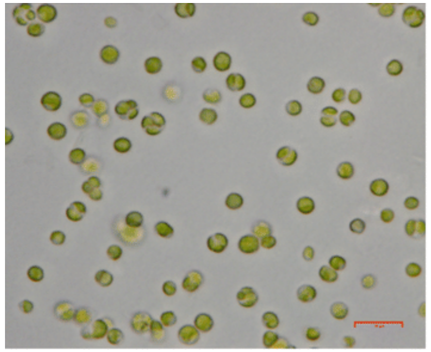
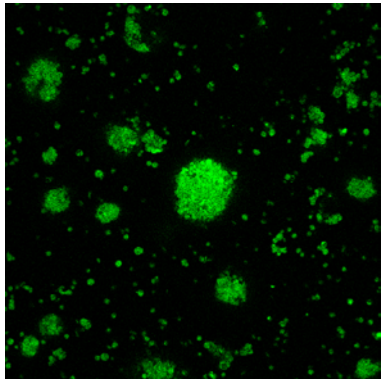
Galactolipids from microalgae as a new source of omega 3 and naturally structured surfactants for human nutrition

Jeanne Kergomard, Nathalie Barouh, Frédéric Carrière, Pierre Villeneuve, Claire Vigor, Thierry Durand, Pierre Emmanuel Millet, Maeva Subileau, Véronique Vié, Claire Bourlieu-Lacanal

Galactolipids from microalgae as a new source of omega 3 and naturally structured surfactants for human nutrition





Jeanne Kergomard, Nathalie Barouh, Frédéric Carrière, Pierre Villeneuve,
Claire Vigor, Thierry Durand, Pierre Emmanuel Millet, Maeva Subileau*#, Véronique Vié*# and Claire Bourlieu*#
*claire.bourlieu-lacanal@inrae.fr, maeva.subileau@inrae.fr, veronique.vie@univ-rennes1.fr
#*authors contributed equally to the work*

CONTEXT

- ✓ Global spread of obesity, overweight and diet-related chronic diseases with its burden of comortalities. How can we turn the tide off ?

https://www.fda.gov/news-events/fda-voices/improving-nutrition-turn-tide-diet-related-chronic-disease

→ cardiovascular diseases (17.9 million deaths globally/y), cancers (9 million deaths/y), and diabetes (1.6 million deaths/y) (WHO, 2019)

- ✓ Global picture but lipid nutrition matters (35-40 % TEI)

Fatty acids	RDA* (% TEI)		% TFA*
Essential	LA (C18:2, ω6)	4 %	10-12 %
	ALA (C18:3, ω3)	1 %	2.5-3 %
	Docosahexaenoic acid, DHA (C22:6 ω3)	250 mg	
Non essential	Eicosapentaenoic acid, EPA (C20:5 ω3)	250 mg	
	Lauric + myristic + palmitic FA	≤ 8 %	**20-23 %**
	Total saturated FA	**≤12 %**	**30-34 %**
	Oleic FA (C18:1, ω9)	15-20 %	38-50 %

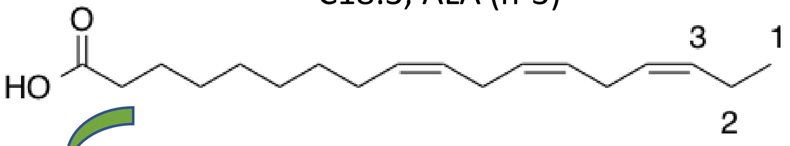
**RDA = Recommended Dietary allowances, TEI=Total energy intake, TFA=total fatty acids of lipid source*

(ANSES 2010 recommandations)

CONTEXT

Omega-3

α-linolenic acid (1%/d)
C18:3, ALA (n-3)



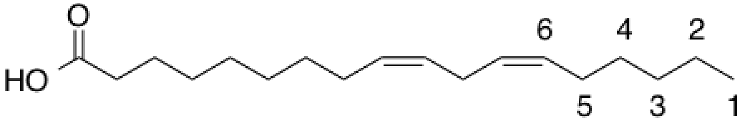
EPA (C20:5), DHA (C22:6) (250 mg/d)

ω6/ω3=4

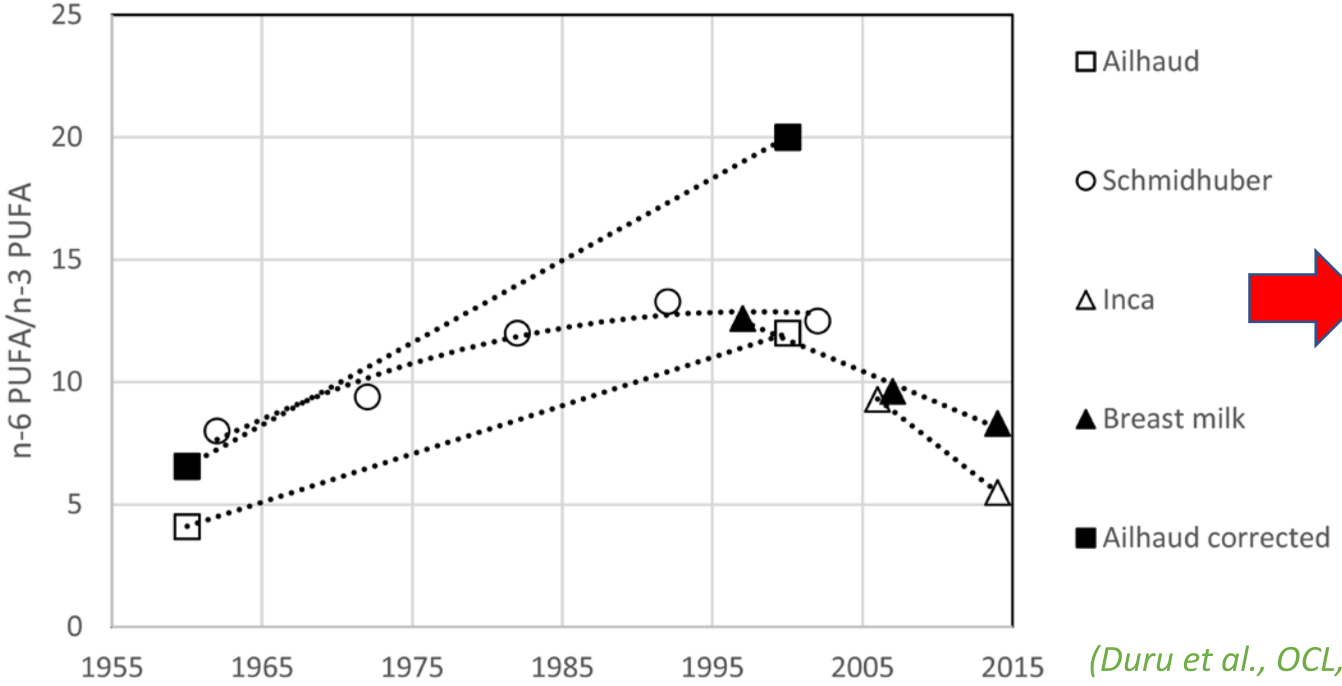
(ANSES 2010 recommandations)

Omega-6

Linoleic acid (4%/d)
C18:2, LA (n-6)



AA (C20:4)…C22:5



(Duru et al., OCL, 2019)

- ✓ Balancing our lipid intake by regulating our intake of omega-6 fatty acids and increasing our intake of omega-3 fatty acids = strong nutritional recommendation from the WHO
- ✓ Unbalanced diets (excess omega-6) promote the onset of chronic inflammatory diseases
- ✓ High imbalance in **ω6/ω3** ratio, still very strong in infants and adolescents *(INCA3; Chuy et al., Chevreul Congress 2023; Simopoulos, Biomed. Pharmacol., 2002)*

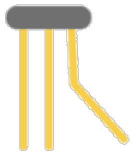
CONTEXT

✓ To rebalance intakes what are the sources that can be used in nutritional strategies ?

Seeds and nuts rich **ω3 precursors – main molecular form TAG >> PL**

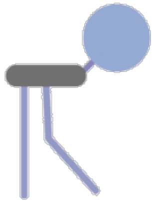
Fish and marine resources rich **ω3 VLCPUFA – main molecular form TAG >>PL**

Photosynthetic vegetals from marine or terrestrial sources



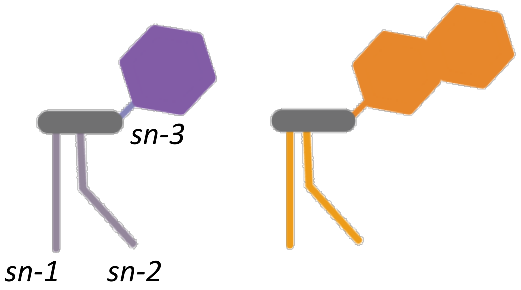
Triacylglycerols (TAG)

80 g/d



Phospholipids (PL)

2-10 g/d



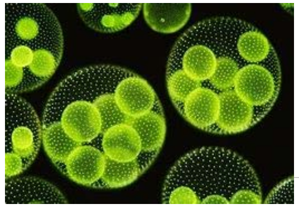
Galactolipids (PL)

0.2 g/d

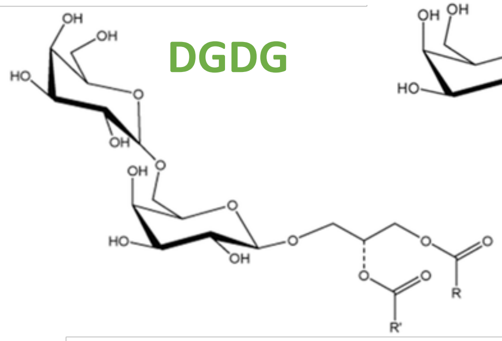
(Cohn & al., Nutrients, 2010; Sahaka et al., Food & Function, 2020)

CONTEXT

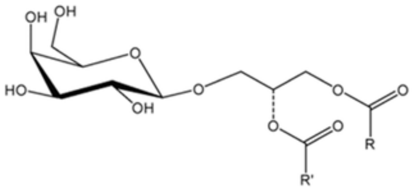
✓ In some microalgae, fatty acids present under specific molecular forms: glycolipids



DGDG



MGDG



With R,R'=$(CH_2)_n$-CH_3

Digested by specific enzymes (pancreatic lipase related type 2 (PLRP2) or cholesterol ester hydrolase (CEH) and not by human pancreatic lipase (HPL)

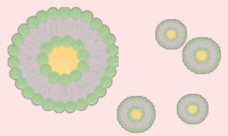
When structured under form of thylakoid membrane => inactivation of pancreatic lipase and weight loss

(Köhnke et al., Scand. J. Gastrol., 2009; Köhnke et al., Phytotherapy Res., 2009; Tabrizi & Farhangi, FRI, 2021)

(Kergomard et al. CRFSN 2021; Sahaka et al. Food Funct. 2020; Vors et al., Cur Op Clin Nutr Metab Care 2020)

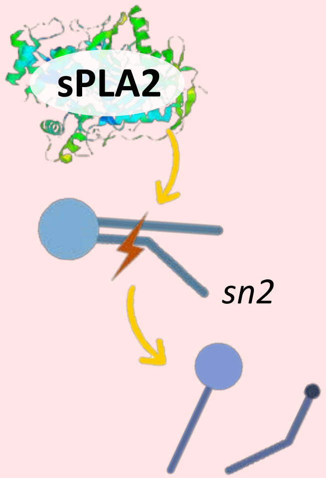
Gastric compartment
Aggregated but stable

Membrane fragments
(Thylakoïds)



Intestinal compartment
Polar lipid hydrolysis

Phospholipids

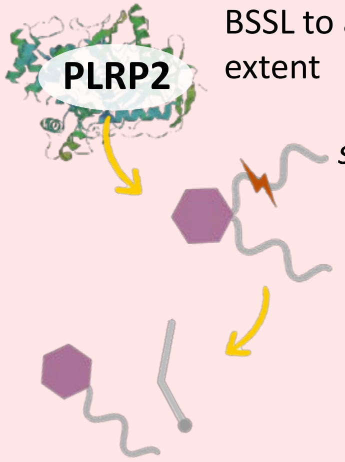


LysoPL + FFA

Latency in HPL lipolysis

(Beisson et al., BBA, 2001)

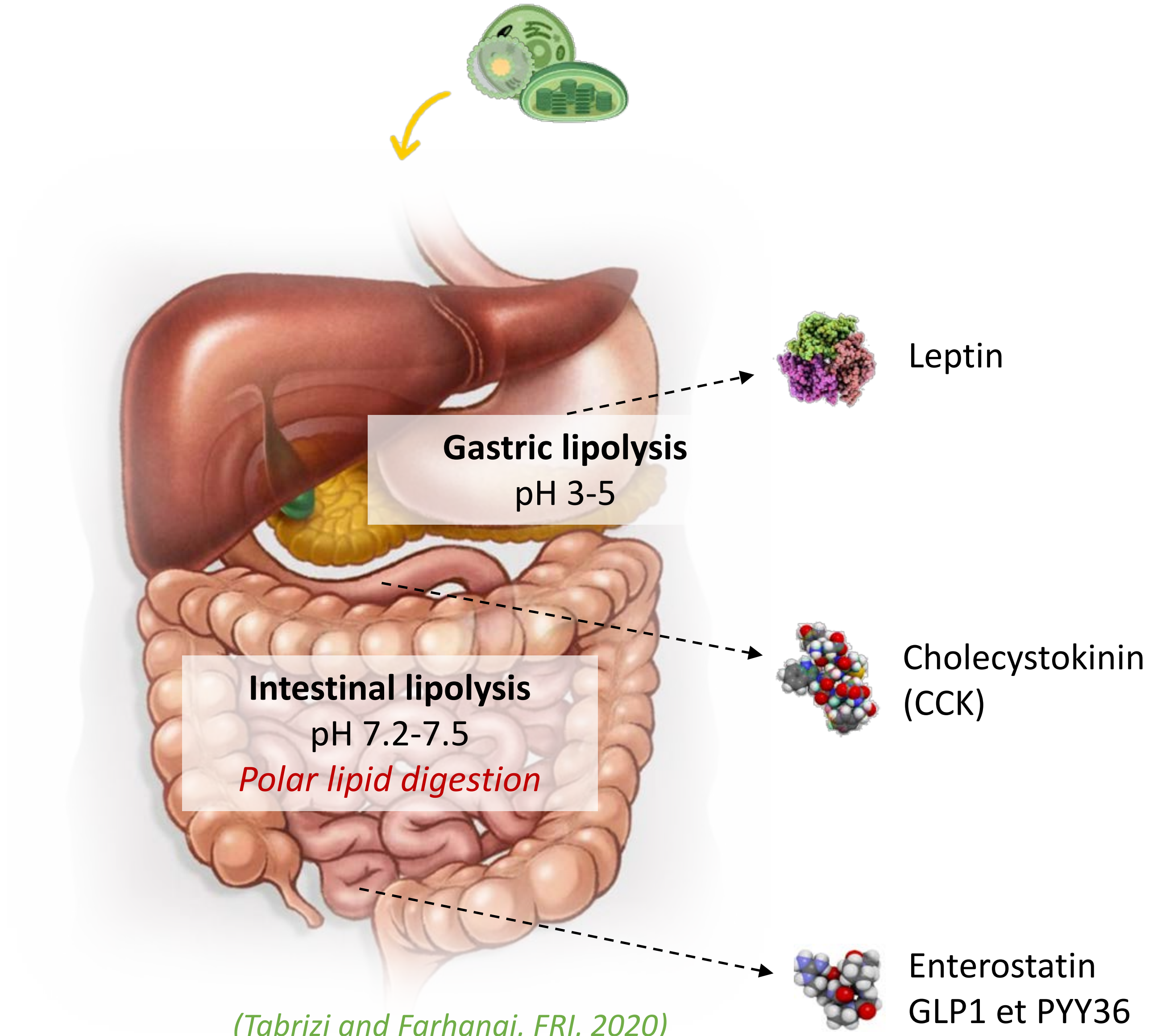
Galactolipids



MGMG/DGMG + FFA
MGDG > DGDG
(Amara et al., BBA, 2010)

Reduction of digestion and TAG absorption

(Stenkula et al., Nutr Metab, 2017)



(Tabrizi and Farhangi, FRI, 2020)

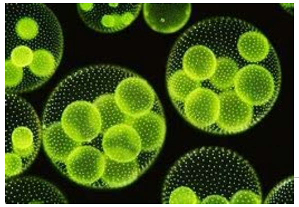
↗ satiety hormones

Ab: Pancreatic phospholipase A2 (sPLA2), Colipase-dependent pancreatic lipase (HPL), Pancreatic lipase related protein 2 (PLRP2), BSSL : bile salt stimulated lipase, DGDG: digalactosyldiacylglycerol, DGMG: digalactosylmonoacylglycerol, FFA: free fatty acids, MGDG: monogalactosyldiacylglycerol, MGMG: monogalactosylmonoacylglycerol, lysoPL: lysophospholipids

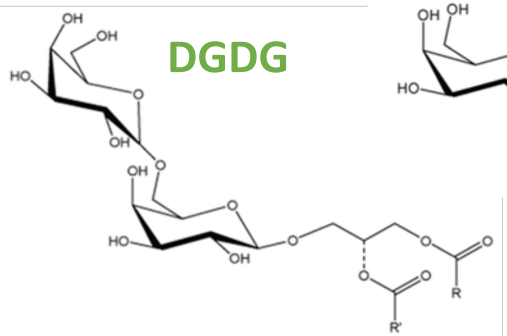
CONTEXT

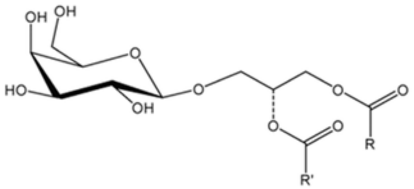
✓ In some microalgae, fatty acids present under specific molecular forms: glycolipids

MGDG



DGDG





With $R,R'=(CH_2)n\text{-}CH_3$

Digested by specific enzymes (pancreatic lipase related type 2 (PLRP2) or cholesterol ester hydrolase (CEH) and not by human pancreatic lipase (HPL)

When structured under form of thylakoid membrane => inactivation of pancreatic lipase and weight loss

(Köhnke et al., Scand. J. Gastrol., 2009; Köhnke et al., Phytotherapy Res., 2009; Fard Tabrizi & Abbasalizad Farhangi, FRI, 2021)

Antioxidant – DGDG > MGDG > TAG

(Yamaguchi et al., J. Oleo Sci., 2012; Hazahari, et al., Food Nutr. Sci., 2018)

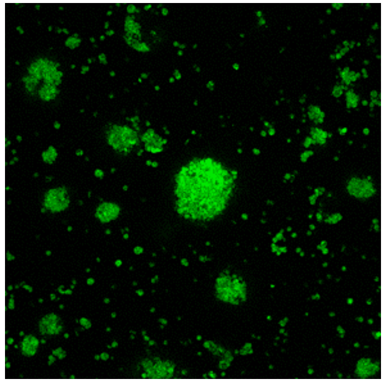
Natural surfactants

(Kergomard et al. CRFSN 2021; Sahaka et al. Food Funct. 2020; Vors et al., Cur Op Clin Nutr Metab Care 2020)

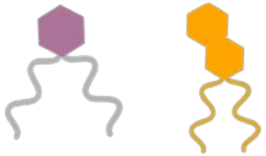
OUTLINE OF THE PRESENTATION

1) Nutritional interest of microalgae lipids

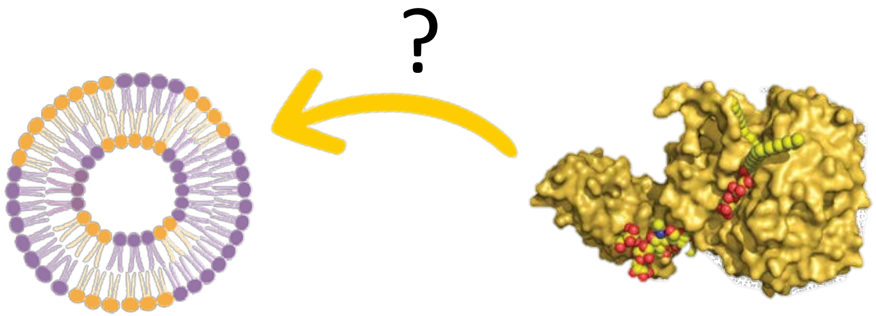
- content in omega 3 and its plasticity
- content in galactolipids
- potential presence of oxylipins



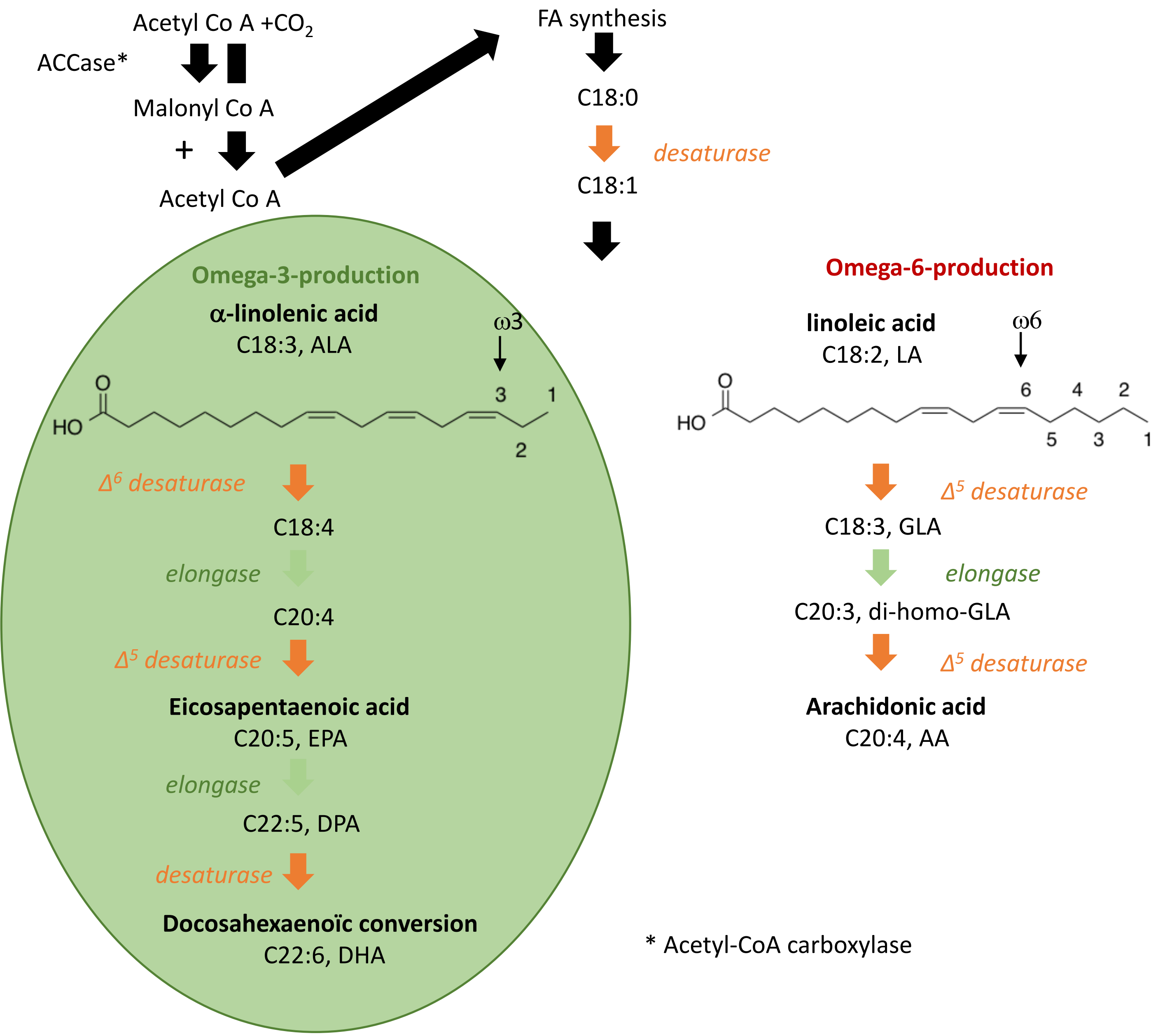
2) Interfacial behaviour of microalgae lipids



3) Digestion of microalgae galactolipids



1) Nutritional interest of microalgae lipids

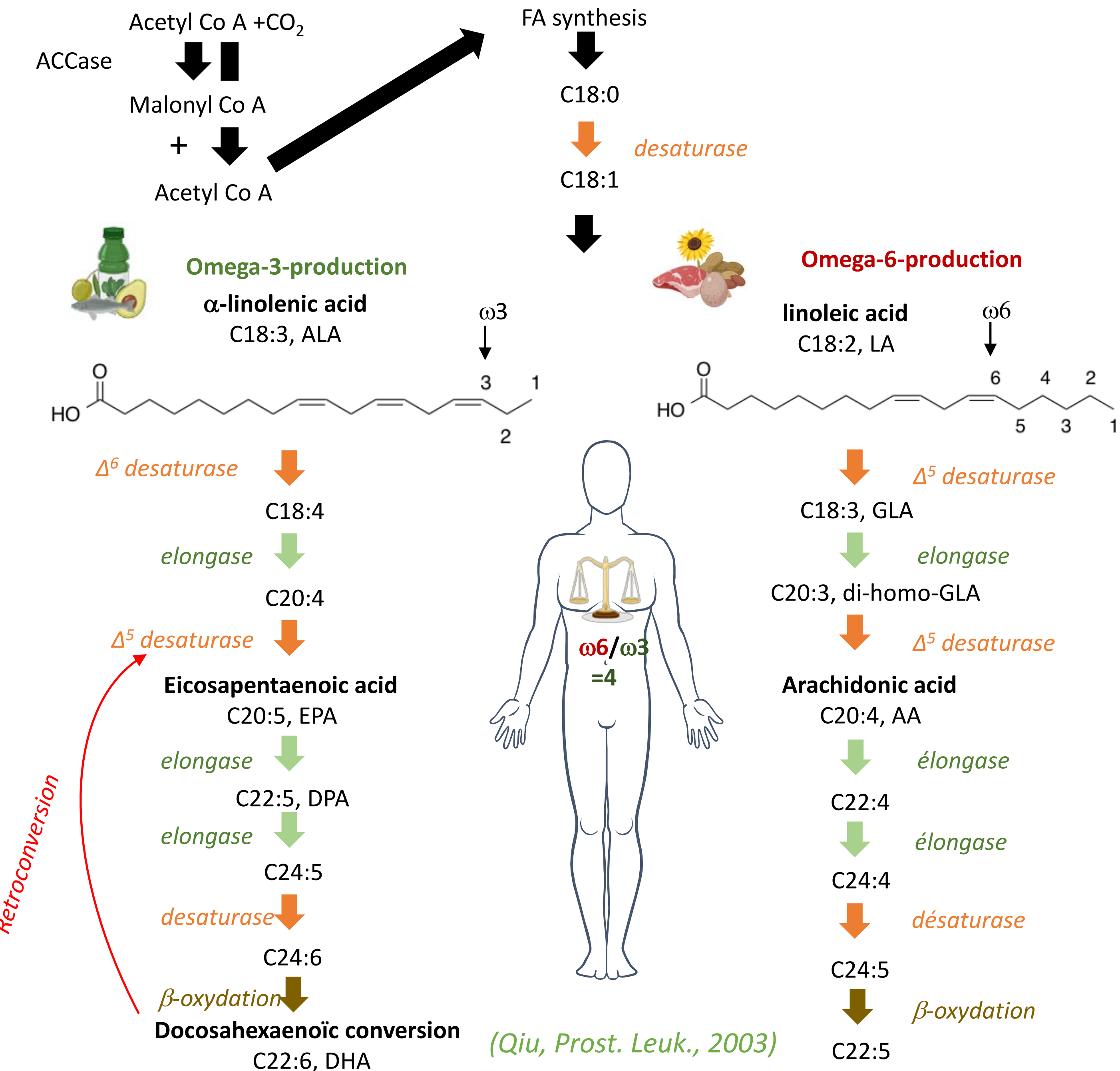


* Acetyl-CoA carboxylase

	PUFA (% wof total FA)			
	AA	ALA	EPA	DHA
Isochrysis galbana	0.7	1.2	22.6	8.4
Phaeodactylum tricornutum	3.4	0.6	29.8	0.8
Porphyridium cruentum	23	1.0	23.9	0.2
Crypthecodinium chnii	-	-	-	51.12
Schizochytrium sp.	--	-	-	25-50
Aurantiochytrium sp.	-	-	-	23-64
Nitzschia sp.	-	-	*16-23*	-
Cod liver oil	**2.7**	**0.8**	**12.5**	**9.2**
Tuna oil	**0.92**	**-**	**7.81**	**24.56**
Shark liver oil	**0.05**	**-**	**0.05**	**0.28**
Soft-shell turtle oil	**0.64**	**-**	**0.19**	**0.42**
Lemuru oil	**2.00**	**-**	**14.36**	**4.60**
Flaxseed, whole, (1 tbsp)	**2.35 g/serving**	**-**	**-**	**-**
English walnuts (1oz)	**2.57 g/serving**	**-**	**-**	

(Katiyar et Arora, Algal Res., 2020)

1) Nutritional interest of microalgae lipids

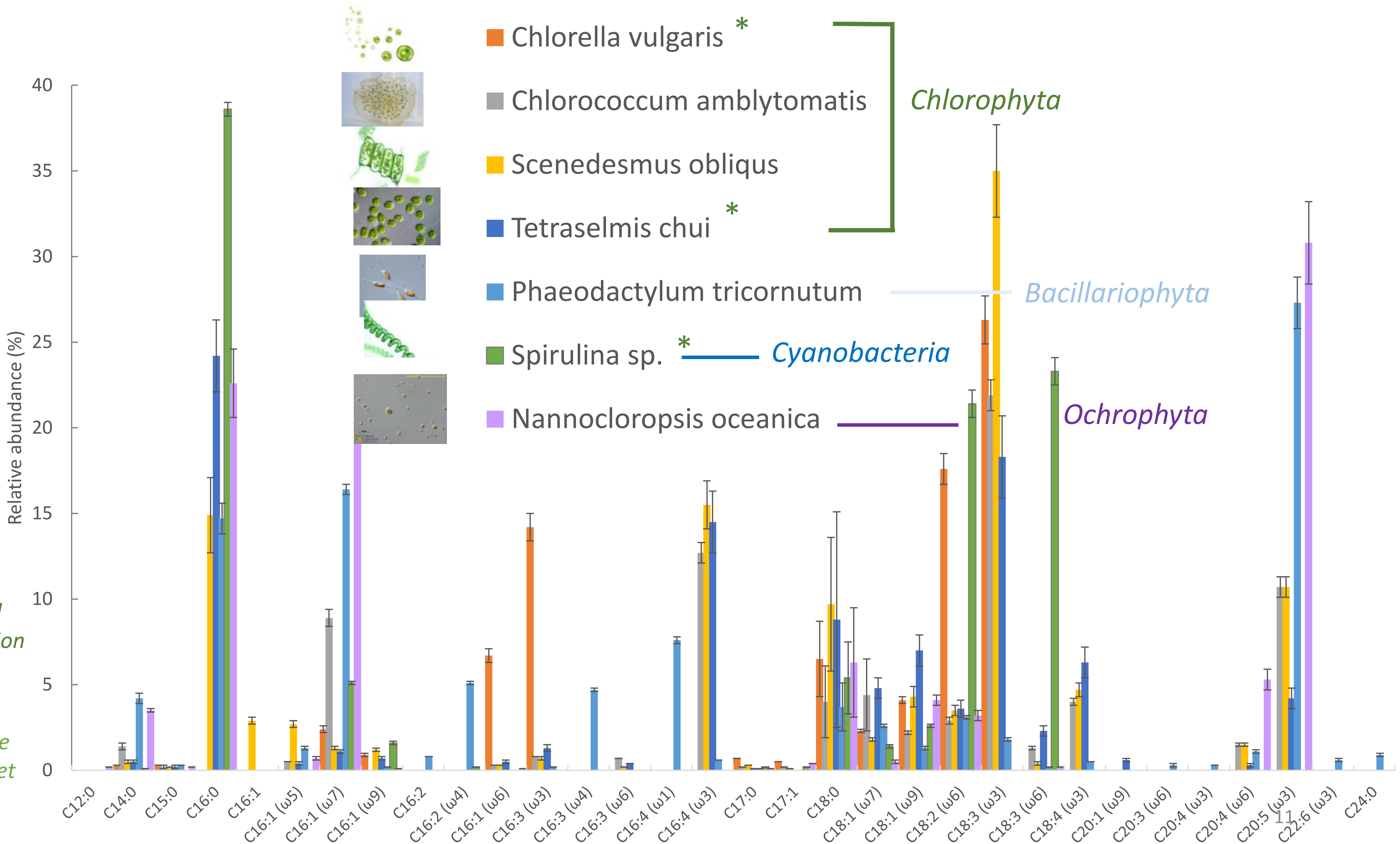


(Qiu, Prost. Leuk., 2003)

	PUFA (% wof total FA)			
	AA	ALA	EPA	DHA
Isochrysis galbana	0.7	1.2	22.6	8.4
Phaeodactylum tricornutum	3.4	0.6	29.8	0.8
Porphyridium cruentum	23	1.0	23.9	0.2
Crypthecodinium chnii	-	-	-	51.12
Schizochytrium sp.	--	-	-	25-50
Aurantiochytrium sp.	-	-	-	23-64
Nitzschia sp.	-	-	*16-23*	-
Cod liver oil	**2.7**	**0.8**	**12.5**	**9.2**
Tuna oil	**0.92**	**-**	**7.81**	**24.56**
Shark liver oil	**0.05**	**-**	**0.05**	**0.28**
Soft-shell turtle oil	**0.64**	**-**	**0.19**	**0.42**
Lemuru oil	**2.00**	**-**	**14.36**	**4.60**
Flaxseed, whole, (1 tbsp)	**2.35** g/serving	**-**	**-**	**-**
English walnuts (1oz)	**2.57** g/serving	**-**	**-**	

(Katiyar et Arora, Algal Res., 2020)

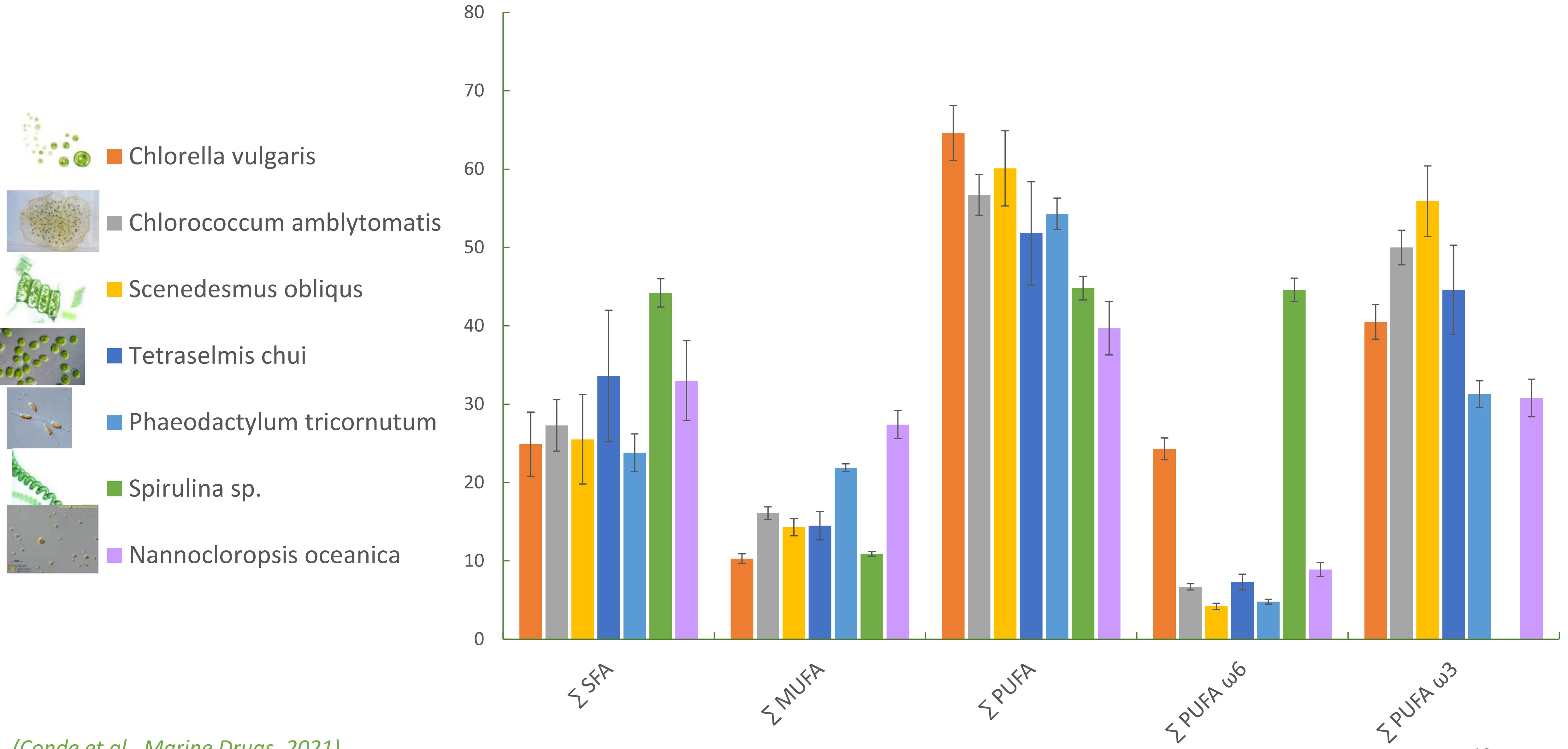
1) Nutritional interest of microalgae lipids



*food grade approval for human consumption

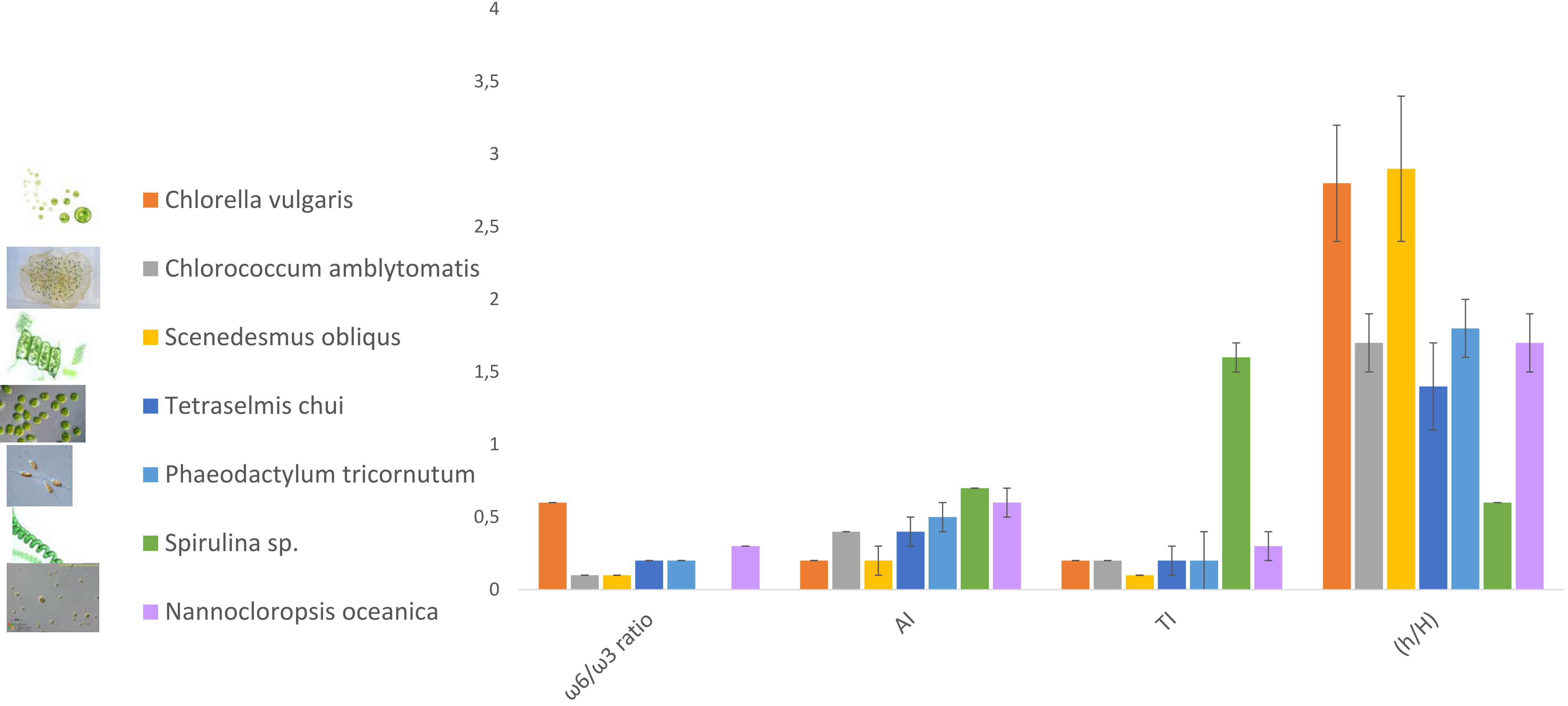
(Conde et al., Marine Drugs, 2021; Jeong et al., BMC Plant Biol., 2011)

1) Nutritional interest of microalgae lipids



(Conde et al., Marine Drugs, 2021)

1) Nutritional interest of microalgae lipids



(Conde et al., Marine Drugs, 2021)

Ab: AI=atherogenic index, TI= thrombotic index, h/H= hypo/hypercholesterolemic index *(Ulbricht and Southgate, Lancet, 1991)*

$$AI = \frac{[C12:0 + 4] \times [(C14:0) + C16:0]}{[\sum MUFA + \sum(n-6) + \sum(n-3)]}$$

Coconut oil AI=14, TI=6, Olive oil AI=0.14, TI=0.32, sunflower oil AI=0.07, TI=0.28, butter AI=2.03, TI=2.07

$$TI = \frac{[C14:0 + C16:0 + C18:0]}{[0.5 \times \sum MUFA + 0.5 \times \sum(n-6) + 3 \times \sum(n-3) + (\frac{\sum(n-6)}{\sum(n-3)})]}$$

$$(h/H) = \frac{[C18:1(\omega-9) + 18:2(\omega-6) + 18:3(\omega-3) + C20:4(\omega-6) + C20:5(\omega-3)]}{[C14:0 + C16:0]}$$

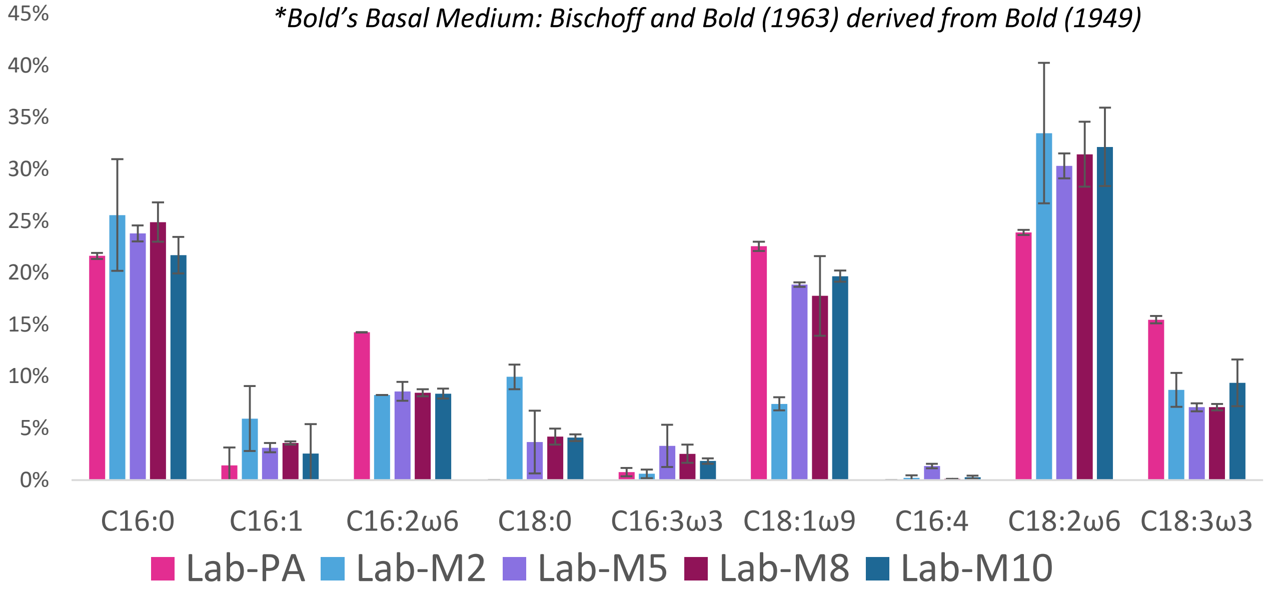
1) Nutritional interest of microalgae lipids

✓Plasticity of FA profiles and molecules on which these FA are esterified

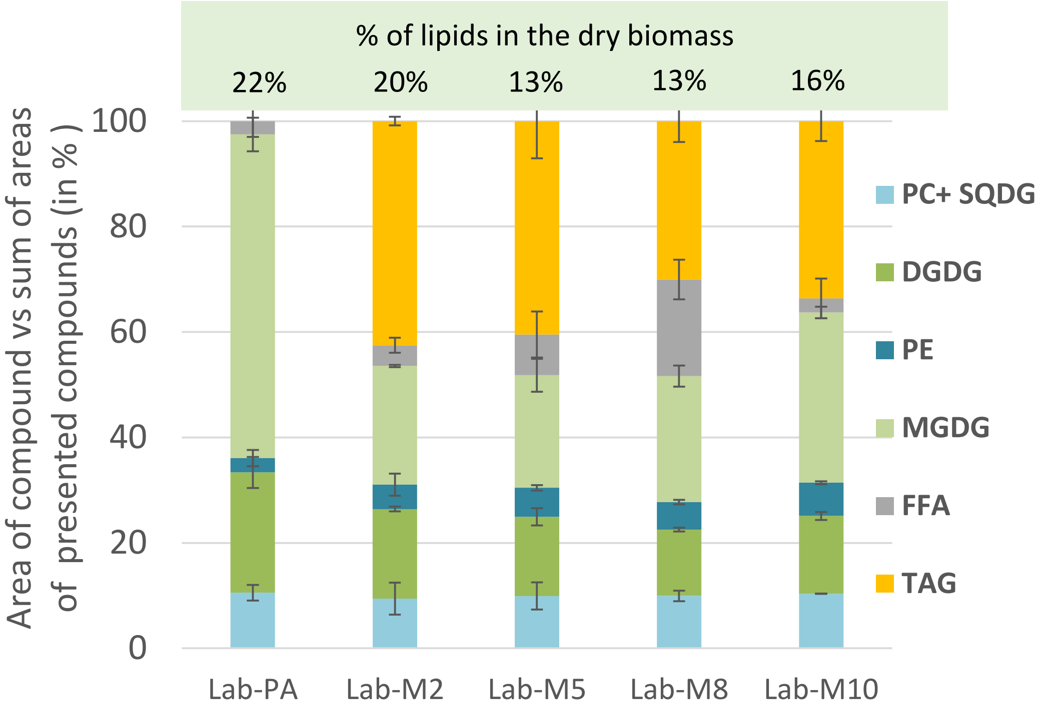
Trophic mode	[Glucose] (g/L added to BBM*)	% lipids in the dry biomass	Abbreviation	ω6/ω3
Photo-autotrophy	0	22	Lab-PA	2.4
Mixotrophy	2	20	Lab-M2	4.5
Mixotrophy	5	13	Lab-M5	3.8
Mixotrophy	8	13	Lab-M8	4.2
Mixotrophy	10	16	Lab-M10	3.6

**Bold's Basal Medium: Bischoff and Bold (1963) derived from Bold (1949)*

Visual aspect of in-lab cultivated Chlorella Sorokiniana



Fatty acid profiles of in-lab cultivated Chlorella



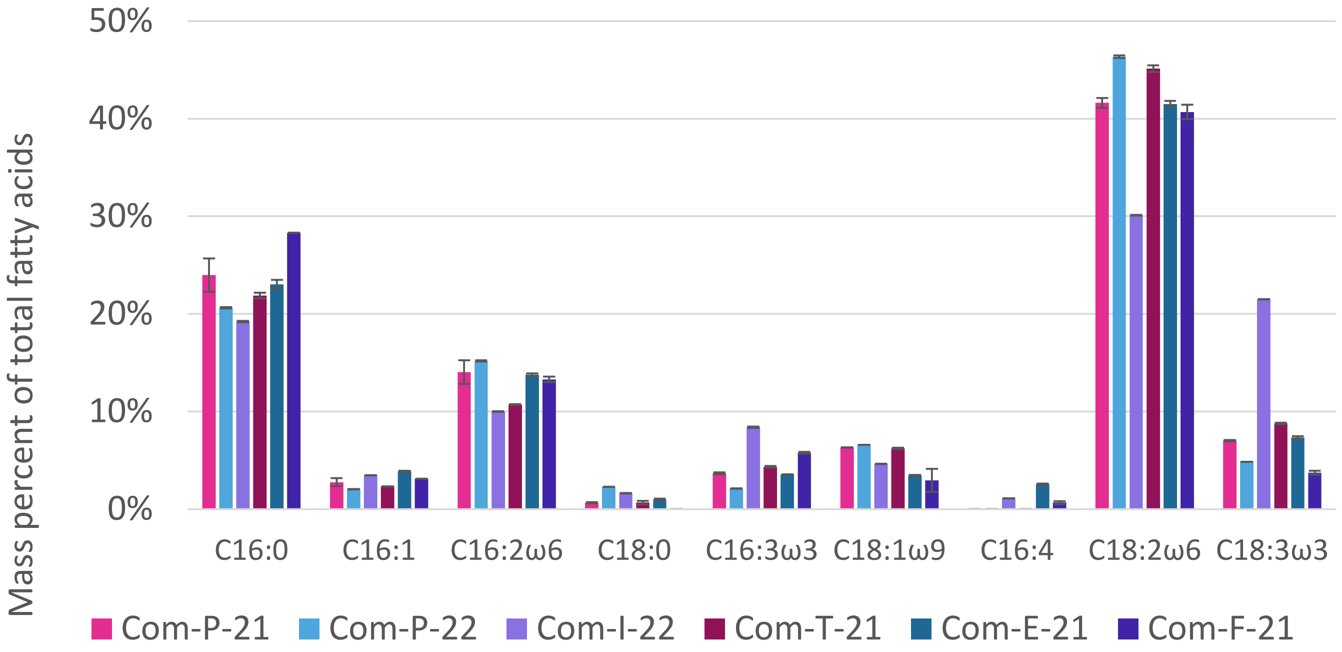
Lipid composition (%) of in-lab cultivated Chlorella

(Wind, Master 2, 2021; Barouh et al., Chevreul Congress 2023, Paris; Couto et al., Algal Res. 2020)

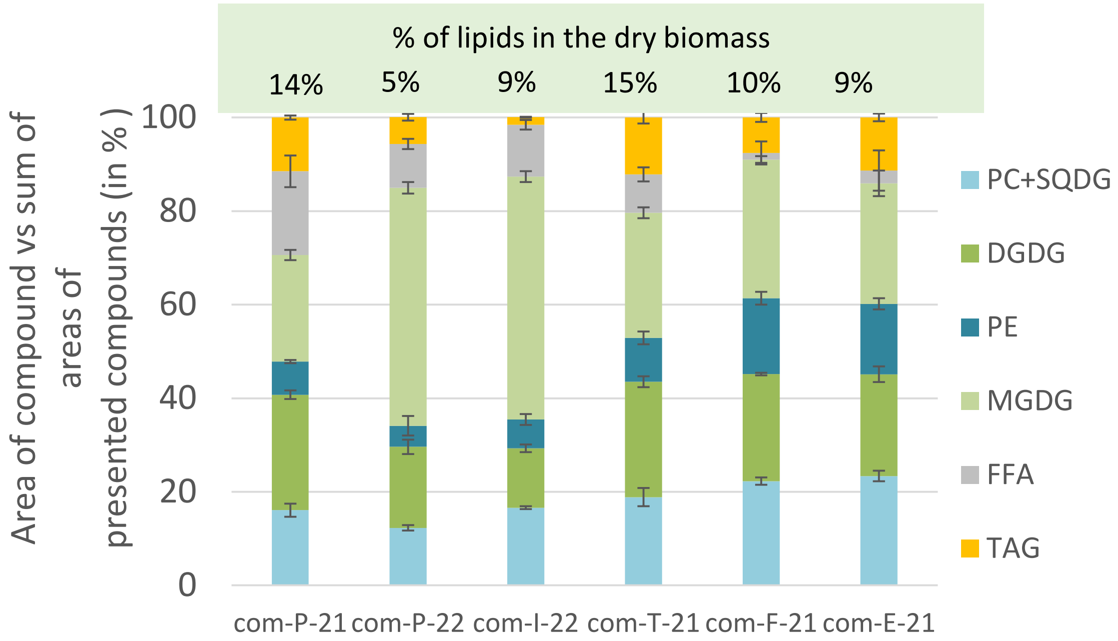
1) Nutritional interest of microalgae lipids

✓Plasticity of FA profiles and molecules on which these FA are esterified

Origin	Species	Year of production	Specifications	Abbreviation	ω6/ω3
Mongolia or Hainan island	*C. vulgaris*	2021	Broken cell wall	Com-P-21	5.2
	C. vulgaris	2022	Broken cell wall	Com-P-22	8.9
France	*C. vulgaris*	2021	Whole cells	Com-T-21	4.3
France	*C. vulgaris*	2021	Whole cells	Com-F-21	5.7
France	*C. pyrenoidosa*	2022	Broken cell wall	Com-I-22	1.3
Netherlands	*C. sorokinana*	2021	Broken cell wall - “fermented”	Com-E-21	5.1



Fatty acid profiles of commercial Chlorella



Lipid composition (%) of commercial Chlorella

(Wind, Master 2, 2021; Barouh et al., Chevreul Congress 2023, Paris)

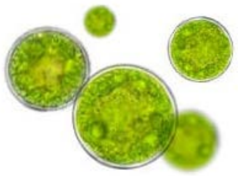
1) Nutritional interest of microalgae lipids

✓ Presence of oxylipins ?

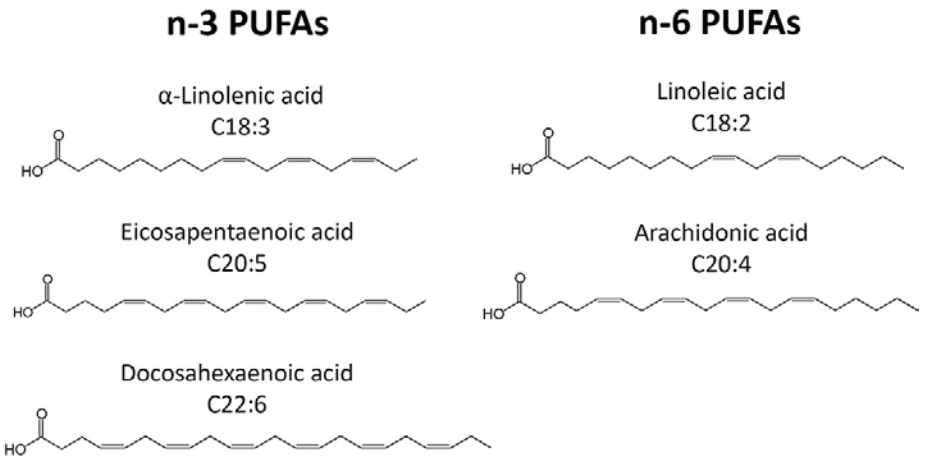
PUFA

oxydation

oxylipins

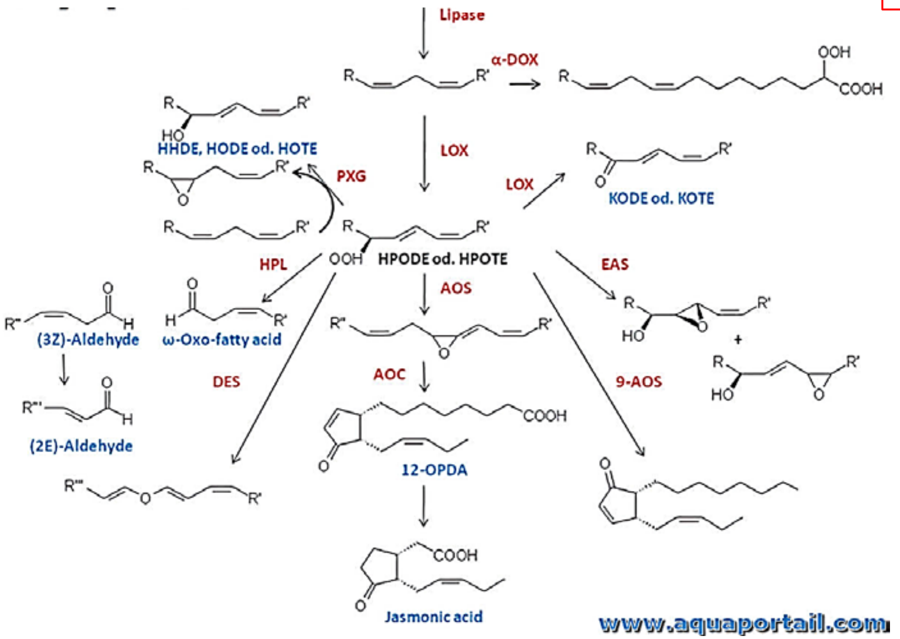


Chlorella



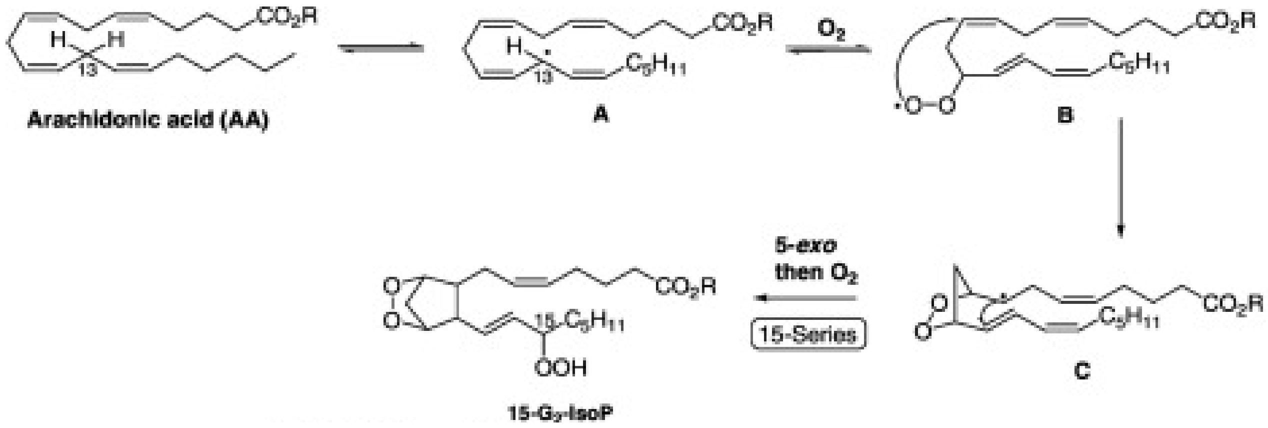
- COX
- LOX
- CYP

Enzymatic



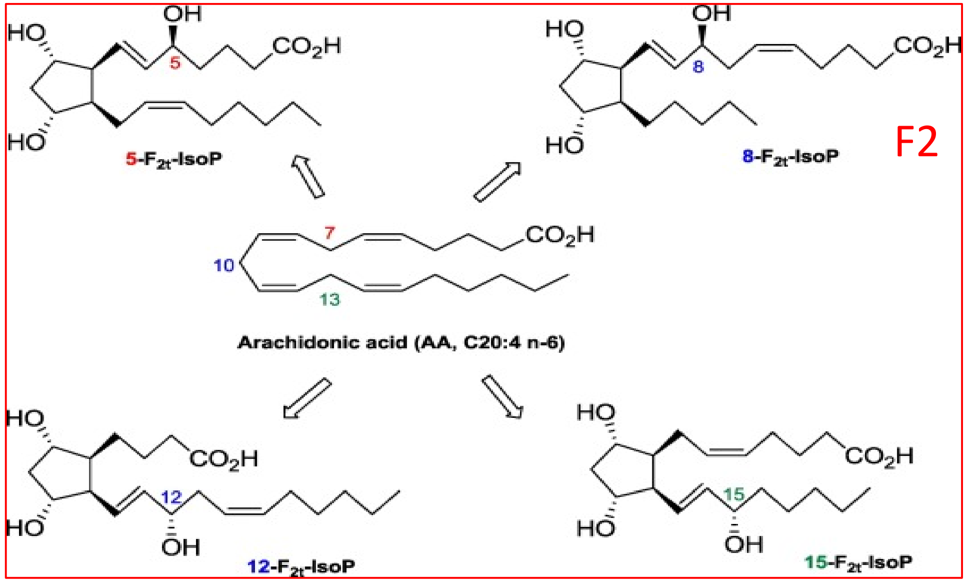
Non – enzymatic

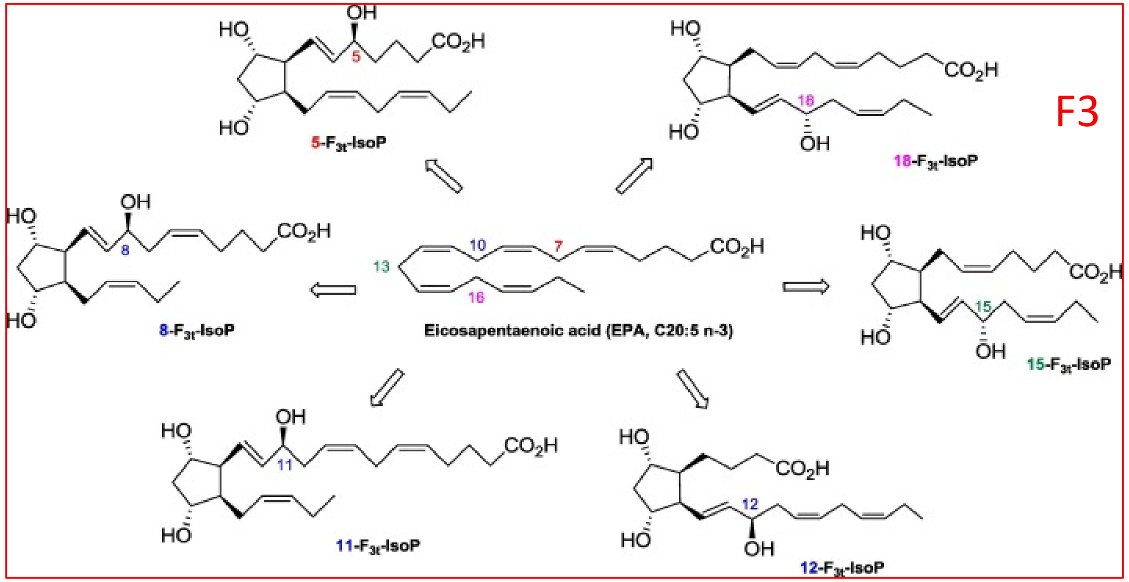
= created by ROS / radical reaction



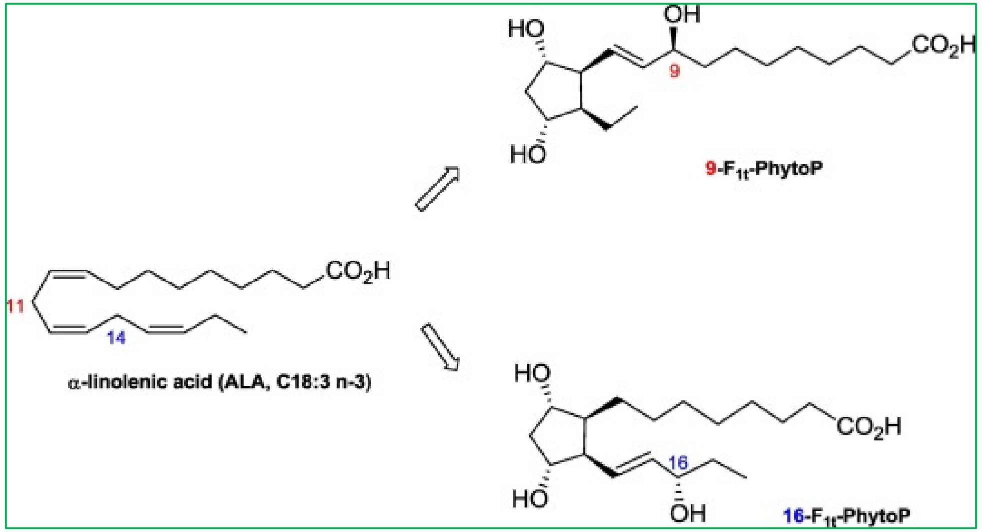
(Galano et al., Prog. Lipid Res., 2017)

Main classes of NE oxylipins

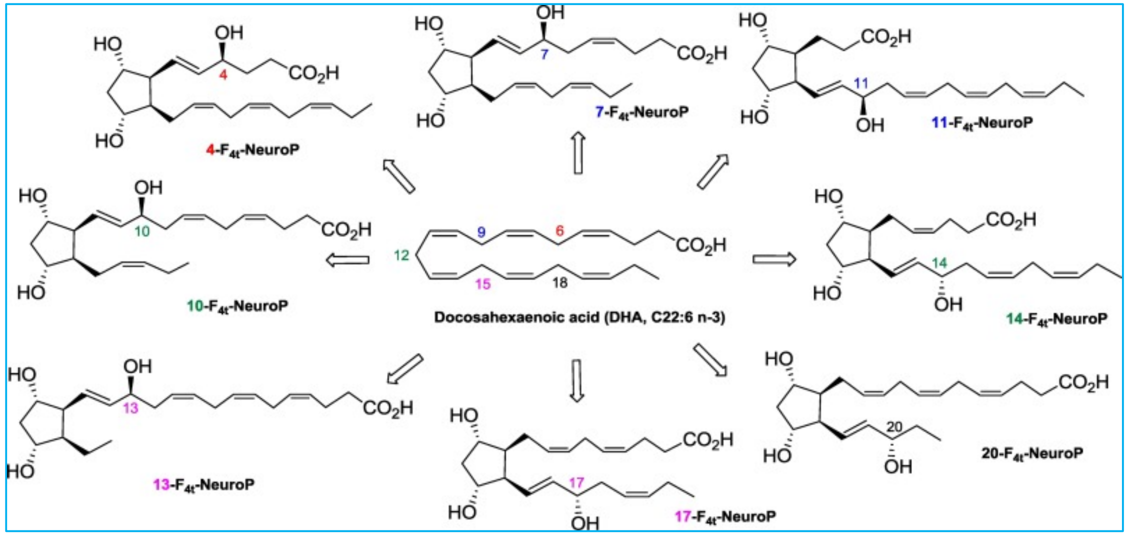




Arachidonic acid (AA, C20:4 n-6) et eicosapentaenoic acid (EPA, C20:5 n-3) → **Isoprostanes** (IsoPs)



Alpha-linolenic acid (ALA, C18:3 n-3)→ **Phytoprostanes** (PhytoPs)



Docosahexaenoic acid (DHA)→ **Neuroprostanes** (NeuroPs)

(Galano et al., Prog. Lipid Res., 2017)

1) Nutritional interest of microalgae lipids

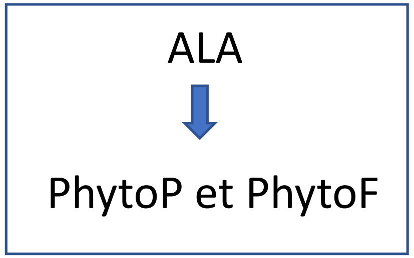
✓ Presence of oxylipins ?

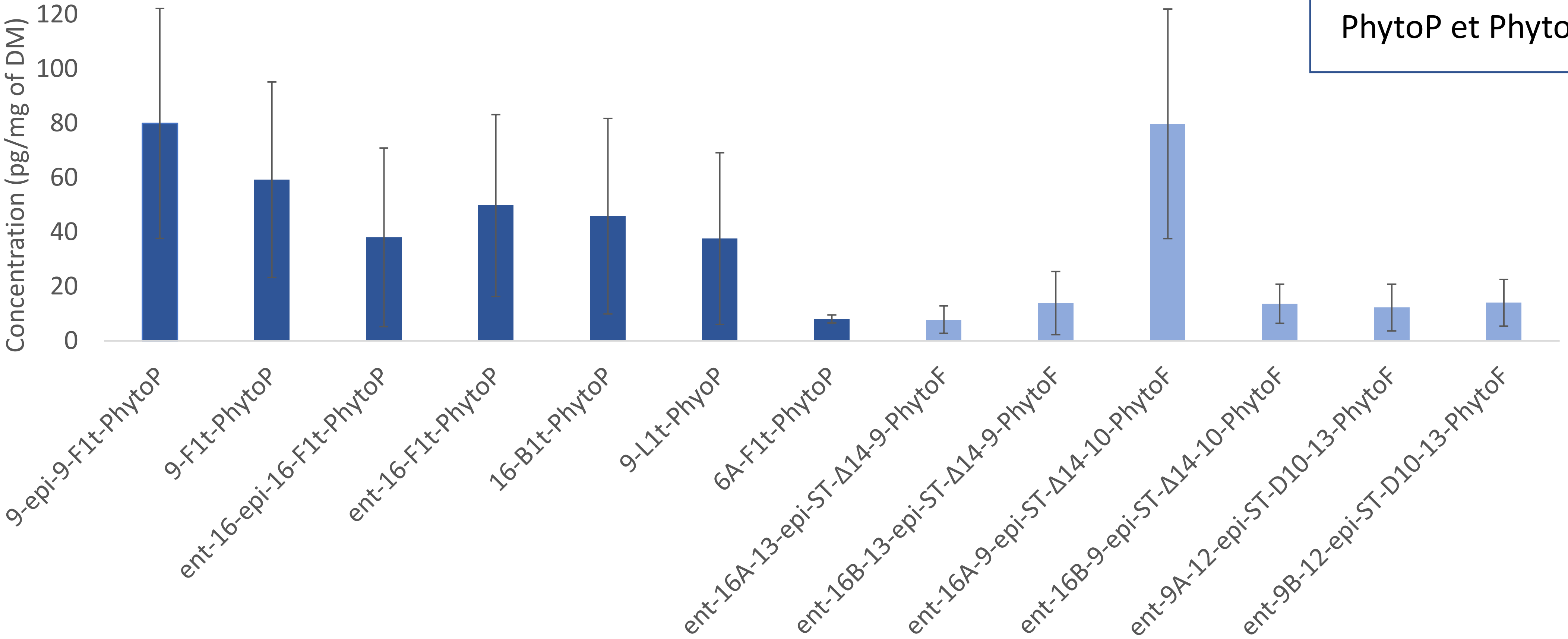
Oxylipins	Activity
Ent-16B1t-PhytoP	Neuroprotectivity
Ent-9L1t-PhytoP	Inflammatory
8-F3-IsoP	Pro-arythmia
10-F4t-NeuroP	Artherosclerosis prevention Anti VIDD (Ventilator Induce Diaphragm Disfunction)
4+F4t-NeuroP	Anti-inflammatory Artherosclerosis prevention Anti VIDD (Ventilator Induce Diaphragm Disfunction) Anti-arythmia Neuroprotectivity Sperm capacitation
14-A4t-NeuroP	Anti-inflammatory

(Galano et al., Prog. Lipid Res., 2017 ; Bosviel et al., Free Rad. Biol. Med., 2017 ; Martinez Sanchez et al., 2020; Signorini et al. Life, 2021 ; Moretti et al. Molecular sciences, 2023)

1) Nutritional interest of microalgae lipids

✓ Presence of oxylipins ?

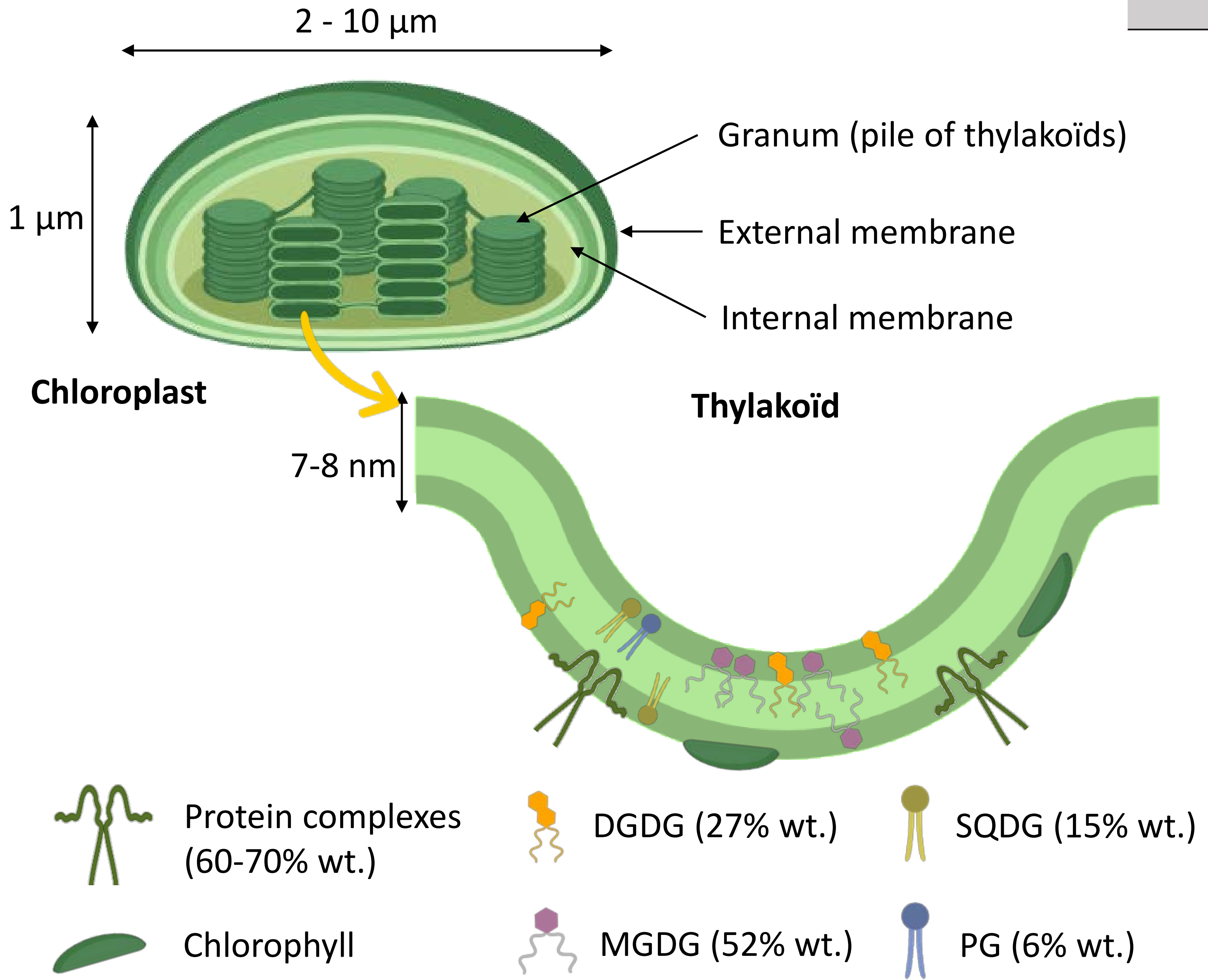


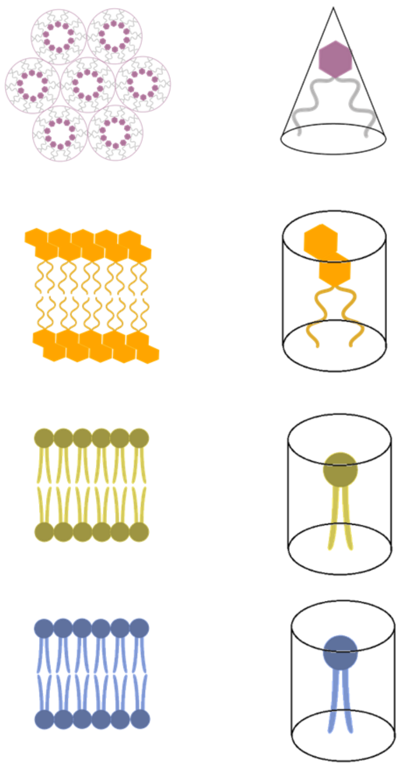


Profile in non enzymatic oxylipins detected in lipid extract of *C. sorokiniana* cultivated in photoautotrophy

(Avila-Roman et al., Pharmacol Res., 2018; Los Reyes et al., Phytochem, 2014; Conde, et al. Int. J. Mol. Sci. 2021)

2) Interfacial behaviour of microalgae lipids





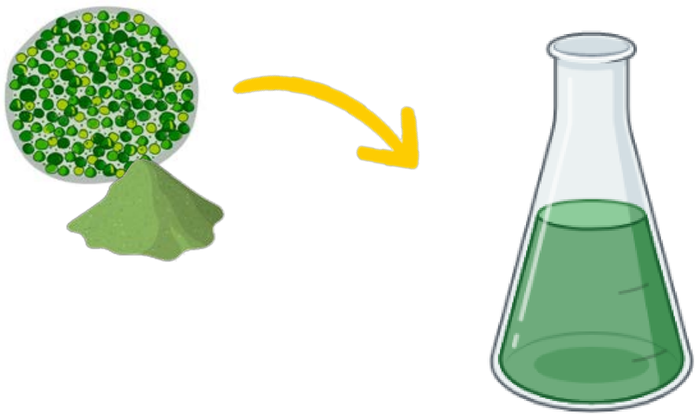
Lipid	Phase		Molecular arrangment
MGDG	Hexagonal inverse (HII)		Conic
DGDG	Lamellar (Lα)		Cylindrical
SQDG	Lamellar (Lα)		Cylindrical
PG	Lamellar (Lα)		Cylindrical

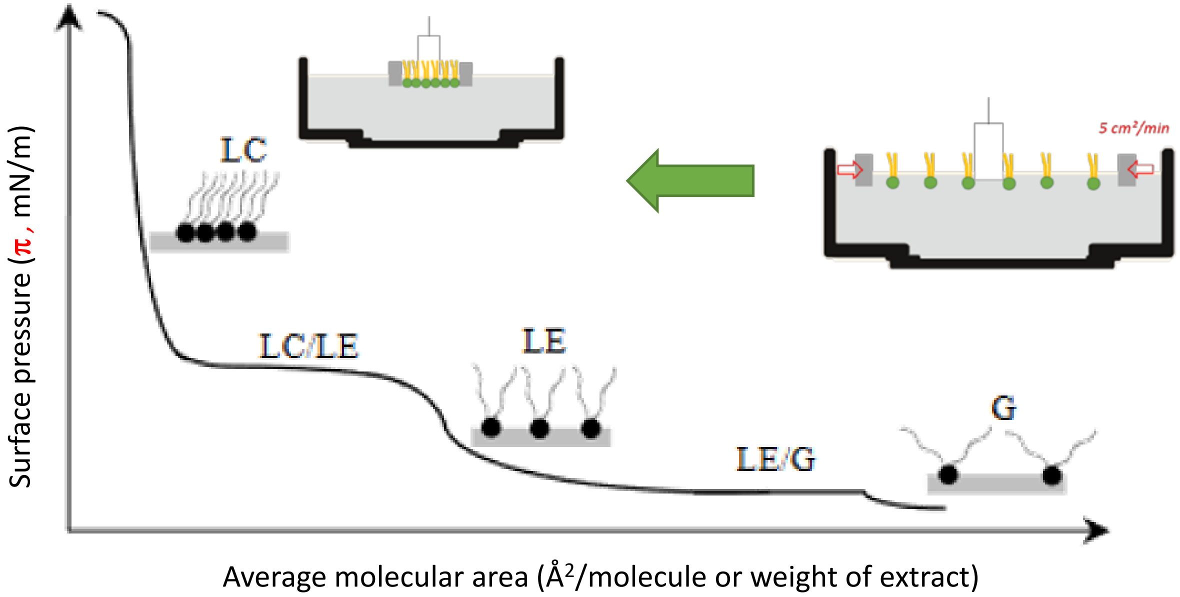
Ab: DGDG: digalactosyldiacylglycerol, DGMG: digalactosylmonoacylglycerol, MGDG: monogalactosyldiacylglycerol, SQDG: sulfoquinovosyldiacylglycerol, PG: Phosphatidylglycerol

(Gurevich et al., Eur. J. Int. Med., 1997; Jouet et al., Front. Plant Sci., 2013; Kergomard et al., CRFSN, 2021; Luesse et al. Plant Physiology, 2006)

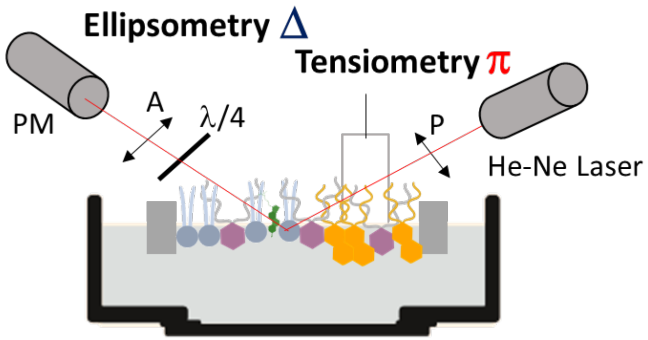
2) Interfacial behaviour of microalgae lipids

Folch extraction of total lipids on commercial or in-lab produced C. sorokiniana extracts





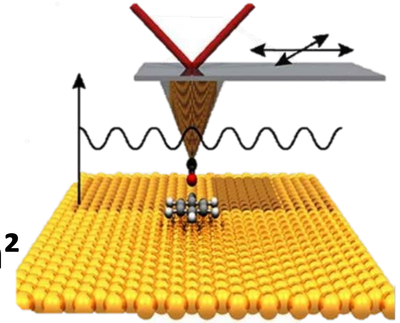
Ellipsometry/Tensiometry

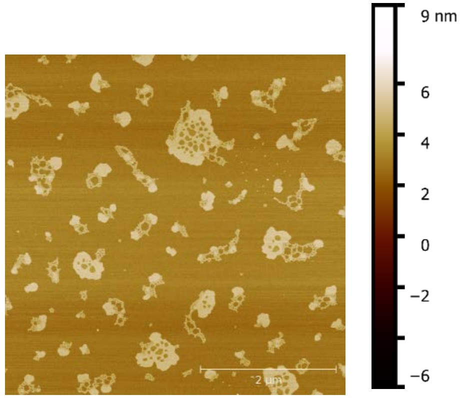


Langmuir Blodgett transfer

Atomic Force Microscopy (AFM)

15 cm²



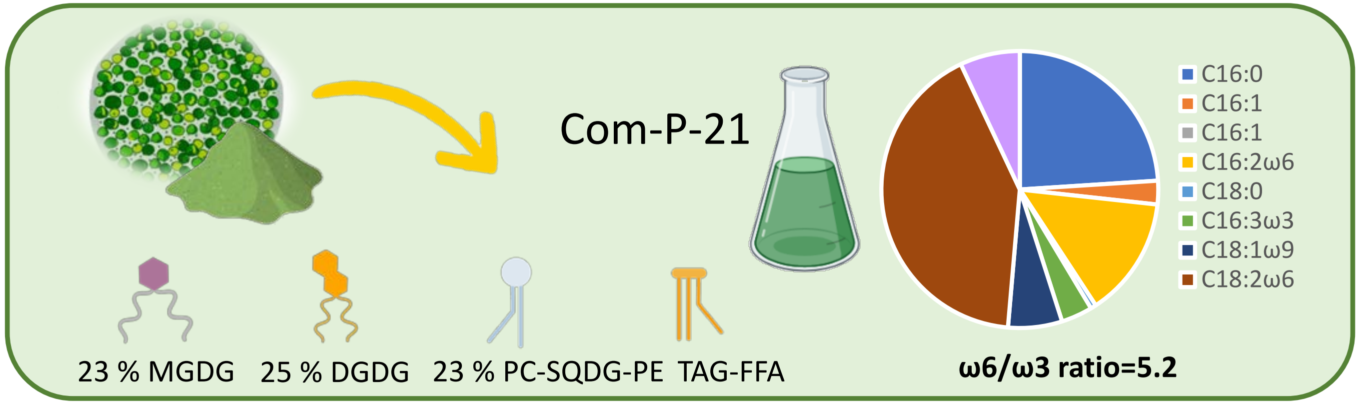


π (surface pressure) → molecular interfacial interactions

***Δ** (ellipsometric angle) → amount of matter at the a/w interface*

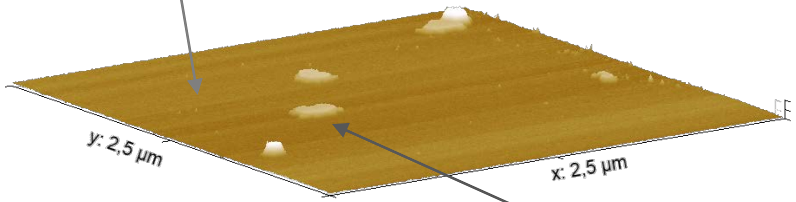
Topographic visualisation at the nanometric scale

2) Interfacial behaviour of microalgae lipids

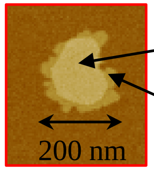


✓ In monolayers, π=19.7±0.5 mN/m, Δ= 8.1±0.5 °

Fluid main organization
(Liquid Expanded, 75 % unsaturated FA)



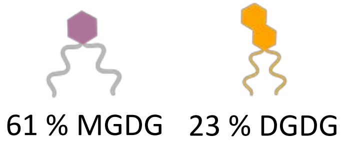
Presence of small liquid condensed domains
(high affinity between saturated FA)
with 2 different heights

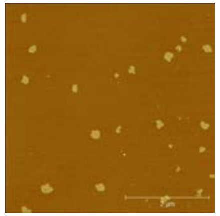


h=2,2 nm

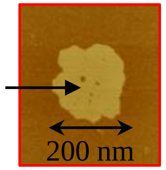
h=1,5 nm

✓ Similar behaviour in lab biomass despite variations in chemical composition

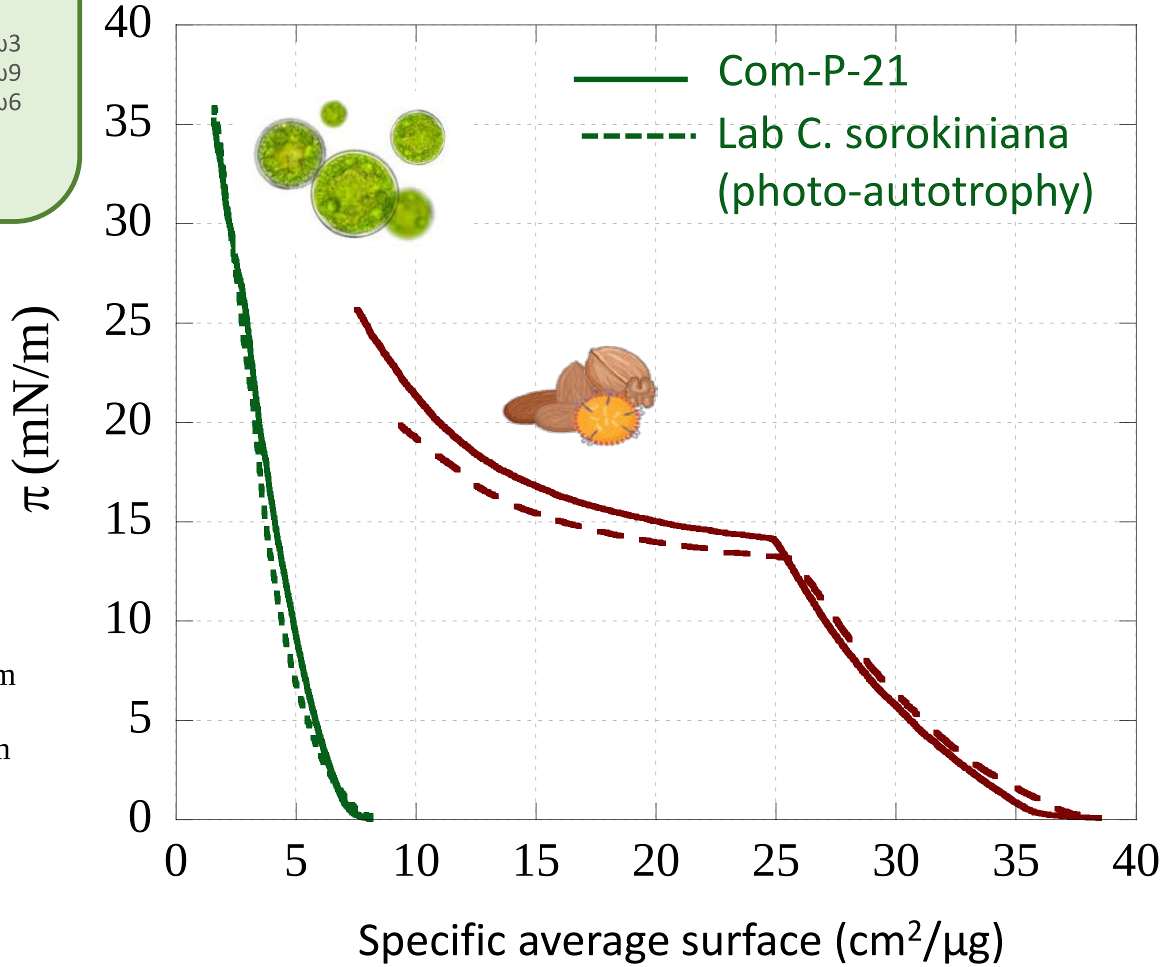




h=1,8 nm

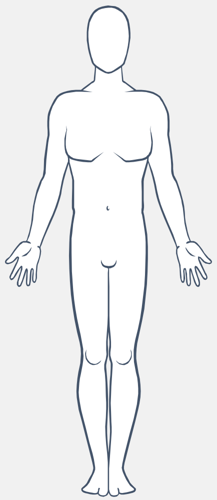


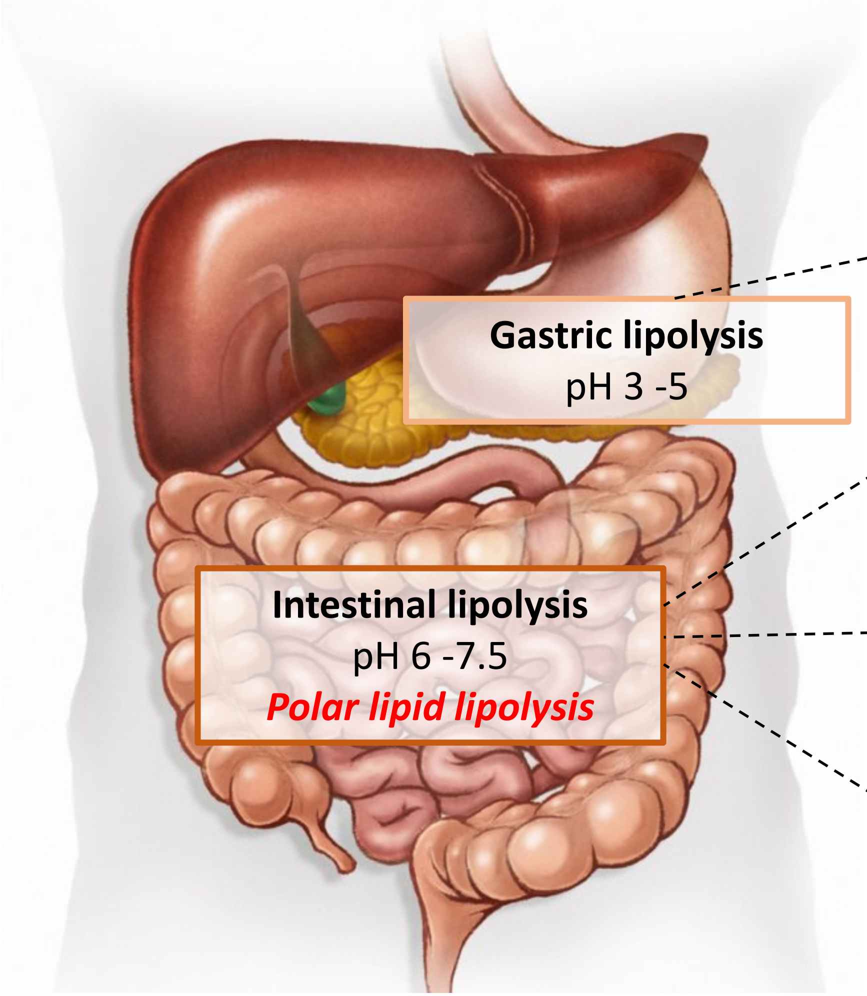
✓ High compressibility specially in comparison to glycerophospholipids dominated sources



3) Digestion of microalgae galactolipids

Enzymes at work in Humans





No lipolytic enzyme acting on polar lipids is produced in the gastric compartement

But the stability of emulsions resulting from gastric digestion influences the kinetics of intestinal digestion.

(Infantes-Garcia et al., JAFC, 2021)

Gastric lipase (HGL) – 47 kDa
Responsible for the digestion of 10 to 30% of TAG

Pancreatic phospholipase A2 (sPLA2) - 14 kDa
Phospholipase activity in sn-2 position

Colipase-dependent pancreatic lipase (HPL) – 48 kDa
Responsible for the digestion of 56% of TAG

Pancreatic lipase related protein 2 (PLRP2) – 50 kDa
(N'Goma et al. 2012)

Responsible for the digestion of galactolipids

(Borgström, Lipids, 1993; Carrière, Gastroenterol. 1993; Kergomard et al., CRFSN, 2021; Andersson et al., J. Lipid Res., 1995, Wattanakul et al. Food Function, 2019)

3) Digestion of microalgae galactolipids

Model systems

1 **GL**

MGDG/DGDG 60:40 mol%

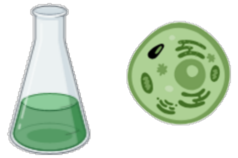
Homogeneous

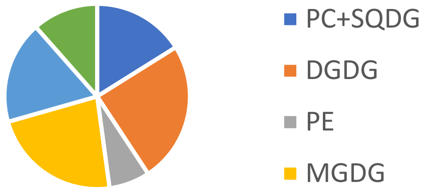
2 **MGDG/DGDG/SQDG/PG**

MGDG/DGDG/SQDG/PG 56:24:10:10 mol%

Biomimetic

3 **Lipid monolayer from *Chlorella vulgaris*** (*Commercial,* Com-P-21)

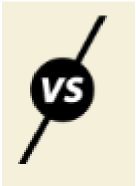




Molecular scale (nm)

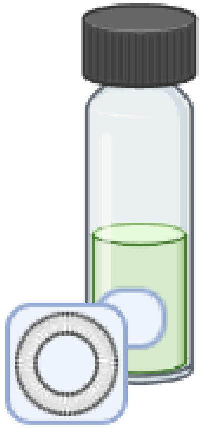
Interfacial characterization in Langmuir trough

Lipid monolayers

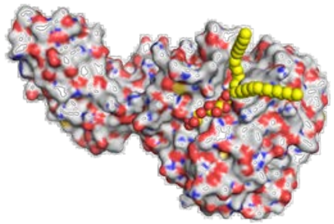


Assembly scale (µm)

Static *in vitro* model (mL) - Bulk



Giant liposomes



Guinea pig* Pancreatic lipase protein-related 2 *PLRP2

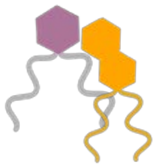
Provided by F. Carrière

50 kDa

Low activity toward TAG and phospholipids
High galactolipase activity on galactolipid films and mixed micelles (best susbtrate)
Specificity for the hydrolysis of ester bonds at the sn-1 position

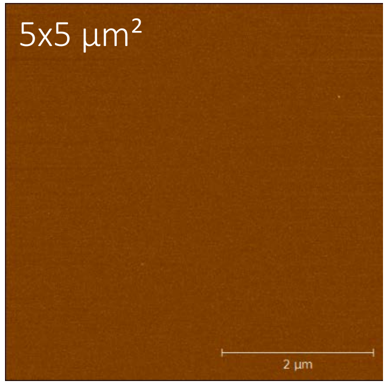
(Eydoux, Biochem., 2008; Amara et al., BBA, 2009 & 2010)

3) Digestion of microalgae galactolipids



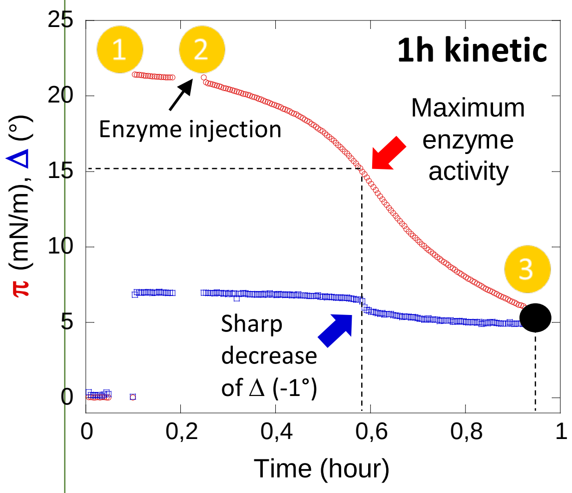
✓ gPLRP2 adsorption and lipolytic activity onto model monolayers at the air/water interface

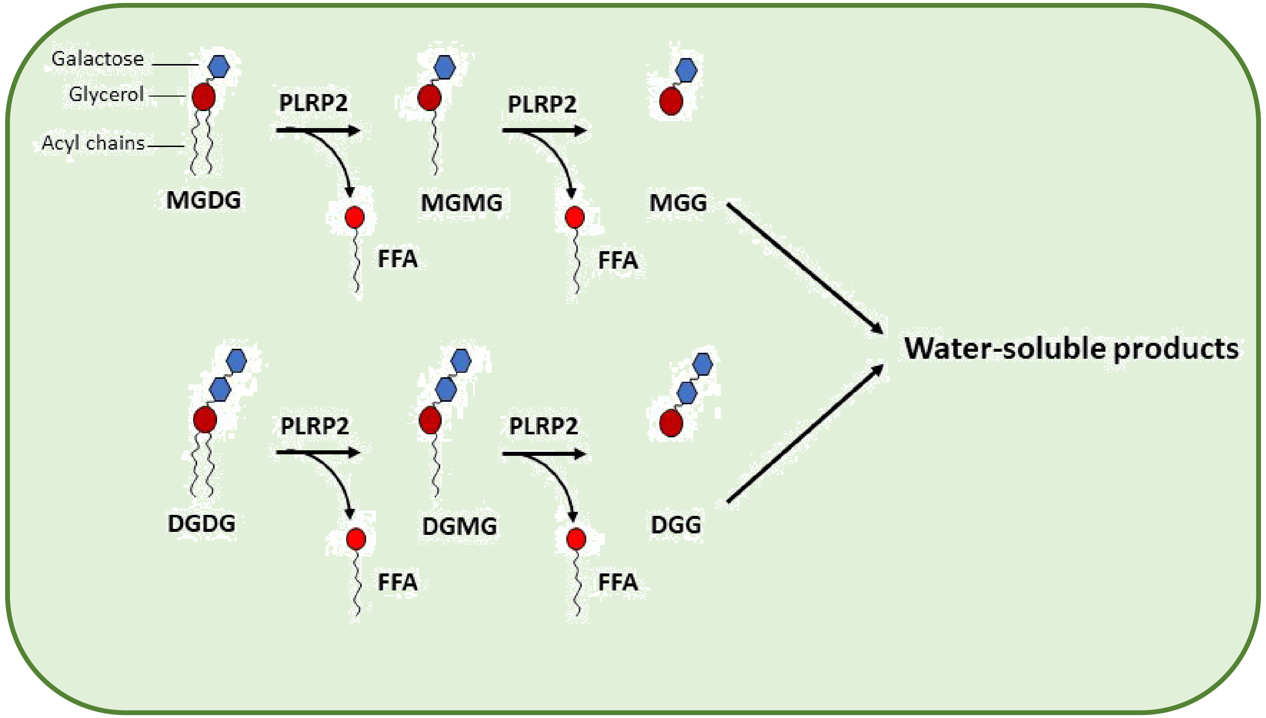
System 1 – GL

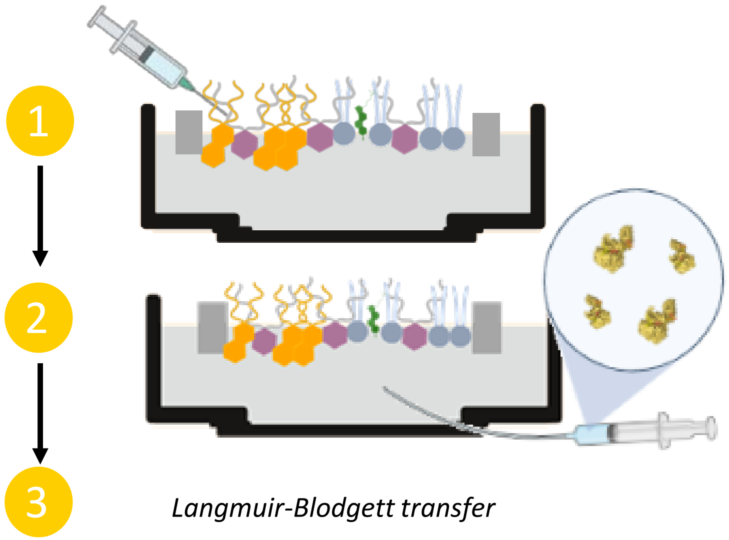


π=20.0 mN/m
Δ=7.5°

+ gPLRP2 (0.128 mg/L)





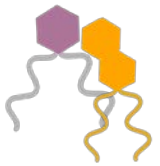


Langmuir-Blodgett transfer

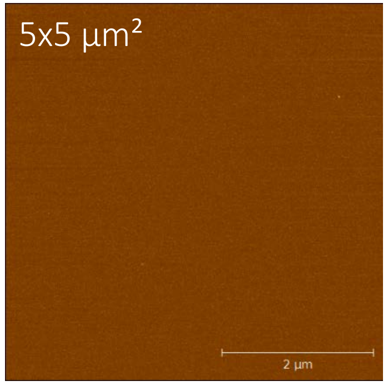
(Kergomard et al, 2022 submitted Biochimie)

3) Digestion of microalgae galactolipids

✓ gPLRP2 adsorption and lipolytic activity onto model monolayers at the air/water interface

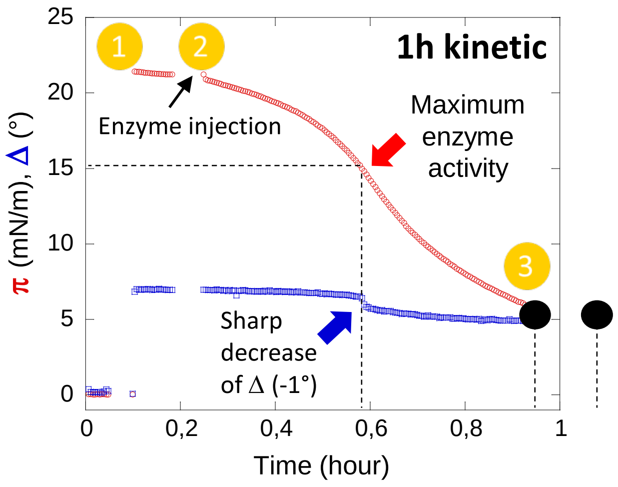


System 1 – GL



π=20.0 mN/m
Δ=7.5°

+ gPLRP2 (0.128 mg/L)

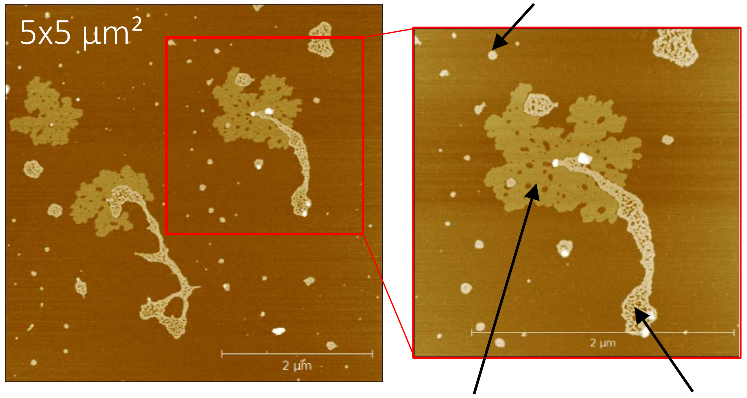


Langmuir-Blodgett transfer

π=6.0 mN/m
Δ=4.9°

AFM

1h kinetic



Adsorbed enzyme?
h=4-5 nm

h=2.5-3 nm
FFA?

h=3.5 nm
Adsorbed enzyme?

- **Enzymatic activity of gPLRP2 on GL monolayer**

Optimal activity at 15 mN/m, decrease of π, marked reduction in thickness (Δ).

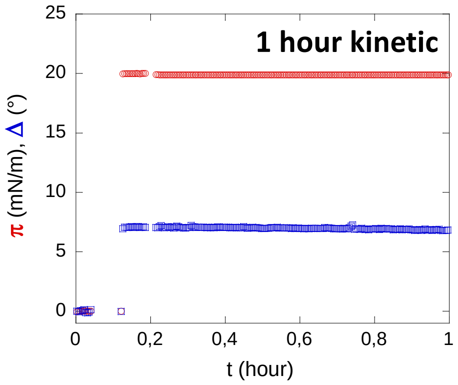
- **Modification of the interfacial organization**

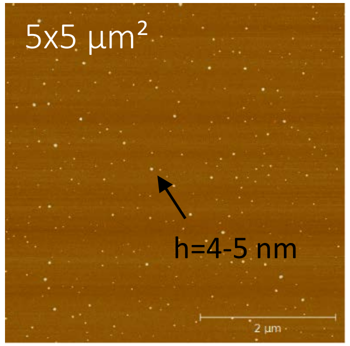
Appearance of domains related to the generation of lipolysis products, adsorption of PLRP2 at the interface

- **No lipolysis activity for the PLRP2 inactive variant**

No evolution of π and Δ, preservation of the PLRP2 structure (central domain 50 Å)

GL + gPLRP2 inactive variant



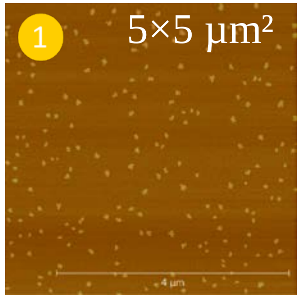


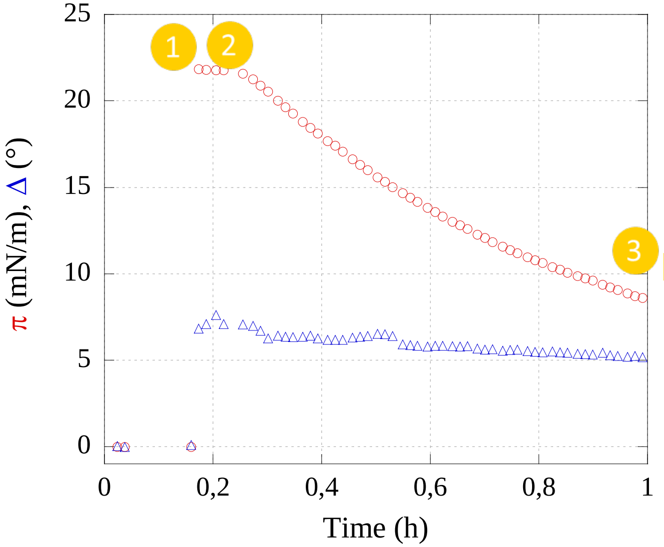
Kergomard et al, 2022 submitted Biochimie

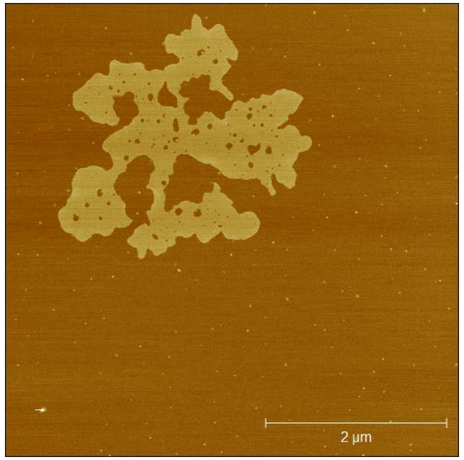
3) Digestion of microalgae galactolipids

Comparison of gPLRP2 adsorption and lipolytic activity onto biomimetic system (2) and **Lipid monolayer from *Chlorella vulgaris*** *(System 3 Commercial,* Com-P-21*)*

System 2 – GL/SQDG/PG



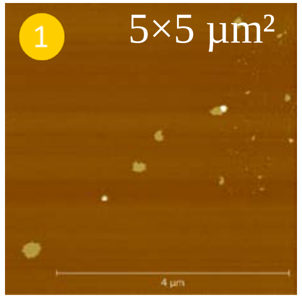


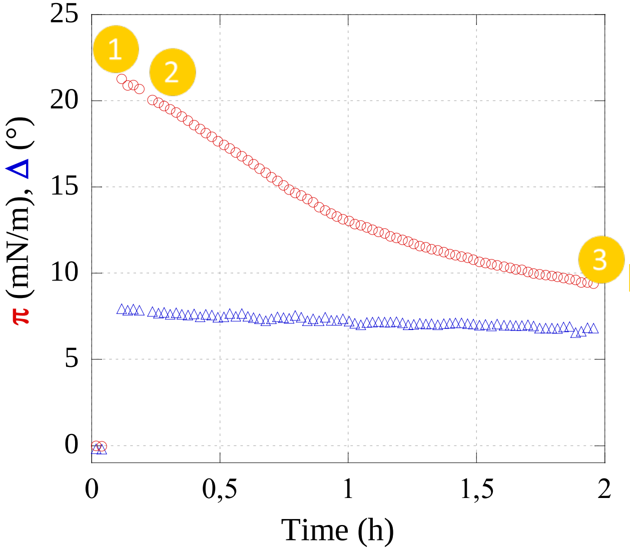


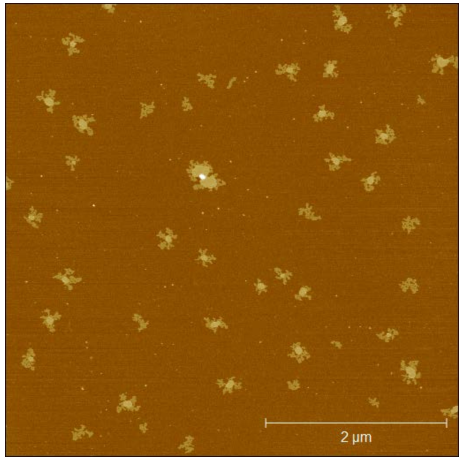
+ gPLRP2

1h, π=8.5 mN/m, Δ=5.2°

System 3 – *Commercial,* Com-P-21







+ gPLRP2

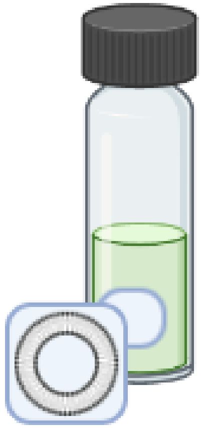
2h, π=9.4 mN/m, Δ=6.9°

(Kergomard et al, 2022 PHD unsubmitted work)

3) Digestion of microalgae galactolipids

Assembly scale (µm)

Static *in vitro* model (mL) - Bulk



Giant liposomes

1 µm liposomes stabilized by model lipid extract (0.2% wt.)
(pH 7, Tris HCl buffer 10 mM, gPLRP2 =3,3 mg/L)

MGDG/DGDG/SQDG/PG

	T_0	T_{5min}		
FFA	-	54,3 ± 2,4	↗	
MGDG	65,4 ± 1,0	10,6 ± 0,1	↘	-84%
MGMG	-	31,3 ± 2,2	↗	
DGDG	34,6 ± 1,0	3,7 ± 0,1	↘	-90%
DGMG	*nq*	*nq*		
SQDG	24,7 ± 0,4	2,3 ± 0,3	↘	-91%

MGDG → MGMG+ FFA
DGDG → DGMG + FFA
SQDG → SQMG + FFA

In the presence of biliary salts:
Galactolipase activity
Phospholipase activity

→ *Generation of new surfactant molecules*

(Kergomard et al, 2022 PHD unsubmitted work)

Ab: Pancreatic lipase related protein 2 (PLRP2), BSSL : bile salt stimulated lipase, DGDG: digalactosyldiacylglycerol, DGMG: digalactosylmonoacylglycerol, FFA: free fatty acids, MGDG: monogalactosyldiacylglycerol, MGMG: monogalactosylmonoacylglycerol, SQDG: sulfoquinovosyldiacylglycerol, SQMG: sulfoquinovosylmonoacylglycerol, PG: Phosphatidylglycerol

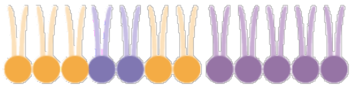
3) Digestion of microalgae galactolipids

0,128 mg/L

3,3 mg/L

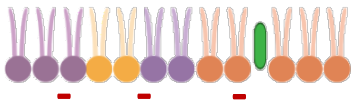
Monolayer

$\pi_{optimal}$=10-15 mN/m



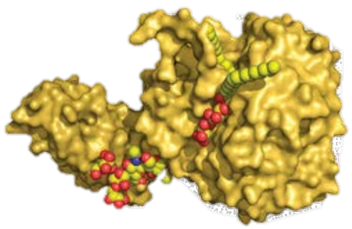
Homogenous monolayer
GL

Galactolipase Activity



Heterogenous monolayer
MGDG/DGDG/SQDG/PG
Chlorella membrane lipids

Galactolipase Activity
Improved enzyme adsorption
But latency and activity slowed by heterogeneity



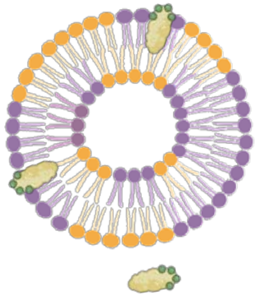
gPLRP2
pH 7

Dispersed form

Liposomes 1 µm

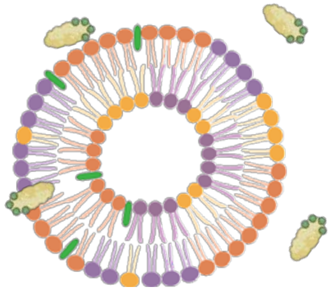
Biliary salts

Galactolipase Activity



Liposomes
GL

Galactolipase Activity
+
phospholipase A1



Liposome
MGDG/DGDG/SQDG/PG

Conclusions

✓ **Microalgae galactolipids can be an interesting complementary source of omega 3 PUFA possibly esterified under the galactolipids form**

Microalgae sources	Terrestrial sources (green leafy vegetables)
VLC omega 3 PUFA	Omega 3 PUFA precursors only
Higher PL/GL ratios in photoautrotrophy, adjustable with environmental conditions	Ratio PL/GL =45:55 in leaves and 30:70 in chloroplasts
~10-15 % (DM) of lipids of which 70-80 % can be GL	2-30 g/kg (DM) MGDG-DGDG
No arable land use / Concentration/ Stabilization energy consuming	Arable land use

✓ **These galactolipids have specific interfacial behaviour compared to glyceroPL**

✓ **Can be easily digested by close analogue of human PLRP2**

✓ **Lots of work remained to be done to understand assembly behaviour in the digestive tract**

Work to stabilize biomass and maintain molecular form by Maeva Subileau

Preclinical trial on GL terrestrial sources by C. Vors

Thanks to all contributors !!

Jeanne Kergomard
Gilles Paboeuf
Véronique Vié

Nathalie Barouh
Bruno Baréa
Amy Joy Carpentier
Pierre Villeneuve

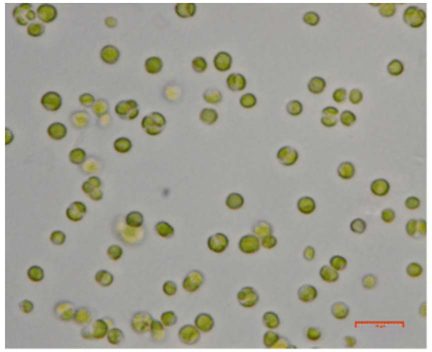
Frédéric Carrière

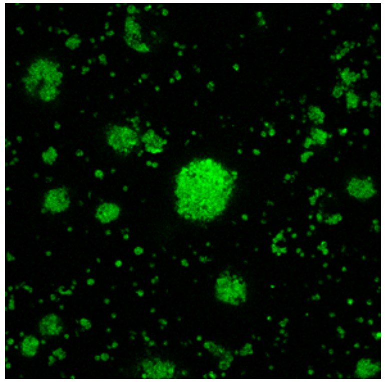
Claire Vigor
Thierry Durand

Pierre-Emmanuel Millet
Luca Costa

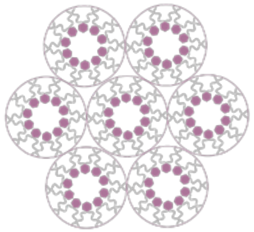
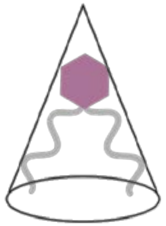
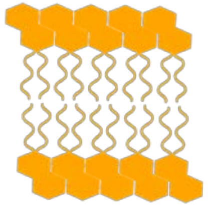
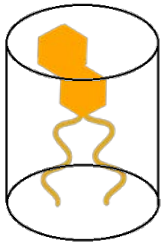
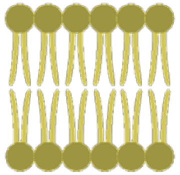
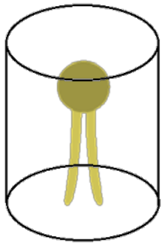
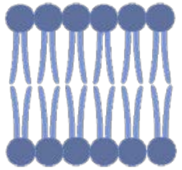
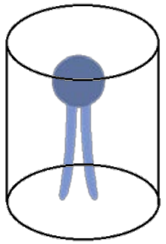
Maeva Subileau
Juliette Wind
Claire Bourlieu-Lacanal

Thank you for your attention



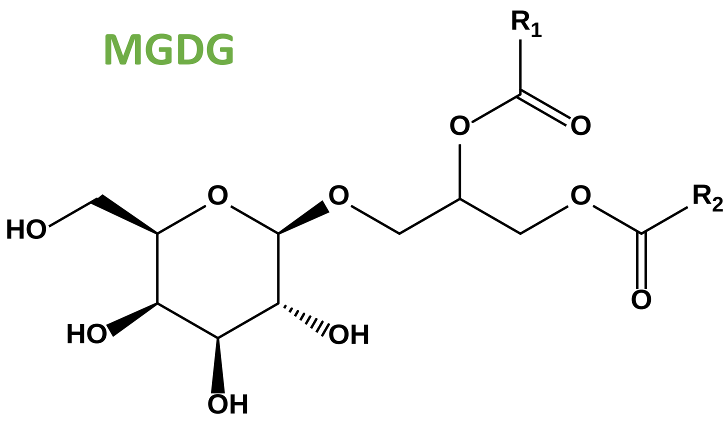


EXTRA-SLIDES

Lipid	Phase		Molecular arrangment	
MGDG	**Hexagonal inverse** (HII)			**Conic**
DGDG	**Lamellar** (Lα)			**Cylindrical**
SQDG	**Lamellar** (Lα)			**Cylindrical**
PG	**Lamellar** (Lα)			**Cylindrical**

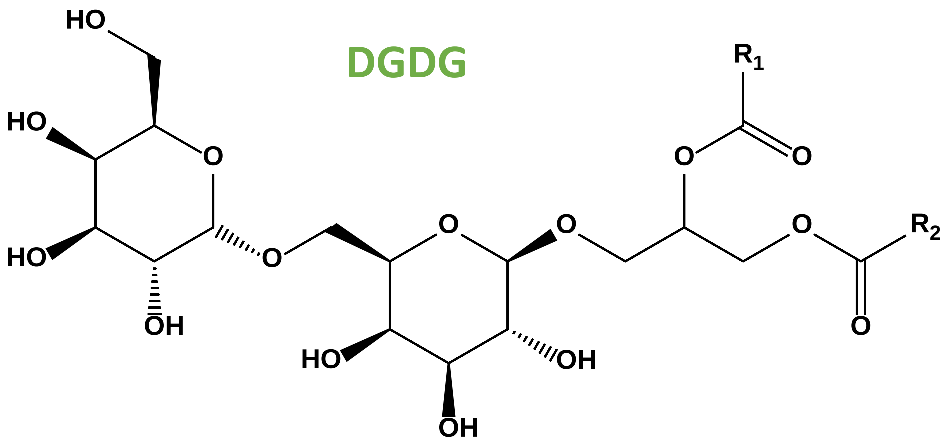
Formes moléculaires et phases polymorphiques du quartet lipidique des thylakoïdes

MGDG



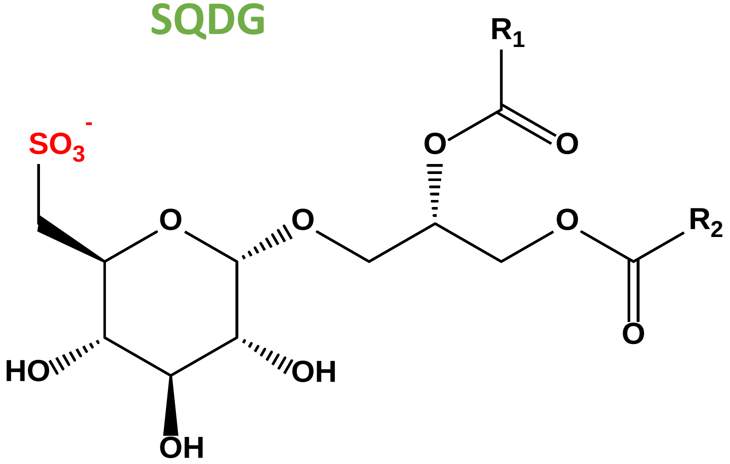
Monogalactosyldiacylglycerol

DGDG



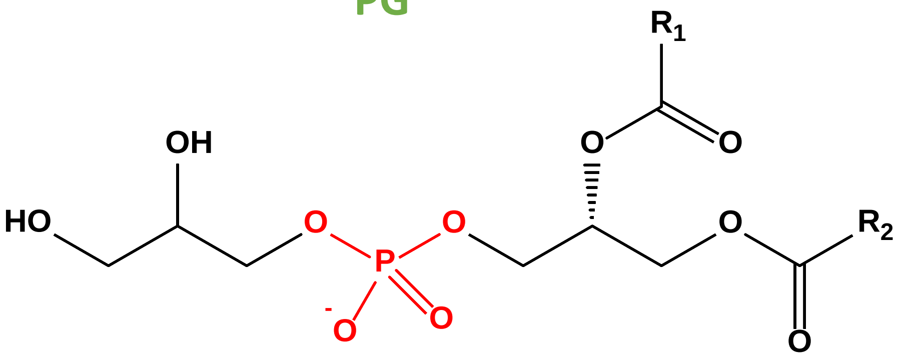
Digalactosyldiacylglycerol

SQDG



Sulfoquinovosyldiacylglycerol

PG



Phosphatidylglycerol