatty acids in microalgae samples changed from 99.8% to 100%.

ICP-AES analysis

For mineral determination, the ash obtained by incineration of the microalgae biomass was dissolved in a mixture of HNO_3 and HCl (1:1 v/v)(Merck KGaA, Darmstadt, Germany) and diluted with water (AOAC 1990). Na, K, Ca, Mg, Fe, P, Zn, Mn, Se, Cd, Cr, Cu, Pb, and As were determined by an inductively coupled plasma atomic emission spectrometer (ICP-AES). (Varian-El97103728, Palo Alto, Calif., U.S.A.). The analytical ICP-AES procedure of algae samples was modified from a published method concerning determination of tea minerals (Fernandez-Caceres and others 2001) and plant minerals using ICP-AES (Choon Ong 1992). A macroelement and a microelement standard mixture (1000 mg/L) were prepared and working standard solutions were obtained by serial dilutions of the standards. Matrix standard solutions were used for plotting calibration curves for macro- and microelements. Their R^2 values were 1.0. The method used was validated by testing and comparing results from a *Chlorella vulgaris* sample (R^2 = 0.9999).

The operating conditions were as follows: operating power, 1.2 kw; coolant argon flow rate, 7.5 L/min; plasma argon flow rate 0.8 L/min; burner type, Minitorch; nebulizer type, Meinhard; sample flow rate, 2.3 mL/min; radio frequency, 27.20 Mhz. Analytical detection wavelengths ranged from 178.38 to 766.33 nm for macro and micro minerals. Mineral data were obtained from 3 different analyses and each was analyzed in triplicate using ICP-AES (n = 3).

Statistical analysis

Data were analyzed with Statistica for Windows (1998 ed., Ver. 6.0, StatSoft Inc., Tulsa, Okla, U.S.A.) by one-way analysis of variance (Kruskal-Wallis ANOVA) with microalgal ash, moisture, protein, lipid, carbohydrate, individual fatty acids, and mineral composition as the source of variance.

Results and Discussion

NUTRIENT PROFILES OF 3 MICROALGAE (*Spirulina platensis, Isochrisis galbana, and Chlorella vulgaris)* were determined. The proximate results of 3 microalgae analyses are provided in Table 1.

The dry mass data were analyzed using the homogeneity test and variance was determined to be homogeneous ($p < 0.01$). Moisture content of *Spirulina* sample 1 was 3.11%, whereas *Spirulina* samples 2 and 3 were 4.08% and 3.76%, respectively, and was low, with a mean of 3.65%. This mean value is in the range of general recommendations for a quality less than 10% (Becker 1994). There was no significant difference between the 3 *Spirulina platensis* samples ($p < 0.01$). The biomass of *Chlorella* had 3.87% moisture, whereas *Isochrisis* had 6.48% moisture. There was no significant difference between the *Spirulina* samples and *Chlorella* as dry weight ($p < 0.01$). The results of the biomass analysis are expressed on 100 g dry wt basis (Table 1).

The total ash contents of freshwater *Spirulina* samples 1, 2, and 3 were 7.43%, 7.51%, and 10.38%, respectively. A freshwater *Chlorella* sample contained 6.30% of total ash, whereas a marine microalgae *Isochrisis* sample had the highest ash content (16.08%)(Figure 1). The Kruskal-Wallis test indicated that there was a significant difference between ash content of the 3 microalgae ($p < 0.01$), except for *Spirulina* samples 1 and 2 ($p < 0.01$). Similar values have been reported for other microalgae used in human nutrition. Freshwater algae showed lower levels of ash, such as *Scnedesmus* and *Spirulina* which had 6 to 15 g of ash on a 100 g dry wt basis (Becker and Venkataraman 1982). Rebolloso Fuentes and others (2000) reported the ash content of *Porphyridum cruentum* to be 16.8 to 23.6%, and Canizares and others (1994) reported that *Tetraselmis chui* had a 21% ash content.

Available carbohydrates of *Isochrisis* was higher (16.98%) than that of the other microalgae and there was no significant difference between carbohydrate content of *Isochrisis* and *Spirulina* samples 1, 2, and 3 ($p < 0.01$) (Table 1).

Protein content was very high in *Spirulina* samples 1, 2, and 3 with a mean of 63.0% ($p < 0.01$), followed by *Chlorella (*47.82%) and *Isochrisis* (26.99%), as shown in Figure 1. Protein content is high for most microalgae (Becker 1994).

Total lipid content of *Isochrisis* was higher (17.16%) than that of the other microalgae ($p < 0.01$). *Spirulina* samples contained 7.53% of average total lipid ($p < 0.01$), whereas *Chlorella* had 13.32% of total lipid (Table 1).

Values obtained for recorded fatty acids were obtained in percentages of total fat in Table 2. The major fatty acids were oleic acids (18:1*n*-9) for *Spirulina* with a mean of 34.44% ($p < 0.01$), followed by *Chlorella* (33.14%)(Figure 2). There were no significant differences regarding C18:1*n*-9 con-

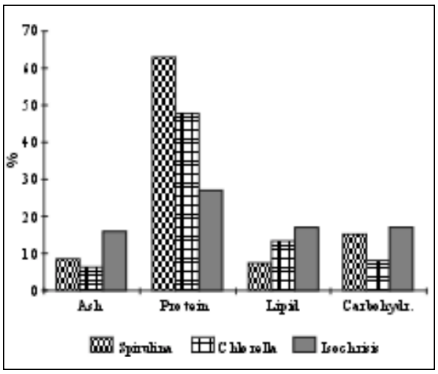

Figure 1—Proximate composition of 3 microalgae

Table 1—The proximate composition parameters of 3 microalgae samples†

Parameters	Spirulina 1	Spirulina 2	Spirulina 3	Chlorella	Isochrisis
Moisture(%)	3.11 ± 0.05	4.08 ± 0.02	3.76 ± 0.04	3.87 ± 0.04	6.48 ± 0.03
Total ash(%)	7.43 ± 0.06	7.51 ± 0.05	10.38 ± 0.05	6.30 ± 0.02	16.08 ± 0.03
Crude protein(%)	63.26 ± 0.04	64.43 ± 0.03	61.32 ± 0.02	47.82 ± 0.05	26.99 ± 0.08
Crude lipid(%)	7.09 ± 0.03	7.14 ± 0.03	8.03 ± 0.06	13.32 ± 0.07	17.16 ± 0.04
Available carbohydrate(%)	15.17 ± 0.02	15.09 ± 0.04	15.81 ± 0.07	8.08 ± 0.09	16.98 ± 0.05
Energy (kJ)	1562.22 ± 2.11	1582.41 ± 2.26	1575.18 ± 3.68	1427.30 ± 4.88	1362.99 ± 3.63

†Data are based on dry wt(%), mean ± SD (n = 3)

tent between these 2 species ($p < 0.01$). The content of 19.7% of oleic acid for *Isochrisis* was lower and significantly different from the other 4 (Table 2). *Isochrisis galbana* had the highest myristic acid (14:0) content (8.40%) between other species ($p < 0.01$) (Table 2). Palmitic acid (16:0) was high in *Spirulina* (avg. 27.22%) ($p < 0.01$), followed by *Isochrisis* with 28.27% of C16:0. Palmitic acid content of *Chlorella* was significantly different from other values (15.41%) (Table 2). *Isochrisis* contained the highest palmitoleic acid (16:1*n*-7) content (6.57%) (Table 2).

Table 2—Fatty acid (FA) composition of 3 microalgae as percent of total lipid

Fatty Acid	Spirulina Plantensis 1	Spirulina Plantensis 2	Spirulina Plantensis 3	Chlorella Vulgaris	Isochrisis Galbana
C14:0	0.43	0.46	0.41	0.38	8.40
C14:1	0.53	0.48	0.30	tr	1.29
C16:0	27.86	26.61	27.19	15.41	28.37
C16:1*n*-7	1.84	2.27	1.92	1.17	6.57
C18:0	5.80	8.82	6.66	6.24	5.82
C18:1*n*-9	32.86	34.71	35.74	33.14	19.73
C18:1*n*-7	1.17	1.64	1.33	1.13	2.40
C18:2*n*-6	10.37	14.45	11.25	9.73	1.14
C18:3*n*-6	4.60	3.64	5.52	tr	0.54
C18:3*n*-3	0.62	0.68	0.71	1.93	0.46
C18:4*n*-3	0.71	0.57	0.81	tr	0.48
C20:0	-	-	-	0.19	0.74
C20:4*n*-6	0.34	0.35	0.41	tr	1.07
C20:5*n*-3	2.33	2.21	2.91	3.23	1.93
C22:5*n*-3	-	-	-	3.11	tr
C22:6*n*-3	3.33	2.30	3.51	20.94	18.79

There was no significant difference concerning stearic acid (C18:0) content between the 3 species of microalgae ($p < 0.01$) except for *Spirulina* sample 2 (Table 2). Linoleic acid (C18: 2*n*-6)levels of *Spirulina* samples were high ($p < 0.01$), with a mean of 12.02% ($p < 0.01$) followed by *Chlorella* (9.73%).

Spirulina is a rich source of g-linolenic acid (C18:3*n*-6) (GLA) (the 1st 18:3 in Figure 2) with a mean of 4.59% ($p < 0.01$), then *Isochrisis* (0.54%). Alpha-linolenic acid (C18:3*n*-3)(ALA) content (the 2nd 18:3 in Figure 2) for *Spirulina* samples 1, 2, and 3 were 0.62%, 0.68%, and 0.71%, respectively, whereas *Chlorella* contained 1.93% and *Isochrisis* contained 0.46%. No significant differences of α-linolenic acid were seen in *Spirulina samples* 1, 2, and 3 ($p < 0.01$). *N*-3 polyunsaturated fatty acids (PUFAs), particularly linolenic acid which is a precursor for prostaglandin, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), exert beneficial effects on human health (Dyeberg 1986; Ricardo and Valenzula 2000; Simopoulos 2000).

The level of arachidonic acid (C20:4*n*-6) of *Isochrisis* was 1.07%, whereas *Spirulina* contained 0.34%, 0.35%, and 0.41%, respectively, and *Chlorella* contained trace amounts of C20:4*n*-6 ($p < 0.01$). EPA content (20:5*n*-3) of *Chlorella* (3.23%) was higher than EPA in *Spirulina* samples 1, 2, and 3 with 2.33%, 2.21%, and 2.91%, respectively. There was no significant difference in EPA levels between *Isochrisis spp.* 1, 2 and 3 ($p < 0.01$). *Isochrisis* contained *a* trace amount of docosapentaenoic acid (C22:5*n*-3), whereas *Spirulina* 1, 2 ,3 did not contain C22:5*n*-3. *Chlorella* had the highest content of docosapentaenoic acid (3.11%). Docosahexaenoic acid (DHA) (C22:6*n*-3) contents of *Chlorella* were extremely high (20.94%), followed by *Isochrisis* (18.79%)($p < 0.01$). *Spirulina* 1, 2, and 3 contained 3.33%, 2.30%, and 3.51% of DHA. The monounsaturated (MUFA), the polyunsaturated (PUFA), and saturated (SFA) fatty acid contents were calculated and total *n*-3/*n*-6 ratios; EPA/DHA ratios were also obtained as shown in Table 3.

Polyunsaturated fatty acid (PUFA) content of *Chlorella* was higher at 38.94% value ($p < 0.01$), followed by *Isochrisis* (24.41%) and *Spirulina* (avg. 23.57%) (Table 3, Figure 3A). There was no significant difference regarding PUFA contents between *Isochrisis* and *Spirulina* samples 1, 2,and 3 ($p < 0.01$). The total omega-3 (*n*-3) level of *Chlorella* was 29.21% and the high between these 3 species ($p < 0.01$), whereas *Spirulina* sam-

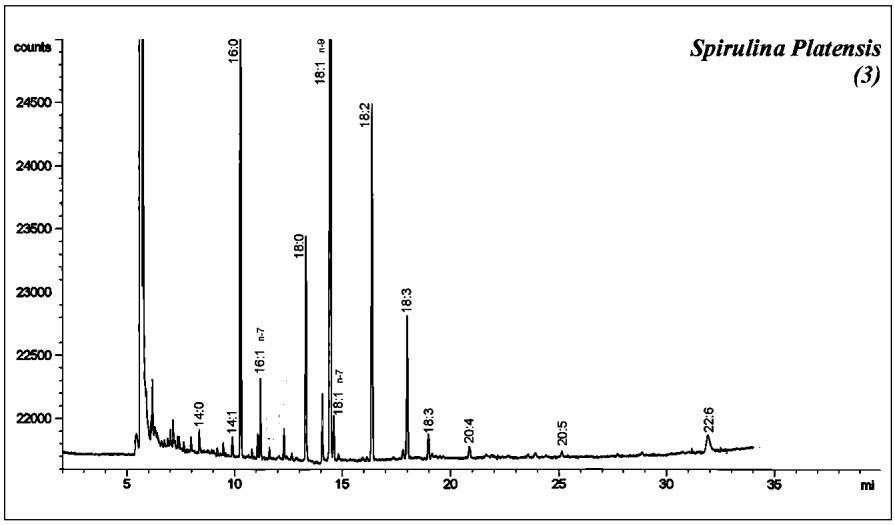

Figure 2—Gas chromatogram of fatty acid methyl esters of *Spirulina platensis*

ples 1, 2, and 3 contained an avg. 16.98% of total *n*-6, higher than other microalgaes types ($p < 0.01$). DHA/EPA proportion of *Isochrisis* was higher than the others (18.79%)($p < 0.01$).

Mineral data (mg/100g) is given in Table 4. *Spirulina* samples 1, 2, and 3 were rich in K (1412.9 mg), Na (929.4 mg), Ca (826.3 mg), P (750.7 mg), Mg (388.9 mg) as average. Average contents of other mineral elements were as follows for *Spirulina* samples: Fe (95.37 mg), Mn (4.29mg), Zn (2.68mg), Cu (0.31mg), Se (0.12 mg), Cr (0.11 mg), Cd (0.02 mg) ($p < 0.01$)(Table 4).

Chlorella was rich in P (1761.5 mg), Na (1346.4 mg), K (749.9 mg), Ca (593.7 mg), Mg (344.3 mg), and Fe (259.1 mg); other mineral contents included Mn (2.09 mg), Zn (1.19 mg), Se (0.07 mg), Cu (0.06 mg), and Cr (0.02mg), whereas Cd element was not detected ($p < 0.01$). *Isochrisis* was rich in P (1252.4 mg), K (1193.2 mg), Na (1109.2 mg), Ca (1081 mg), Mg (688.6 mg), and Fe (228.4 mg). The contents of other elements were Mn (5.69 mg), Zn (2.74 mg), Cu (1.49 mg), Se (1.02 mg), Cr (0.64 mg), and Cd (0.13 mg), respectively ($p < 0.01$) (Table 4).

Mineral element contents of 3 microalgae were sufficient to meet the recommended daily intakes for an adult. According to Recommended Dietary Allowances (RDA), the recommended daily intake of calcium (Ca) is 1000 mg/day for an adult male and an adult female, and 800 mg/day for children (4 to 8 y), whereas the RDA is 270 mg/day for infants (7 to 12 mo) (USDA 2002). A daily consumption of 92.5 g of *Isochrisis galbana* microalgae ($p < 0.01$) entirely meets the Ca needs for an adult (Table 4). The RDA of phosphorus (P) is 700 mg/day for an adult male and an adult female, 500 mg/day for children (4 to 8 y), and 275 mg/day for infants (7 to 12 mo) (USDA 2002). About 40 g of *Chlorella vulgaris* microalgae ($p < 0.01$) fulfills the RDA for phosphorus (P) (Table 4).

An amount of 142 g of *Spirulina platensis* microalgae ($p < 0.01$) meets the recommended daily allowance for potassium (K) for an adult; 42.5 g of this microalgae fulfills the RDA for infants (2000 mg/day for an adult and 1600 mg/day for children, whereas 500 to 700 mg/day for infants) (USDA 2002) and 37 g of *Chlorella vulgaris* ($p < 0.01$) microalgae meets the RDA for an adult (500 mg/day) (Table 4). A daily consumption of about 60 g and 47 g of *Isochrisis* ($p < 0.01$) fulfills the RDA for magnesium (Mg) for an adult male and adult female, respectively (420 mg and 320 mg per day), whereas about 11 g of this microalgae ($p < 0.01$) entirely meets the Mg needs for infants (75 mg/day) (USDA 2002).

Iron contents of 3 microalgae were sufficient for the recommended daily intakes for an adult. Daily consumption of about 4 g of *Chlorella vulgaris* ($p < 0.01$), about 4.5 g of *Isochrisis galbana* ($p < 0.01$), and 10.5 g of *Spirulina platensis* ($p < 0.01$) (Table 4) meets the recommended daily intakes for iron (Fe) for adult males, children, and infants (10 mg), whereas about 5.8 mg/day of *Chlorella vulgaris,* about 6.6 g/day of *Isochrisis galbana,* and 15.7 g/day of *Spirulina platensis* (Table 4) fulfills the RDA of Fe for an adult female (15 mg) (USDA 2002).

Isochrisis is rich in selenium (Se) and manganese (Mn) (Table 4). Daily consumption of about 6.86 g of *Isochrisis galbana* ($p < 0.01$) fulfills the RDA for Se for an adult male (70 μg), whereas 58.3 g/day of *Spirulina platensis* ($p < 0.01$) and 100 g/day of *Chlorella vulgaris* ($p < 0.01$) meets *the* RDA for Se for an adult male (USDA 2002). According to Recommended Dietary Allowances (RDA), recommended daily intake of Se is 55 μg/day for an adult female, 30 μg/day for children (4 to 8 y), and 15 μg/day for infants (7 to 12 mo) (USDA 2002). About 52.7 mg/day of *Isochrisis* ($p < 0.01$) also meets RDA for Mn for both adults and children (USDA 2002).

Heavy metals (Pb, Cd) were lower than the recommended values ($p < 0.01$) for 3 microalgae and were Pb<0.02 mg, Cd<0.02 mg ($p < 0.01$). It was found that < 0.05 mg of arsenic (As) was contained in 3 microalgae ($p < 0.01$). There is evidence that As may be beneficial to the human body and may have a role in the metabolism of methionine and in the regulation of gene expression (Anon 2002).

Spirulina has been used in salads, soups, and dip foods in Turkey's food sector. Further study concerning utilization of 3 microalgae in infant formulas, popcorn, spice mixtures, fruit juice mix, potato chips, smoothies made with apples and blueberries, dilled beans, macaroni, and avocado dressing is in progress. Moreover, further study regarding nutrient profiles of *Spirulina platensis*, *Chlorella vulgaris,* and *Isochrisis galbana* in different steady state culture characteristics is in progress.

This study reported nutrient profiles of 3 microalgae: *Spirulina platensis*, *Chlorella vulgaris,* and *Isochrisis galbana.* Above-mentioned microalgae are good potentials to human nutrition due to their high protein content, the presence of polyunsaturated fatty acids (PUFA), and sufficient mineral composition. These microalgae could be an important food additive. This study is a step towards objective determination for microalgae utilization in the food industry.

Table 3—SFA, MUFA, PUFA , total ω-3, total ω-6, and calculated results as percent of total lipid

	Spirulina 1	Spirulina 2	Spirulina 3	Chlorella	Isochrisis
Σ SFA	34.09	35.89	34.26	22.22	43.33
Σ MUFA	36.40	39.10	39.29	35.44	29.99
Σ PUFA	22.30	24.20	25.12	38.94	24.41
Σ ω-3	6.99	5.76	7.94	29.21	21.66
Σ ω-6	15.31	18.44	17.18	9.73	2.75
Σ *n*-3/*n*-6	0.46	0.31	0.46	3.00	7.87
DHA/EPA	3.33	2.30	3.51	6.73	18.79

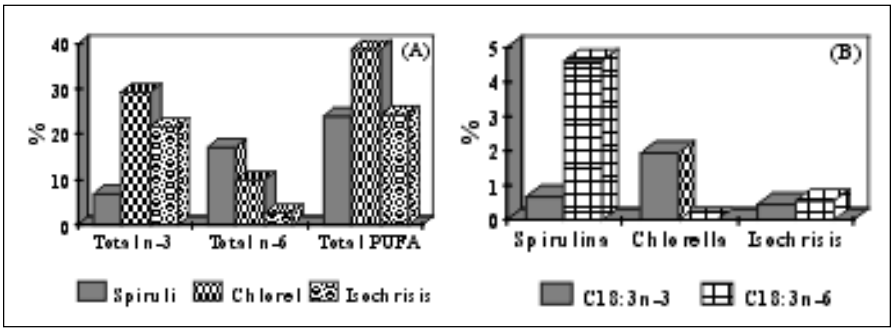

Figure 3—(A) Total *n*-3 and *n*-6 levels of 3 microalgae, (B) γ and α linolenic acid contents of these microalgae

Conclusions

NUTRITIONAL COMPOSITION OF *SPIRULINA platensis, Chlorella vulgaris,* and *Isochrisis galbana* cultures were determined. Data obtained include the proximate composition (moisture, ash, crude protein, available

Table 4—Mineral element content in 3 microalgae samples as mg/100g dry weight (mean ± S.D.)

Sample	Na	K	Ca	Mg	Fe	Cd	Cr	Cu	Zn	Mn	Se	P
Spirulina 1	1897.3 ± 0.04	1326.9 ± 0.02	883 ± 0.09	398.6 ± 0.01	90.1 ± 0.01	0.02 ± 0.04	0.09 ±0.01	0.32 ±0.06	2.45 ± 0.02	3.84 ± 0.08	3.6800	703.4 ± 0.03
Spirulina 2	988.6 ± 0.04	1504 ± 0.05	893 ± 0.11	368.3 ± 0.06	92.4 ± 0.02	0.02 ± 0.02	0.09 ±0.02	0.49 ±0.01	2.57 ± 0.06	3.80 ± 0.03	0.13 ±0.04	746 ± 0.05
Spirulina 3	902.3 ± 0.02	1408 ± 0.04	703 ± 0.04	399.7 ± 0.09	103.6 ± 0.14	0.01 ± 0.05	0.15 ±0.05	0.12 ±0.21	3.01 ± 0.04	5.23 ± 0.08	0.11 ±0.02	802.7 ± 0.02
Chlorella	1346.4 ± 0.177	49.92 ± 0.09	593.7 ± 0.07	344.3 ± 0.12	259.1 ± 0.04	ND	0.02 ±0.01	0.06 ±0.10	1.19 ± 0.07	2.09 ± 0.15	0.07 ±0.03	1761.5 ± 0.02
Isochrisis	1109.2 ± 0.04	1193.2 ± 0.09	1081 ± 0.06	688.60 ± 0.1	228.4 ± 0.04	0.13 ± 0.01	0.64 ±0.03	1.49 ±0.14	2.74 ± 0.05	5.69 ± 0.02	1.02 ±0.09	1252.4 ± 0.13

carbohydrates, total lipids); energy value; mineral elements (Na, K, Ca, Mg, Fe, P, Zn, Mn, Se, Cd, Cr, Cu, Pb, As); and fatty acid (FA) composition. C14:0, C14:1, C16:0, C16:1*n*-7, C18:0, C18:1*n*-9, C18:1*n*-7, C18:2*n*-6, C18:3*n*-6, C18:3*n*-3, C18:4*n*-3, C20:0, C20:4*n*-3,C20:5*n*-3, C22:5*n*-3, and C22:6*n*-3 of these microalgae were obtained as a percentage of total fat. *Spirulina* samples contained high amounts of protein (avg. 63.0%) ($p < 0.01$), whereas *Isochrisis* had the highest ash content (16.08%) ($p < 0.01$). *Spirulina* is a rich source of g-linolenic acid (C18:3*n*-6) (GLA), whereas *Chlorella* was an good source of polyunsaturated fatty acids (PUFAs) (38.94%) ($p < 0.01$). Mineral element contents have shown that *Spirulina platensis* is a rich source of K (1413.0 mg) ($p < 0.01$), whereas *Chlorella vulgaris* is rich in P (1761.5) ($p < 0.01$), and *Isochrisis galbana* is an important source of Ca (1081.0 mg) ($p < 0.01$) and Mg (688.6 mg) ($p < 0.01$) as major minerals. *Isochrisis* also contained high content of Se (1.02 mg) ($p < 0.01$).

This study is a step towards the objective determination of nutrients in 3 microalgae for utilization in the food industry.

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