4. Conclusions

The results of this study demonstrate that enzymatic treatment of microalgal cells can be a promising alternative to conventional methods of lipid extraction. In particular, we have shown that very high lipid recovery can be achieved by proper selection of process conditions. The high cost of enzymes, which is one of the major obstacles to the large-scale implementation of these treatments, can be at least partly overcome by using mixtures of commercial enzyme preparations. In this regard, enzymes already proven to be effective in the recovery of bioactives from plant material should be tested at first (Zuorro et al., 2014a).
Future research should focus on the development of optimal enzyme cocktails based on the cell-wall composition of the algal species of interest. The possible recovery and reuse of the enzyme solution is another important issue to be investigated in future studies.

Acknowledgements

We are grateful to Prof. Mario Tredici and Dr. Liliana Rodolfi of the University of Firenze (Dipartimento di Scienze delle Produzioni Agroalimentari e dell'Ambiente) for the kind gift of *Nannochloropsis* sample.

References

Biondi N., Bassi N., Zittelli G.C., Faveri D.D., Giovannini A., Rodolfi L., Allevi C., Macrì C., Tredici M.R., 2013, Nannochloropsis sp. FandM-M24: Oil production, effect of mixing on productivity and growth in an industrial wastewater, Environ. Prog. Sustain. Energy, 32, 846-853.

Bondioli P., Della Bella L., Rivolta G., Chini Zittelli G., Bassi N., Rodolfi L., Casini D., Prussi M., Chiaramonti D., Tredici M.R., 2012, Oil production by the marine microalgae Nannochloropsis sp. F&M-M24 and Tetraselmis suecica F&M-M33, Bioresour. Technol., 114, 567-572.

Boom A., Sinninghe Damsté J.S., de Leeuw J.W., 2005, Cutan, a common aliphatic biopolymer in cuticles of drought-adapted plants, Org. Geochem., 36, 595-601.

Chabrand R.M., Glatz C.E., 2009, Destabilization of the emulsionformed during the enzyme-assisted aqueous extraction of oil fromsoybean flour, Enzyme Microb. Technol., 45, 28–35.

Gerken H.G., Donohoe B., Knoshaug E.P., 2013. Enzymatic cell wall degradation of Chlorella vulgaris and other microalgae for biofuels production, Planta, 237, 239-253.

Lam M.K., Lee K.T., 2012, Microalgae biofuels: A critical review of issues, problems and the way forward, Biotechnol. Adv., 30, 673-690.

Lee A.K., Lewis D.M., Ashman P.J., 2012, Disruption of microalgal cells for the extraction of lipids for biofuels: Processes and specific energy requirements, Biomass Bioenerg., 46, 89–101.

Leu S., Boussiba S., 2014, Advances in the production of high value products by microalgae, Ind. Biotechnol., 10, 169-183.

Liang K., Zhang, Q. Cong W., 2012. Enzyme-assisted aqueous extraction of lipid from microalgae, J. Agric. Food Chem., 60, 11771-11776.

Ma Y., Wang Z., Zhu M., Yu C., Cao Y., Zhang D., Zhou G., 2013, Increased lipid productivity and TAG content in Nannochloropsis by heavy-ion irradiation mutagenesis, Bioresour. Technol., 136, 360-367.

Makareviciene V., Skorupskaite V., Andruleviciute V., 2013, Biodiesel fuel from microalgae-promising alternative fuel for the future: A review, Rev. Environ. Sci. Biotechnol., 2, 119130.

Montgomery D.C., 2012, Design and Analysis of Experiments 8th Ed., Wiley, New York, USA.

Perin G., Segalla A., Basso S., Simionato D., Meneghesso A., Sforza E., Bertucco A., Morosinotto, T., 2014, Biotechnological optimization of light use efficiency in Nannochloropsis cultures for biodiesel production, Chemical Engineering Transactions, 37, 763-768, DOI: 10.3303/CET1437128

Vidotti A.D.S., Coelho R.S., Franco L.M., Franco T.T., 2014, Miniaturized culture for heterotrophic microalgae using low cost carbon sources as a tool to isolate fast and economical strains, Chemical Engineering Transactions, 38, 325-330, DOI: 10.3303/CET1438055

Wu J., Johnson L.A., Jung S., 2009, Demulsification of oil-rich emulsion from enzyme-assisted aqueous extraction of extruded soybean flakes, Bioresour. Technol., 100, 527-533.

Zuorro A., 2014, Response surface methodology analysis of polyphenol recovery from artichoke waste, Am. J. Appl. Sci., 11, 1463–1471.

Zuorro A., Lavecchia R., Medici F., Piga L., 2014a, Use of cell wall degrading enzymes for the production of high-quality functional products from tomato processing waste, Chemical Engineering Transactions, 38, 355-360, DOI: 10.3303/CET1438060

Zuorro A., Maffei G., Lavecchia R., 2014b, Effect of solvent type and extraction conditions on the recovery of phenolic compounds from artichoke waste, Chemical Engineering Transactions, 39, 463-468, DOI: 10.3303/CET1439078