Nanofood Process Technology, Sustainability, and Applications for Human Space Exploration

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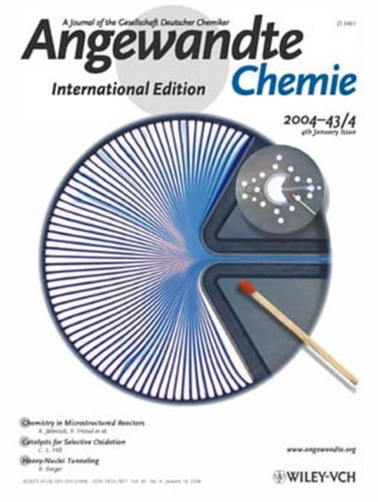

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1994

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NANOFOOD: DEFINITION

Nanofoods are developed from a wide range of ingredients including lipids, polysaccharides, and proteins. These are used to form a range of materials with varying properties including emulsions, liposomes, and particles.

The range of ingredients, materials, and properties highlight the conceptual diversity of formed nanostructures spanning from nanoemulsions to nanoliposomes. Most findings of nanofoods to date are broadly descriptive.

ACS Sustainable Chemistry & Engineering
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Research Article

Nanofood Process Technology: Insights on How Sustainability Informs Process Design

Volker Hessel,* Marc Escribà-Gelonch,* Svenja Schmidt, Nam Nghiep Tran, Kenneth Davey,

https://doi.org/10.1021/acssuschemeng.3c01223

See also:

Y. Abdul Wahab, L. A. Al-Ani Food Control 163 (2024) 110466

Nanomaterials: A critical review of impact on food quality control and packaging

NANOFOOD PRODUCTS

NANOFOOD SAFETY

Topics

European Parliament

Defining nano-food: a big problem at a very small scale

WHY NANOFOOD? (1)

Mayonnaise Mayonnaise comprises typically 70% fat – far from ideal if you're on a diet. One way to reduce the fat content below 40% is to add more water, plus some starch to make sure the mayonnaise does not become too runny. But an altogether tastier approach is to **manipulate the droplets' structure on the nanoscale**. Techniques are developed to replace the insides of the fat droplets with water, creating an emulsion that has the same texture, but less fat than the real thing - Contract research company Leatherhead Food Research, UK.

Iron The body stores iron as solid, insoluble nanoparticles that are only broken down into useful atoms once they get inside our cells. Supplements containing iron in a soluble form can be toxic in very high doses, because they damage the gut. The method is to sneak iron directly into cells in their **insoluble, nanoparticle form** – piggybacking on the body's natural route – to make a more effective supplement.

Salt Nanometre-sized grains of salt, comprise surface area a million-fold smaller than normal salt, which means that **food needs far less salt to give a taste buds the same savoury kick**. That could be a boon for those who, worried about high blood pressure, are trying to reduce their salt intake.

https://www.theguardian.com/what-is-nano/what-you-need-know-about-nano-food

WHY NANOFOOD? (2)

Meat-Antibiotics Nanoparticles could take the place of antibiotics in chickens. The particles bind to bacteria and then clump together, passing through the chicken along with other fecal matter.

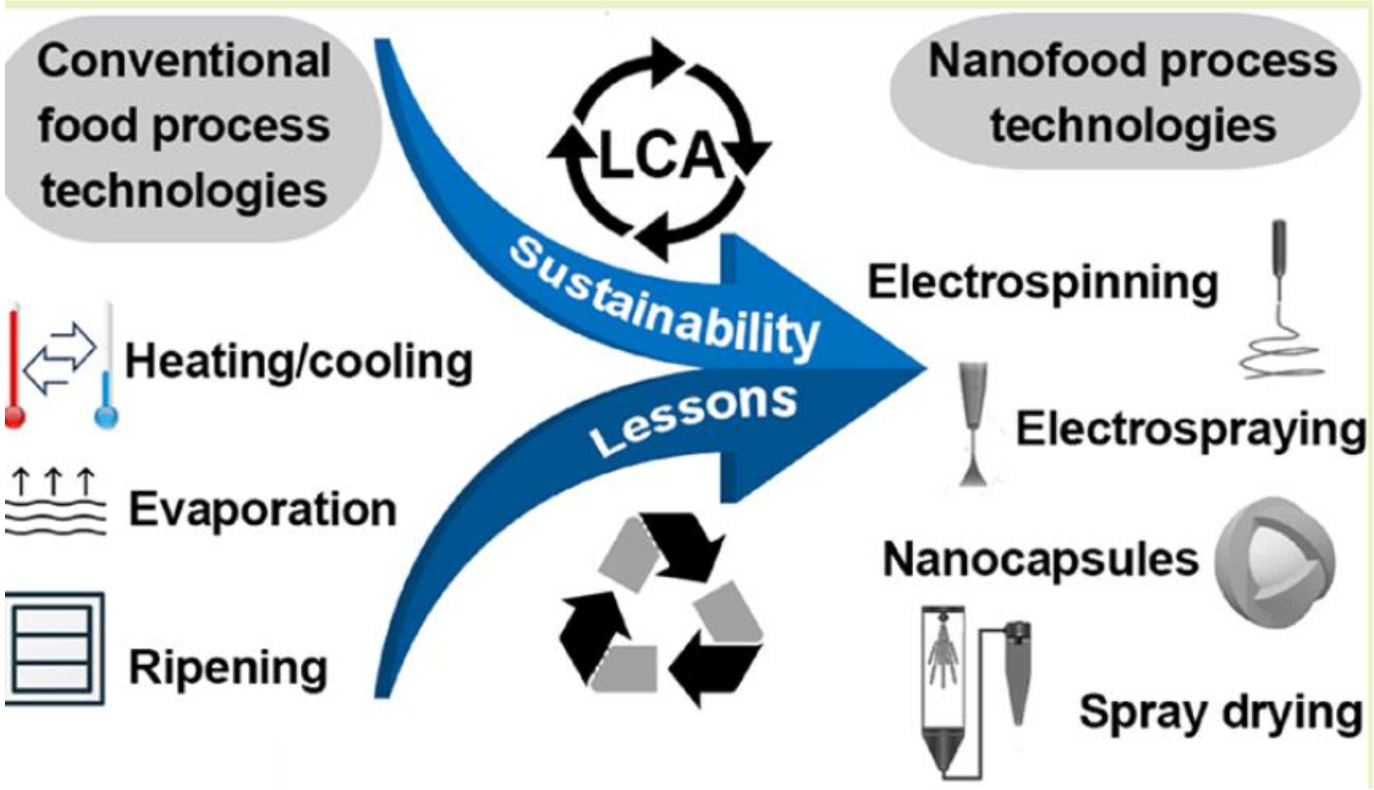
Food as Supplement Vitamins and minerals could be delivered through the food we eat. Nanoparticles could encapsulate vitamin supplements, which **could be added to everyday foods** such as bread.

Food packaging As for packaging, nanotech is already being used in the US to stop beers going flat. Plastic beer bottles used by brewer SABMiller contain flaky nanoparticles of clay, which fill up much more space in the walls of the bottle than molecules of plastic. That makes it **much harder for fizzy carbon dioxide to escape from the beer** – or for oxygen, which can spoil the beer's flavour, to get in.

https://www.theguardian.com/what-is-nano/what-you-need-know-about-nano-food

OUR STARTING POINT

Are there ChemEng sustainability lessons for nanofood process technology?
To promote an emerging technology.

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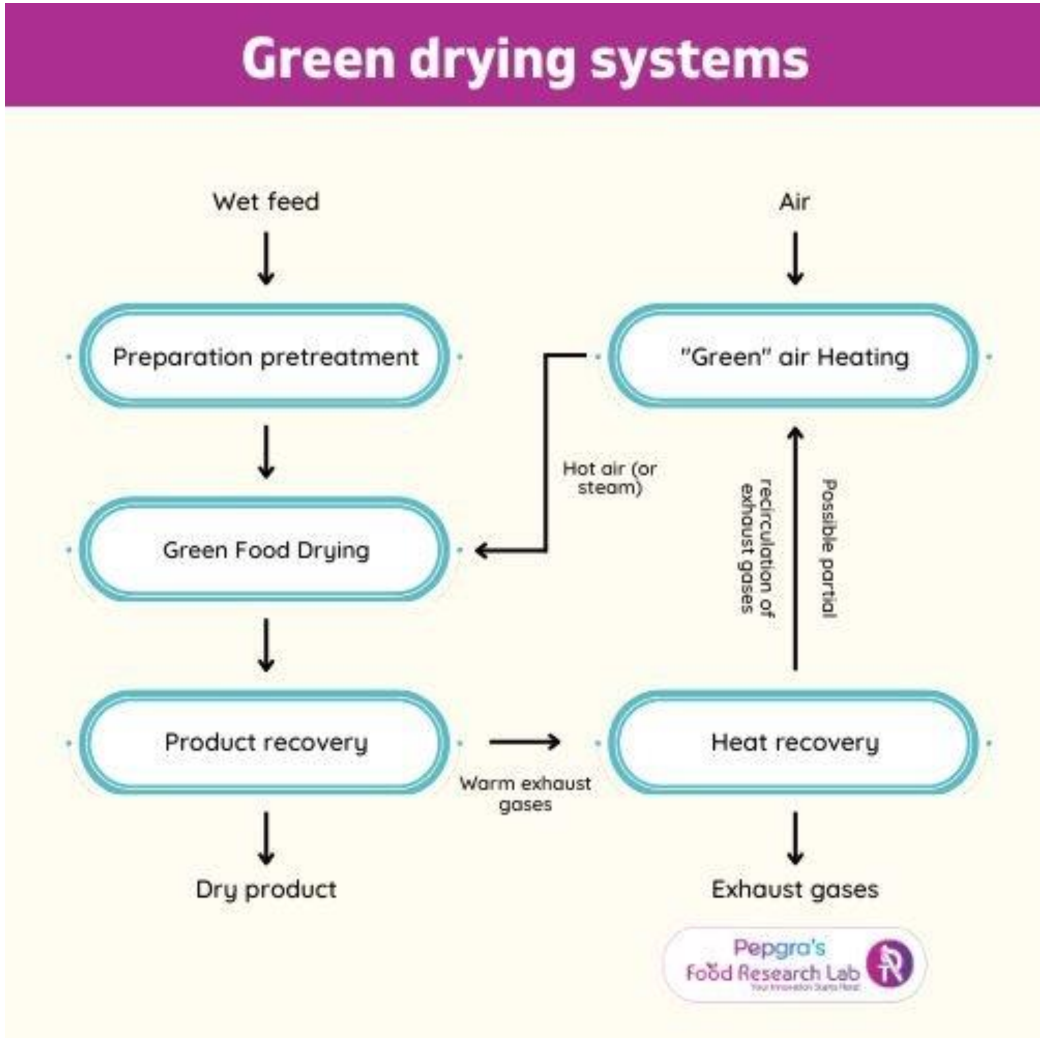
FIRST LESSONS ARE TAKEN FOR SUSTAINABILITY IMPROVEMENT

Food Research Lab
A Unit of guires

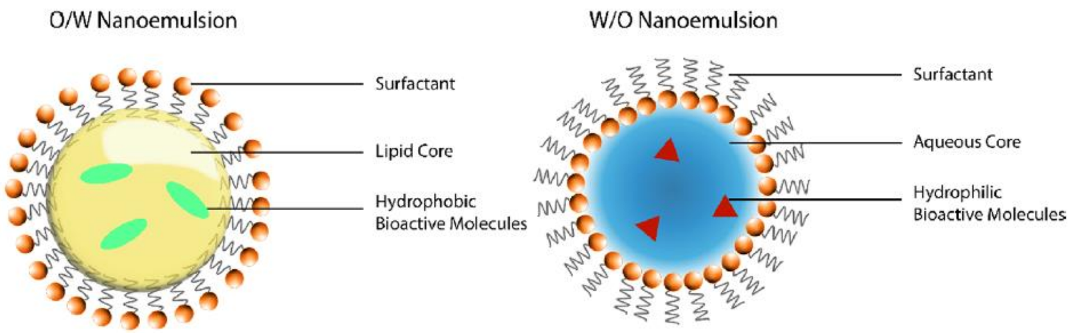


NANOFOOD AND BIOACTIVES (HEALTH SUPPLEMENTS)

architecture	main material	origin	embedded molecules	ref.
nanoliposomes from lipids	lecithin	egg yolk/ soybean	vitamins C, D, and E	44
			curcumin	45
	phospholipids	milk	tea polyphenol	46
		soybean	essential oil	47
			vitamin D_3	48
		egg yolk	carotenoids	49
	chitosan	sea food	essential oil	50
			vitamin C	51
			w-3 PUFAs (fish oil)	52
nanoemulsions	chitosan	sea food	curcumin	53
			trehalose	54
	gelatin	pork	carotenoid	55
			buriti oil	56
	lecithin	soybean	thymol	57
		chicken	rosemary extract, cinnamon essential oil	58
nanohydrogels	protein	whey	D-limonene	59
			caffeine	60
			iron	61
			folic acid	62
	β-lactoglobulin	milk	caffeine	63
			iron	64

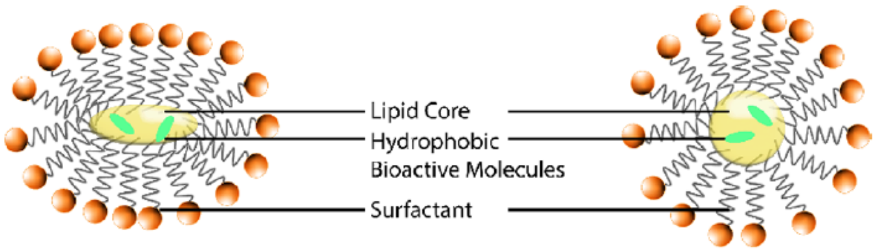
NANO-CARRIERS FOR FOOD (1)

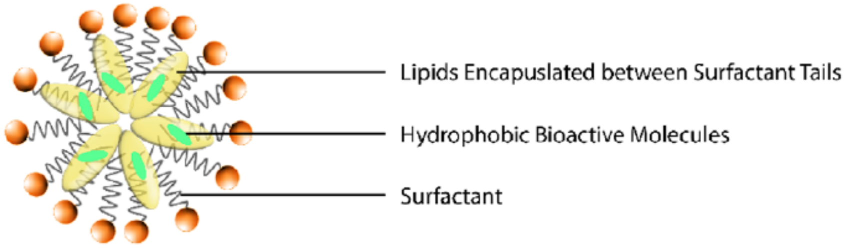
Oil-in-water (O/W) nanoemulsion and water-in-oil (W/O) nanoemulsion



- ✓ Transparent or slighly turbid appearance
- ✓ Improved kinetic stability compared to conventional emulsions
- ✓ Suitable for controlled release of flavor and coloring compounds
- ✗ Instability due to Ostwald ripening

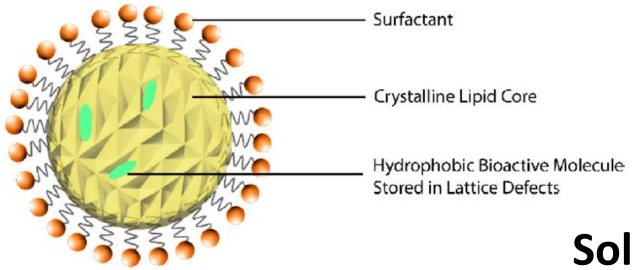
Oil-in-water (O/W) microemulsions





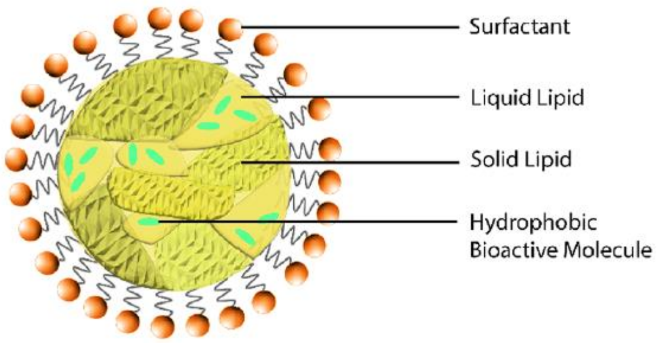
- ✓ Thermodynamically stable
- ✗ Requires high concentrations of synthetic surfactants
- ✗ Sensitive to environmental changes

Solid-Lipid Nanocarrier (SLN)



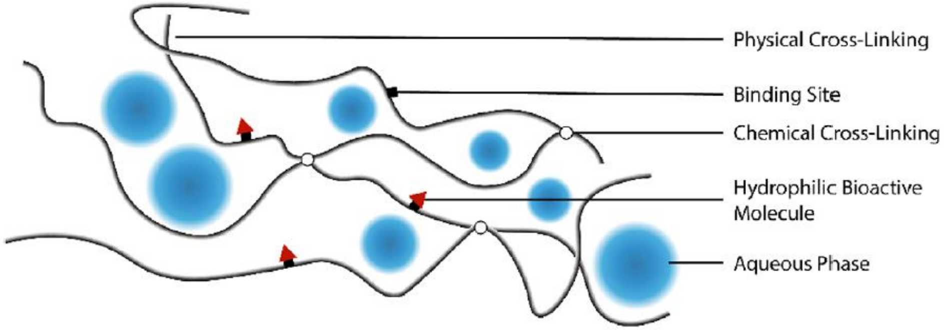
- ✓ Decreased diffusion rate of bioactive molecules compared to liquid lipid carrier
- ✗ Instability due to polymorphic transitions
- ✗ Limited loading capacity

NANO-CARRIERS FOR FOOD (2)



Nanostructured lipid carrier

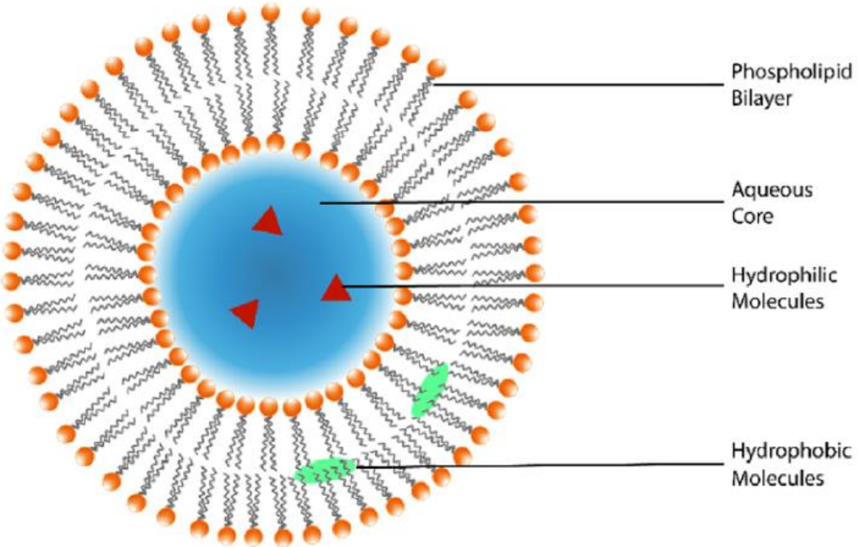
- ✓ Increased loading capacity compared to SLNs
- ✗ Complex system consisting of several components



- ✓ Binding sites can be modified and can react to environmental stimuli
- ✓ Allows Incorporation of Water
- ✗ Sensitive to Mechanical Stress

Swollen nano hydro gel

Nanoliposomes



- ✓ Encapsulation of both hydrophilic and hydrophobic molecules
- ✓ Release of molecules induced by diverse stimuli
- ✗ Sensitive to shear and environmental stresses

NANOFOOD PROCESS TECHNOLOGIES: SPINNING & SPRAYING

Use conventional and advanced ChemEng technologies

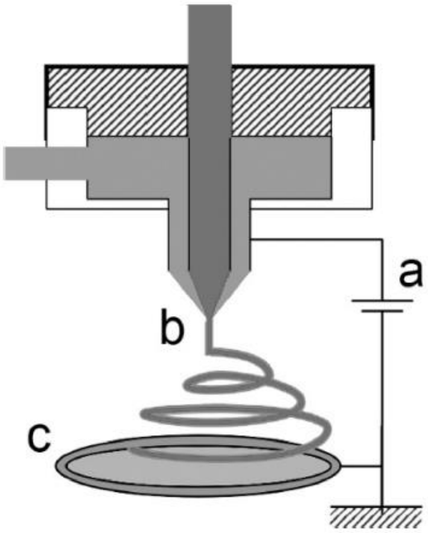


Figure 9. Coaxial spinning for fabrication of nanofibers. (a) High-voltage power supply, (b) coaxial jet, and (c) collector.

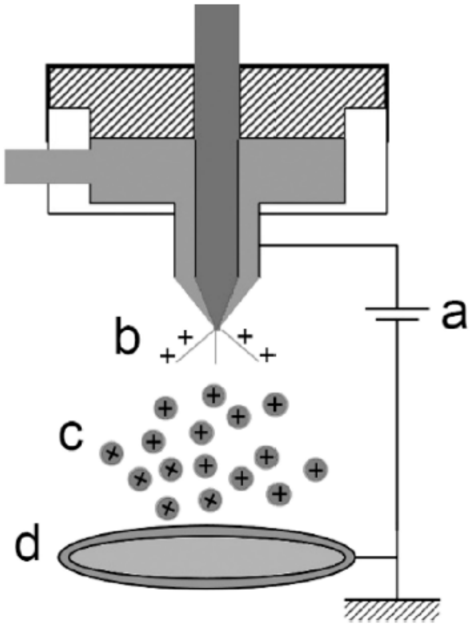
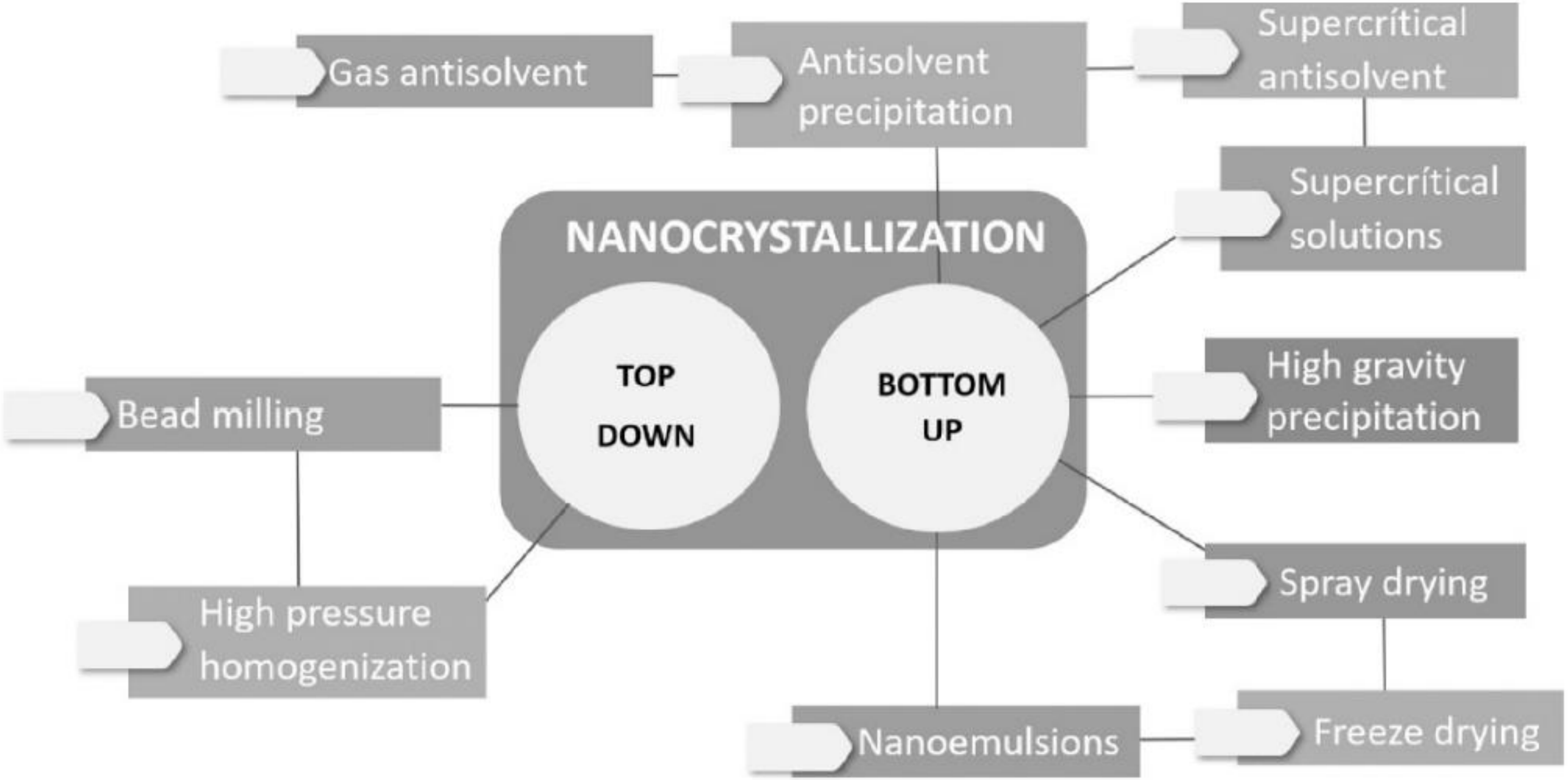


Figure 10. Conventional electrosprayer. (a) Power supply, (b) Taylor cone, (c) nanoparticle generation, and (d) nanoparticle collection.

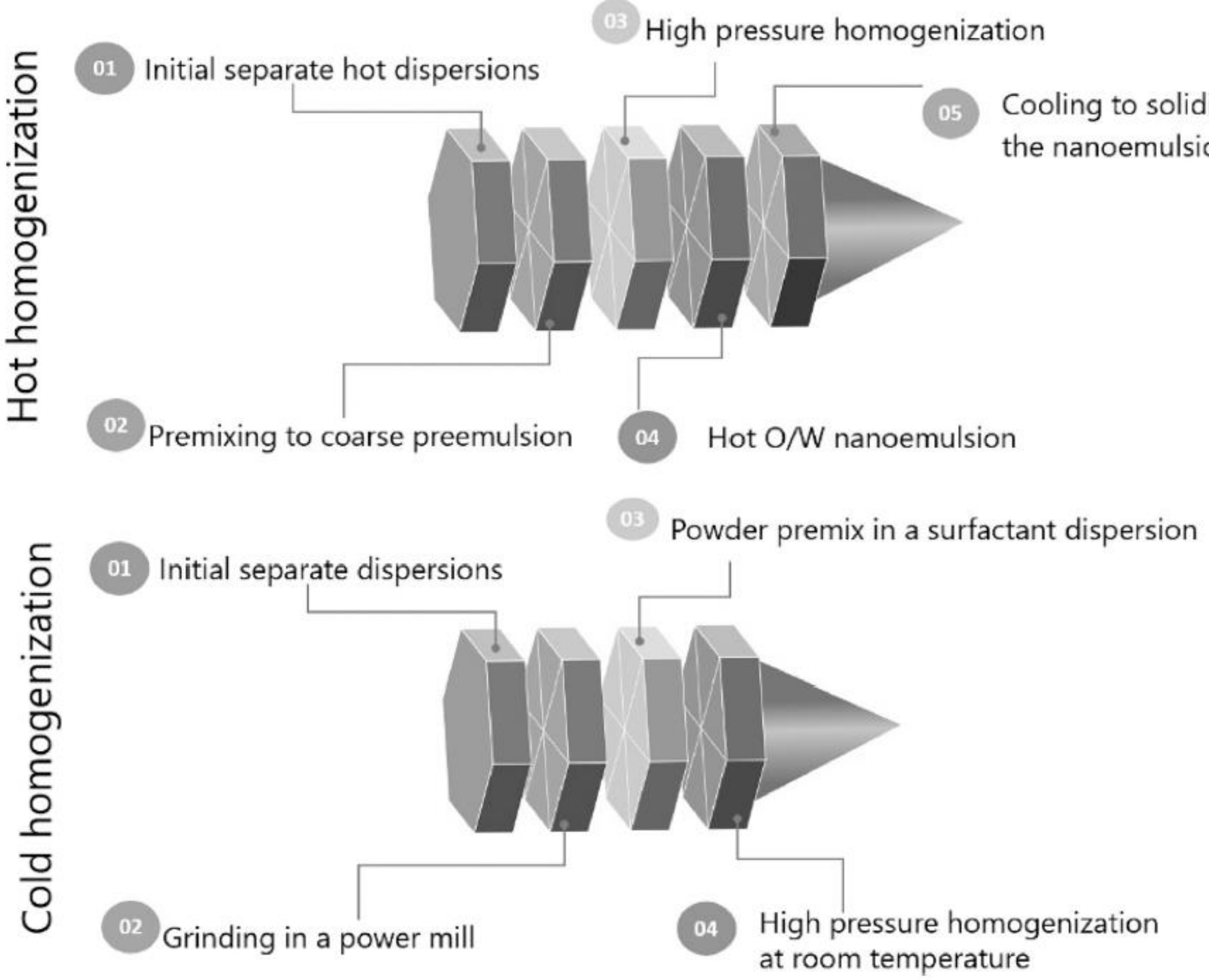
NANOFOOD PROCESS TECHNOLOGIES: CRYSTALLIZATION

Use conventional and advanced ChemEng technologies



INTEGRATED FOOD PROCESS TECHNOLOGIES

Several ChemEng technologies are used in series: thermal and mechanical.
Sustainability impact can be large by carry-forward effects.



GLOBAL WARMING POTENTIAL OF FOOD PROCESS TECHNOLOGIES

Table 3. Comparative Summary of Global Warming Potential (GWP) for Selected Food Technologies

food technology	operation	product	GWP (kg CO_2-eq kg^{-1})	reference
drying	drum-drying	apples	2.67	74
	freeze-drying	strawberries	1.54	75
	spray-drying	apple pulp	0.80	74
	infrared-drying	apricots	0.71	76
heating	pasteurization	milk	0.42	77
		cream	0.43	78
		cheese	1.65	79, 80
	ultra-heat treatment	milk	0.21–0.59	78, 81
	inoculation + incubation	yogurt	0.49	78
	evaporation	milk powder	1.60	82
	smoking	Galician cheese	1.92	83
cooling	freezing	beans	0.70	84
		broccoli	2.64	84

MANY OPPORTUNITIES *VIA* CONVENTIONAL FOOD PROCESS TECHNOLOGIES

technology	engineering operation(s)	sustainability learned from conventional operation(s)
electrospinning	ohmic heating electromagnetic activation evaporation	reduction in energy demand reduction of global warming potential and terrestrial acidification wastewater reduction
electrospraying	ohmic heating high pressure electromagnetic activation	reduction in energy demand
spray drying	evaporation heating electromagnetic activation	reduction in energy demand reduction of global warming potential and terrestrial acidification wastewater reduction
desolvation	mechanical treatment	reduction in energy demand
nanocrystallization	heating cooling mechanical treatment electromagnetic activation evaporation	reduction in energy demand reduction of global warming potential and terrestrial acidification wastewater reduction
nanoemulsions	heating cooling mechanical treatment ultra-sound evaporation	reduction in energy demand reduction of global warming potential and terrestrial acidification wastewater reduction

PROCESS-SPECIFIC SUSTAINABILITY LESSONS FOR NANOFOOD PROCESSING

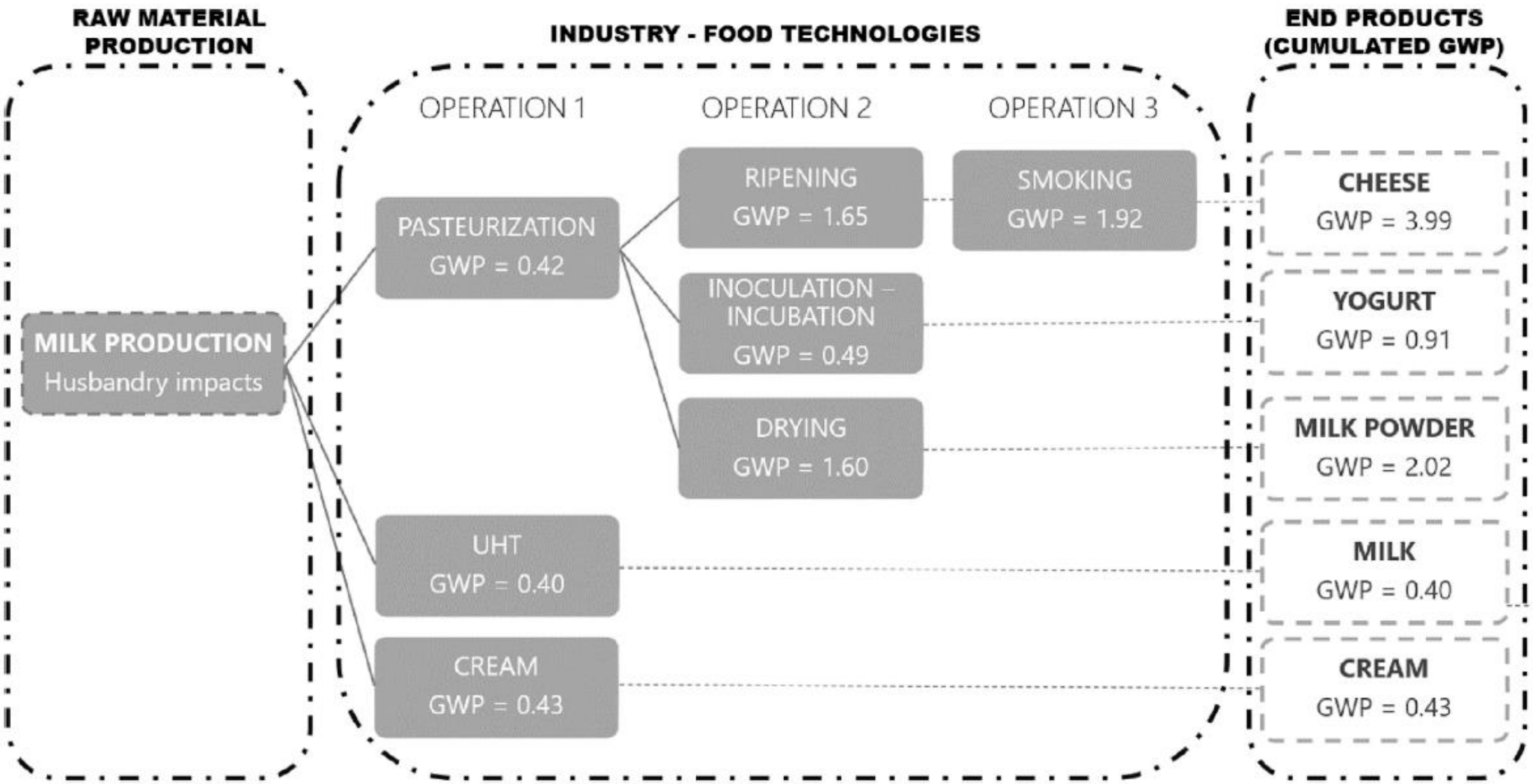
These lessons were given for all classes of nanofood processing discussed (in our review paper)

For example, for 'Thermally Driven Nanofood Technologies and Operation-Specific Sustainability'.

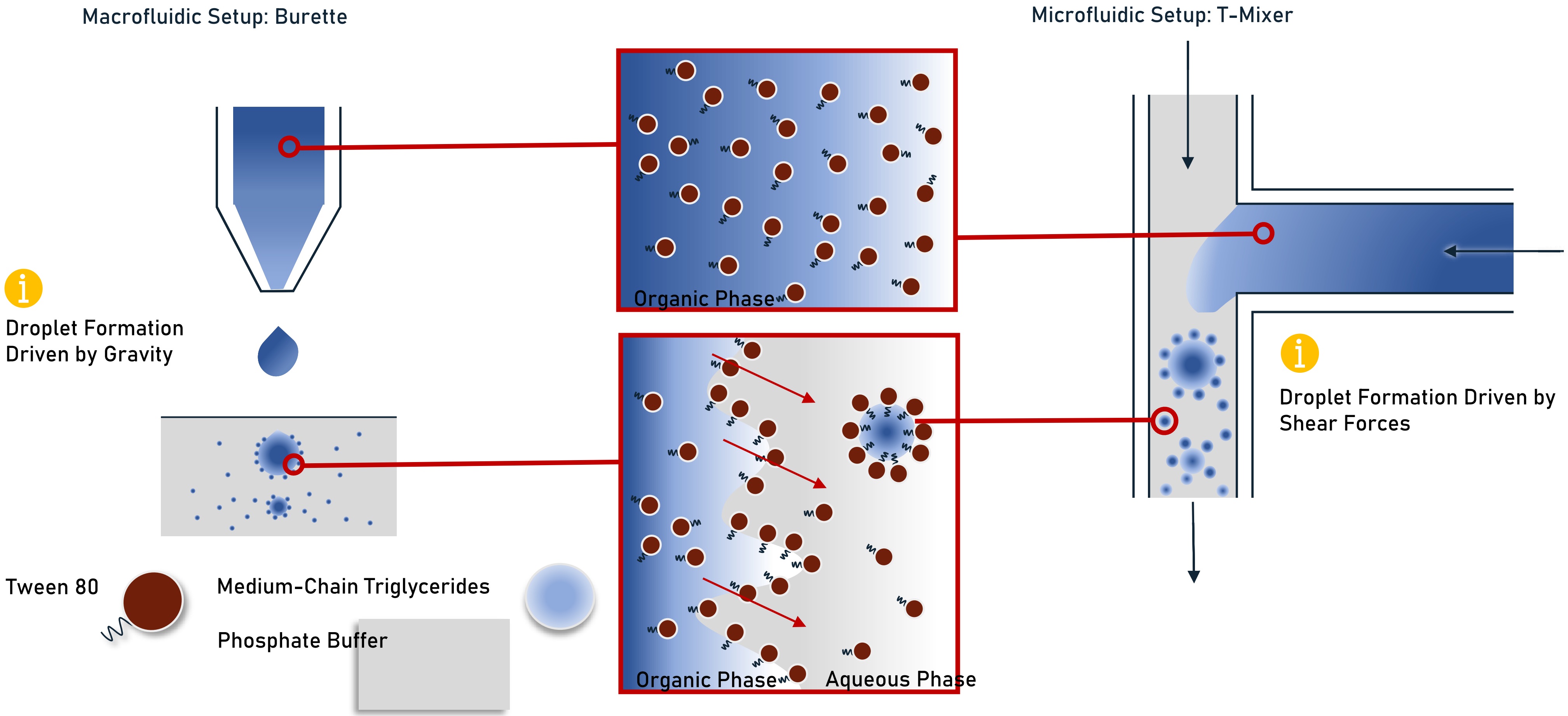
"Thermally driven process technologies involved in nanofood preparation and nanospraying involve (1) evaporation, (2) heating, and (3) electromagnetic activation. Lessons from conventional food technologies are available therefore from (2) heating."

- ***"Drying, including evaporation, accounts for most thermal energy and electricity consumption within food processing. For milk powder production for example, this is ca. 44% of the total fuel consumption, equivalent to 616 MJ kg^{-1}."***
- ***"A reported means to reduce energy consumption is to combine non-conventional drying methods, such as dehumidification, with conventional high-temperature drying. In this way, GWP can be reduced to ca. 48% and terrestrial acidification potential (TAP) can be reduced to ca. 59% for apricots by sequentially using osmotic dehydration and freeze drying."***
- ***"Microwave drying of sardines reportedly reduces energy consumption by 55% and similarly for bananas."***

GLOBAL WARMING POTENTIAL OF MILK PRODUCTS PROCESSING

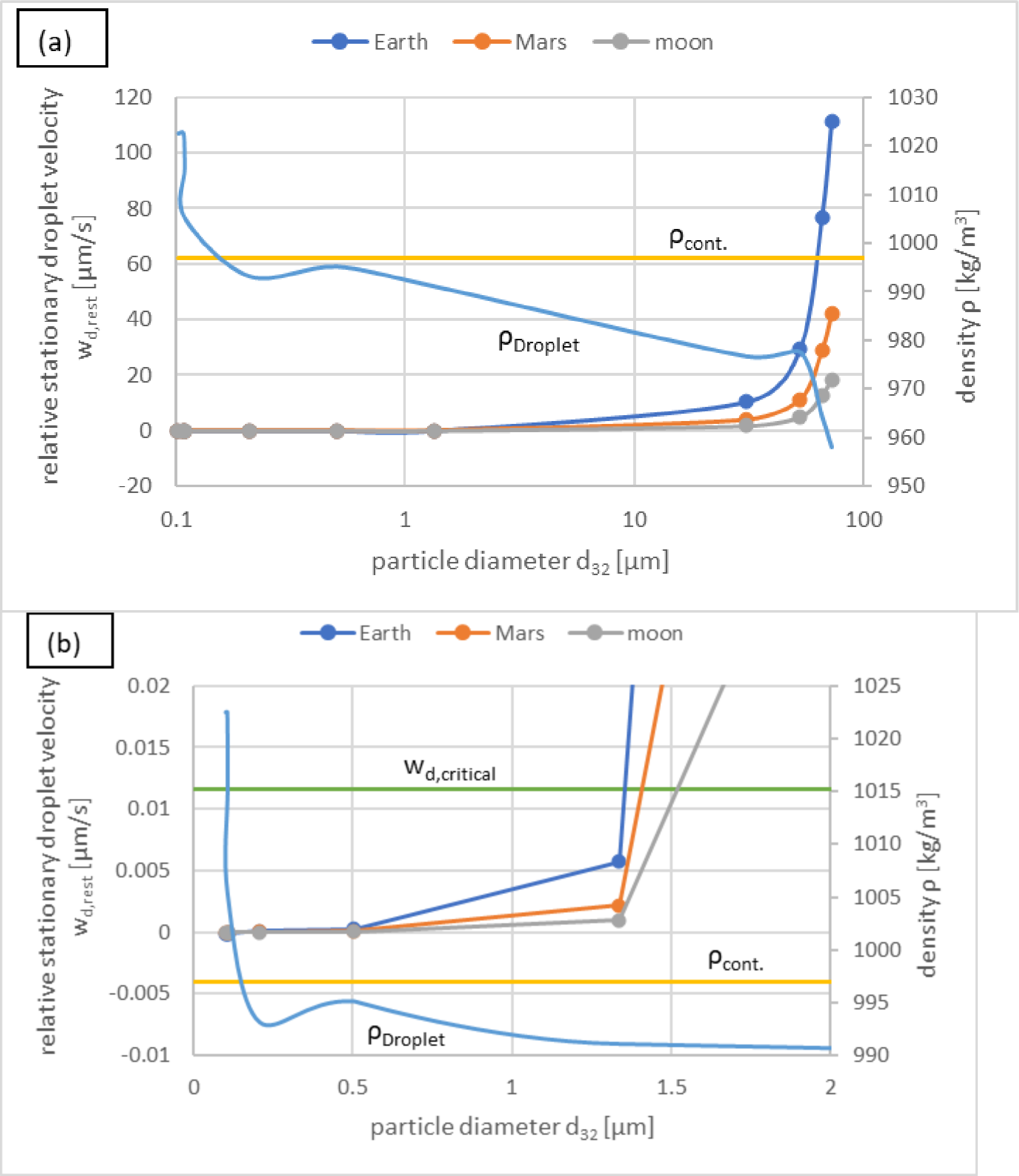


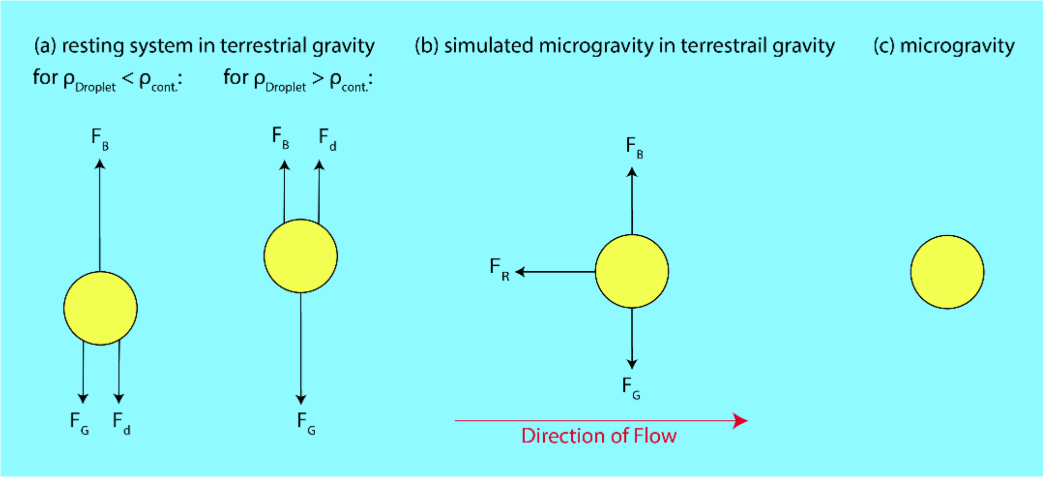
SPONTANEOUS EMULSIFICATION FOR ASTRONAUT BEVERAGES

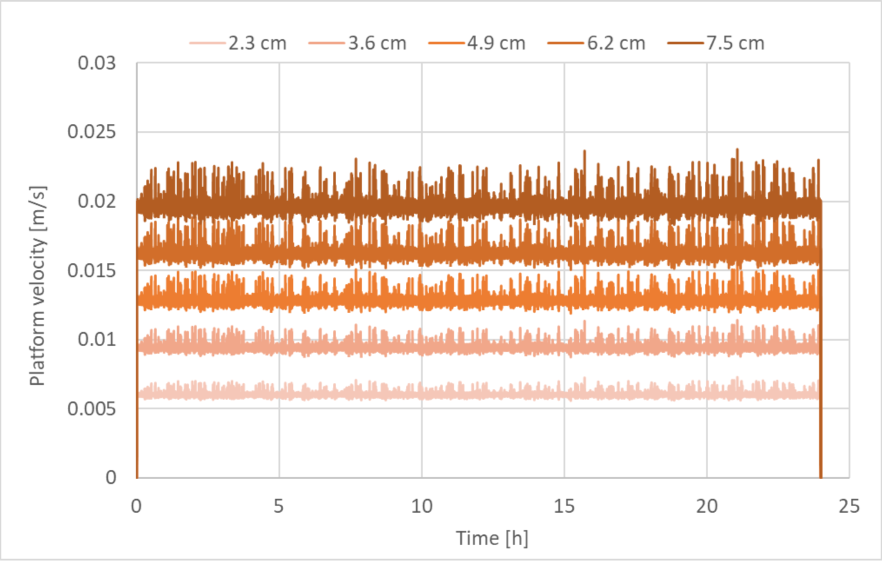


Komaiko, J. et al., (2015), *Journal of Food Engineering*, 146, 122-128;
[8]Fukuyama, M. and Hibara, A., (2015), *Analytical Chemistry*, 87, 3562-3565.

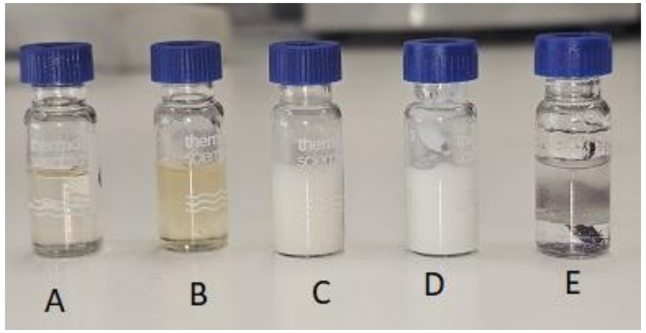
RELEVANT MICROGRAVITY EXPERIMENTS OF NANOFOOD ON EARTH

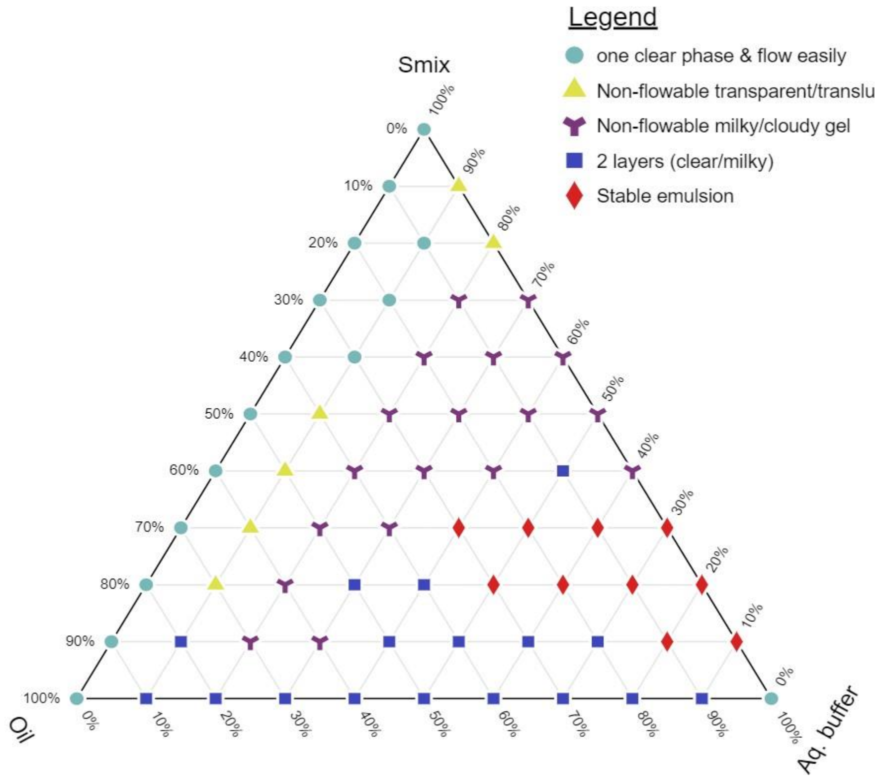


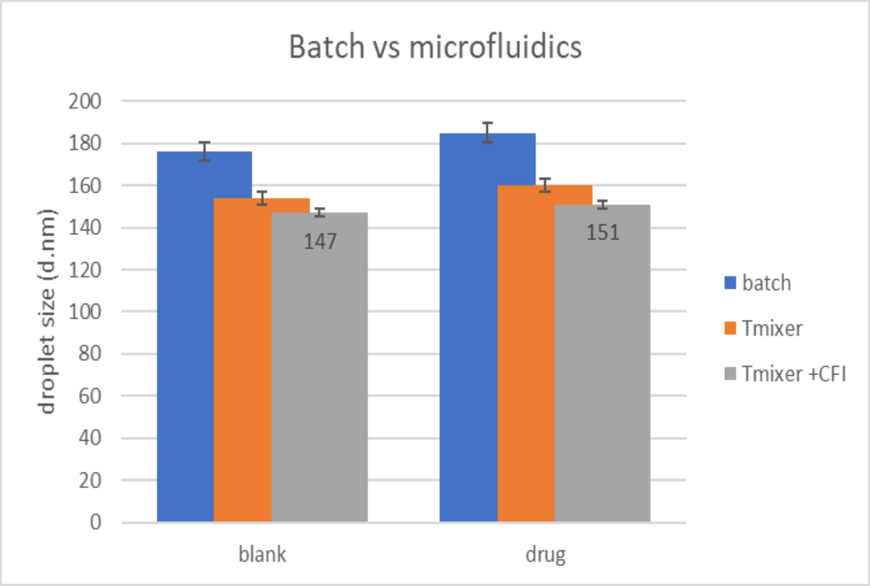


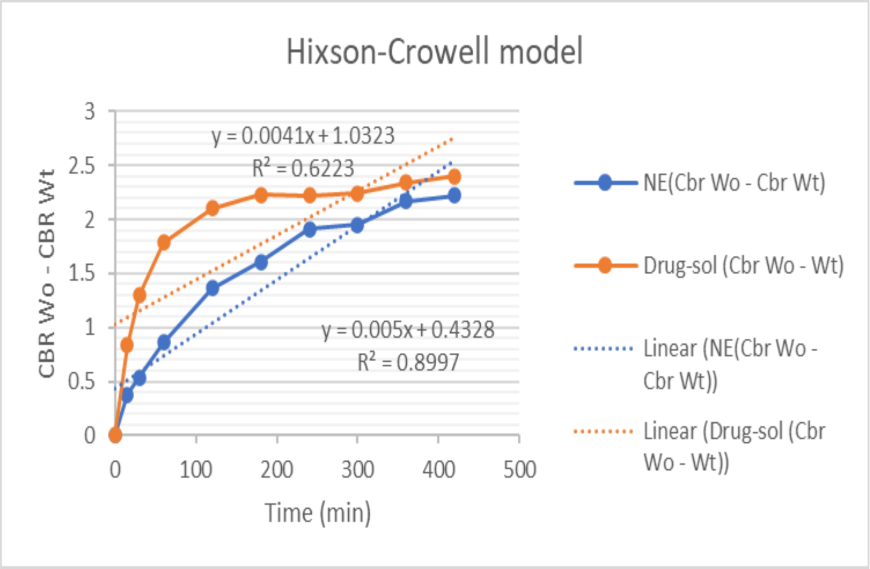


SPONTANEOUS EMULSIFICATION FOR ASTRONAUT MEDICINES










PLANTS FOR SPACE
ARC CENTRE OF EXCELLENCE
RECYCLE
PLANTS
LAW
MEDICINE
05
SPINACH
DAYS TO YIELD: 6
06
SPINACH
DAYS TO YIELD: 6
07
TOMATO
DAYS TO YIELD: 2
08
TOMATO
DAYS TO YIELD: 2
09
CARROT
DAYS TO YIELD: 3
10
FOODS
FLAVOUR
TEAMS
MATERIAL
PANTRY

FOUR P4S MISSIONS

ZERO-WASTE PLANTS OPTIMISED FOR CONTROLLED ENVIRONMENTS

COMPLETE NUTRITION PLANT-BASED FOODS

ON DEMAND BIORESOURCE PRODUCTION

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La Trobe University · UC Davis (University of California)

PLANTS AS BIORESOURCES
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FOOD PROCESSING
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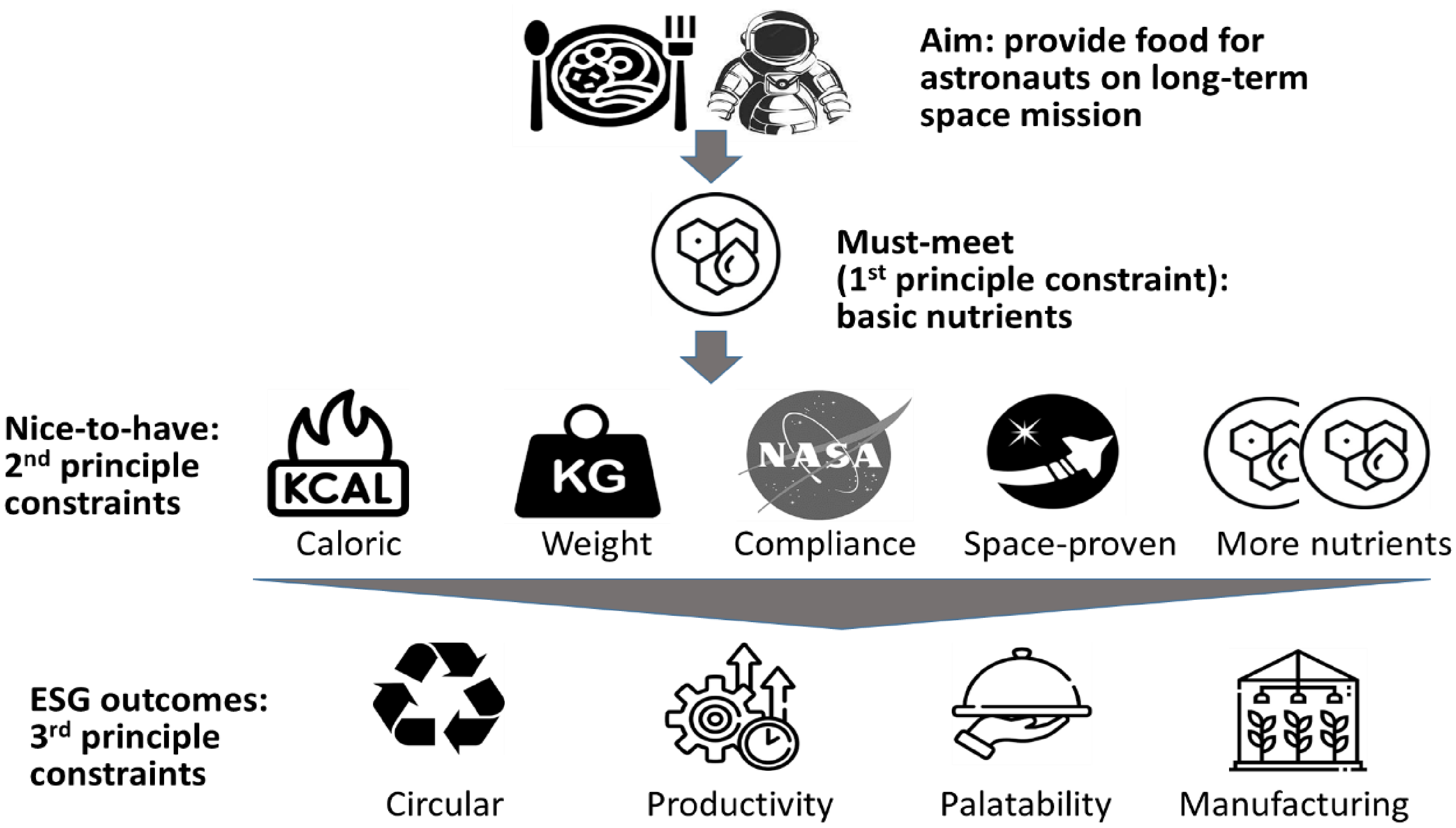
OUTREACH
NASA · Botanic Gardens of South Australia · dr. Joanna

PSYCHOLOGY
Flinders University · Rice · NASA

SENSORY SCIENCE
The University of Melbourne · The University of Adelaide · The University of Nottingham

COMPUTER MODELLING OF ASTRONAUT FOOD (1)



COMPUTER MODELLING OF ASTRONAUT FOOD (2)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The Perfect Astronaut Meal Might Be a Vegan Salad


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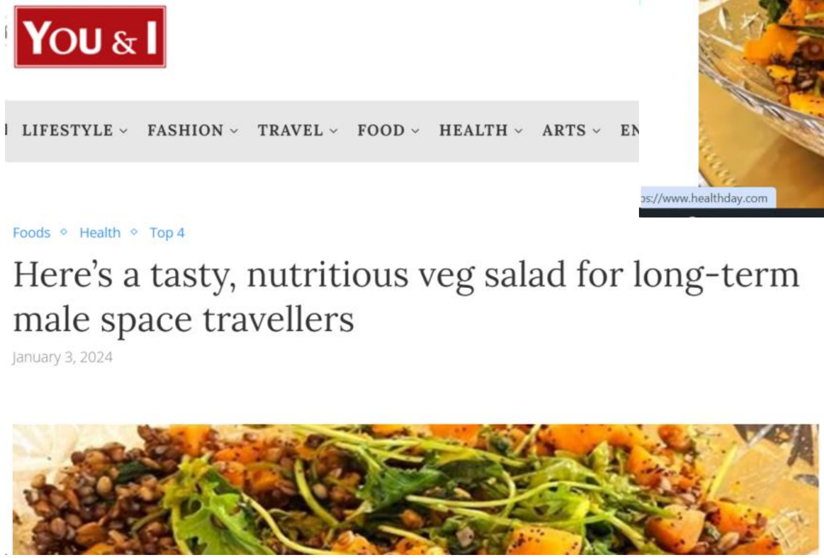
ALIMENTAÇÃO

Salada para astronautas, com soja, couve e cevada, ajuda em viagens espaciais

Edição da newsletter Menu explica refeição vegetariana que pode ser feita com alimentos cultivados no espaço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LIFESTYLE FASHION TRAVEL FOOD HEALTH ARTS EN

Foods ◦ Health ◦ Top 4

Here's a tasty, nutritious veg salad for long-term male space travellers

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