



Does replacing palm oil in follow-on formulas with other sources of saturated fat provide a better nutritional profile without affecting oxidative stability?

Thèse de doctorat - 2<sup>ème</sup> année

Étude des mécanismes de l'oxydation lipidique et des antioxydants dans les matrices alimentaires complexes en vue d'en améliorer la stabilité : Exemples des formules et farines infantiles enrichies en acides gras polyinsaturés

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Biodiversité  
Agriculture  
Alimentation  
Environnement  
Terre  
Eau



# Context

**Significant growth and development**



**1000 day period**

*Martorell, Am. J. Hum. Bio, 2017*

**Cognitive development**

*Willatts and Forsyth, Prostaglandins Leukot. Essent. Fatty Acids, 2000*  
*Cusick and Georgieff, J Pediatr, 2016*

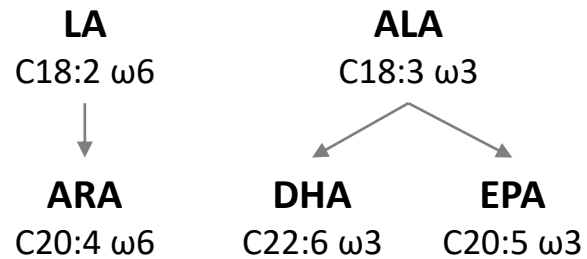
**Specific nutritional requirements**



**Dominant energy provider**  
(~45-55% of total energy)

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

**Essential fatty acids:**



*Innis, Adv Nutr J., 2011*

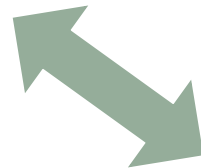
*Agostoni, J. Pediatr. Gastroenterol. Nutr., 2008*

**Fortification of infant products with LC-PUFA**



**New European regulation**  
Requires DHA supplementation of follow-on formulas

*European regulation 2016/127/EC*



## Recent regulatory changes

*Entry into force in February 2020*

- ✓ Reduced protein content  
*To limit the risk of developing overweight in adulthood*
- ✓ Changes to the threshold values for certain vitamins and minerals
- ✓ 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*)

**Fortification of infant products with LC-PUFA**



### **New European regulation**

Requires DHA supplementation of follow-on formulas

*European regulation 2016/127/EC*



**Sensitive to the lipid oxidation**

# Context

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Significant  
growth and  
development



Specific  
nutritional  
requirements



Fortification of  
infant products  
with LC-PUFA



Research question:

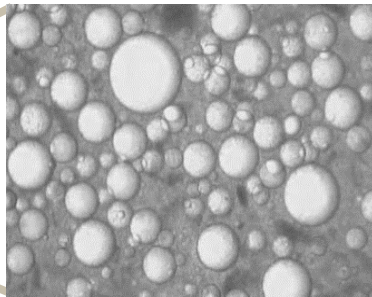
**What are the key physico-chemical levers that must be regulated to protect enriched in LC-PUFA dispersed systems from oxidation while maintaining acceptable bioaccessibility of LC-PUFA ?**

# Context

## Follow-on formulas



Oil-in-Water emulsion



### Oil phase

Mixtures of oils mainly of vegetable origin  
*Palm, coconut, sunflower and rapeseed oils*



Fatty acid profile not adapted to the infant's nutritional needs

### Research question:

**Does replacing palm oil with other saturated fat sources provide a better nutritional profile without affecting oxidative stability?**

# Material and methods

1. Setting an overview of marketed follow-on formulas

2. Determination of representative target nutritional values

3. Formulation of model systems representative of marketed follow-on formulas

4. Declination into a range of modalities depending on the saturated fat sources

## Oil mixture 1



- 63.2% **Palm oil**
- 9.2% Sunflower oil
- 10.7% Oleic sunflower oil
- 13.7% Rapeseed oil
- 2.3% Cod liver oil
- 0.9% ARA oil

## Oil mixture 2



- 32.4% **Coconut oil**
- 14.9% Sunflower oil
- 36.2% Oleic sunflower oil
- 13.3% Rapeseed oil
- 2.3% Cod liver oil
- 0.9% ARA oil

## Oil mixture 3



- 52.1% **Dairy fat**
- 18.0% Sunflower oil
- 18.5% Oleic sunflower oil
- 8.2% Rapeseed oil
- 2.3% Cod liver oil
- 0.9% ARA oil

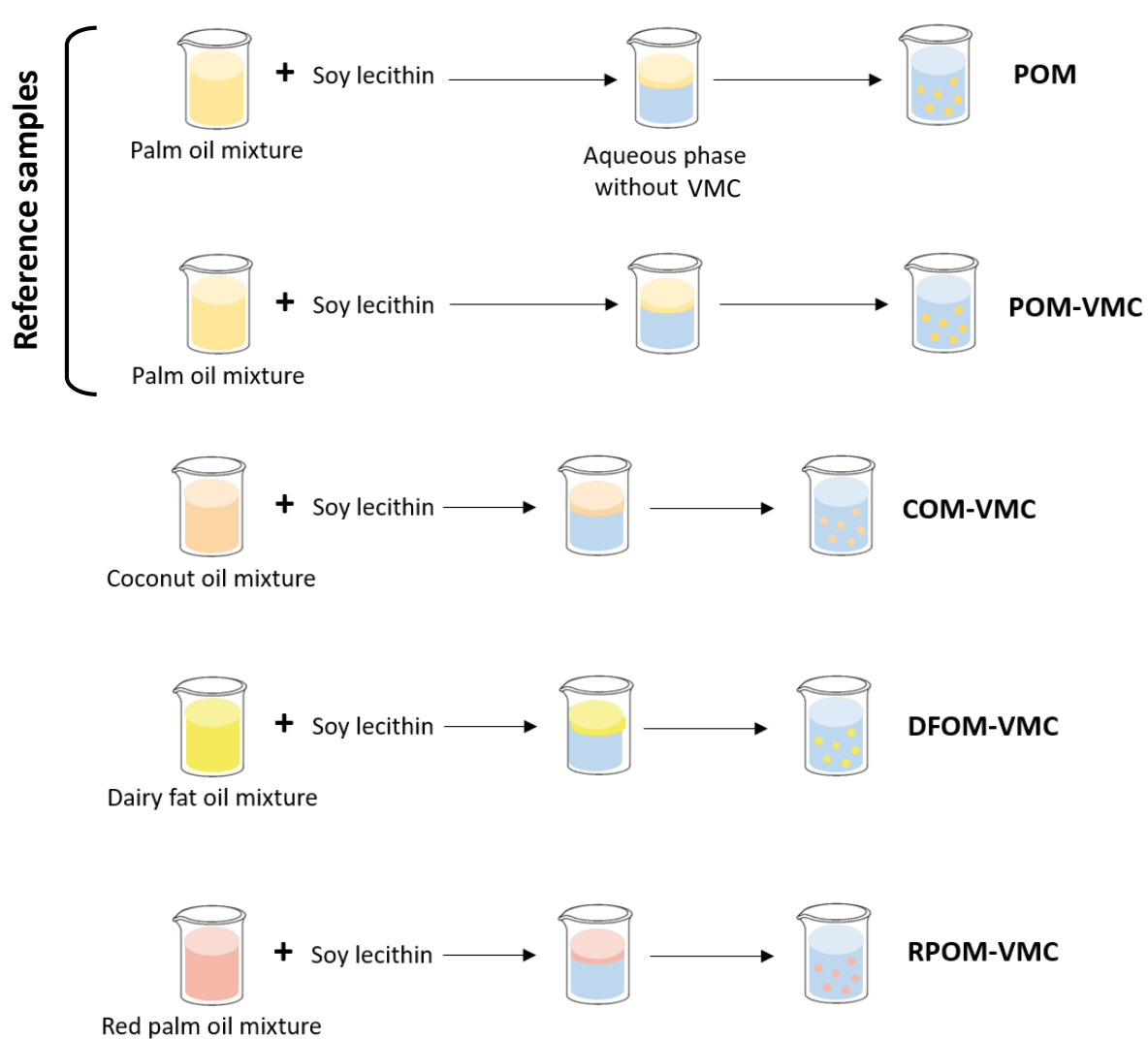
## Oil mixture 4



- 67.7% **Red palm oil**
- 12.0% Sunflower oil
- 6.3% Oleic sunflower oil
- 10.8% Rapeseed oil
- 2.3% Cod liver oil
- 0.9% ARA oil

	Objective	Oil mixture 1	Oil mixture 2	Oil mixture 3	Oil mixture 4
<b>SFA (g)</b>	33.3	33.3	36.3	33.3	33.3
<b>MUFA (g)</b>	45.5	48.5	45.5	49.1	48.5
<b>PUFA (g)</b>	18.2	18.2	18.2	18.2	18.2
<b>LA (g)</b>	15.2	15.2	15.2	15.2	15.2
<b>ALA (g)</b>	1.6	1.6	1.6	1.7	1.6
<b>ARA (mg)</b>	284.8	289.2	289.2	289.2	289.2
<b>DHA (mg)</b>	448.5	468.4	468.4	468.4	468.4

# Material and methods



- **POM:** Reference sample with palm oil mixture without VMC
- **POM-VMC:** Reference sample with palm oil mixture enriched with VMC
- **COM-VMC:** Sample based on coconut oil mixture enriched with VMC
- **DFOM-VMC:** Sample based on dairy fat oil mixture enriched with VMC
- **RPOM-VMC:** Sample based on red palm oil mixture enriched with VMC



20 days



Closed amber vials



40 or 25°C



Orbital shaking or no shaking

# Material and methods

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1. Setting an overview of marketed follow-on formulas

2. Determination of representative target nutritional values

3. Formulation of model systems representative of marketed follow-on formulas

4. Declination into a range of modalities depending on the saturated fat sources

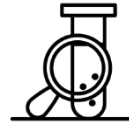
5. Normalization of vitamin A & E contents

## Vitamins normalization

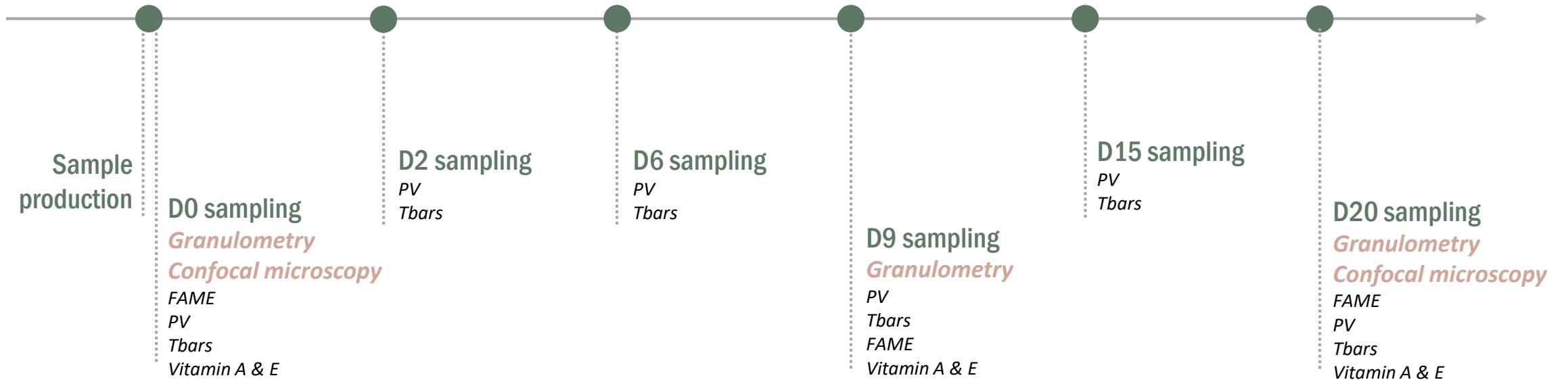
- **Addition of a vitamin and mineral complement** made of:
  - Vitamin A
  - Vitamin D
  - Vitamin C
  - Iron sulfate
- **Normalization of vitamin A & E contents** by adding retinol and  $\alpha$ -tocopherol



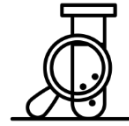
# Material and methods



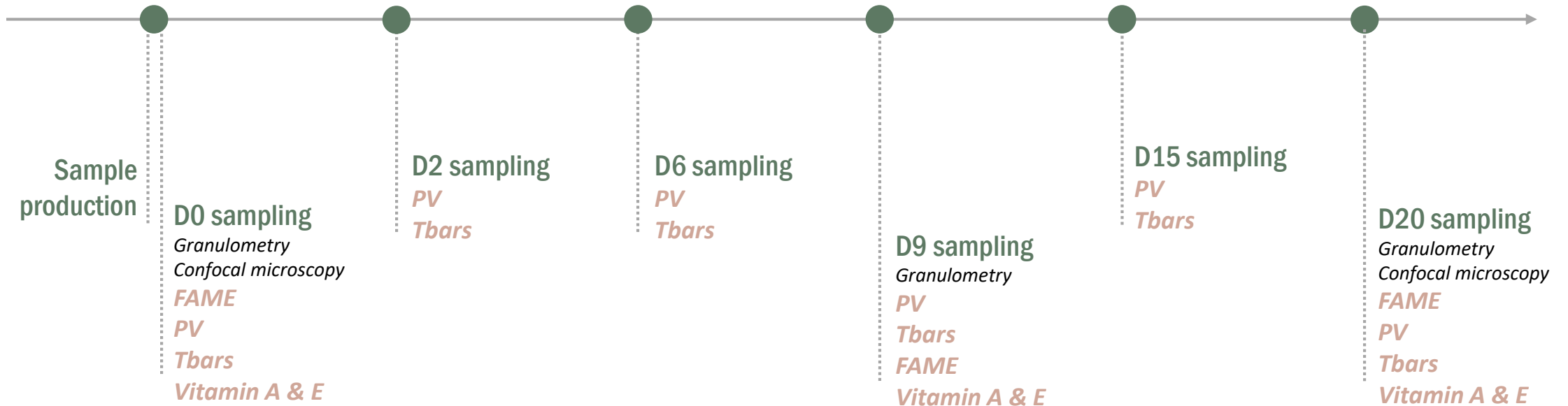
## Physical stability analysis



# Material and methods



## Chemical stability analysis



# Results and discussion

## 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 tbars

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

**The whole dataset is needed to explain the oxidation kinetics but statistical analysis shows that the most descriptive indicators are the PV and Toco**

	ALA	ARA	DHA	LA	PV	Tbars	Toco	Vit A
ALA	1.0000	0.3398	0.2002	0.5117	0.0161	-0.0201	-0.0011	0.4336
ARA	0.3398	1.0000	0.3748	0.6846	0.3556	0.2820	-0.0749	0.4455
DHA	0.2002	0.3748	1.0000	0.5483	-0.0888	-0.1530	0.2809	0.4724
LA	0.5117	0.6846	0.5483	1.0000	0.3393	0.2654	-0.1575	0.4359
PV	0.0161	0.3556	-0.0888	0.3393	1.0000	0.7456	<b>-0.8158</b>	-0.2806
Tbars	-0.0201	0.2820	-0.1530	0.2654	0.7456	1.0000	-0.8640	-0.3913
Toco	-0.0011	-0.0749	0.2809	-0.1575	<b>-0.8158</b>	-0.8640	1.0000	0.5039
Vit A	0.4336	0.4455	0.4724	0.4359	-0.2806	-0.3913	0.5039	1.0000

# Results and discussion

Fatty acid profile at D0

## Target values (%)

SFA	33.30
MUFA	45.50
PUFA	18.20
ALA	1.60
ARA	0.29
DHA	0.45

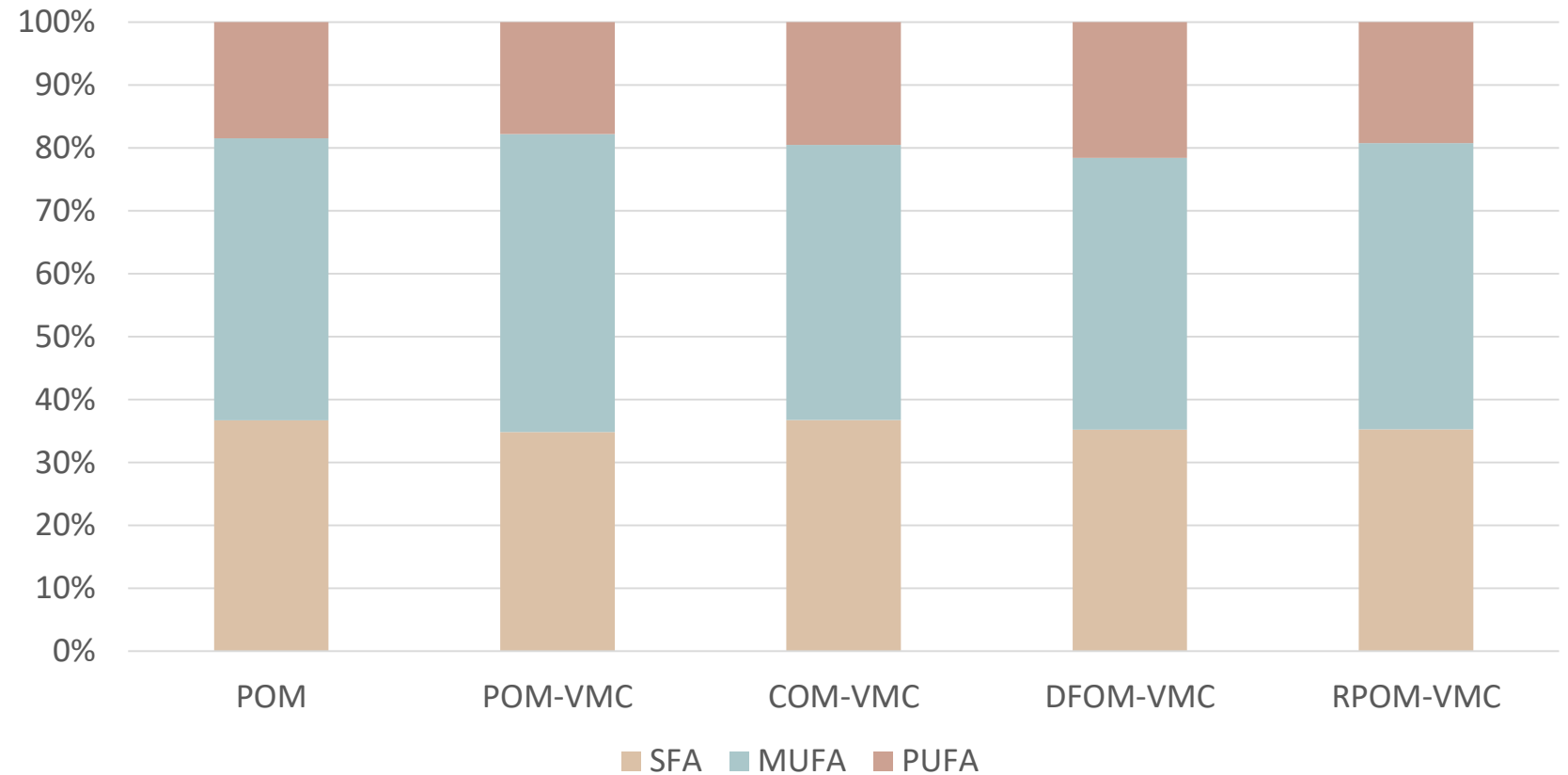
**DHA: 12 to 35 mg/100mL**

→ 0.31% = 9.92 mg/100mL

→ 0.38% = 12.16 mg/100mL

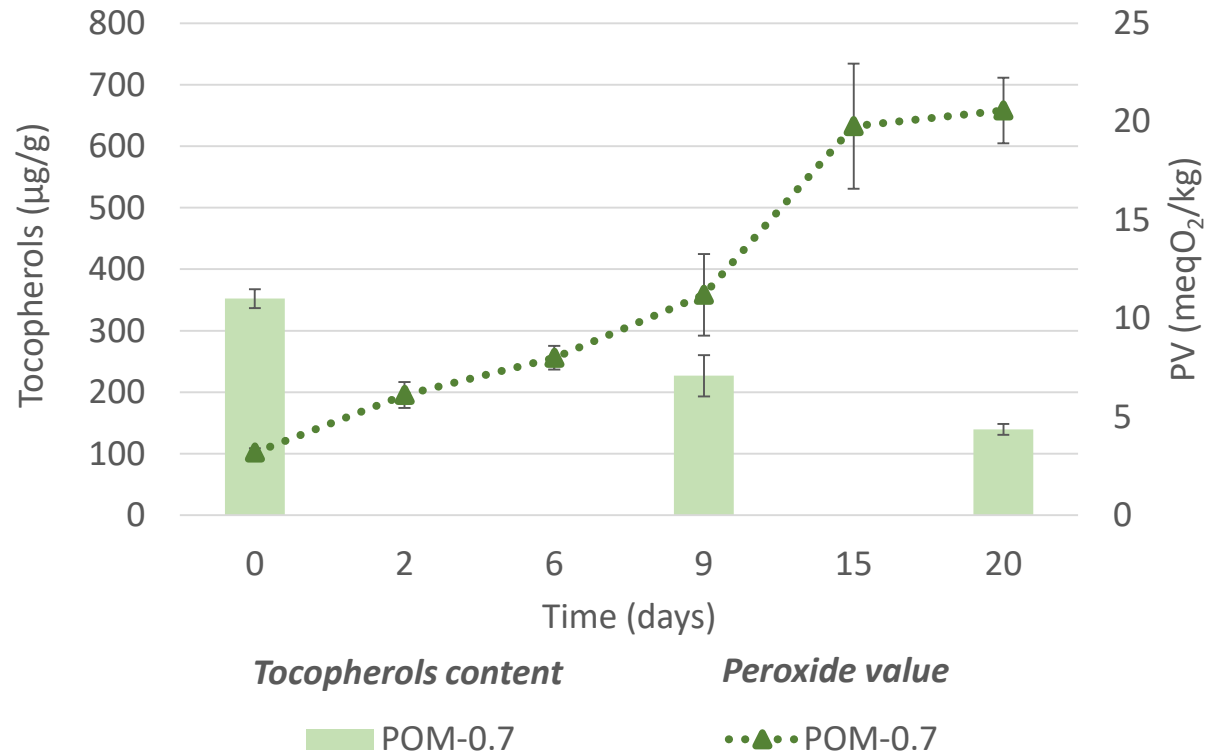
*Mean: 0.34% = 10.88 mg/100mL*

## Repartition of fatty acids contents

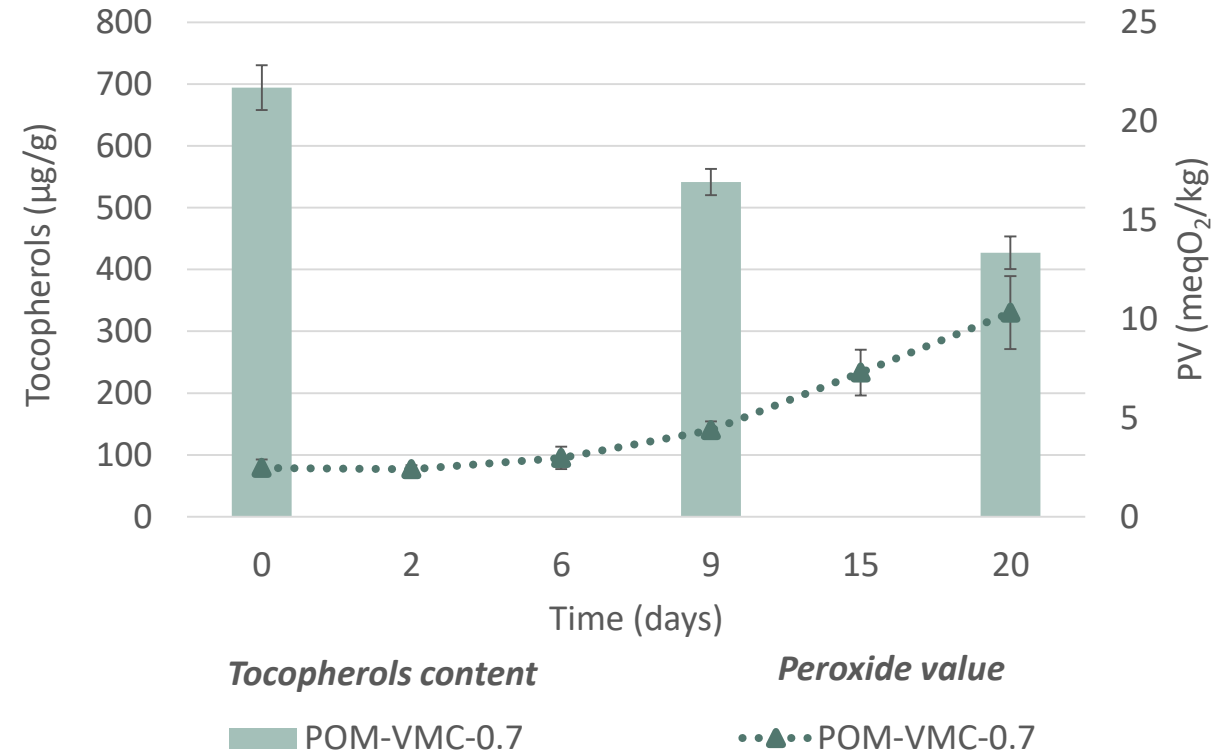


# Results and discussion

## Unenriched with VMC samples



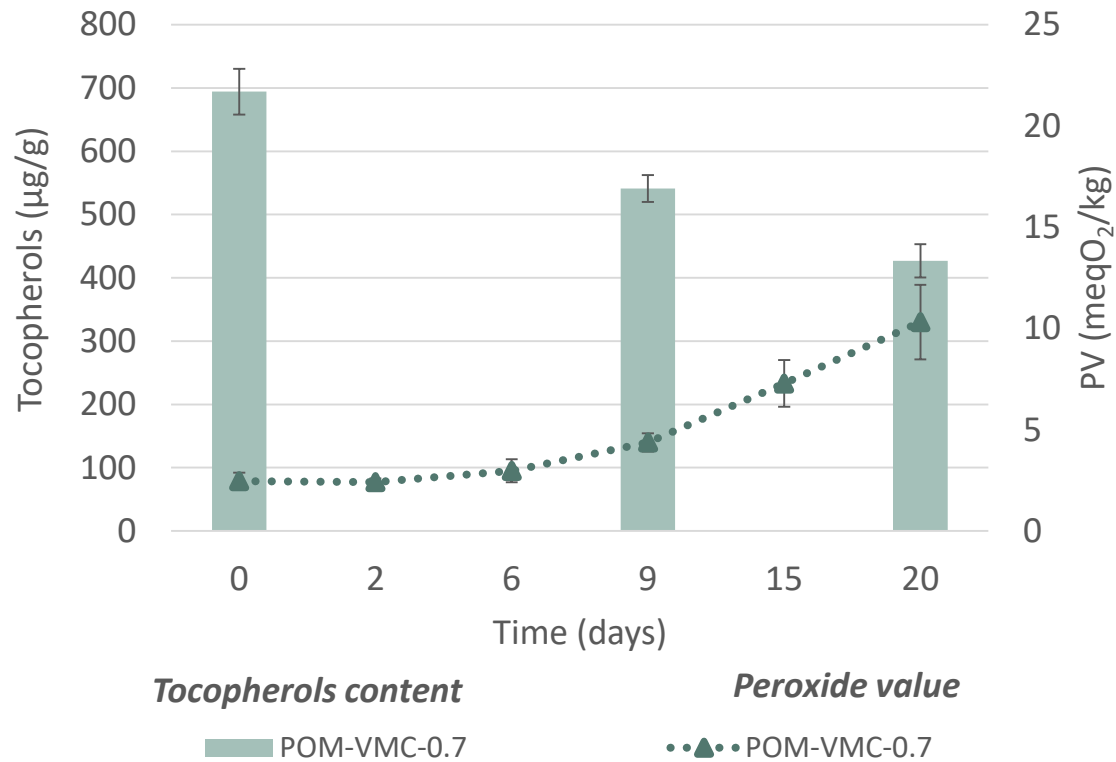
## Enriched with VMC samples



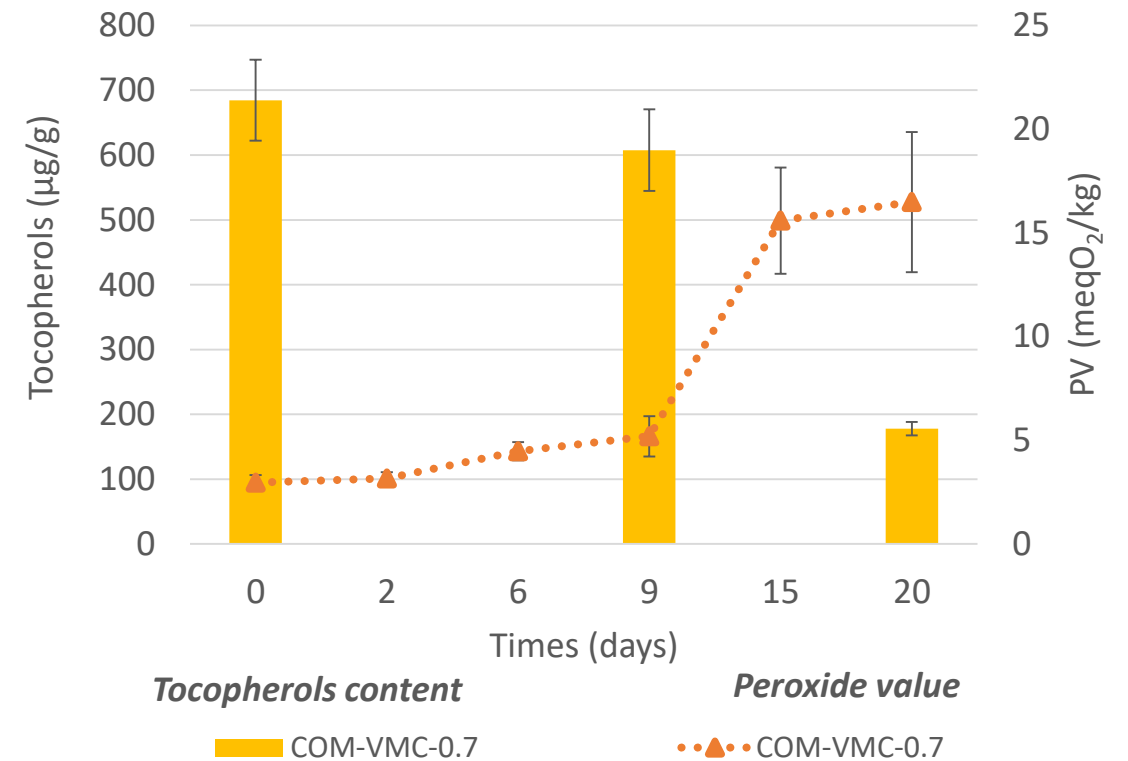
**VMC has an antioxidant effect**

# Results and discussion

## Palm oil based samples



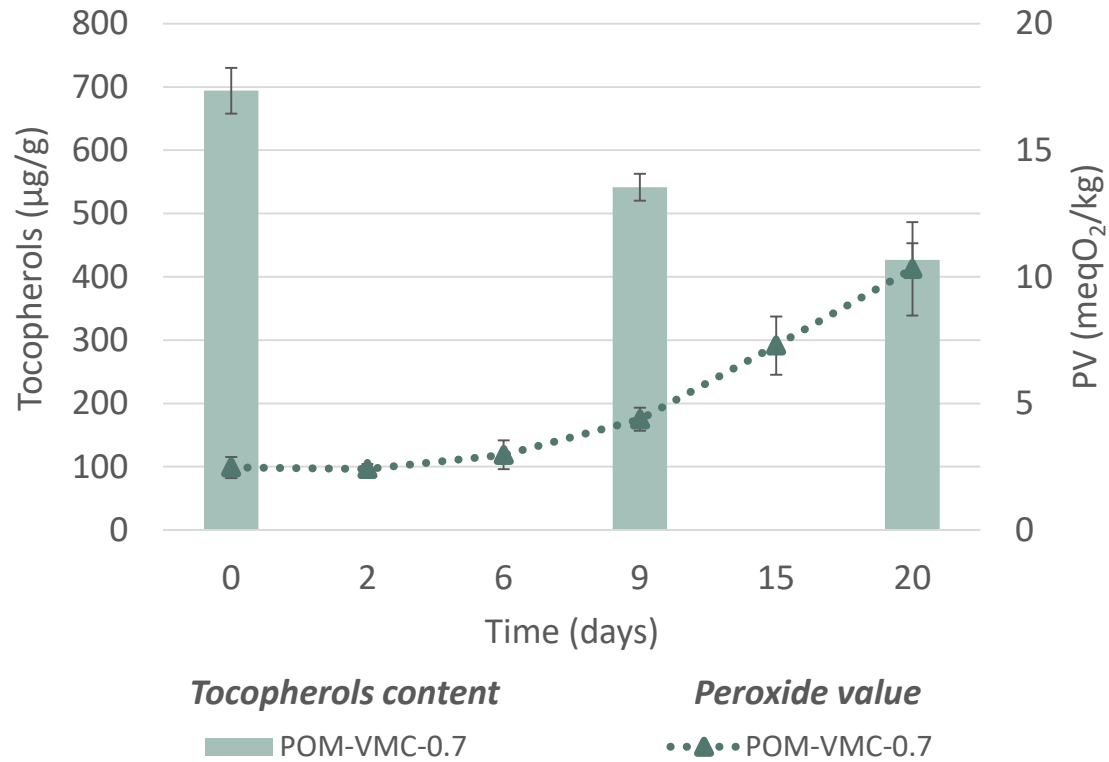
## Coconut oil based samples



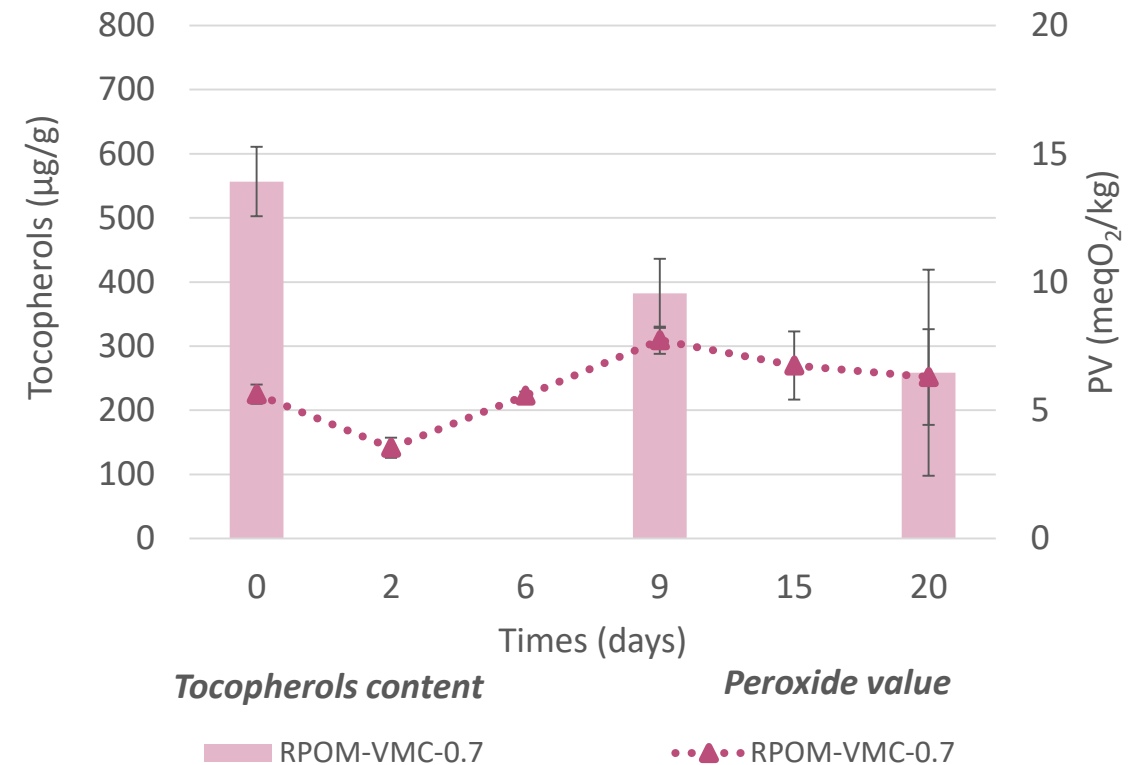
**The substitution of palm oil by coconut oil improves the fatty acid profile but decreases the lipid oxidation stability**

# Results and discussion

## Palm oil based samples



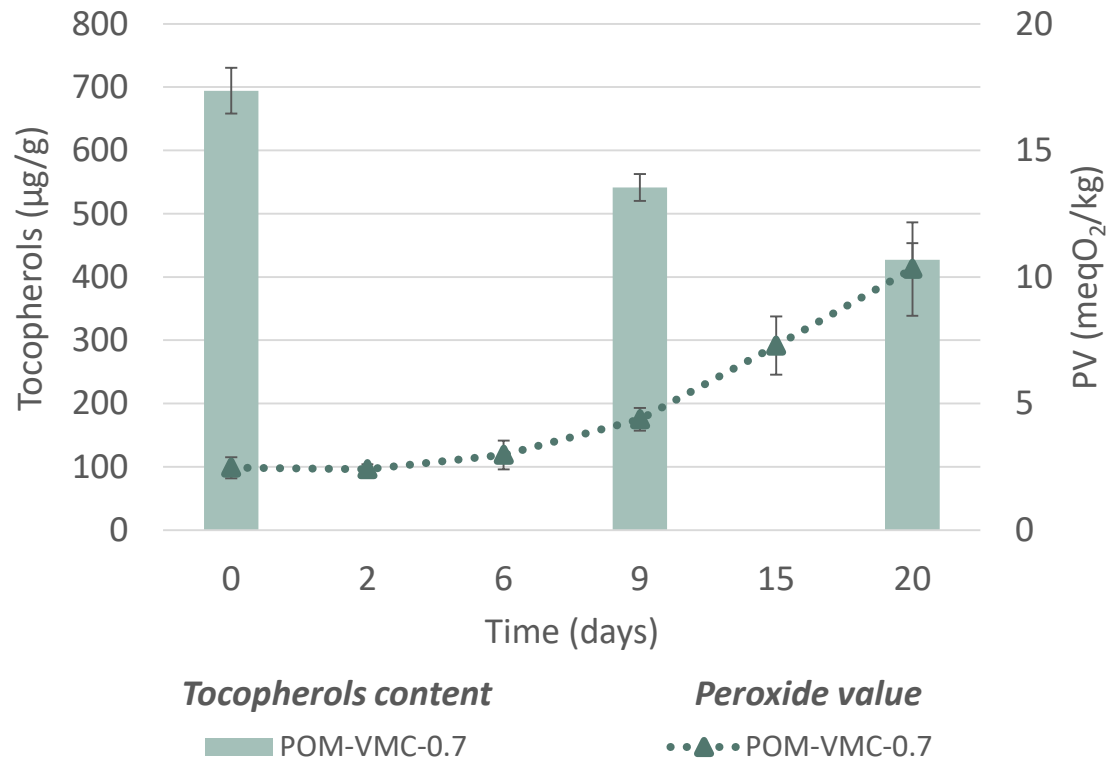
## Red palm oil based samples



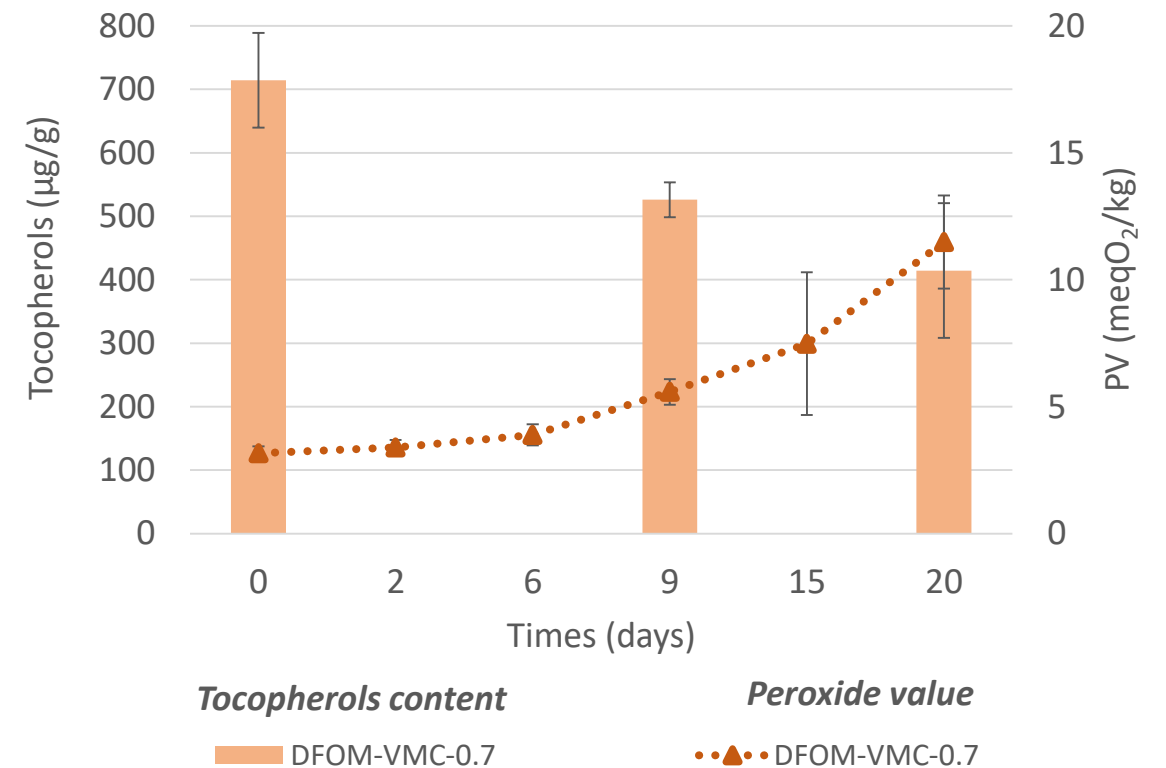
The substitution of palm oil by red palm oil has no impact on fatty acid profile but improves oxidative stability

# Results and discussion

## Palm oil based samples



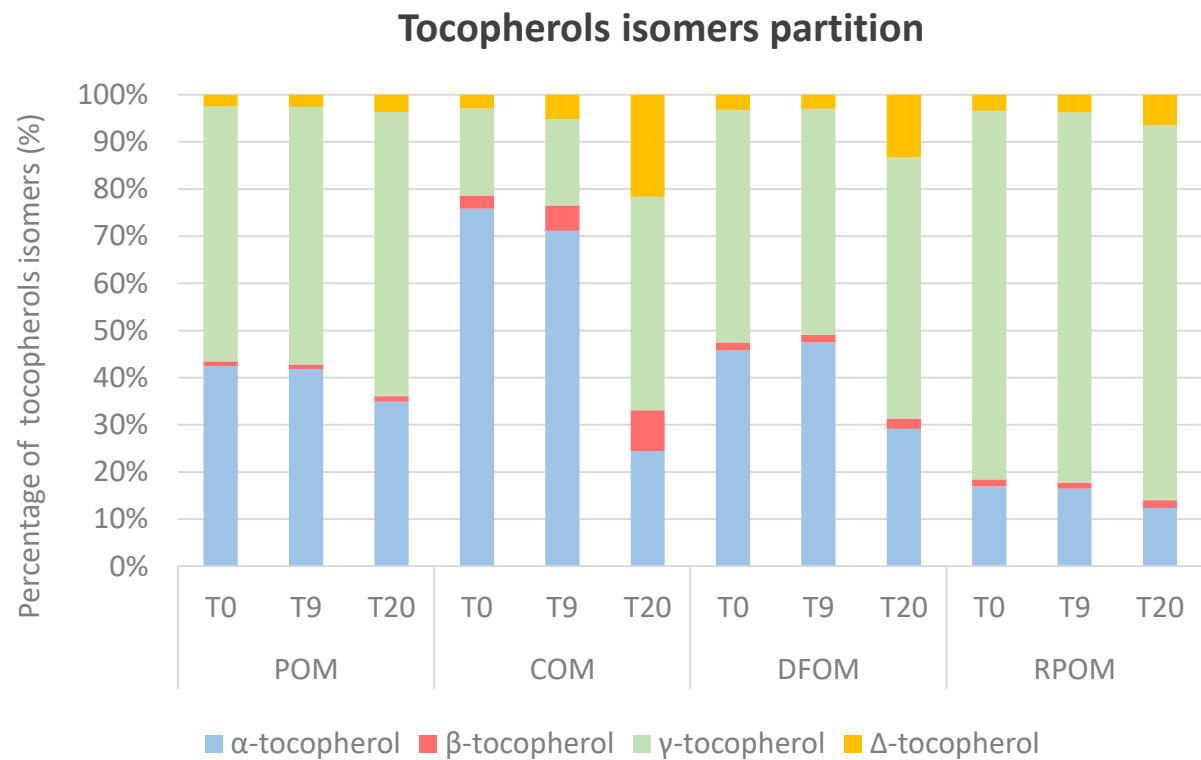
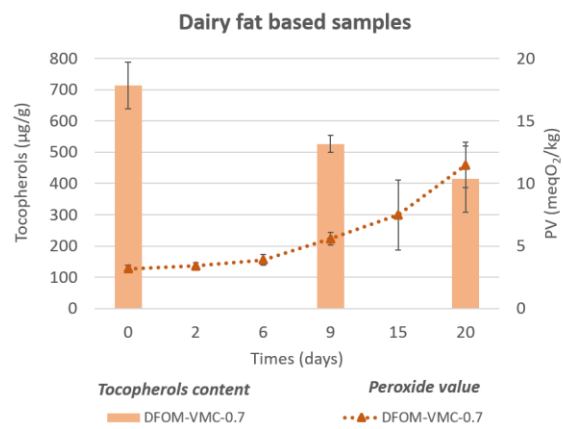
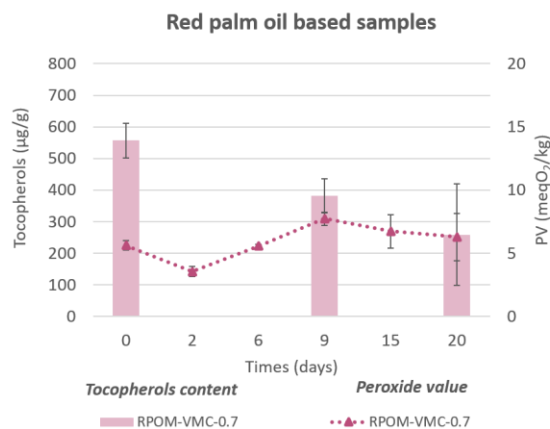
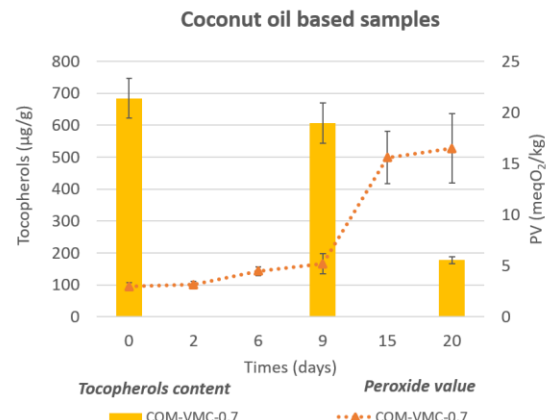
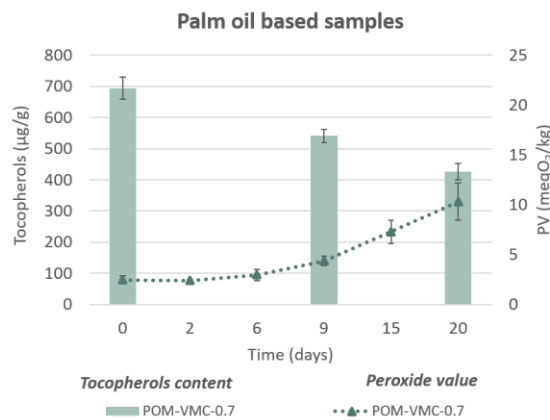
## Dairy fat based samples



**The substitution of palm oil by dairy fat improves fatty acid profile and has no impact on oxidative stability**



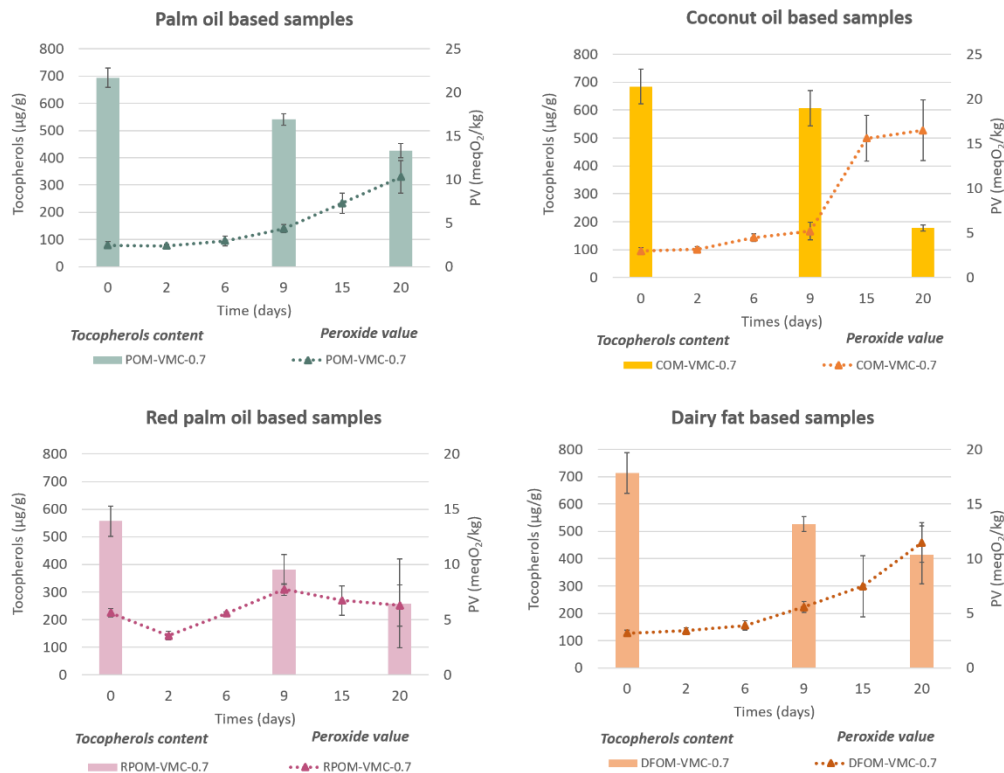
# Results and discussion



Depending on the type of tocopherol isomers the degradation kinetics are different

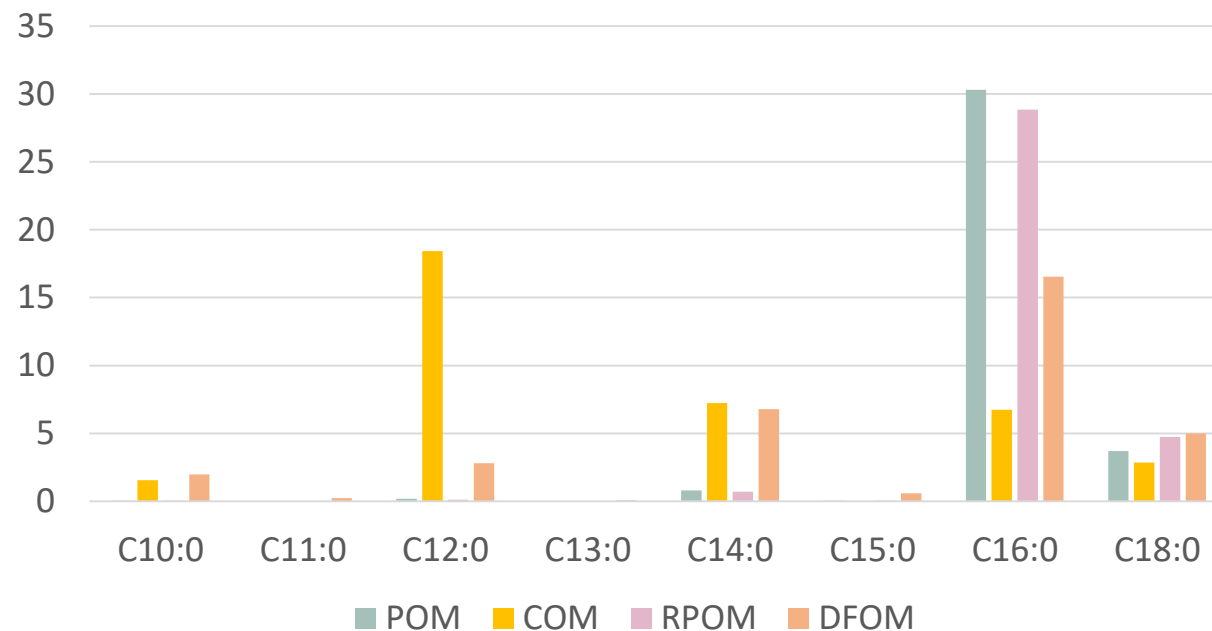
# Results and discussion

## Oxidative stability



## Nutritional properties

### Saturated fatty acid profile



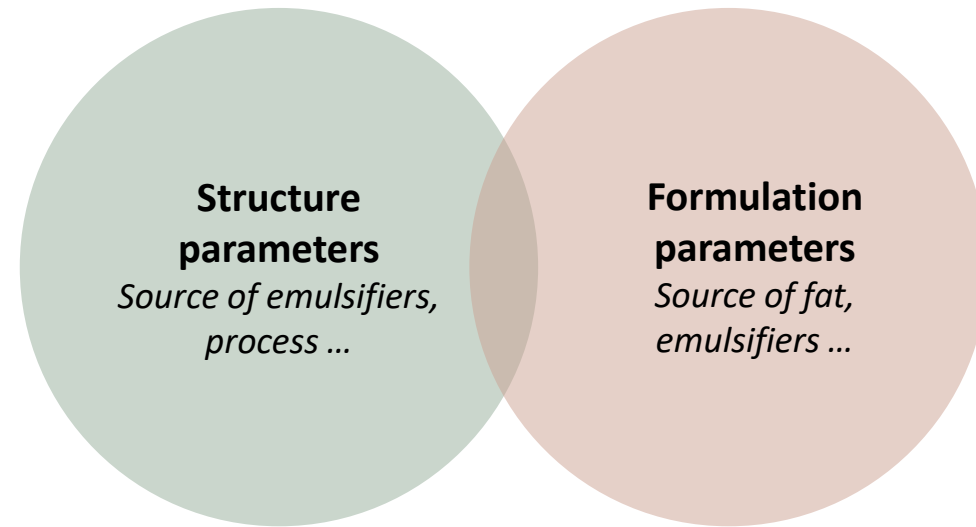
	Fatty acid profil	Oxidative stability
Coconut oil	+	-
Red palm oil	=	+
Dairy fat	+	=

# Conclusion

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**Follow-on formulas**  
*Aim: Biomimetic of breast milk*



**A re-introduction of dairy fat in infant formulas would improve both nutritional profile and oxidative stability**  
*Strongly encouraged due to its wide array of nutritional and functional benefits*



Thank you for your attention



Any questions ? 