



*International Society for the  
Study of Fatty Acids and Lipids*

# Effect of various saturated fatty acids sources on oxidative stability and nutritional profile of DHA-enriched infant follow-on formulas

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# CONTEXT

Significant growth and development



Specific nutritional needs depending of the age

Involved in the infant development



Cognitive



Visual



Digestive system



Immune system

Carlson et al., J Nutr, 2021 ; Lepping et al., Dev. Psychobiol., 2019

## LIPIDS



**Dominant energy provider**

(~45-55% of total energy)

Delplanque, Gibson et al., J. Pediatr. Gastroenterol. Nutr., 2015

**Essential fatty acids:**

**LA**  
C18:2 ω6

**ARA**  
C20:4, ω6

**ALA**  
C18:3 ω3

**DHA**  
C22:6 ω3

**EPA**  
C20:5 ω3

Innis, Adv Nutr J., 2011

Agostoni, J. Pediatr. Gastroenterol. Nutr., 2008

# CONTEXT

Optimization  
of lipid profile  
of infant  
products

## New European regulation - European regulation 2016/127/EC

Entry into force in 2020

- ✓ Revision of the limits for certain essential fatty acids:
  - Increase of the lower limit in LA
  - Increase of the upper limit for ALA
  - Obligation to supplement formulas with 20 to 50 mg of DHA per 100 kcal (i.e. 0.5 to 1% of total fatty acids)



What about ARA ?



Still not mandatory *despite its proven importance for child development*

A maximum limit 1% of the total fat content (*maximum of 60 mg per 100 kcal or 42 mg per 100 mL of formula*)

Cancelon et al., CND, 2022

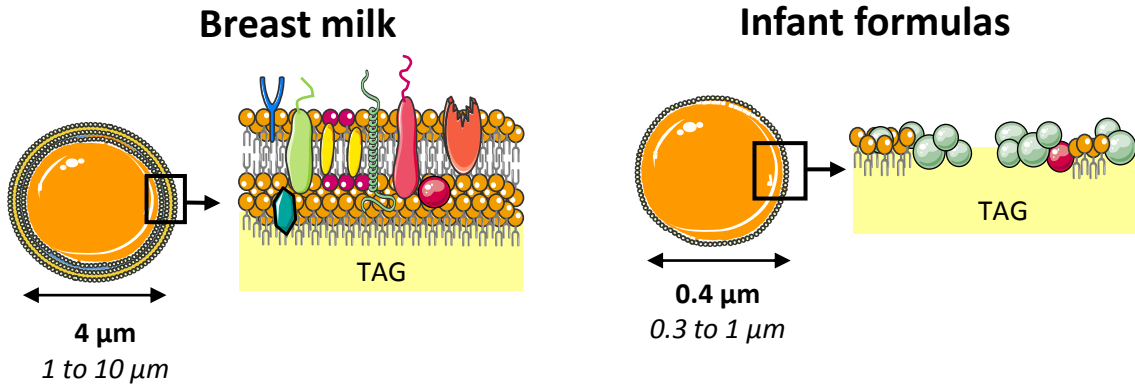


Increase susceptibility  
to lipid oxidation

# CONTEXT

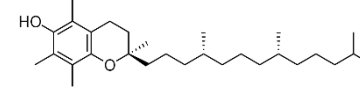
## How to limit lipid oxidation in infant formulas playing on lipid parameters ?

### Lipids structure

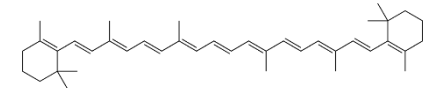


### Antioxidant composition, type and synergic effects

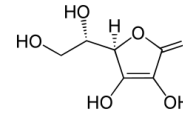
Tocopherols



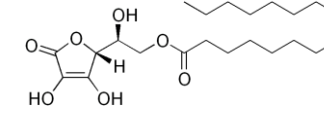
Carotenoids



Vitamin C



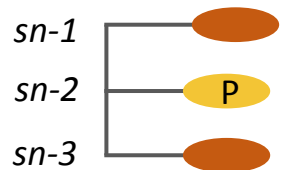
L-ascorbyl palmitate



And their combination ...

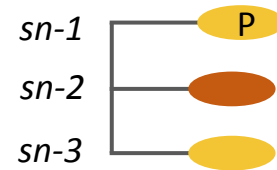
### Fatty acid regiodistribution and TAG structure

**Breast milk**



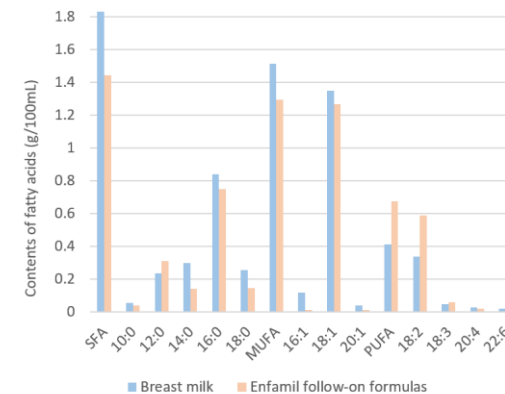
About 70% of C16:0 is internally esterified (*sn*-2)

**Infant formulas**

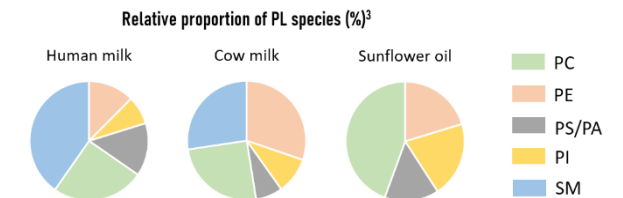


C16:0 esterified mainly at external positions (*sn*-1,3)

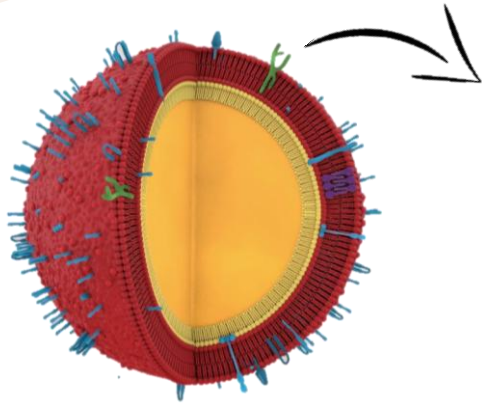
### TAG Fatty acid profile



### Polar lipids profile



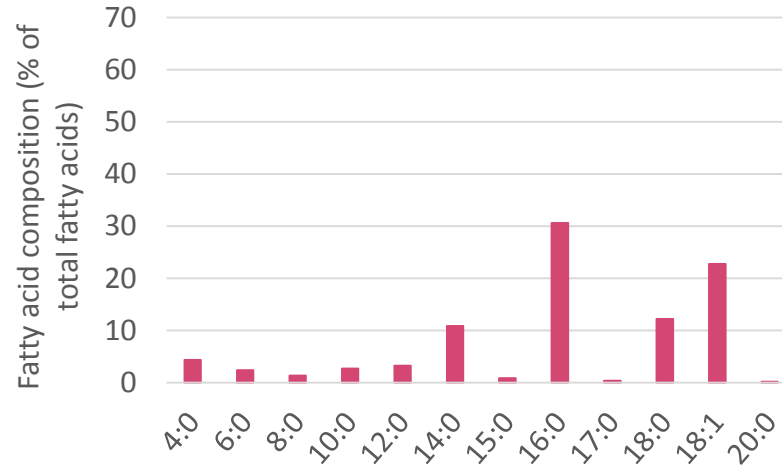
# CONTEXT



Milk fat globule

## Fatty acid profile of bovine milk fat

Lindmark Mansson et al. 2008

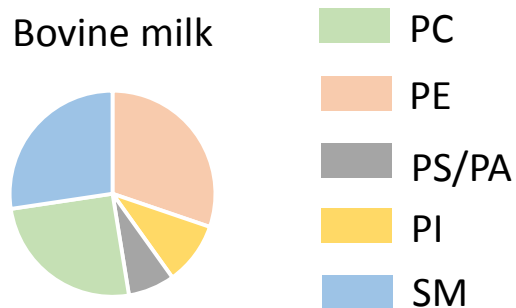


## Interest of dairy fat

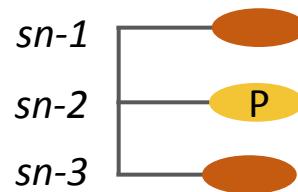
- Biomimetic lipid structure of breast milk
- Short and medium chain saturated fatty acids (C4:0 to C12:0)
- Very long chain SFA (>C20:0) both as TAG and polar lipids
- Biomimetic TAG organization of breast milk
  - C16:0 mainly esterified at sn-2 position
  - Heterogeneous TAG

## Relative proportion of PL species (%)

Changhoon et al., Food Sci Anim Resour, 2022



## Fatty acids regidistribution



Palmitic acid (C16:0) mainly internally esterified (sn-2)

→ Improves lipid digestion and metabolism

→ Protection effect against lipid oxidation

# AIM OF THE STUDY



Identifying key lipid formulation parameters that improve the nutritional profile and the oxidative stability of DHA-enriched IFF



1.

Setting an overview of marketed infant flours formulas



Analysis of the nutritional values of **91 infant formulas** on the world market

2.

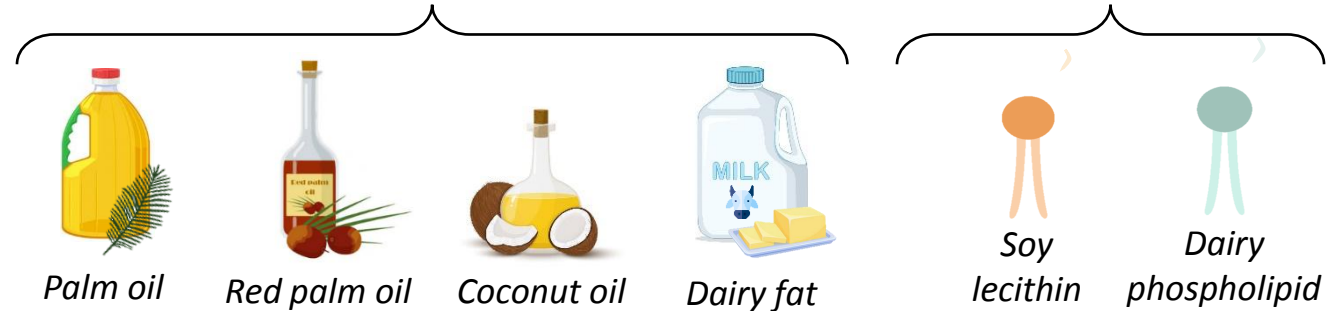
Formulation of model systems representative of marketed IFF

*Fatty acids profile: iso SFA, MUFA, PUFA, n-6, n-3*

*Vitamins: normalization of vitamins A & E contents*

*SFA sources*

*Emulsifier sources*



3.

Comparison of oxidation stability through a storage test



20 days



40°C



Monitoring of indicators descriptive of oxidation rate



# 1. OVERVIEW OF INFANT FORMULAS

For 100 mL of preparation

## Overview of follow-on formulas (N=91)

### Selection criteria

- Type of products - *follow-on formulas only*
- « Classic » formulas- *no hypoallergenic, AR formulas, etc.*
- Widely consumed products

→ 91 follow-on formulas from 16 brands

### Ingredient list analysis

14%

Oil phase includes **dairy lipids**

70%

Soy lecithin as emulsifier

	Overview <sup>1</sup>	Breast milk <sup>2</sup>	EU Regulation <sup>3</sup>	
			Min	Max
<b>Energy (kcal)</b>	67.2 ± 1.3	67	60	70
<b>Fat (g)</b>	3.3 ± 0.2	3.5	2.64	4.2
SFA (g)	1.1 ± 0.4	1.65	-	-
MUFA (g)	1.5 ± 0.4	1.54	-	-
PUFA (g)	0.6 ± 0.1	0.35	-	-
LA (mg)	502.2 ± 0.1	310	300	840
ALA (mg)	53.7 ± 12.6	28	30	70
ARA (mg)	9.4 ± 5.6	18	-	42
DHA (mg)	14.8 ± 4.0	7 to 42	12	35
<b>Carbohydrates (g)</b>	7.8 ± 0.4	7.5	5.4	9.8
<b>Proteins (g)</b>	1.4 ± 0.2	1	1.08	1.75
Caseins (g)	0.8 ± 0.3	0.4	-	-
<b>Vitamin A (µg)</b>	61.5 ± 6.4	-	42	79.8
<b>Vitamin D (µg)</b>	1.4 ± 0.3	-	1.2	2.1
<b>Vitamin E (mg)</b>	1.4 ± 0.4	-	0.36	3.5
<b>Vitamin C (mg)</b>	9.7 ± 2.3	-	2.4	21
<b>Iron (mg)</b>	0.976 ± 0.155	0.05	0.36	1.4
<b>Copper (mg)</b>	0.052 ± 0.006	-	0.036	0.070

Dataset: Cancalon et al. Food Chem, 2023

<sup>1</sup>Average values extracted from the follow-on formulas overview

<sup>2</sup>Mäkelä, Linderborg et al., Eur. J. Nutr, 2013

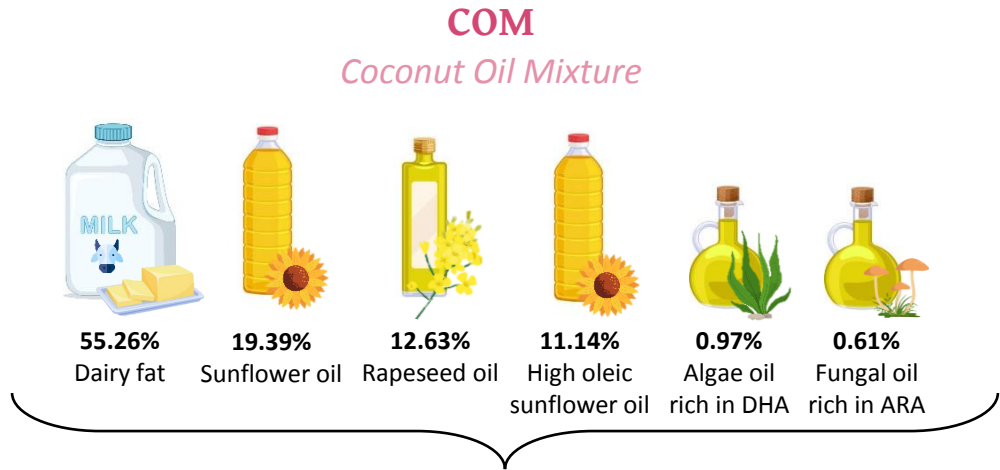
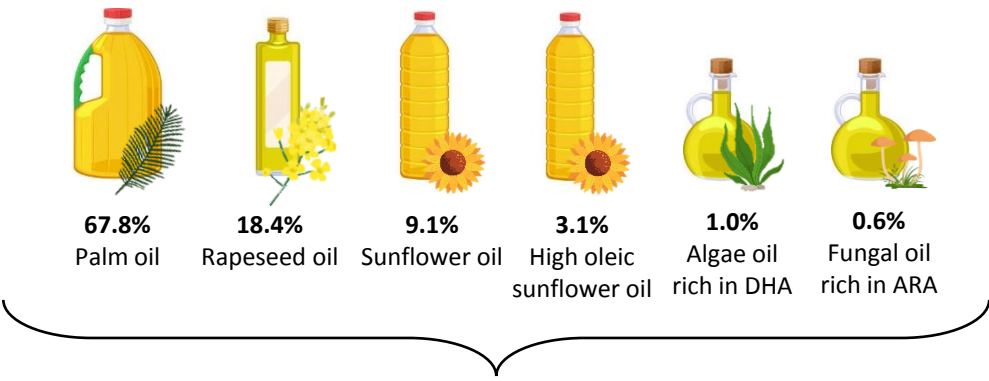
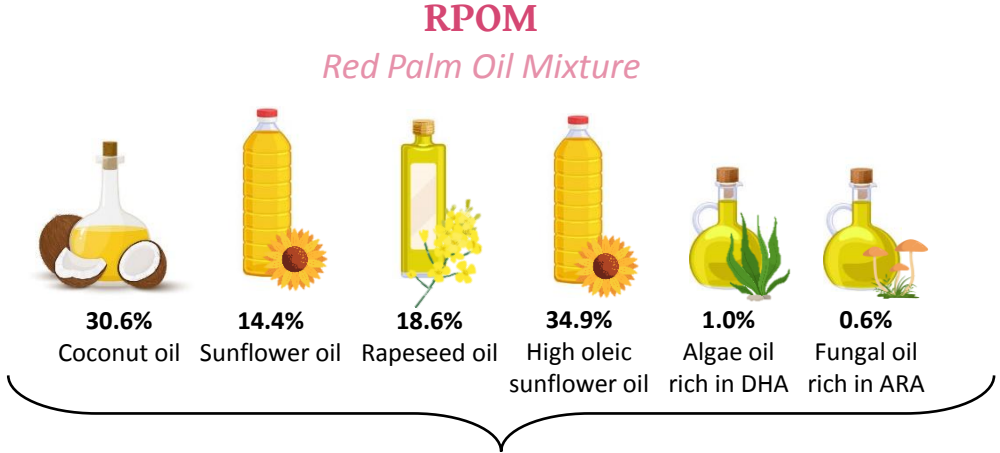
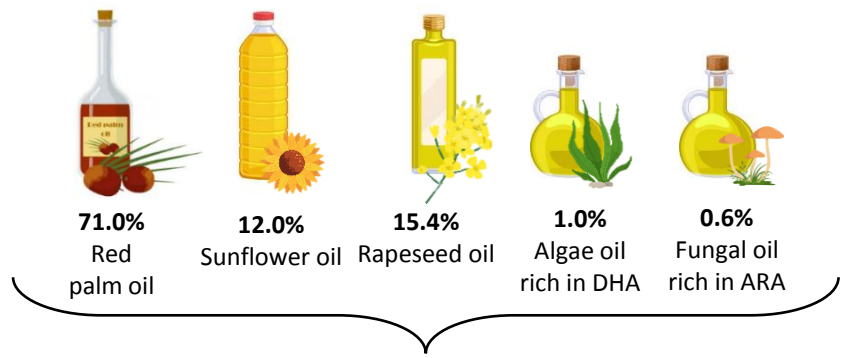
<sup>3</sup>Commission Delegated Regulation (EU) 2016/127, September 25, 2015

# 2. FORMULATION OF MODEL IFF

## Objective

SFA (g)	33.3
MUFA (g)	45.5
PUFA (g)	18.2
LA (g)	15.2
ALA (g)	1.6
ARA (mg)	284.8
DHA (mg)	448.5

Normalization  
of the fatty  
acid profile

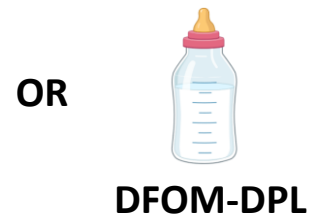
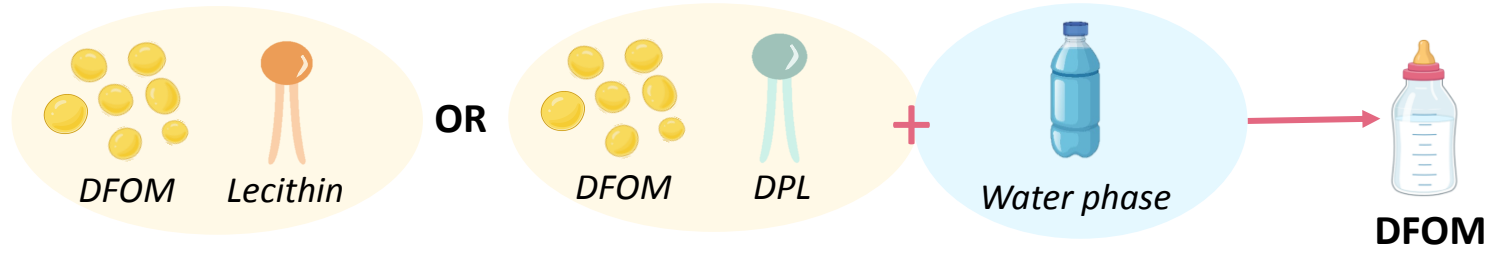
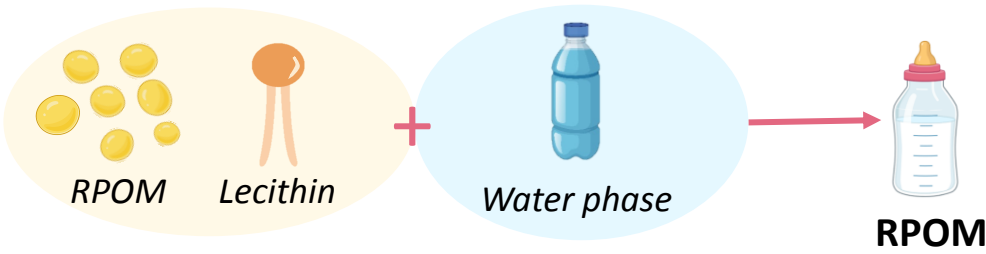
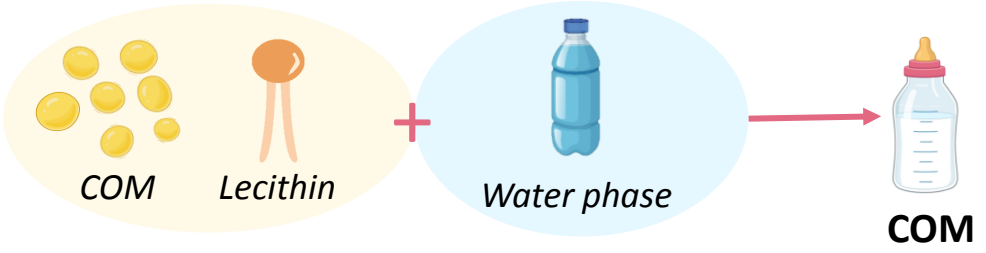
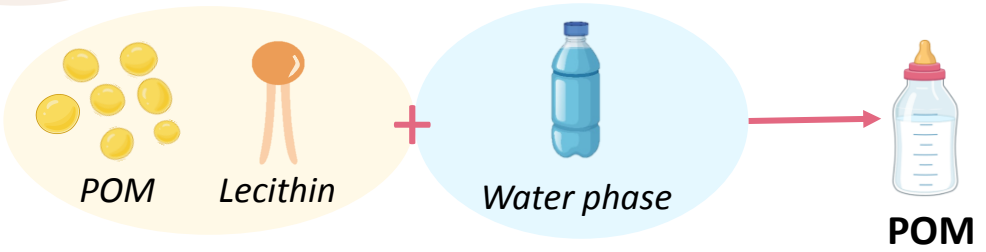


**POM**  
Palm Oil Mixture


**DFOM**  
Dairy Fat Oil Mixture







# 2. FORMULATION OF MODEL IFF



Normalization of the mineral and vitamin contents

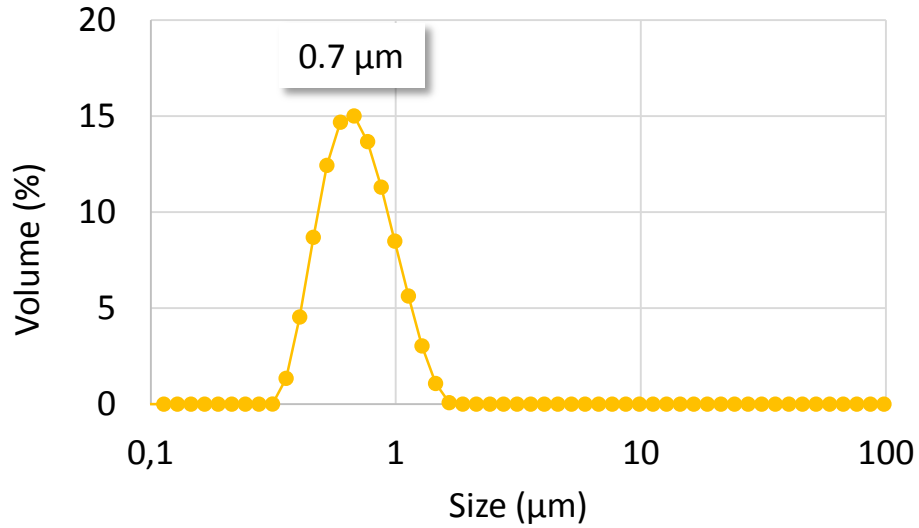


- Primary oxidation compounds - PV
- Secondary oxidation compounds - Tbars
- Vitamins A & E degradation
- Fatty acid profile evolution

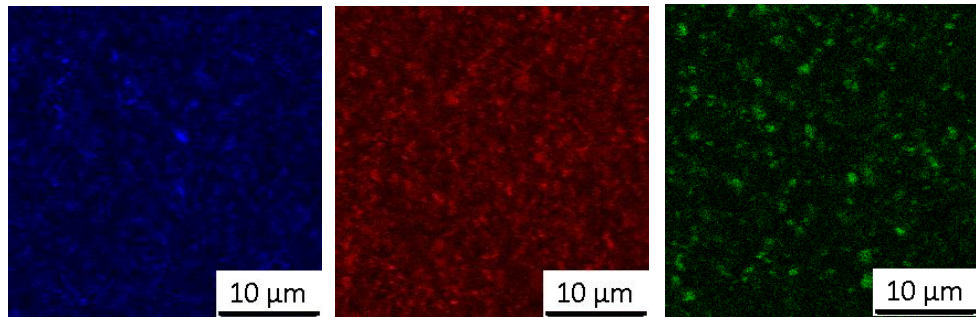
  
 20 days    
  Hermetically sealed vials    
  40°C    
  Orbital shaking

# 3. RESULTS – Physical state

Typical droplet distribution size



Confocal microscopy

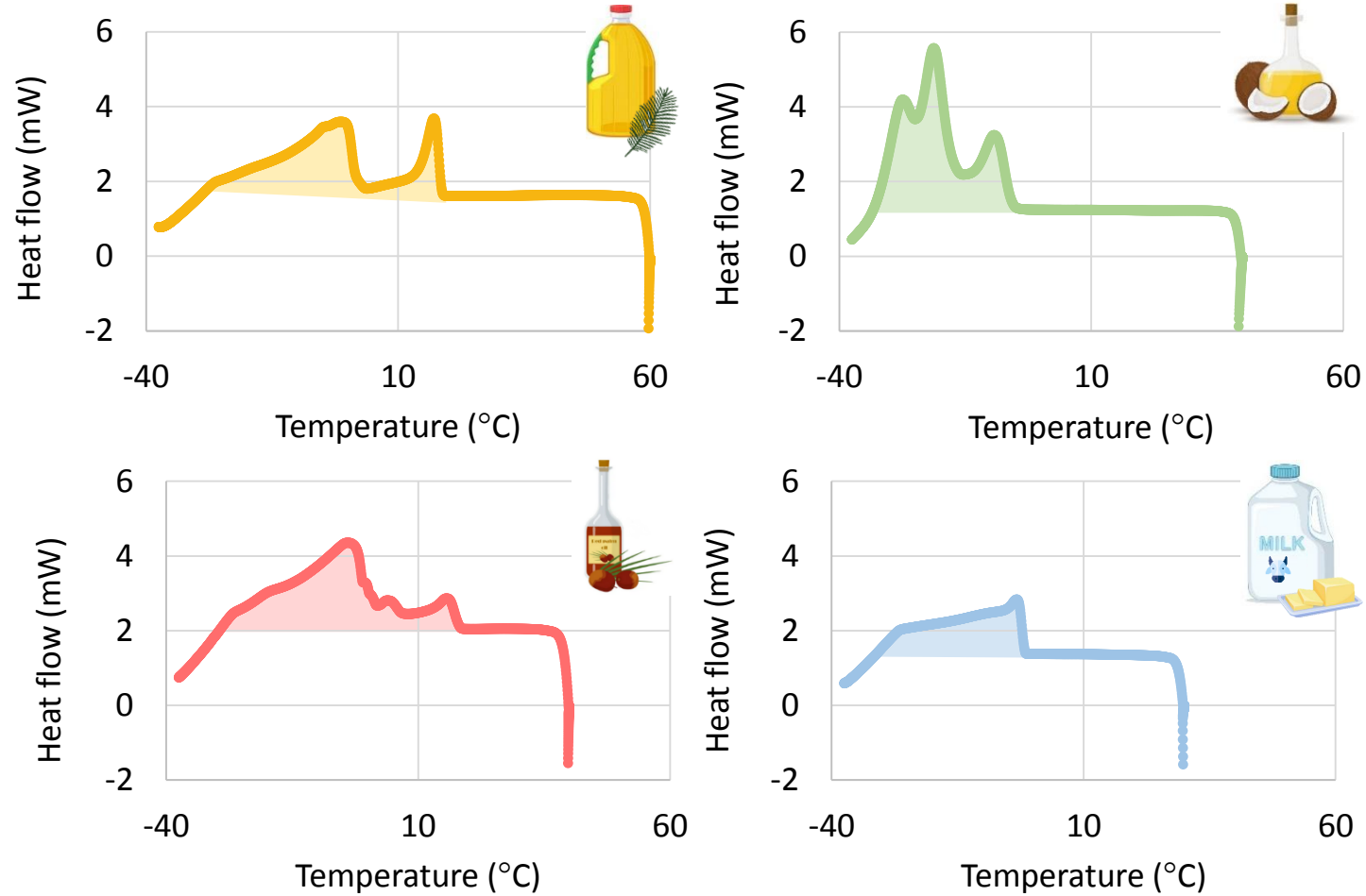


Proteins

Amphiphiles

Apolar lipids

Crystallization behavior



Depending on the used SFA source the thermogram profiles varied strongly

### 3. RESULTS - Indicators of oxidation rate among the monitored parameters

#### Statistical analysis of dataset

Using Rstudio software



Low oxidation level in the presence of AOX despite the addition of DHA and ARA

No significant evolution of the fatty acid profile and secondary oxidation compounds

Vitamin A undergoes a strong degradation according to complex mechanisms  
*No strong correlation with PV and tocopherols evolutions*

*30 to 75%  
degradation*



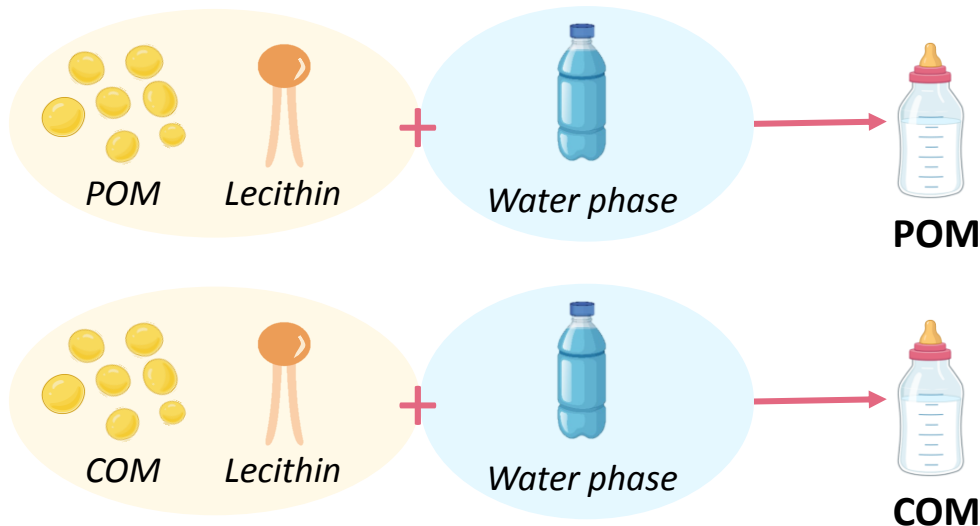
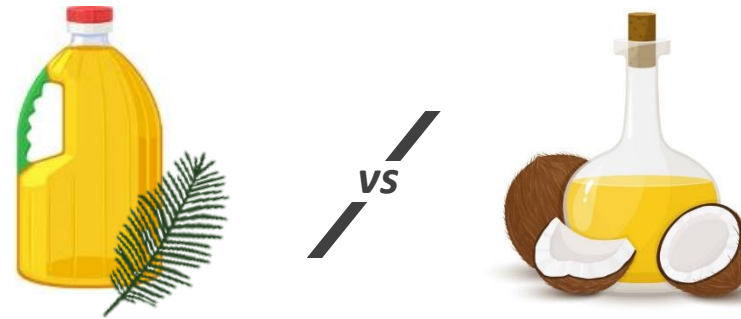
#### Descriptive indicators

- **Peroxide value evolution** - *Primary oxidation compounds*
- **Tocopherols degradation**

*Jiang et al., LWT, 2021*

# RESULTS – Impact of SFA sources on oxidative stability

## Comparison of palm and coconut oils



### Nutritional benefits

**Provides medium chain fatty acids (C12:0)**

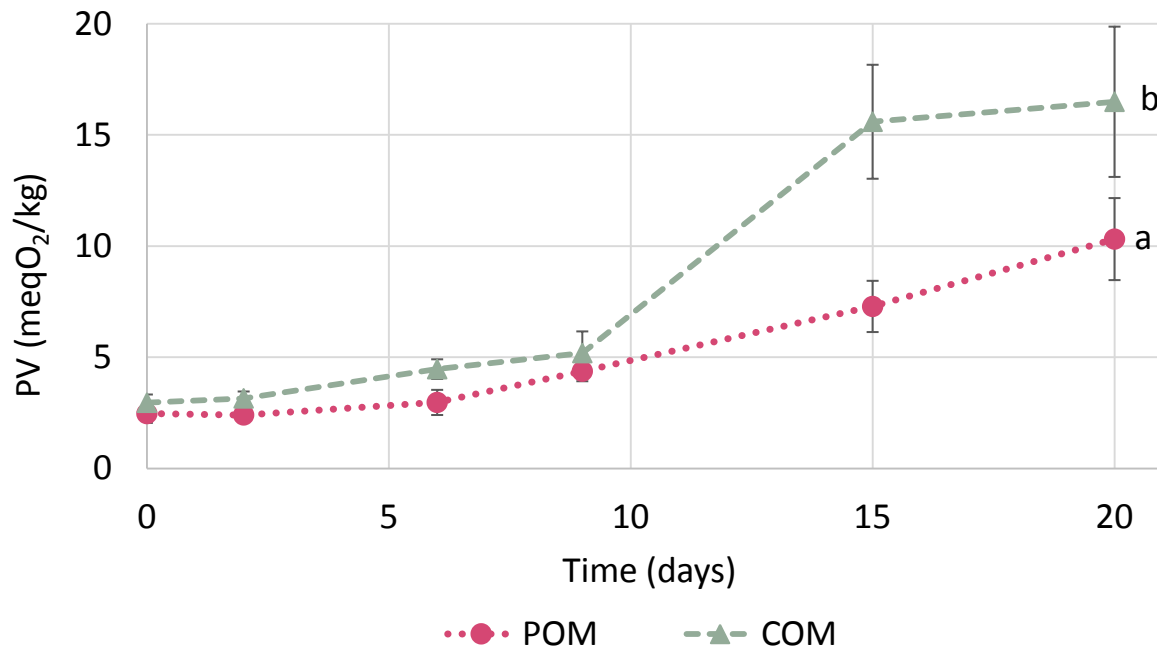
*Improves lipid digestion and metabolism*

# RESULTS – Impact of SFA sources on oxidative stability

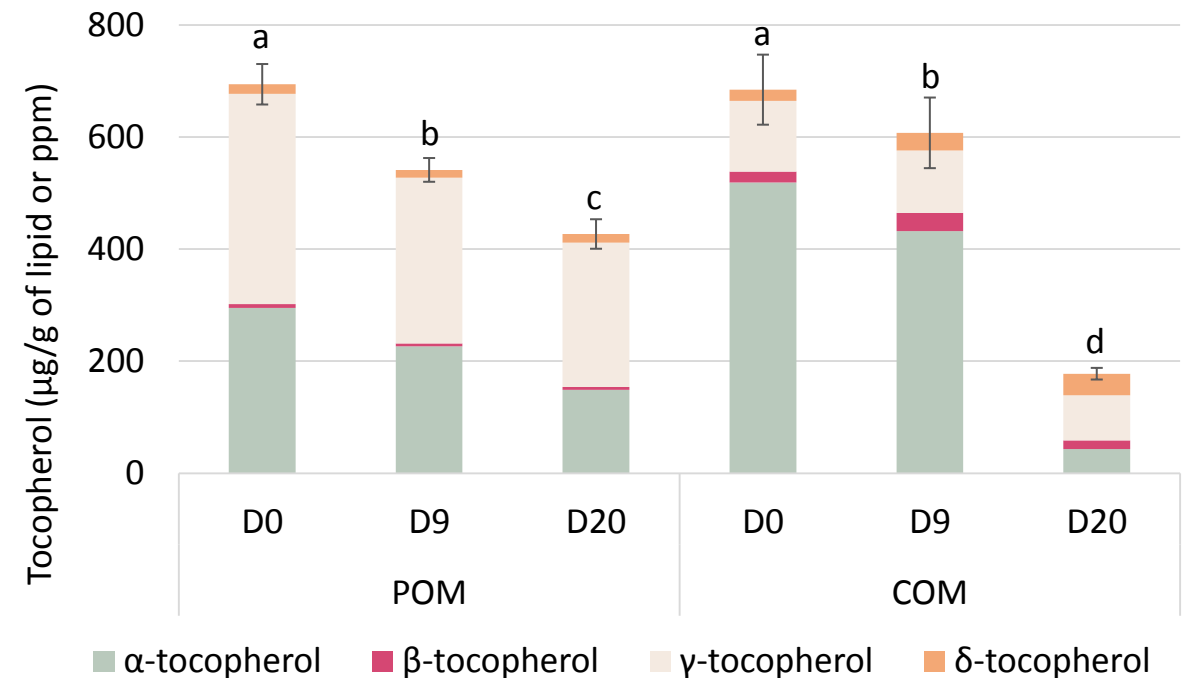
## Comparison of palm and coconut oils



### Peroxide value evolution



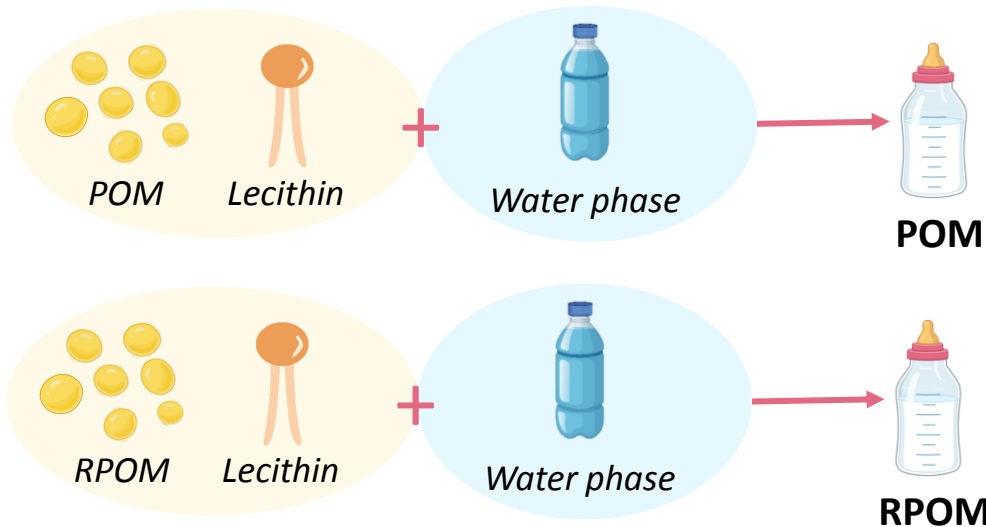
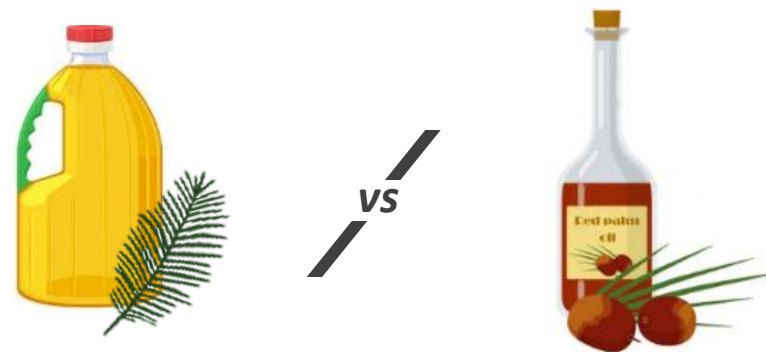
### Tocopherols isomers distribution and degradation



- Coconut oil is more adapted to the infant's nutritional needs
- The substitution of palm oil by coconut oil increases the oxidative sensitivity
- Tocopherols act as sacrificial agents – Isomer content impact the oxidation kinetics

# RESULTS – Impact of SFA sources on oxidative stability

## Comparison of palm and red palm oils



### Nutritional benefits

**High amount of provitamin A carotenoids ( $\alpha$ - and  $\beta$ -carotenoids) and tocotrienols**

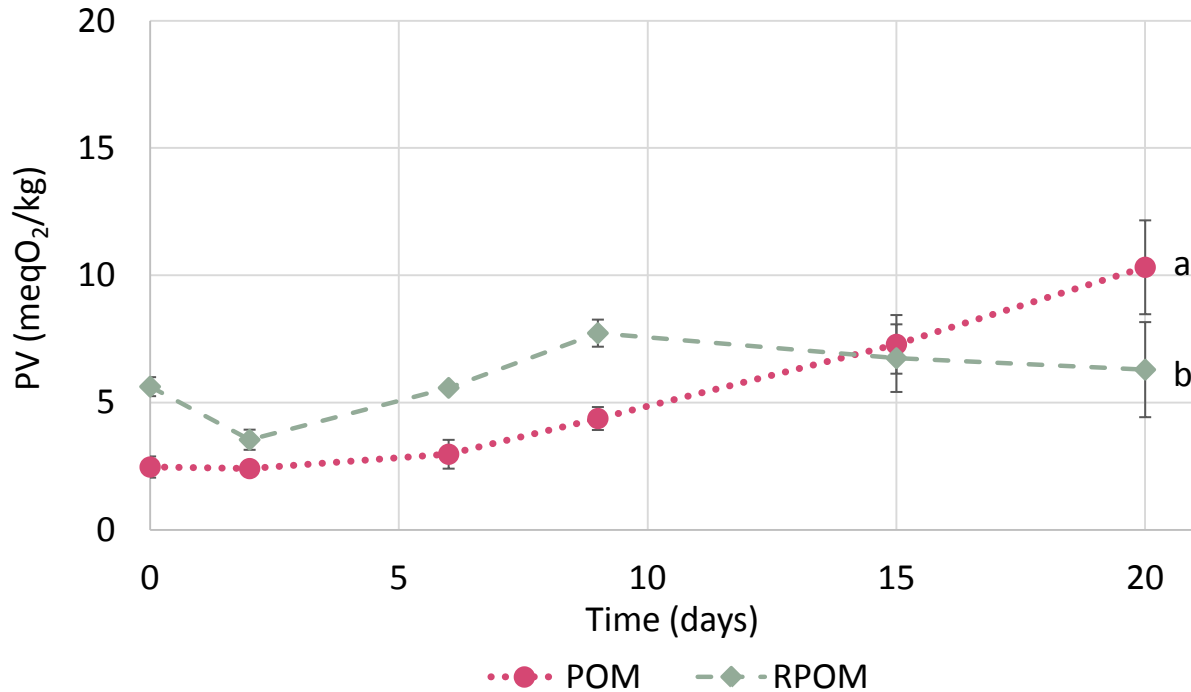
*Effective strategy to fight against vitamin A deficiency disease especially for infant and lactating women in developing countries*

# RESULTS – Impact of SFA sources on oxidative stability

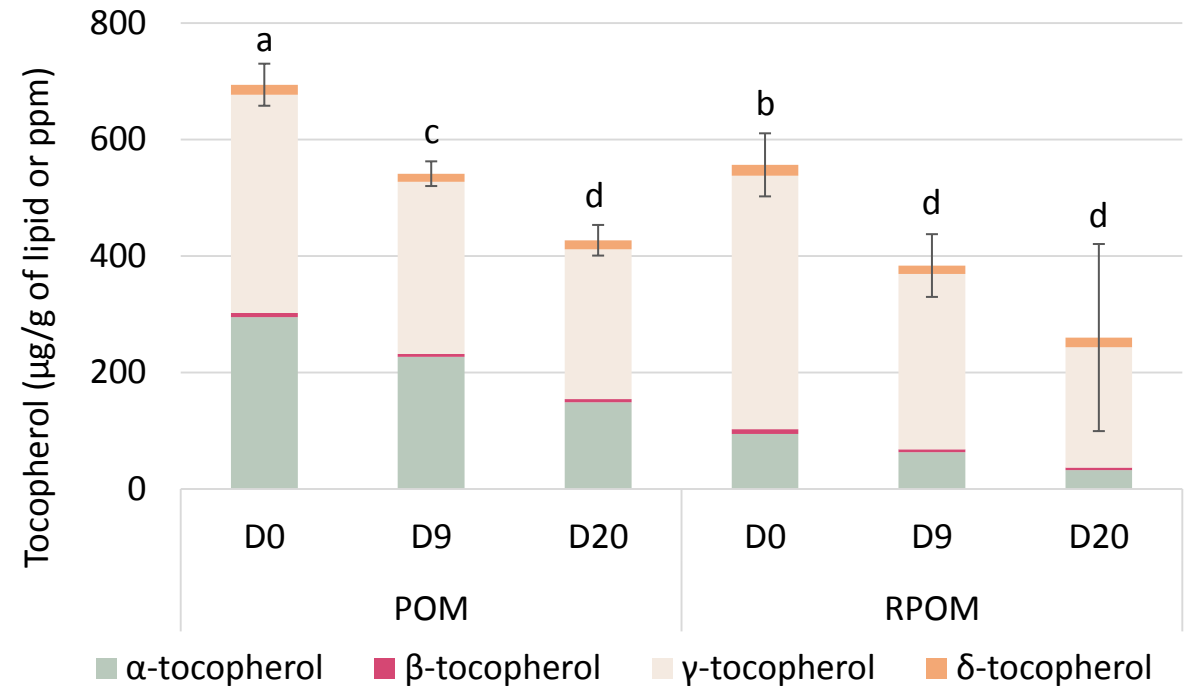
## Comparison of palm and red palm oils



### Peroxide value evolution



### Tocopherols isomers distribution and degradation

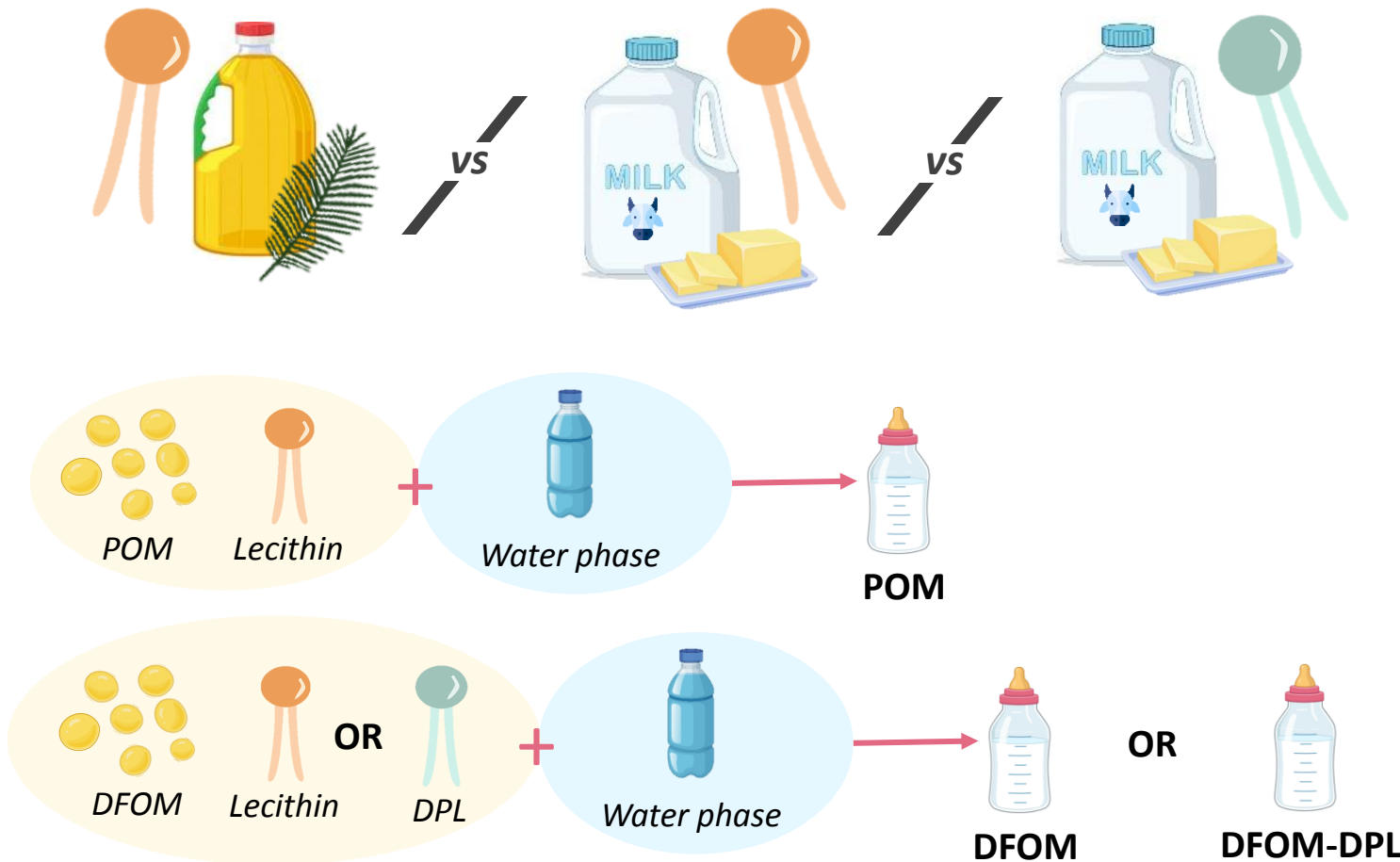


- **The substitution of palm oil by red palm oil improve the oxidative resistance**  
*Due to its carotenoids and tocotrienols content*

↘ *Regeneration of tocopherols*

# RESULTS – Impact of SFA sources on oxidative stability

## Comparison of palm oil and dairy fat with soy lecithin or DPL



### Nutritional benefits

#### **More diversified fatty acid profile**

*Provides short and medium saturated chains*

#### **Particular organization of fatty acids on the TAG backbone**

*Better lipidic absorption by avoiding the formation of insoluble soaps*

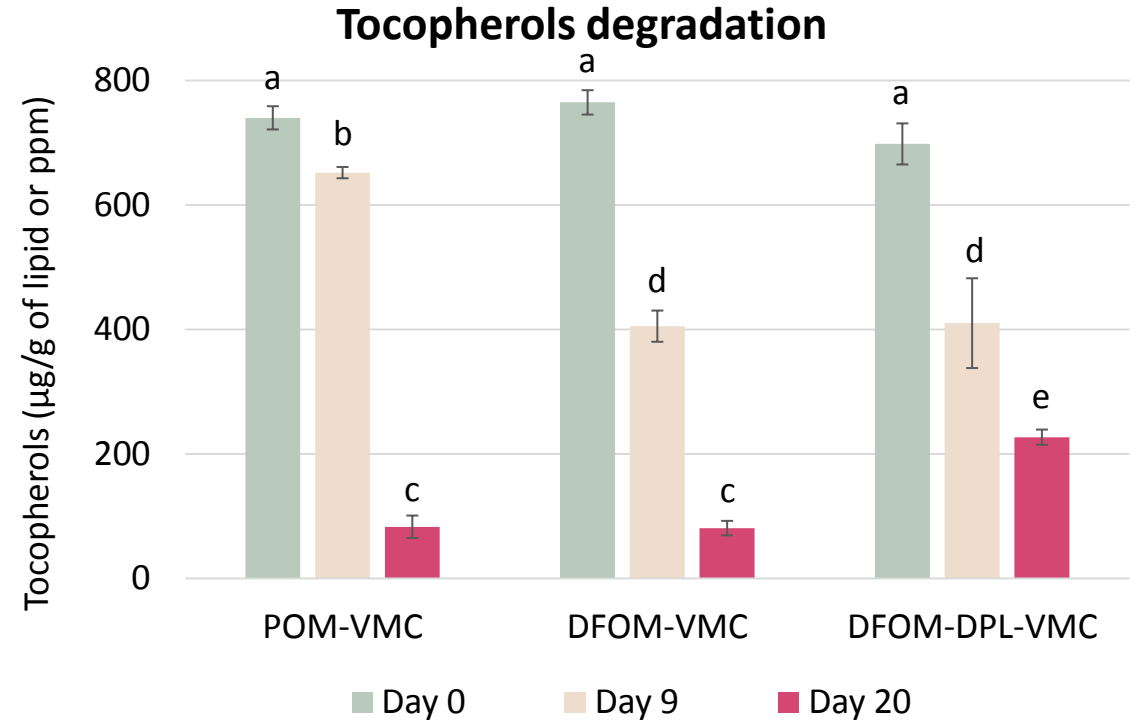
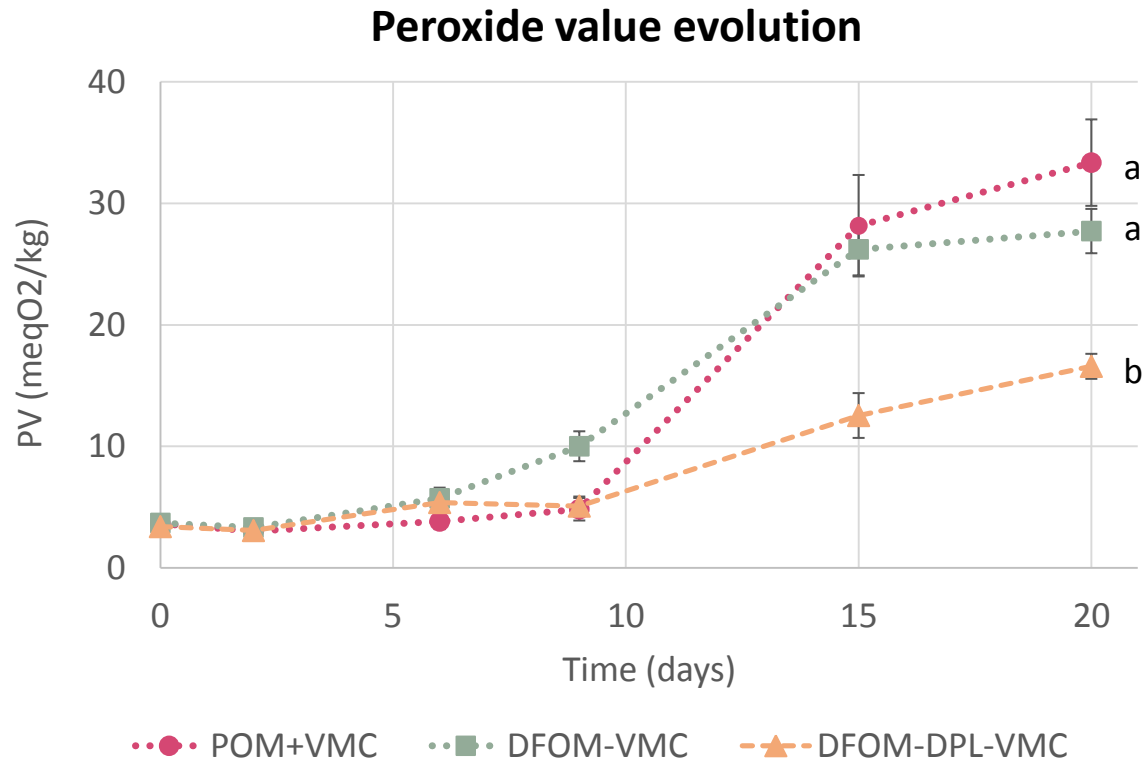
#### **Provides different PL species like SM and very long saturated chains**

*Formation of rigid domains at the interface*



# RESULTS – Impact of SFA sources on oxidative stability

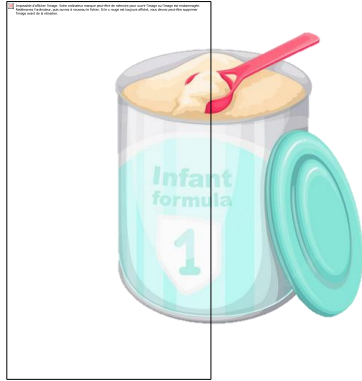
## Comparison of palm oil and dairy fat with soy lecithin or DPL



- Dairy fat is more adapted to the infant's nutritional needs
  - The substitution of palm oil by dairy fat results in a similar oxidative stability resistance
- The combined use of dairy fat and dairy phospholipids improves the oxidative resistance**

# CONCLUSION

## TAKE HOME MESSAGES



**Higher Inclusion of carotenoids and dairy lipids in infant formulas would improve both nutritional profile and oxidative stability**



**Balanced with other formulation or technological solutions**

*Balance between stability and nutritional profile to meet the infant nutritional needs*

**Protein sources**  
*Addition of dairy proteins*

**Pro-oxidant metals**  
*Iron fortification*

**Packaging**  
*Inert atm  
AOX packaging*

*Zou et al., Food Chem, 2015  
Jia et al. Cyta-J Food, 2019  
Wang et al., Food Sci Nutr, 2020  
Jo et al., Food Packag, 2020*



*International Society for the  
Study of Fatty Acids and Lipids*

# Thank you for your attention

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*Any questions ?*

INRAE

cirad

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UMR QualiSud

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