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Optimization of supercritical carbon dioxide extraction of rice bran oil and γ-oryzanol using Multi-Factorial Design of Experiment

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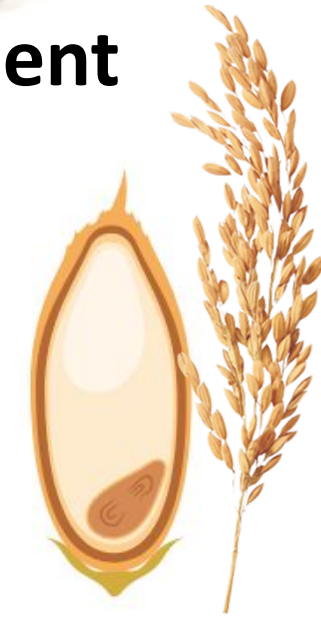
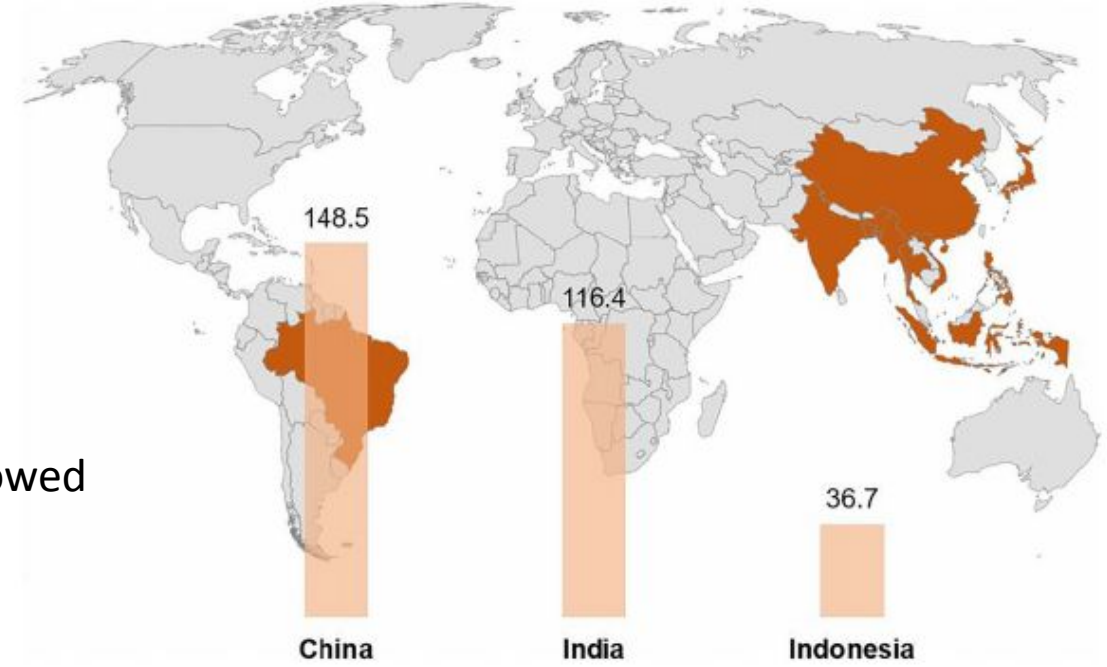


Introduction

Rice represents around **20% of the dietary energy intake** of the global population

According to estimations, the world's rice production reached **499.31 million metric tons** over the 2019–2020 period

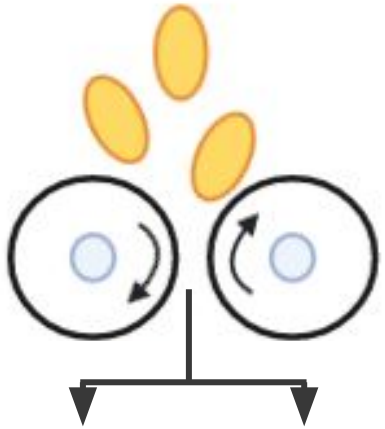


The primary producer and consumer of rice is **China**, followed by **India and Indonesia**

Fraterrigo et al., 2020, *Biomass Conv. Bioref,* 11, 569–587

Introduction

MILLING



White rice

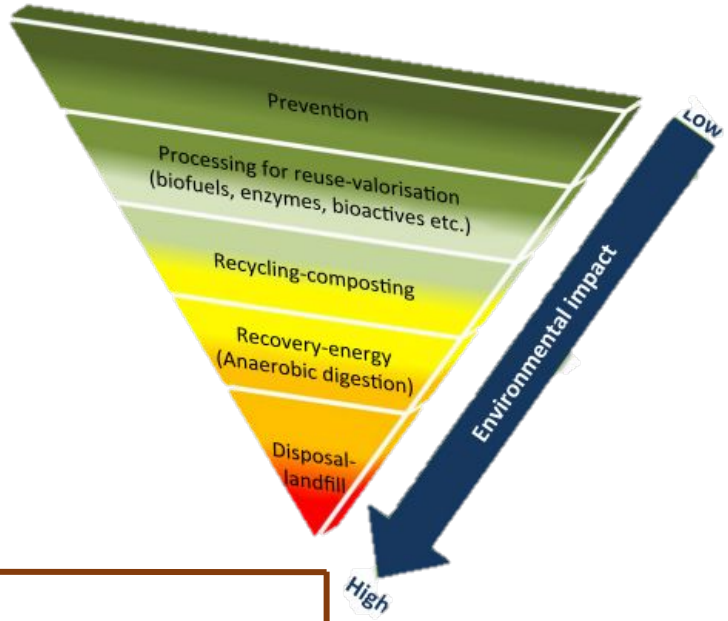
By-products

Husk

Bran

Germ

Waste Hierarchy:



The whole milling process generates more than **30%** of byproducts, which are still rich in nutritive substances and high-value molecules

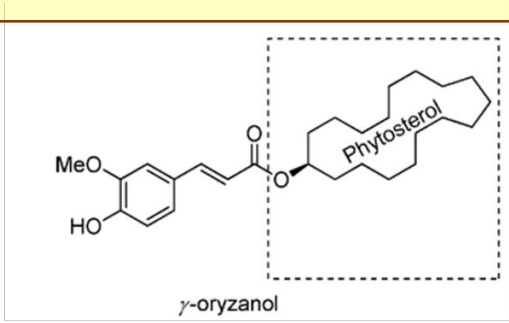
Fraterrigo et al., 2020, *Biomass Conv. Bioref,* 11, 569–587
Min et al., 2011, *Journal of Food Science*, 76(1), 117–126
Directive (2008/98/EC),2008, *Official Journal of the European Union*
Andreola et al., 2015, Conference of European Ceramic Society (ECERS)

Introduction

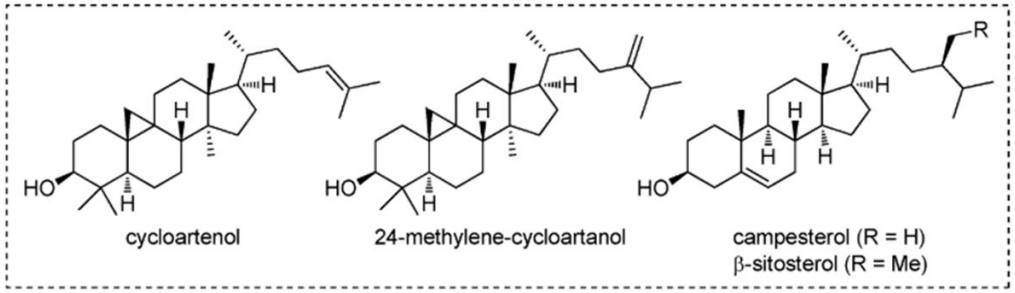
9% Bran:

- Protein
- Fat
- Fiber
- Vitamins
- Minerals
- Phenolic compounds
- Lipophilic antioxidants:
  - Tocopherols
  - Tocotrienols
  - γ-oryzanol

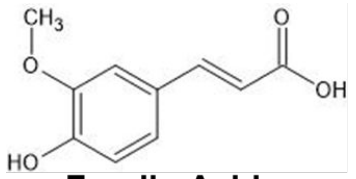
- lowering cholesterol
- antioxidant effect
- inducing apoptosis cancer cells



γ-oryzanol



phytosterols



Ferulic Acid

+ Phytosterols

Fraterrigo et al., 2020, Biomass Conv. Bioref, 11, 569–587
Lesma, G. et al., 2018, *Journal of Natural Products*, *81*(10), 2212–2221.

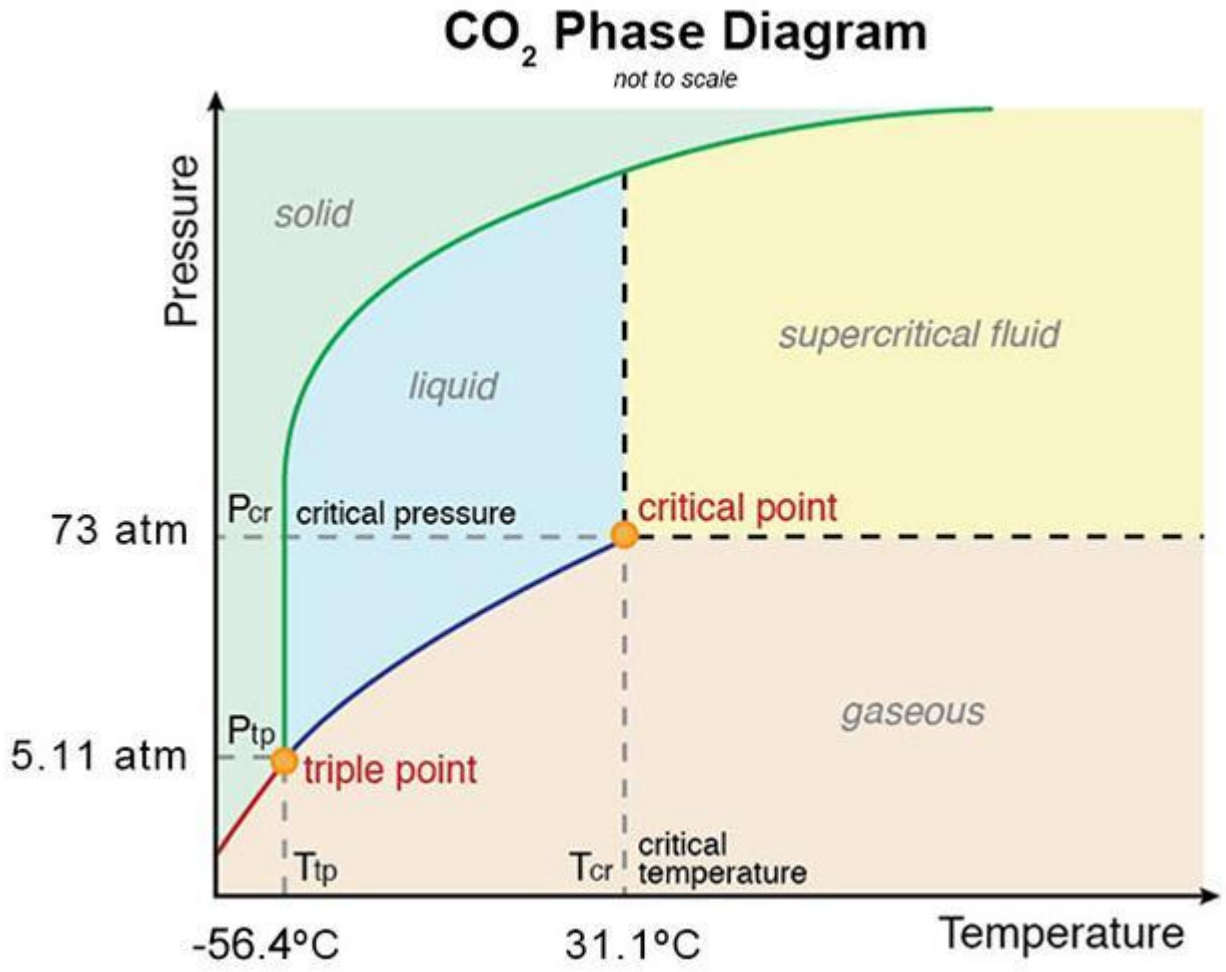
Rice Bran Oil (RBO)

The World Health Organization (WHO), the American Heart Association (AHA), and other international food and health organizations have recognized RBO as a **"healthy oil,"** because of its well-balanced fatty acid content.

Conventional **solvent extraction** using non-polar solvents, such as **hexane**

Rohman A, 2014, *Wheat and Rice in Disease Prevention and Health*. Academic Press, 481–490
Fraterrigo et al., 2020, *Biomass Conv. Bioref*, 11, 569–587

Supercritical CO_2 extraction

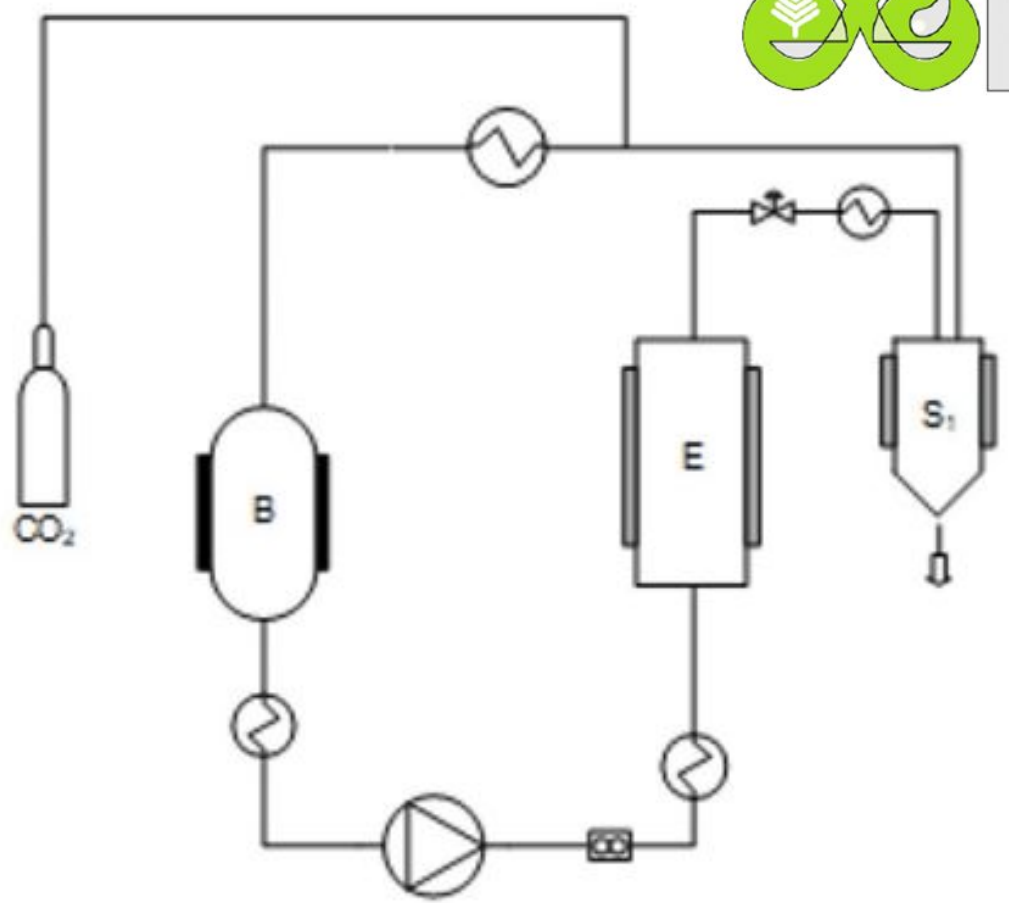


Produced by the Harvard-Smithsonian Center for Astrophysics. 2014.

- Pressure
- Temperature
- Time
- Co-solvent (eventually ethanol)

Casas et al., 2010, *Journal of Food Engineering*, 96(2), 304–308.
Salvador et al., 2001, *Talanta*, 54, 735–740.
Xu et al., 2000, *JAOCS, Journal of the American Oil Chemists' Society*, *77*(5), 547–551.
Jesus et al., 2010, *Journal of Supercritical Fluids*, *55*(1), 149–155.

Supercritical CO_2 extraction



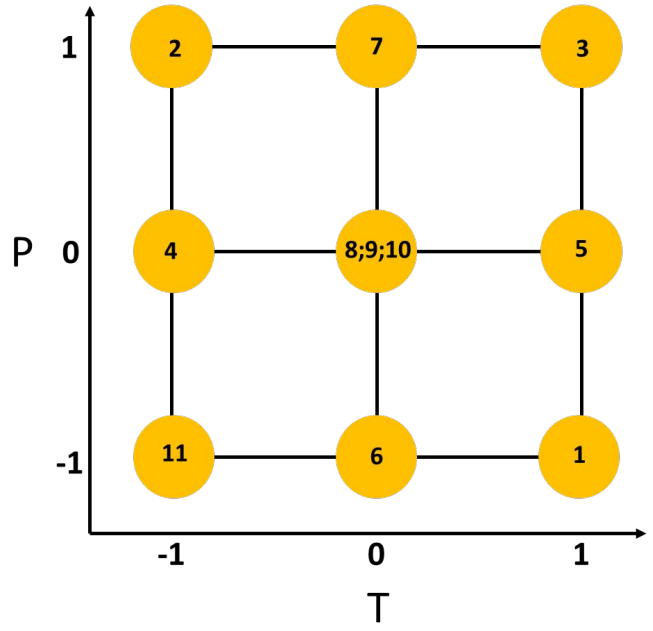
CO_2 flow = 20 kg/h
Time = 3 hours
Pressure = 300, 350 and 400 bar
Temperature = 40, 50 and 60 °C

Design of Experiment

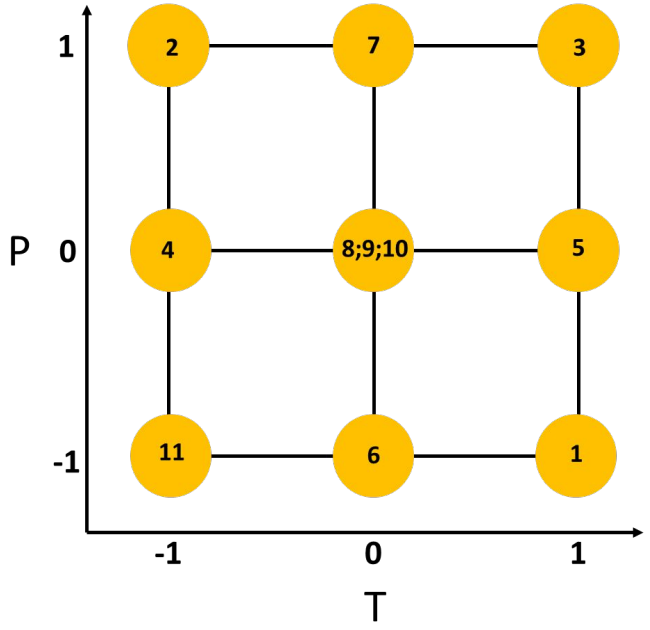
DoE (MODDE 7 and CAT)

Full factorial

Factors: T(°C), P(bar)
Levels: T (40-50-60 °C)
P (300-350-400 bar)



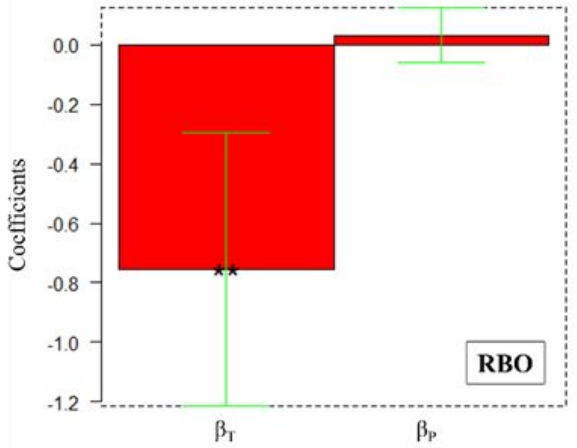
Experiment N°	T (coded)	P (coded)	T (°C) (uncoded)	P (bar) (uncoded)
1	1	-1	60	300
2	-1	1	40	400
3	1	1	60	400
4	-1	0	40	350
5	1	0	60	350
6	0	-1	50	300
7	0	1	50	400
8	0	0	50	350
9	0	0	50	350
10	0	0	50	350
11	-1	-1	40	300

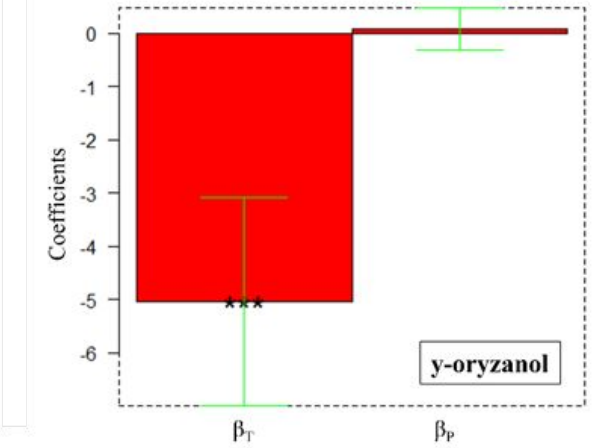


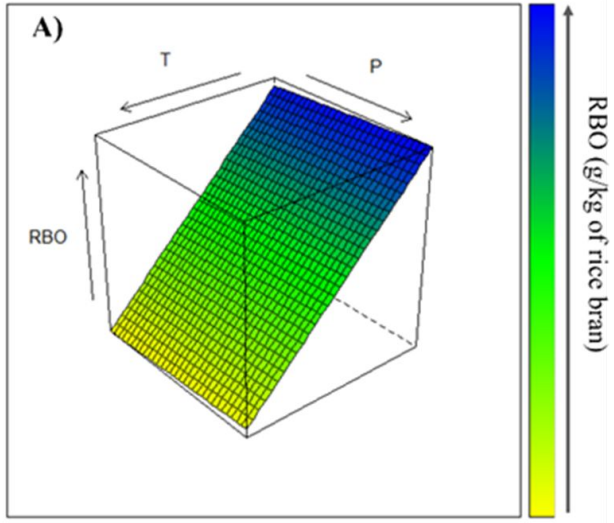
N°	T (coded)	P (coded)	Temperature °C (uncoded)	Pressure bar (uncoded)	RBO (g/kg of rice bran)	γ-oryzanol (mg/kg of rice bran)
1	1	-1	60	300	15	73
2	-1	1	40	400	37	200
3	1	1	60	400	10	59
4	-1	0	40	350	28	179
5	1	0	60	350	11	65
6	0	-1	50	300	26	140
7	0	1	50	400	20	98
8	0	0	50	350	27	151
9	0	0	50	350	19	104
10	0	0	50	350	20	125
11	-1	-1	40	300	24	147
12	-1	-1	40	300	19	139

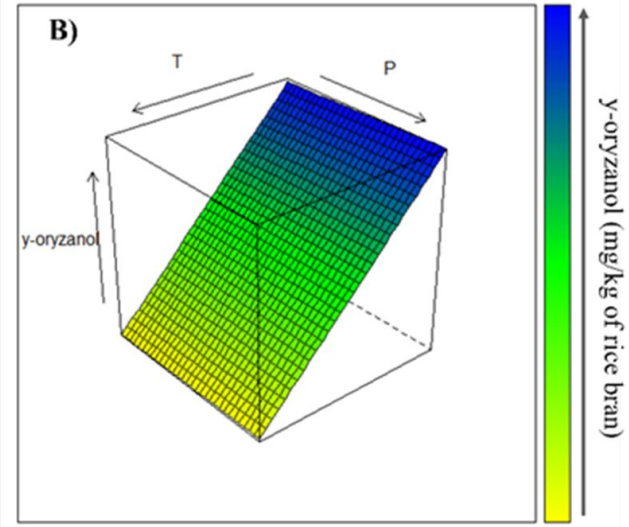
MLR

$$y = \beta_0 + \beta_T T + \beta_P P + \varepsilon$$







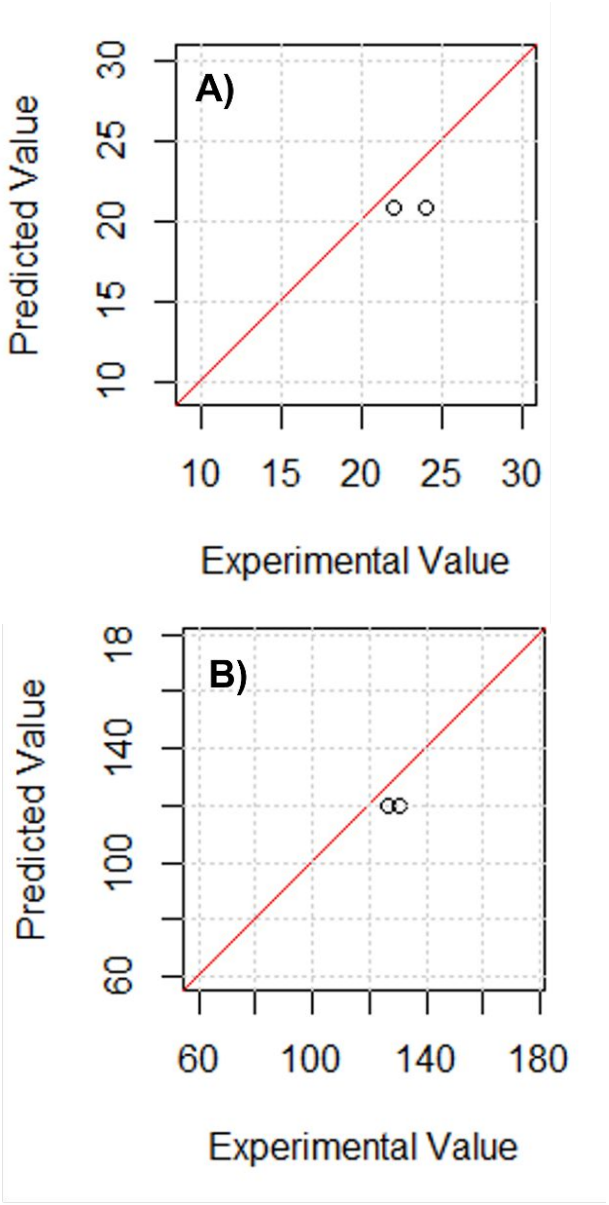


Response surface

	Coefficients			Significance of the coefficients			Explained Variance %
	β_0	β_T	β_P	β_0	β_T	β_P	
RBO (g/kg of rice bran)	47,163	-0,754	0,033	0,0171*	0,0048**	0,4434	52,01
y-oryzanol (mg/kg of rice bran)	342,486	-5,027	0,081	0,0008***	0,0003***	0,6505	74,39

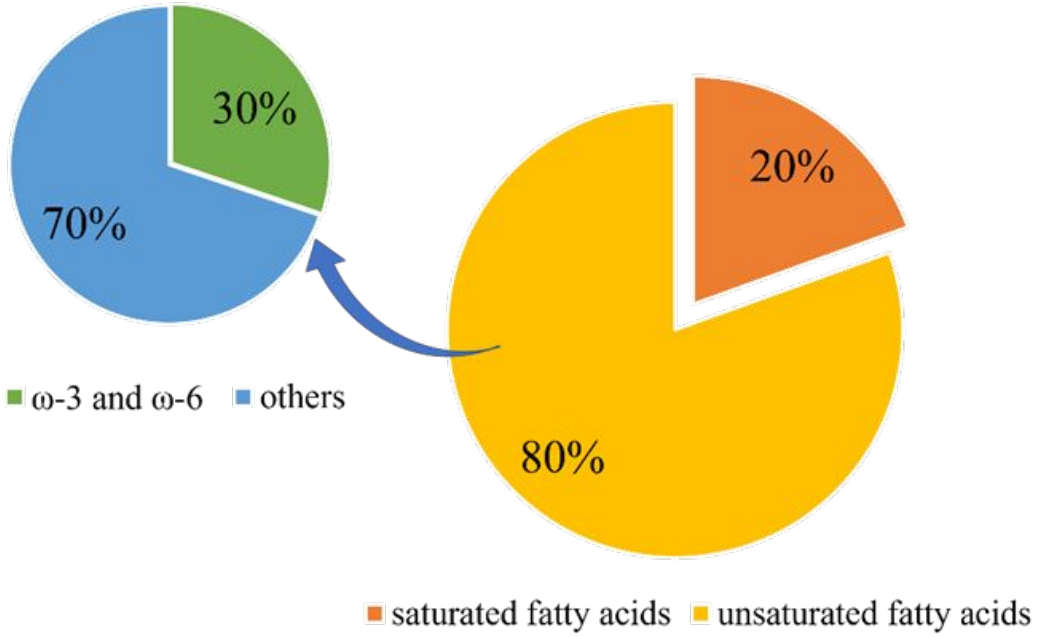
Prediction

RBO (g/kg of rice bran)					
N° Exp	experimental	lower	upper	predicted	residual
13	24,00	17,35	24,33	20,84	-3,16
14	22,00	17,35	24,33	20,84	-1,16
y-oryzanol (mg/kg of rice bran)					
N° Exp	experimental	lower	upper	predicted	residual
13	126,67	104,61	134,32	119,46	-7,24
14	130,56	104,61	134,32	119,46	-11,09



Rice Bran

Humidity	6.9±0.3	g/100g
Aashes	10.8±0.3	g/100g
Protein	45.5±4.7	g/100g
Carbohydrates	20.6±4.8	g/100g
Total fatty substances	8.1±0.5	g/100g



Rice bran extract

Humidity	0.3±0.02	g/100g
Aashes	nr	g/100g
Protein	0.2±0.03	g/100g
Carbohydrates	nr	g/100g
Total fatty substances	99.1±3.0	g/100g

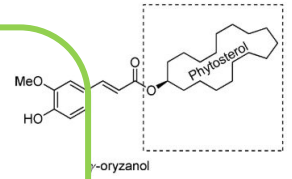
Fatty acids	**g/100g**
C14:0 Myristic acid	0.27±0.01
C16:0 Palmitic acid	15.50±0.5
C16:1 Palmitoleic acid	0.13±0.01
C18:0 Stearic acid	1.80±0.05
C18:1 Oleic acid	42.40±1.7
C18:2 Linoleic acid (omega-6)	35.10±1.4
C18:3 γ-Linolenic acid (omega-6)	0.86±0.03
C18:3 α-Linolenic acid (omega-3)	1.00±0.03
C20:1 Eicosenoic acid	0.58±0.02
C22:0 Behenic acid	0.96±0.04
C20:3 Eicosatrienoic acid (omega-6)	0.49±0.01
C24:0 Lignoceric acid	0.97±0.04

0.84 €/kg
γ-oryzanol: 200mg/kg

17.27 €/kg
γ-oryzanol: 7g/kg

γ-oryzanol recommended daily doses **50 - 800 mg/die**

InnovaEcoFood final products
γ-oryzanol **≈700mg/kg**



Berger et al., 2005, *Eur J Nutr* 44, 163–173

Conclusions

- SCO_2 is suitable for extracting RBO
- RBO obtained has an excellent lipid composition
- RBO is suitable for food preparations
- The extraction from rice bran can minimize wastage, promote income growth and job creation, and prompt sustainable local development.

Thanks for your attention!