

# Innovative Food Science and Emerging Technologies

**Dietrich Knorr**  
TU-Berlin, Germany

.... every 18-21 days or so, we each consume our body weight in food and drink.

1.5 t/a

Hormann, I. 1995

# FOOD and WATER SECURITY

INCREASE  
PRODUCTION

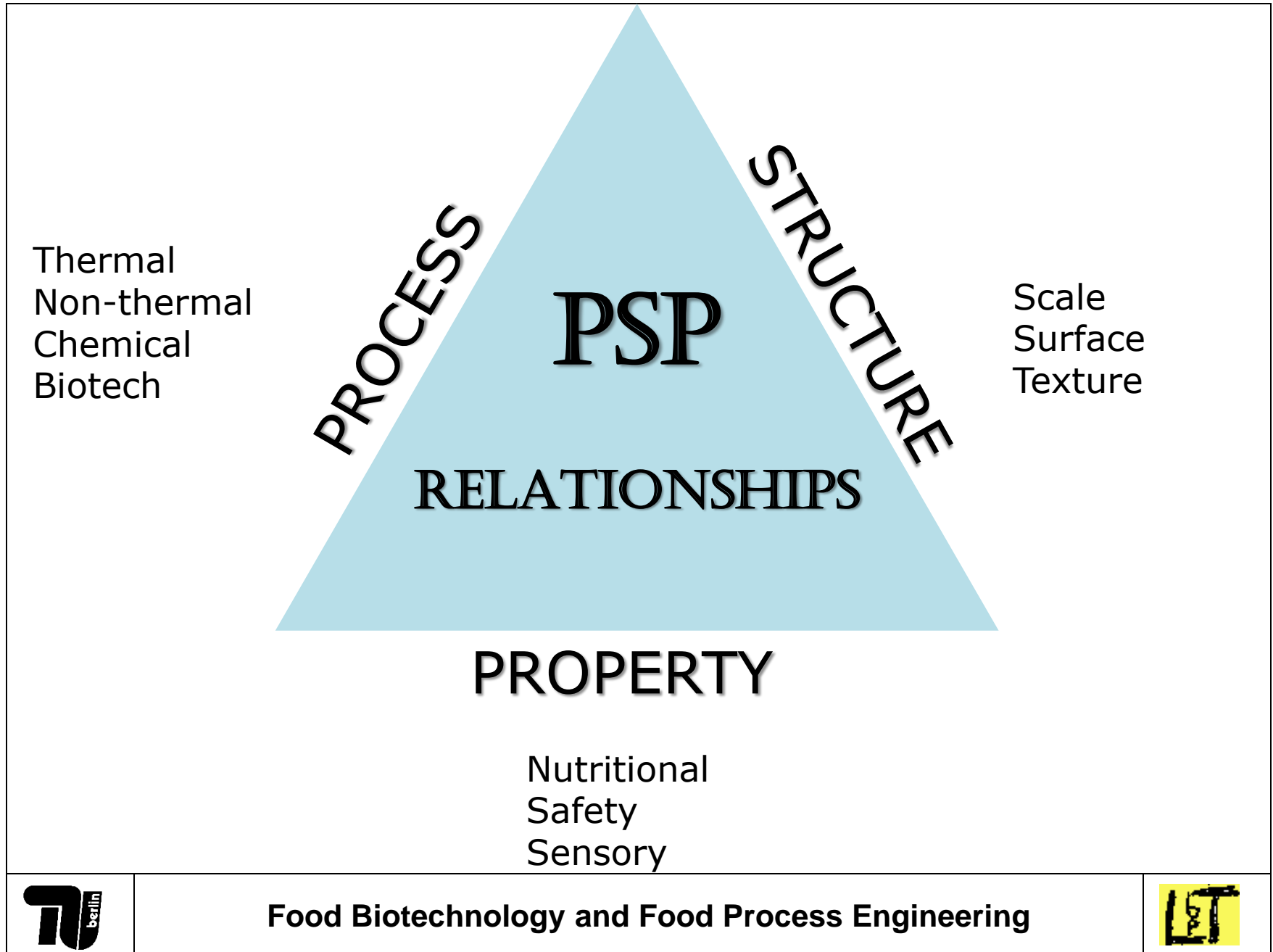
GMO's  
ALTERNATIVE SOURCE  
(SCP, MCP)  
INCREASE RESOURCE  
EFFICIENCY

REDUCE  
WASTE

FOOD BIOMASS  
FROM WASTE  
INCREASE  
RESPECT FOR FOOD  
REDUCE POST HARVEST  
And COOKING LOSSES

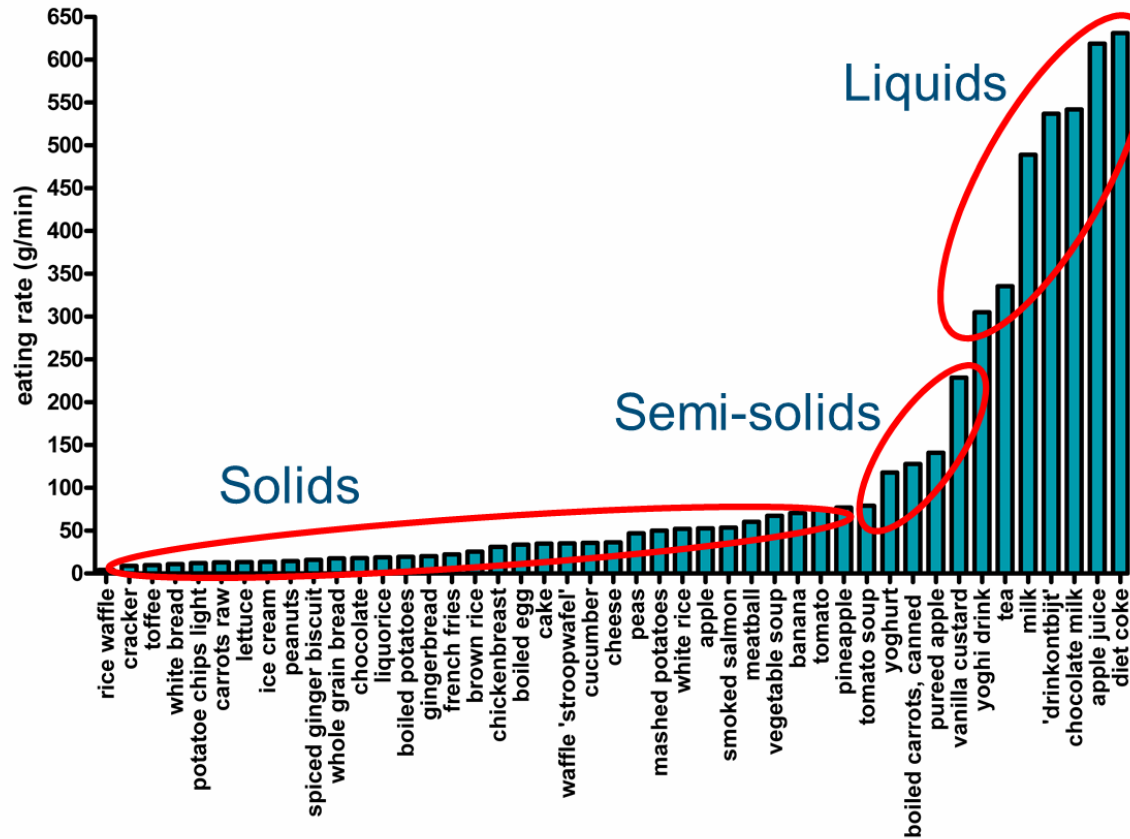
REDUCE  
INTAKE

SATIETY MANAGEMENT  
REDUCE ENERGY  
DENSITY



# TAILOR MADE FOODS

## Eating rate (g/min)



range: 4 – 630 g/min

M. Mars, 2011

# FUTURE FOODS MODE OF ACTION

## Graveyard mining

SCP, LPC

## Underutilized resources

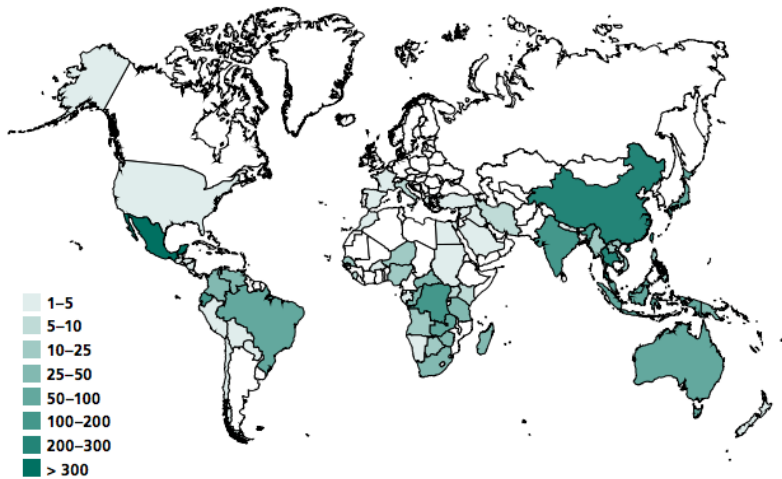
Chitin, Insects, biomass, blood

## New toolboxes

High pressure, pulsed electric fields,  
subcritical water, Transglutaminase

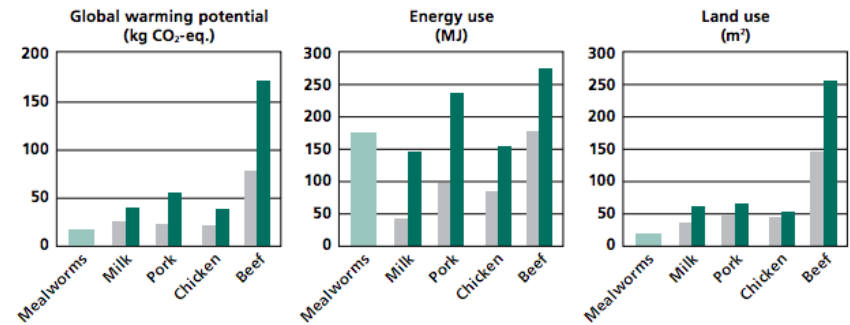
# Impact of HPP and Plasma on the decontamination of edible insects (Mealworm)

FIGURE 2.1  
Recorded number of edible insect species, by country



Source: Centre for Geo Information, Wageningen University, based on data compiled by Jongema, 2012.

FIGURE 5.5  
Greenhouse gas production (global warming potential), energy use and land use due to the production of 1 kg of protein from mealworms, milk, pork, chicken and beef



Note: The grey bars are minimal values and the dark green bars are maximum values found in the literature.  
Source: Ooninx and de Boer, 2012.

- Insects are eaten by 2 billion people worldwide

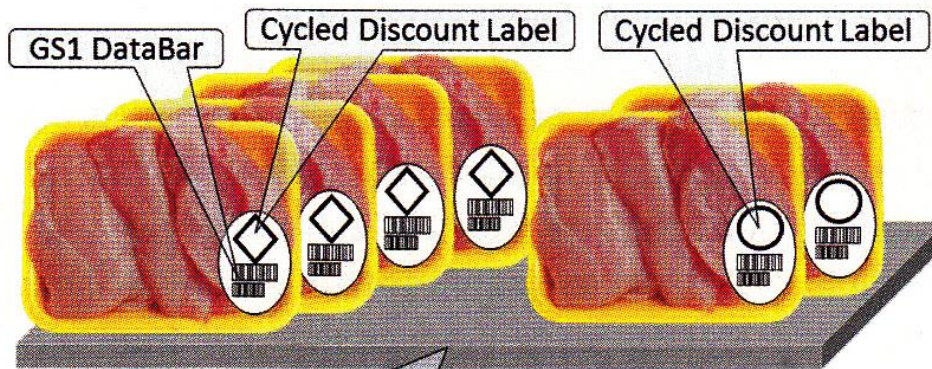
TABLE 6.3

Comparison of average protein content among insects, ~~reptiles, fish~~ and mammals

Animal group	Species and common name	Edible product	Protein content (g/100 g fresh weight)
Insects (raw)	Locusts and grasshoppers: <i>Locusta migratoria</i> , <i>Acridium melanorhodon</i> , <i>Ruspolia differens</i>	larva	14–18
	Locusts and grasshoppers: <i>Locusta migratoria</i> , <i>Acridium melanorhodon</i> , <i>Ruspolia differens</i>	Adult	13–28
	<i>Sphenarium purpurascens</i> (chapulines – Mexico)	Adult	35–48
	Silkworm ( <i>Bombyx mori</i> )	Caterpillar	10–17
	Palmworm beetles: <i>Rhynchophorus palmarum</i> , <i>R. phoenicis</i> , <i>Callipogon barbatus</i>	Larva	7–36
	Yellow mealworm ( <i>Tenebrio molitor</i> )	Larva	14–25
	Crickets	Adult	8–25
	Termites	Adult	13–28
Cattle		Beef (raw)	19–26



Date Packed → Lot(x)-◇ March 3    Lot(y)-○ March 4



Poultry products on supermarket shelf on March 5<sup>th</sup> and 6<sup>th</sup>, 2014

March 5<sup>th</sup> Offer



Cycled Discount Label

March 6<sup>th</sup> Offer

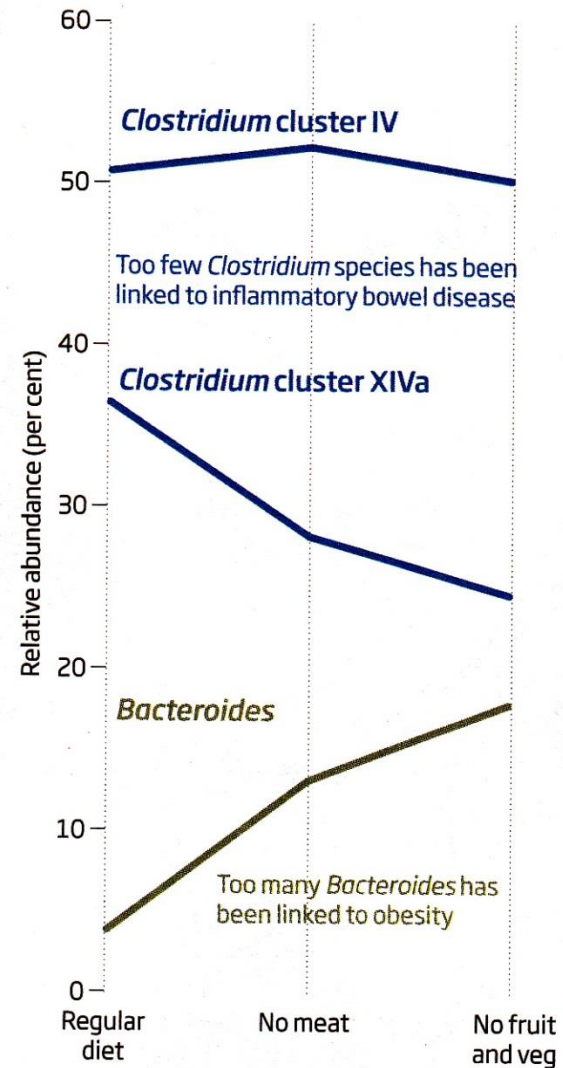


**The End Grocery Waste App** utilizes GS1 DataBar to help food retailers identify expired or recalled perishable food items.

Photo courtesy of Rod Averbuch of EndGroceryWaste.com

# Mayor of Microbe Metropolis

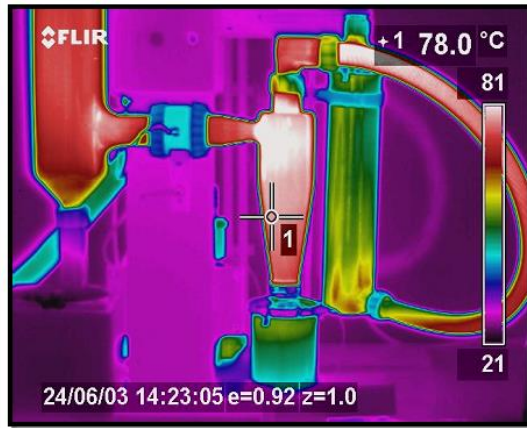
When **Jop de Vrieze** met the microbes that call him home, he suddenly realised he had responsibilities



# NEW TOOLS

## "Gut ENGINEERING"

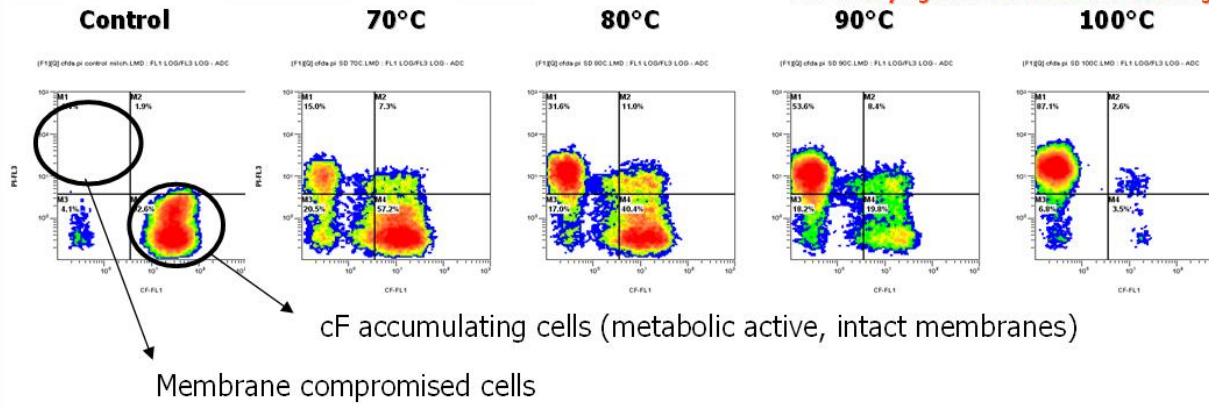
### PROBIOTICS: PROCESS DEVELOPMENT



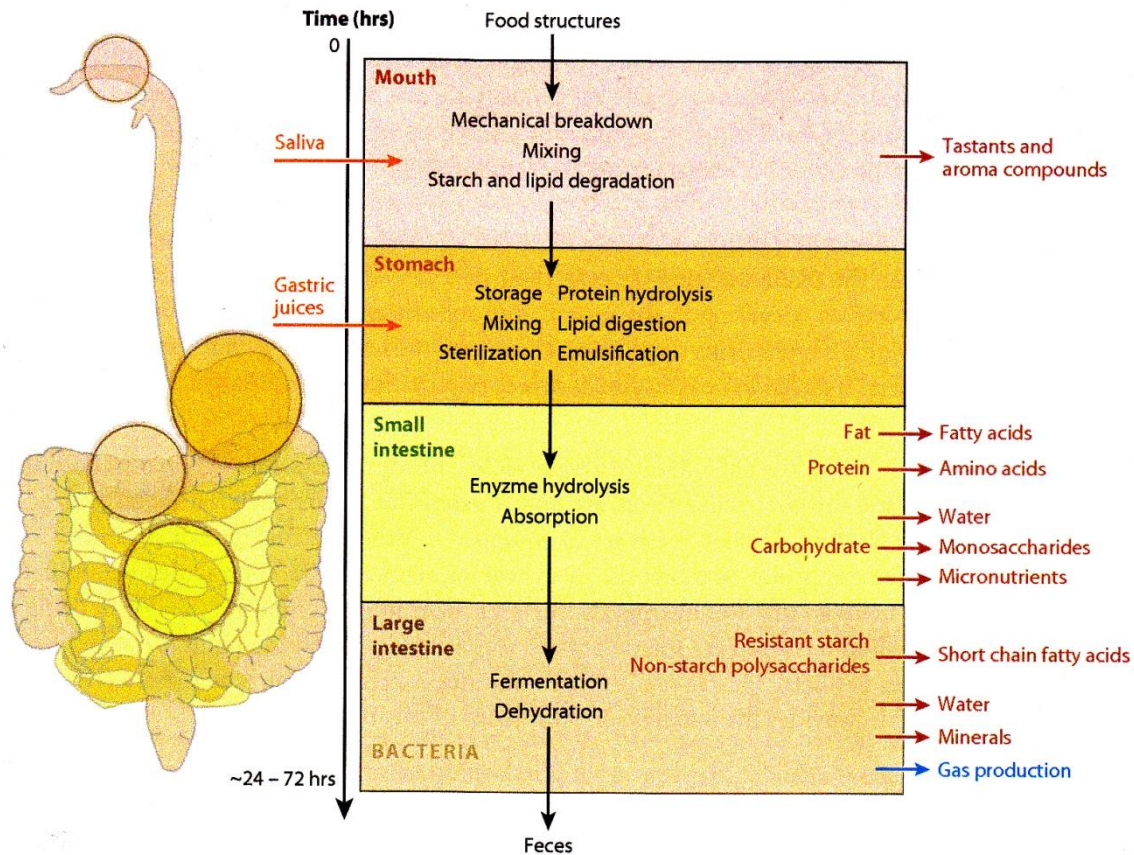
Type of drying equipment	Energy consumption (kJ/kg water evaporated)
Membrane filtration (ultrafiltration and reverse osmosis)	50-150
Evaporator	
- one-step ("single-effect")	2600
- series ("double-effect")	1300
Spray dryer	
- one-step ("single effect")	6000
- series ("double effect")	4000
Drum dryer	5000
Tunnel dryer	4000
Freeze-dryer	100 000

**Spray drying of LGG in skim milk as carrier**  
 Flow cytometric assay with dye combination : cFDA/PI to

assess **drying induced membrane damage**







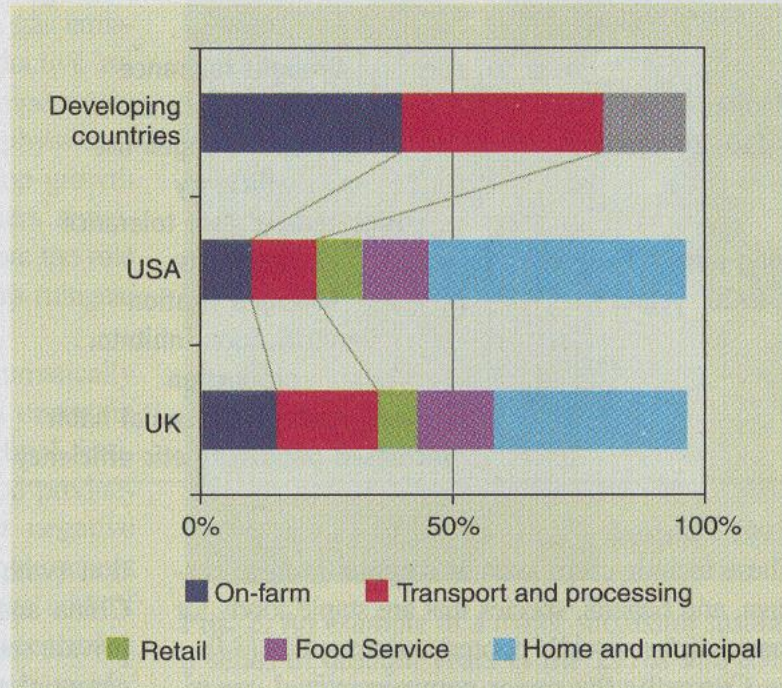
**Figure 1**

A schematic of the transit of food structures through the mouth, stomach, and small and large intestines (considered here as a series of batch reactors), illustrating the process operations taking place at each stage and the nutrients digested and absorbed. Adapted from Topping & Clifton (2001).



# Science

12 February 2010 | \$10



**Fig. 3.** Makeup of total food waste in developed and developing countries. Retail, food service, and home and municipal categories are lumped together for developing countries. [Source: (16, 37–39)]

Food Sec

AAAS

# Processes to combat waste & losses

## postharvest

- solar dryers
- fermentation
- concentration
- extrusion
- salting
- antimicrobials
- emerging technol

## storage / transportation

- packaging
- T & Aw control
- logistics
- sensors
- emerging technol

## processing

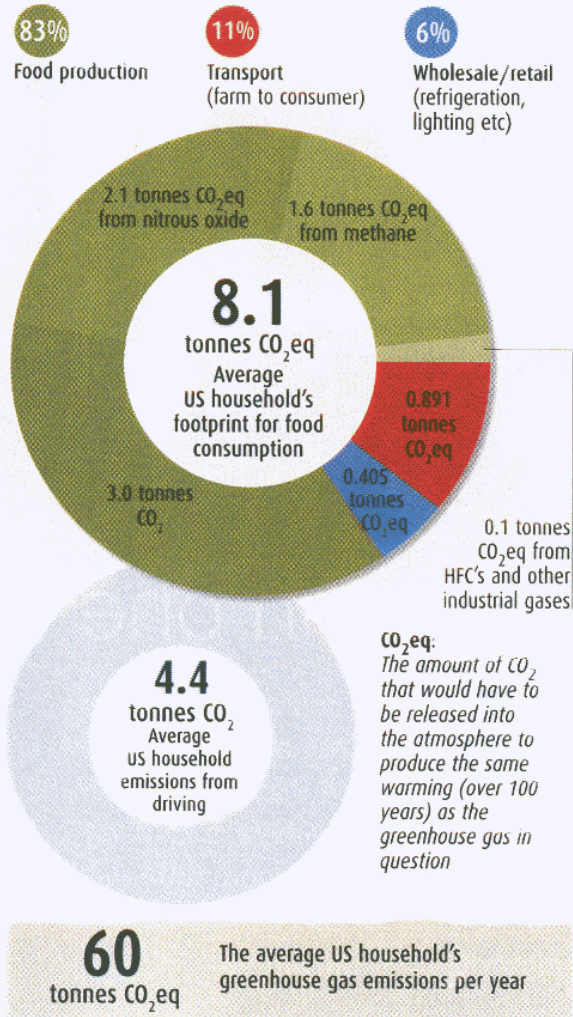
- re-evaluation
- bioconversion
- re-use
- wholistic approach
- emerging technol

## market / home / consumption

- expiration data
- freshness sensors
- training
- respect
- home appliances
- emerging technol

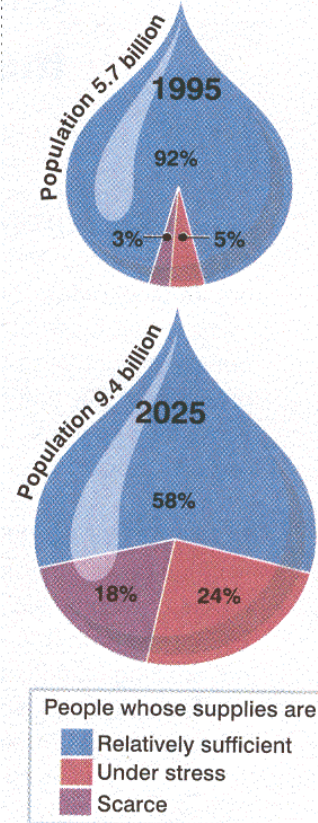
### FOOD FOR THOUGHT

Household greenhouse gas emissions from food account for almost twice those produced by driving. Most of this comes from the food production process itself, rather than food-miles, as is often believed

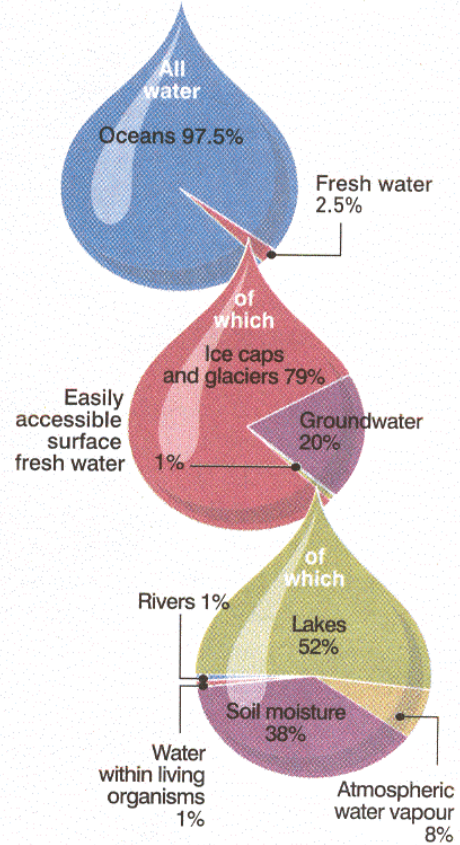




### Water for life



### Where is our water?





# CLIMATE CHANGE IMPACT ON FOOD SECURITY

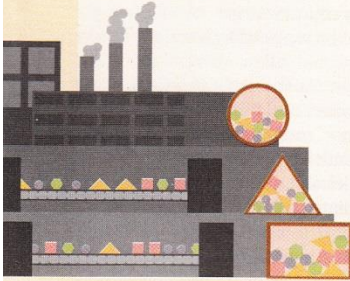
## ➤ MESSAGES FOR DECISION MAKERS

- (1) Climate change (CC) impact will be worst in countries already suffering of hunger and worsen over time
- (2) Food inequalities will increase
- (3) Communities already vulnerable to effects of extreme weathers will become more vulnerable
- (4) Extreme weather events will be more frequent and increase food insecurity

## A better way of getting from here to there

What it would take to create the Physical Internet

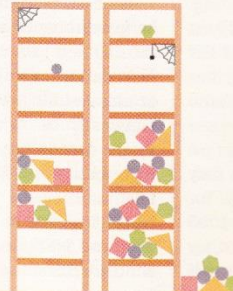
### The problems



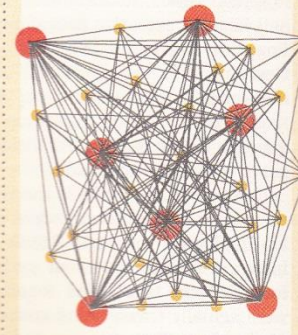
Products and shipping containers are not standard or modular.



Transportation assets are fragmented and uncoordinated.



Inefficient use of storage and transfer centers.



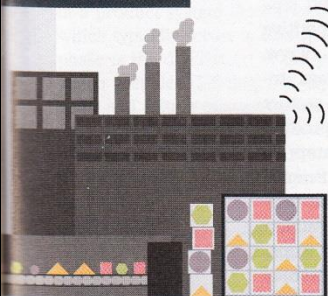
Sub-optimal delivery routes.

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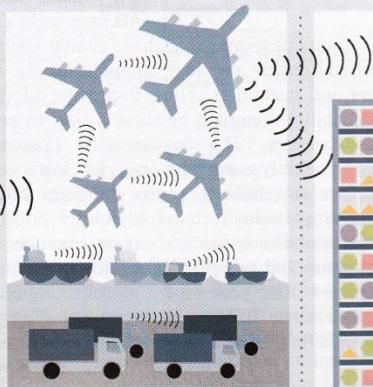
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### The solutions



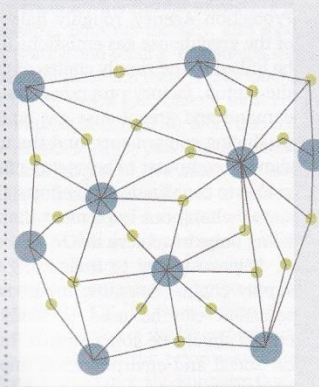
Products and shipping containers become standardized and modular.



Transportation assets are pooled and interconnected.



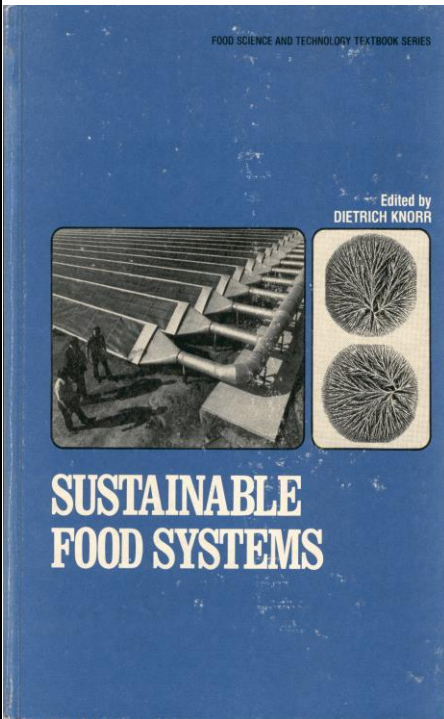
Warehouse assets get more efficiently utilized ...



... leading to a more logical supply chain.

**SCIENCE** sciencemag.org

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Systematic attempts to explore existing methods and to develop new technologies of more sustainable food production systems have so far been scarce.

Dietrich Knorr, 1983

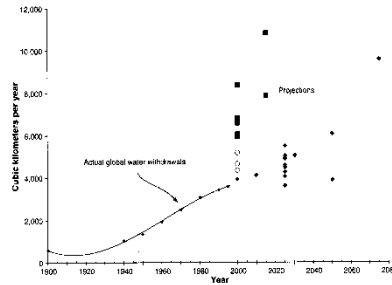
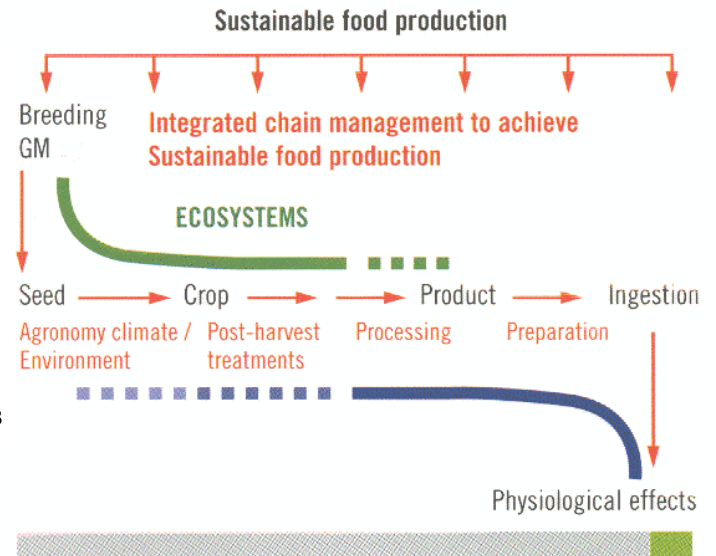


Fig. 3. Projections of water use and actual global water withdrawals, as compiled from various projections of global water withdrawals made since the 1950s (14), together with an estimate of actual global water withdrawals, as estimated in (45). Note that projections made before 1980 forecast very substantial increases in water use, more recent forecasts have begun to incorporate possible improvements in water productivity to reflect recent historical experience. Symbolic squares, projections made before 1980 (includes forecasts for 2000 or 2015); circles, projections made between 1980 and 1995 (includes forecasts for 2000); diamonds, projections made after 1995 (includes forecasts for 2000, 2010, 2025, 2050, 2075, and 2075).

Figure 8. Sustainable food production along the food chain



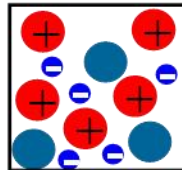
Source: K. Waldron, IFR, UK, 2004



# Plasma:



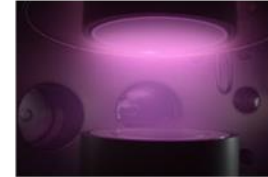
Ionization



Sun



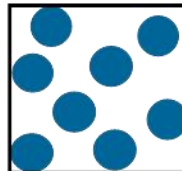
Northern lights



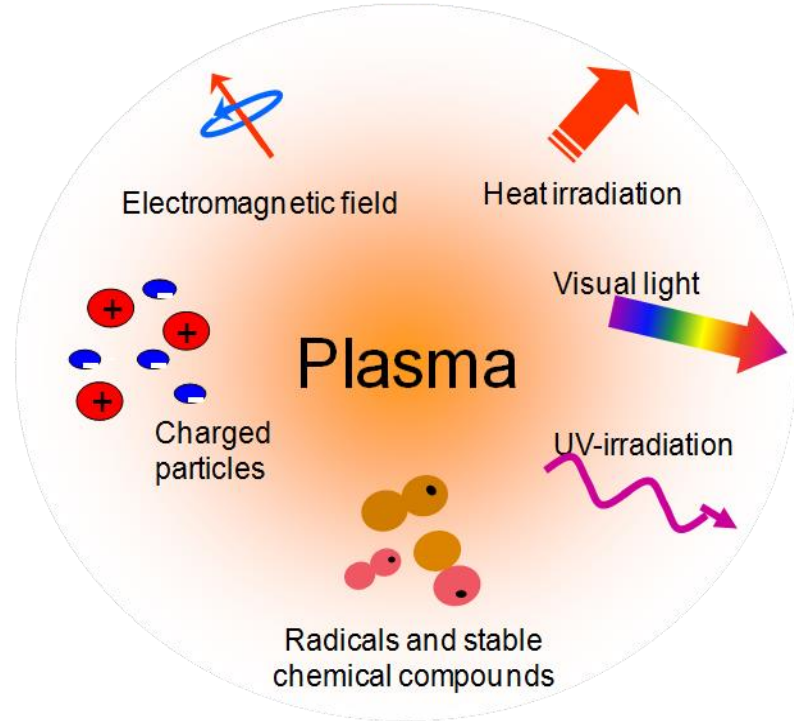
Fluorescent lamps



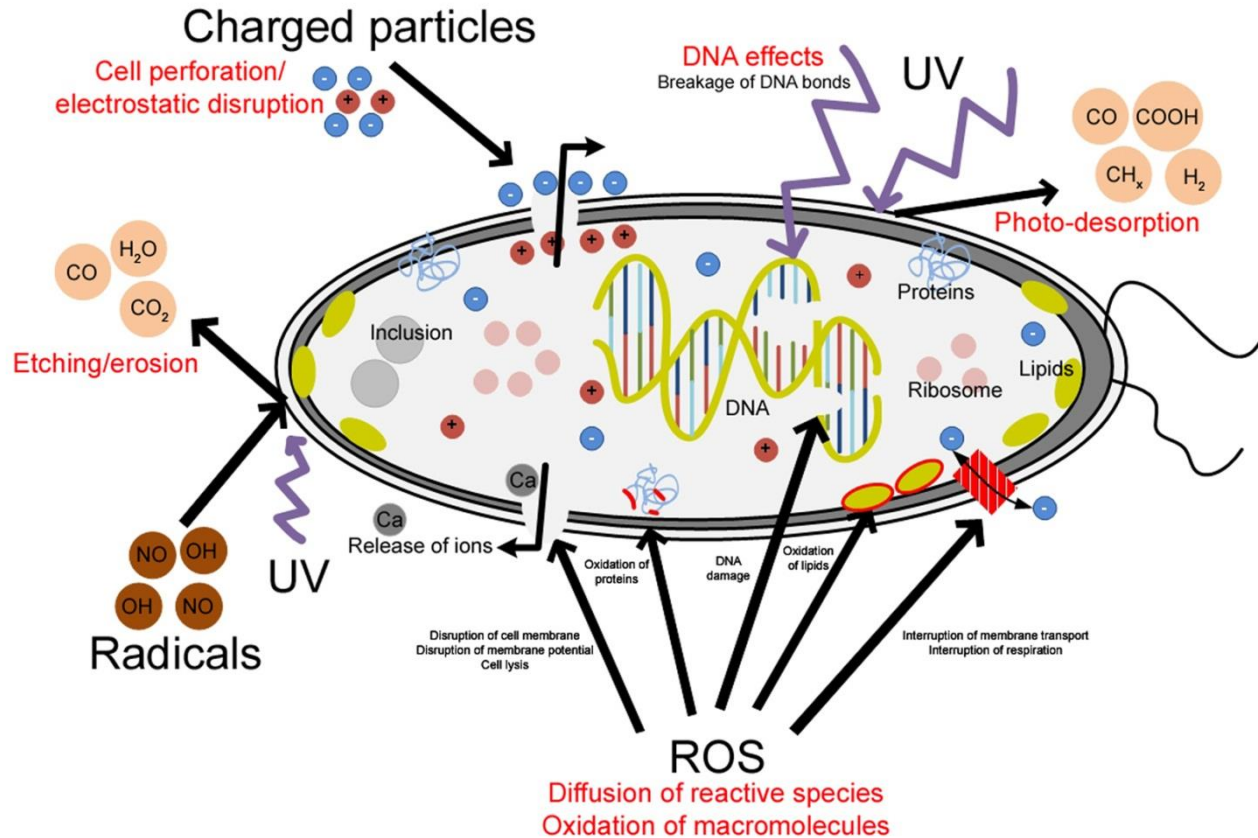
Evaporation



Melting

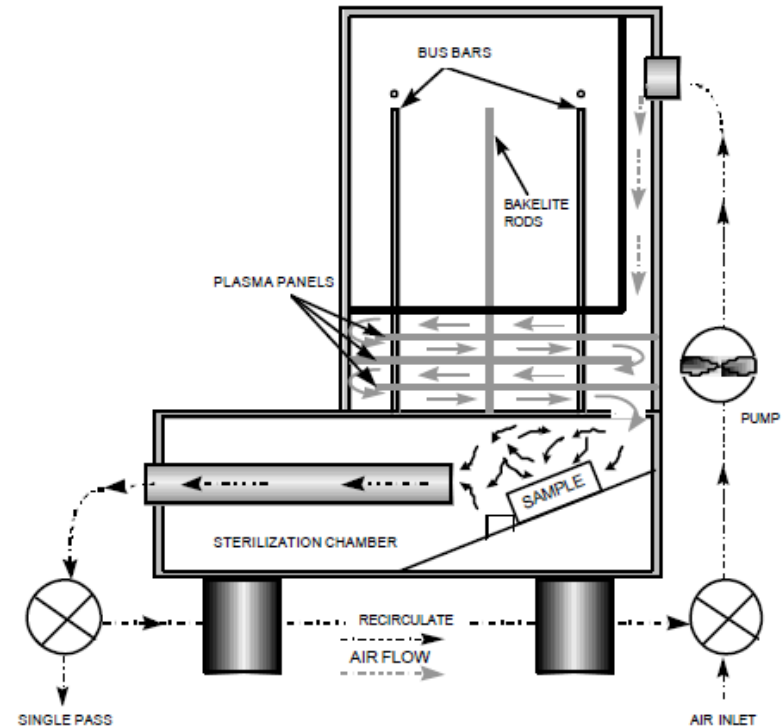
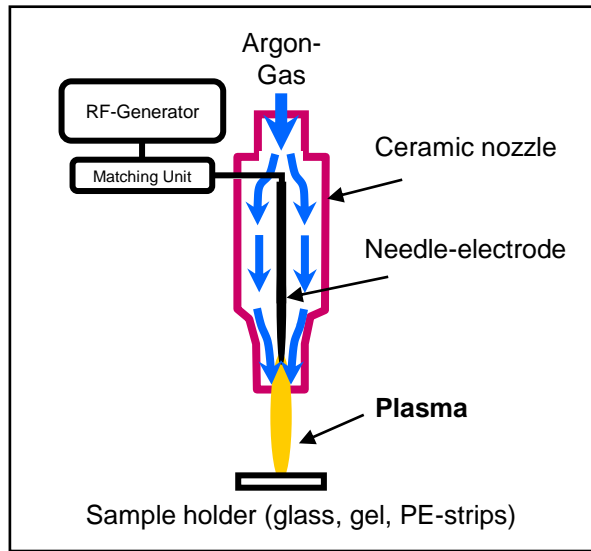


# Plasma: Possible inactivation mechanisms



Schlüter & Fröhling (2012) Cold plasma for bio-efficient food processing. Encyclopedia of Food Microbiology (submitted)

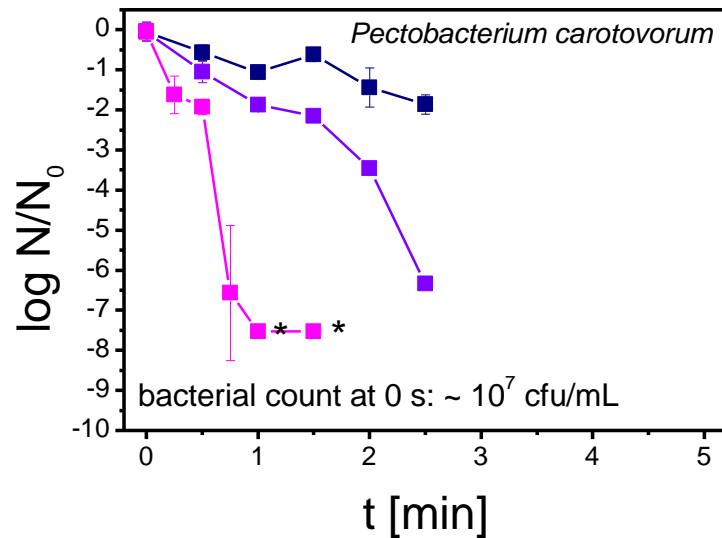
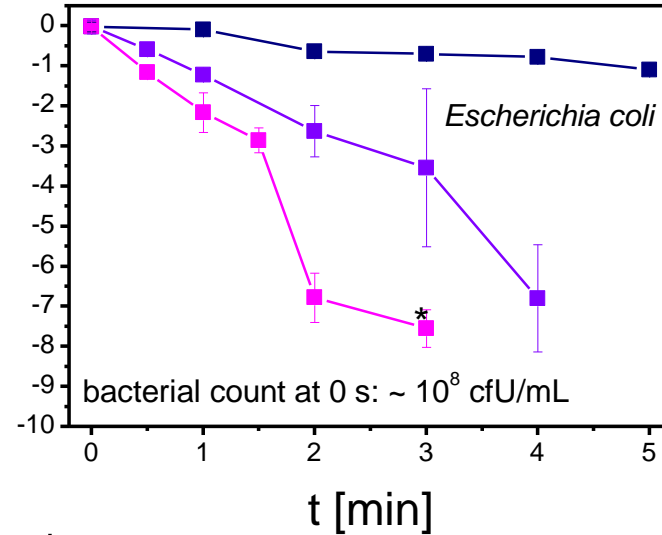
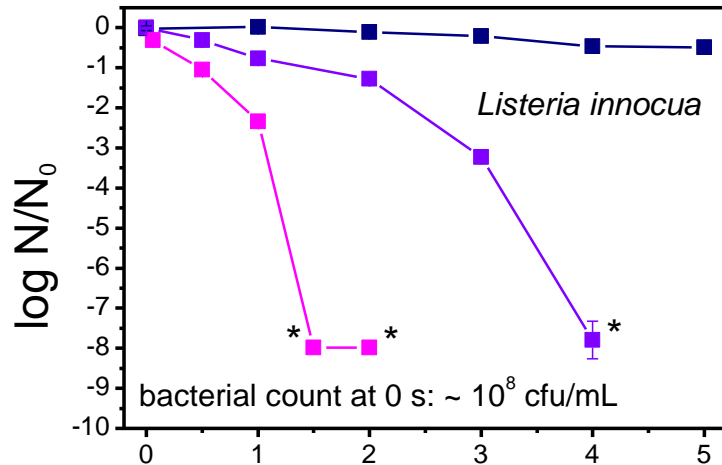
Courtesy of ATB



#### Areas of application:

- Fresh Cut products (Salat, fruits)
- Surface decontamination (Meat, Herbs and Spices, Eggs, working surfaces etc.)
- Surface treatment to improve the slip properties of bulk materials

# Plasma Inactivation of vegetative microorganisms in model-systems (gel-plates)



\* below the detection limit of  $10^2$  cfu/mL

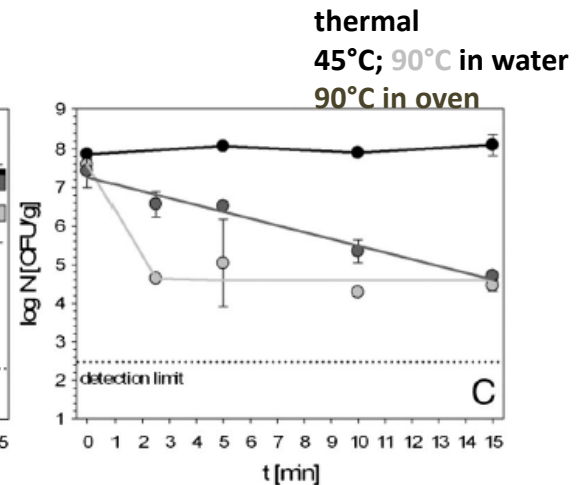
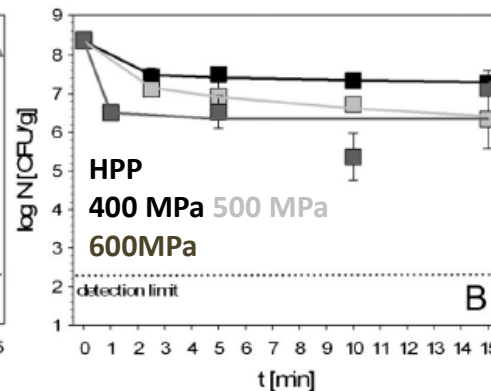
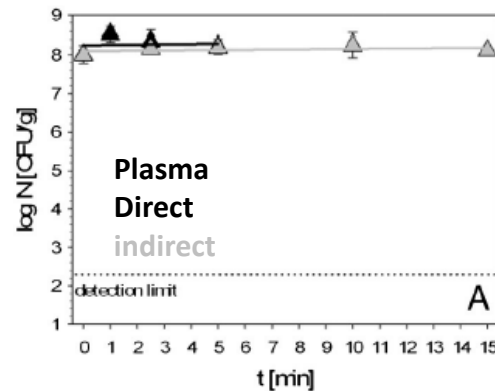
- 10 W
- 20 W
- 40 W



Courtesy of ATB

# Impact of HPP and Plasma on the decontamination of edible insects (Mealworm)

Overall microbial activity (inside+outside)



- Indirect Plasma effective for surface decontamination
- For the overall microbial inactivation (+gut microbiota) volumetric treatment is needed
- Combination of indirect plasma and thermal treatment (90°C) seems to be promising



WWW.SNACK-INSECTS.COM

Source: Rumpold, B.A., Fröhling, A., Reineke, K., Knorr, D., Boguslawski, S., Ehlbeck, J. & Schlüter, O., Comparison of volumetric and surface decontamination techniques for innovative processing of mealworm larvae (*Tenebrio molitor*), *Innovative Food Science and Emerging Technologies* (2014)



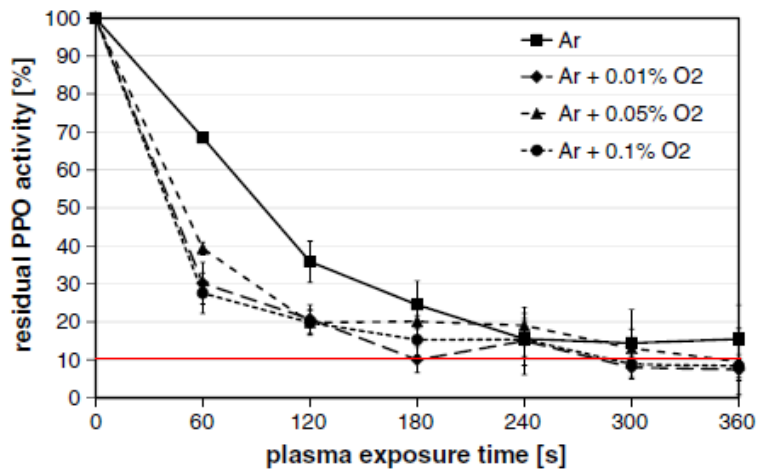


Fig. 3. Plasma inactivation kinetics of *Agaricus bisporus* polyphenoloxidase for different plasma gas compositions and for plasma exposure times of 0–360 s.

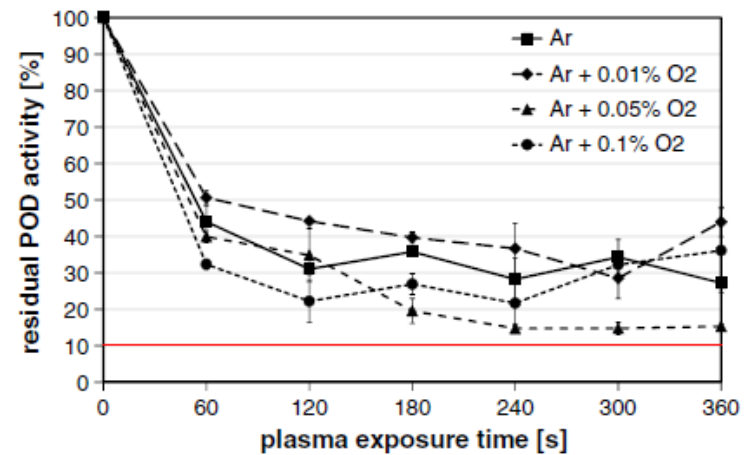


Fig. 4. Plasma inactivation kinetics of horseradish peroxidase for different plasma gas compositions and plasma exposure times of 0–360 s.

**ARTICLE IN PRESS**

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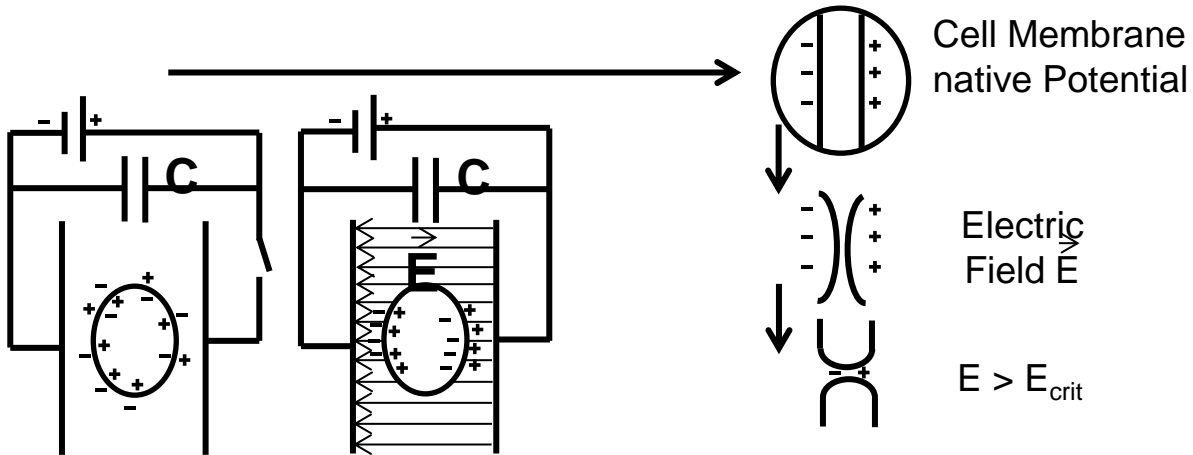
journal homepage: [www.elsevier.com/locate/ifset](http://www.elsevier.com/locate/ifset)

Cold plasma effects on enzyme activity in a model food system

Bjoern Surowsky <sup>a,\*</sup>, Axel Fischer <sup>a</sup>, Oliver Schlueter <sup>b</sup>, Dietrich Knorr <sup>a</sup>

<sup>a</sup> Technische Universität Berlin, Department of Food Biotechnology and Food Process Engineering, Königin-Luise-Str. 22, 14195 Berlin, Germany  
<sup>b</sup> Leibniz Institute for Agricultural Engineering Potsdam, Department of Horticultural Engineering, Max-Eyth-Allee 100, 14469 Potsdam, Germany

## Pulsed electric fields (PEF)



- **Biotechnological processes (0.5 - 1.5 kV/cm)**
- **Reduction of cutting force (0.5 - 1.5 kV/cm)**
- **Enhancement of mass transport (0.7 - 3 kV/cm)**
- **Inactivation of microorganisms (15-40 kV/cm + 40°C)**



A reporter examines  
her own DNA p. 1167

Wishlist-worthy books  
for young readers p. 1172

Reducing youth violence  
via summer jobs p. 1219

# Science

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## *A shocking predator*

Electric eels remotely control muscles of their prey p. 1231



Food Biotechnology and Food Process Engineering



Direct resistance heating in the food industry

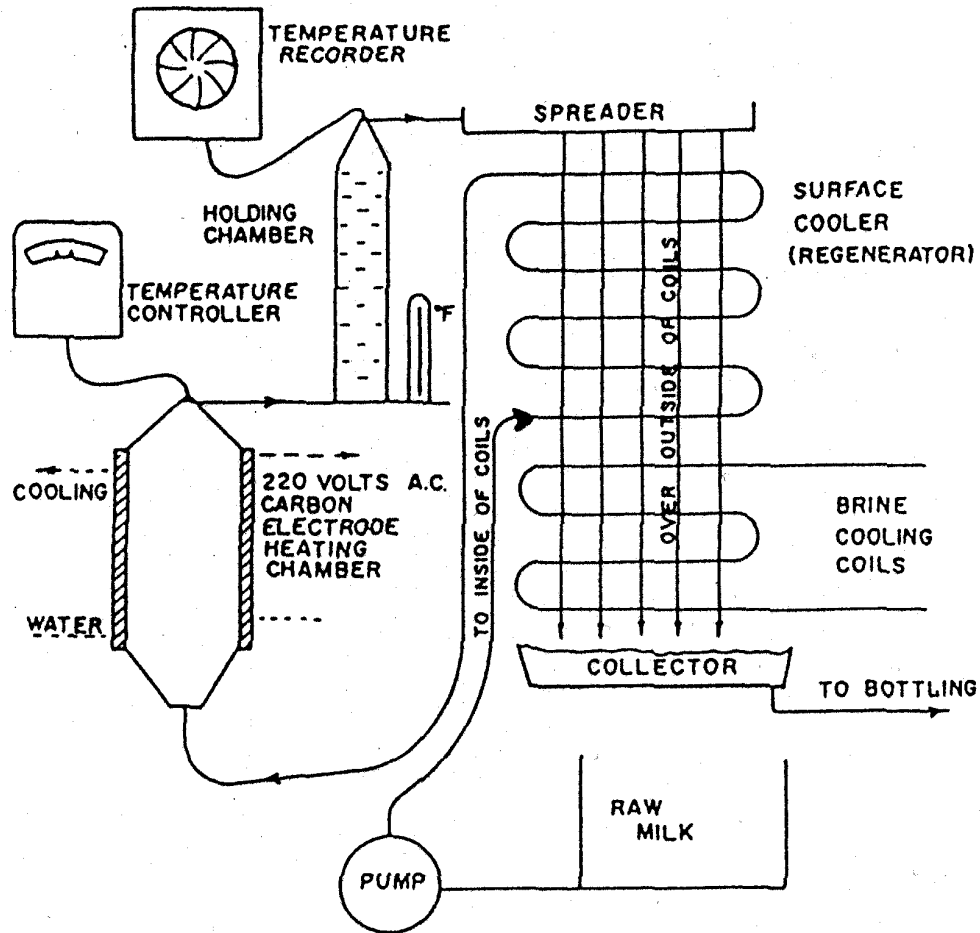
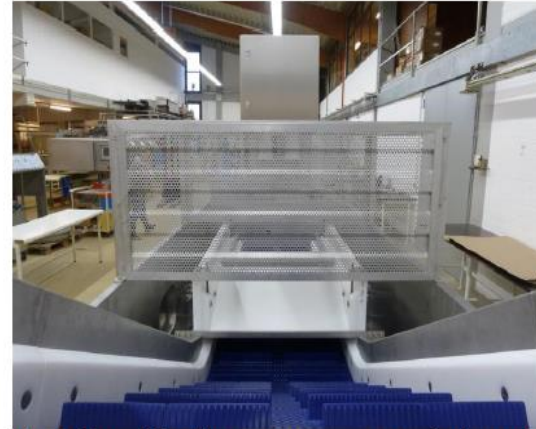


Fig. 8. Schematic diagram of an improved Electro-pure process with temperature control (Getchell, 1935).

# Pulsed Electric Fields

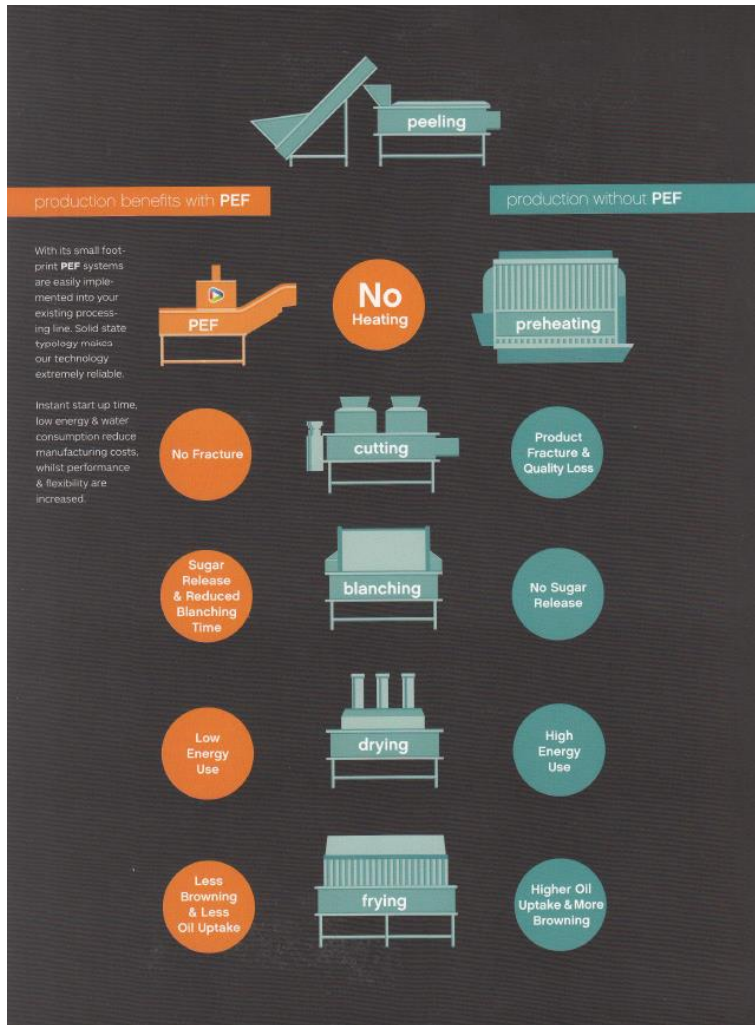
## Industrial scale equipment



Turn-key, 50 t/h system, potato industry



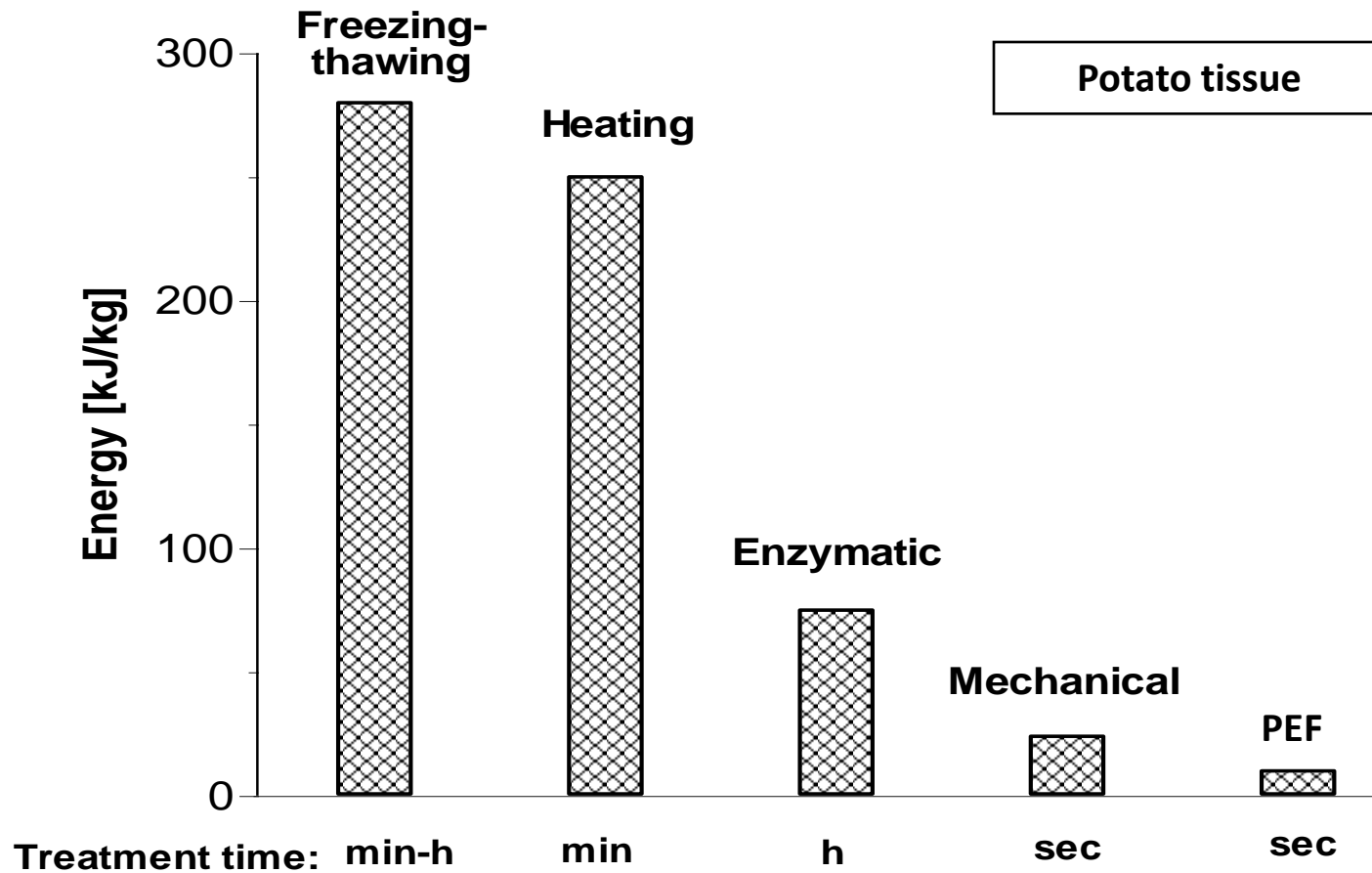




## Products that work with PEF

- |                    |                  |                               |
|--------------------|------------------|-------------------------------|
| Microalgae         | Nutrient media   | Cooling water                 |
| Kelp & Seaweed     | Enzyme solutions | Dairy products                |
| Vegetable oil      | Food supplements | Protein concentrates          |
| Herbal extracts    | Baby food        | Seafood & fish                |
| Flower extracts    | Cosmetics        | Marinades, sauces & dressings |
| Pigments & colours | Pharmaceuticals  |                               |
| Flavour extracts   | Process water    |                               |

# Energy expenditure for cell membrane disintegration



Cell disintegration in potato tissue

Mechanical disintegration (starch)

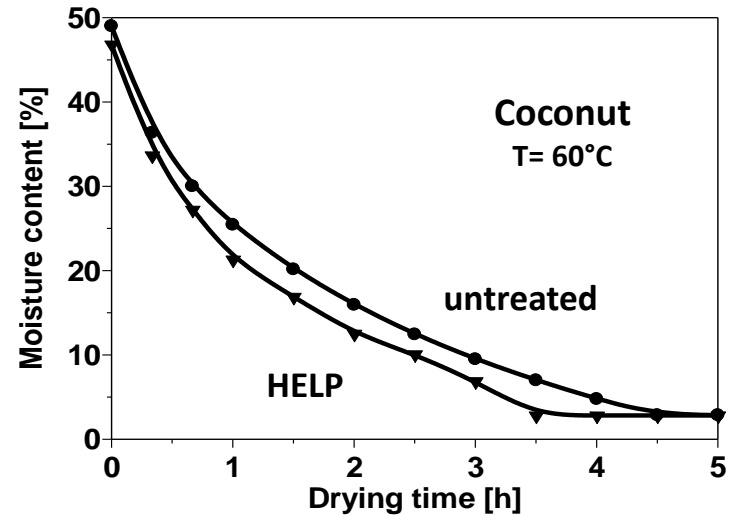
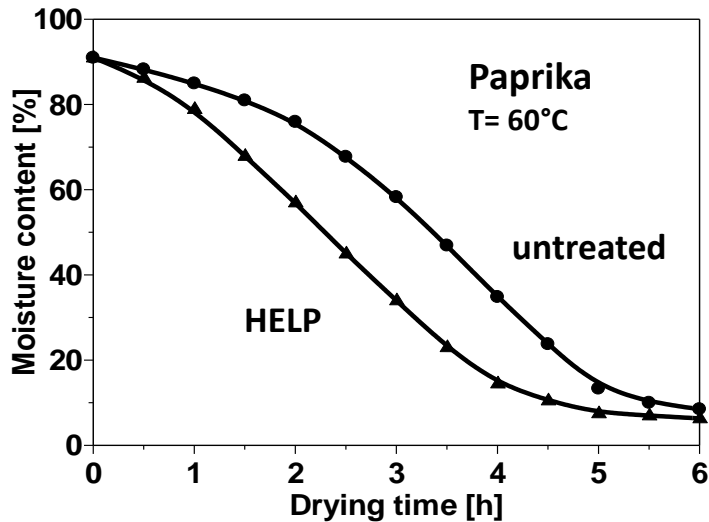
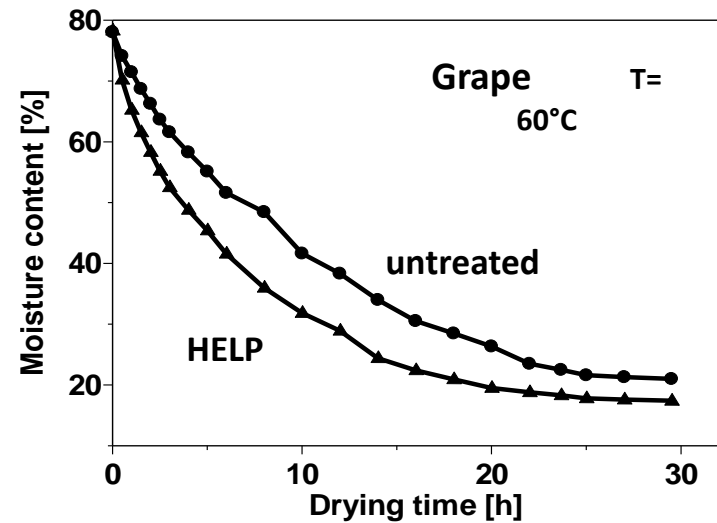
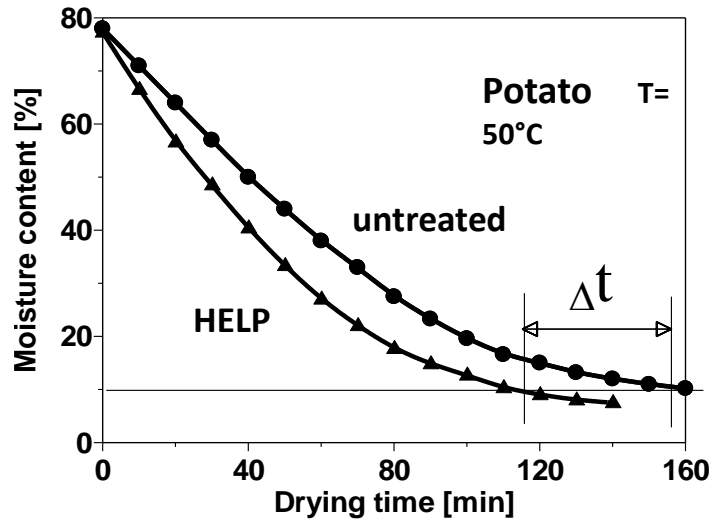
90 ± 2 %

HELP

100 %

# PROCESS DEVELOPMENT

## Fluidized bed drying of PEF pretreated vegetables

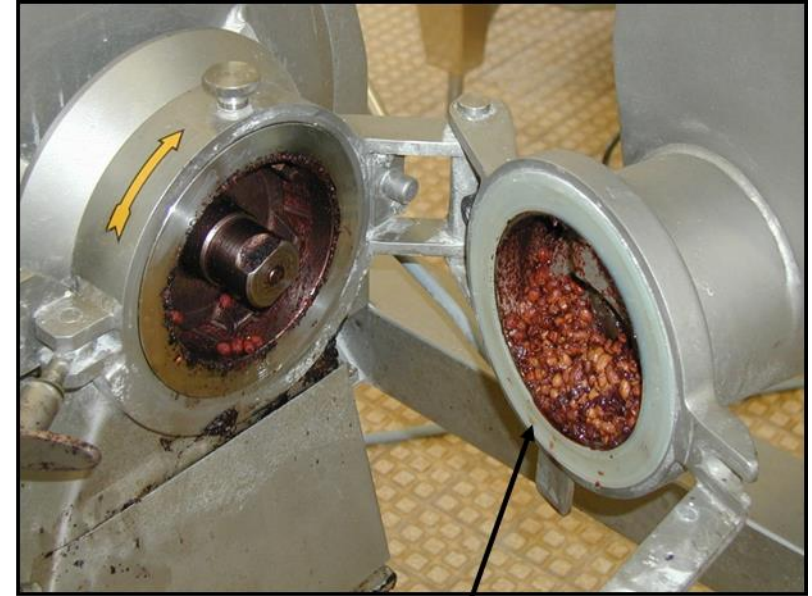
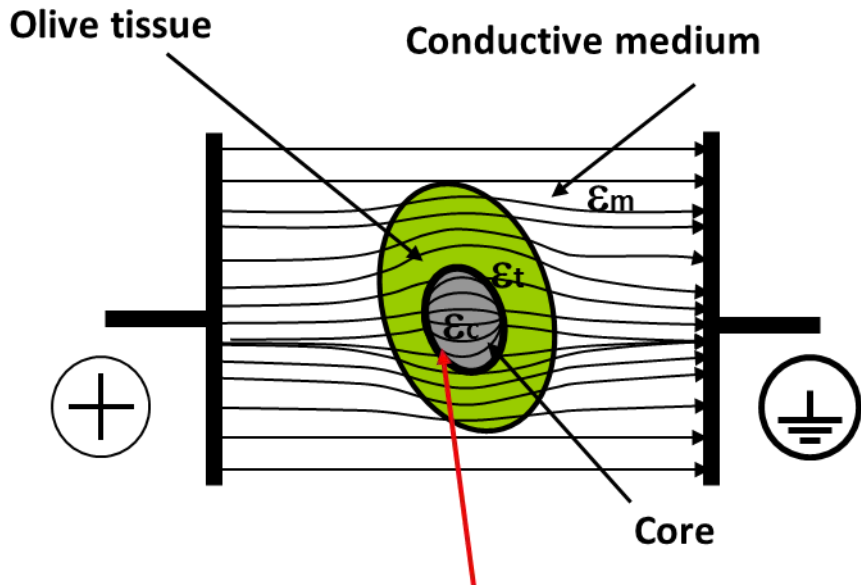




## Additional Positive Effects

Dielectric transmissivity

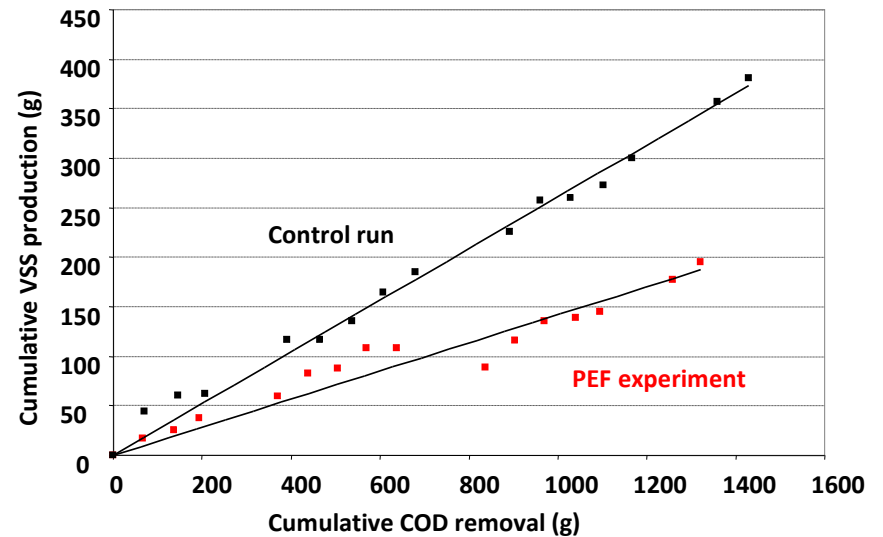
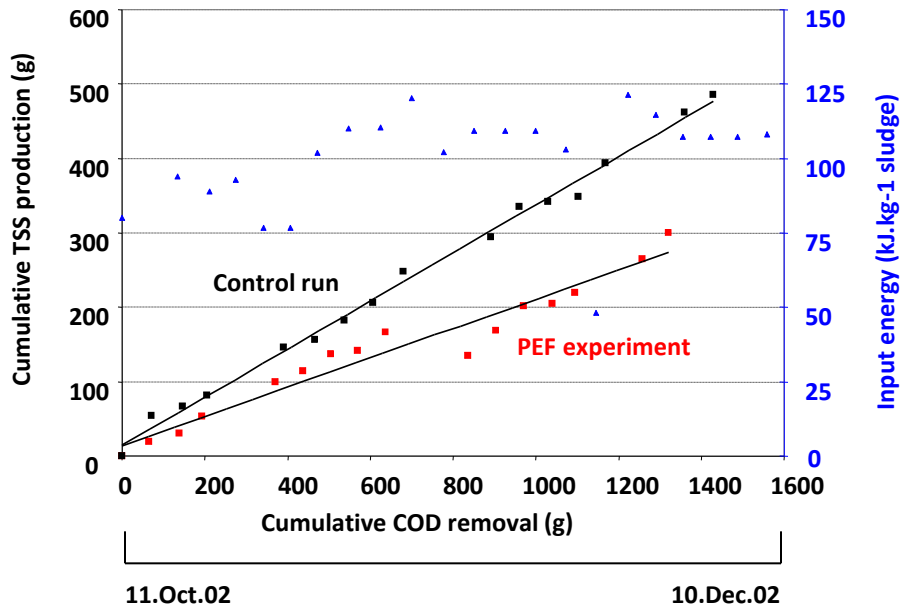
$$\epsilon_c < \epsilon_t \approx \epsilon_m$$

Tissue-Core  
Separation

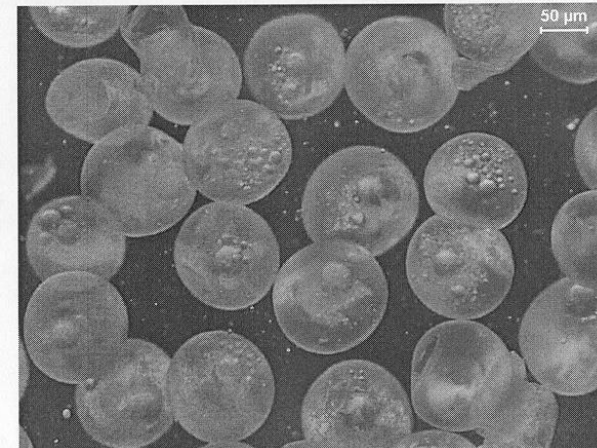
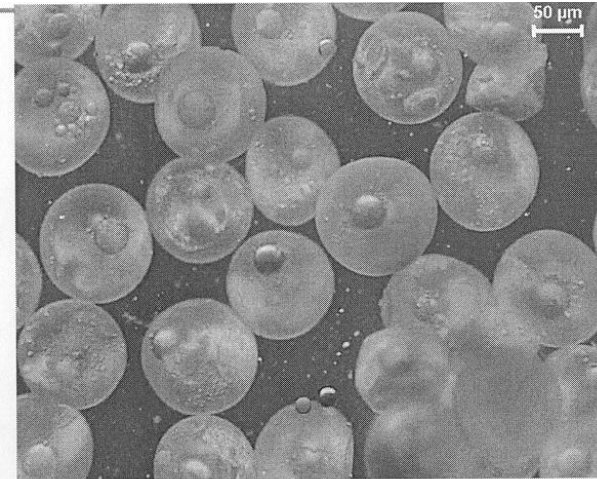
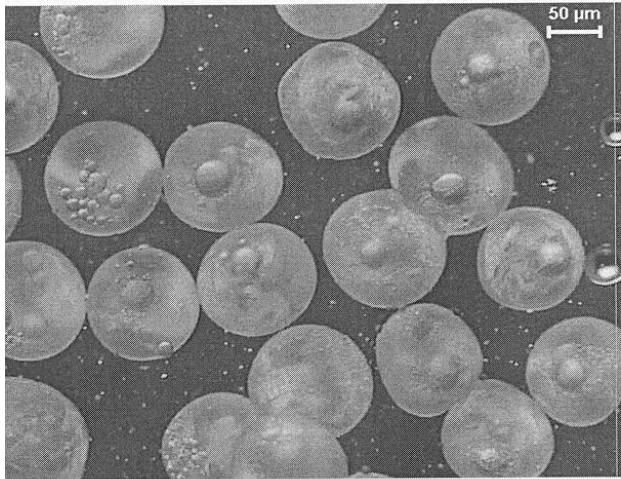
- Concentration of PEF energy at boundary surfaces with different dielectric properties ?
- Split of pectin chain ?

# Continuous PEF Treatment for the Reduction of Sludge

	$Y_{obs}^{TSS}$	$Y_{obs}^{VSS}$	$Y_{obs}^{MSS}$
	(mg XSS produced.mg <sup>-1</sup> COD removal)		
Control run	0.356	0.277	0.072
PEF run (E ~ 100kJ.kg <sup>-1</sup> )	0.197	0.129	0.068
RSP (%)	45	53	6



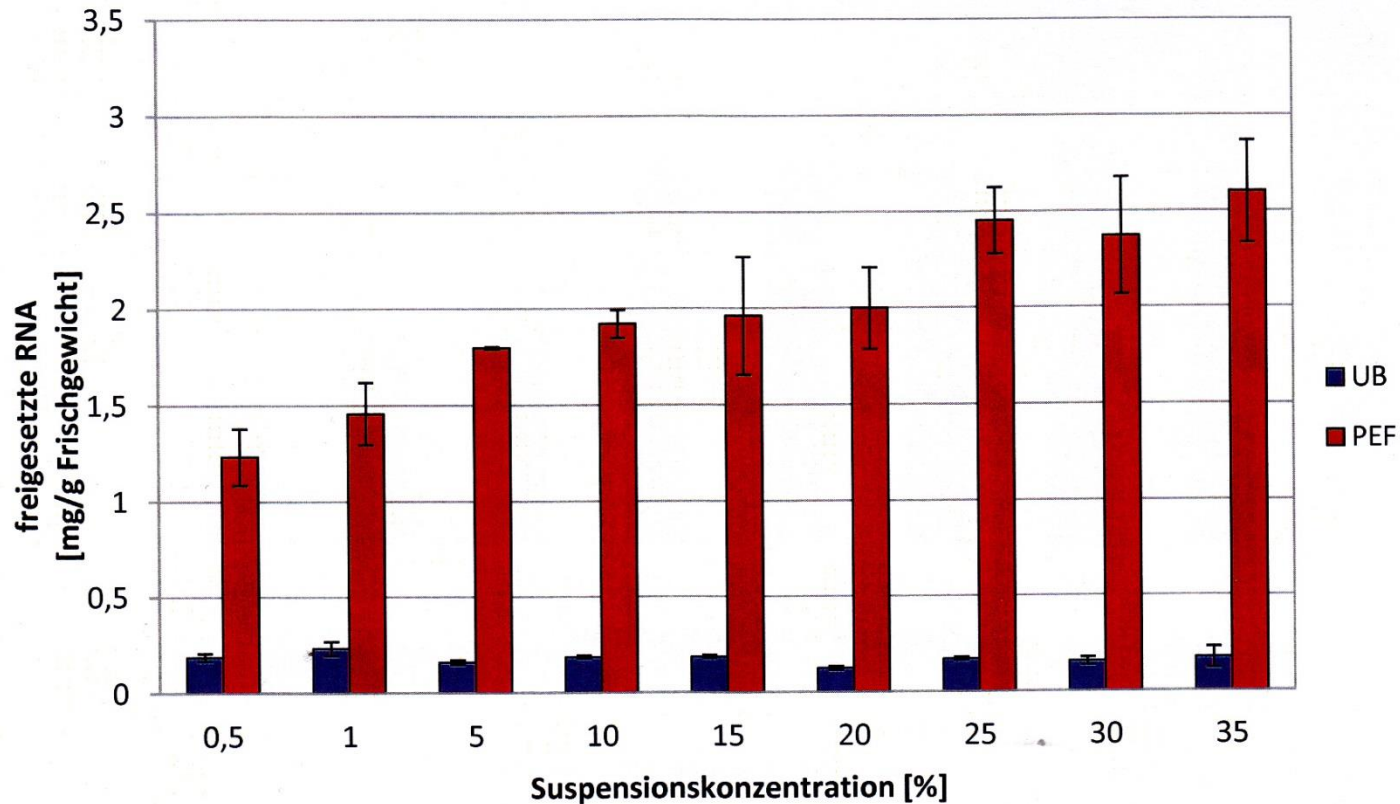
# PEF SEPARATION



Top left: Control  
Top right: 8kV/cm/12 pulses  
Bottom: 12kV/cm/9 pulses



### 4.3.2 Nukleinsäurefreisetzung in Abhängigkeit von der Suspensionskonzentration



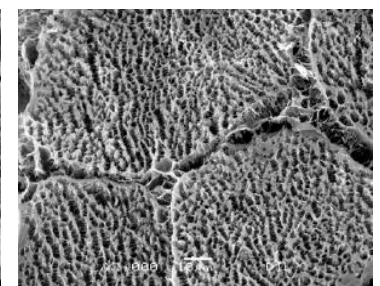
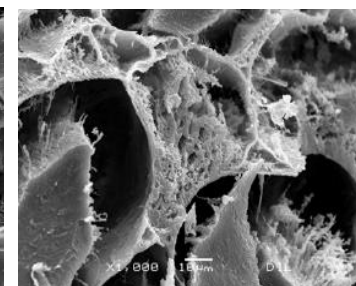
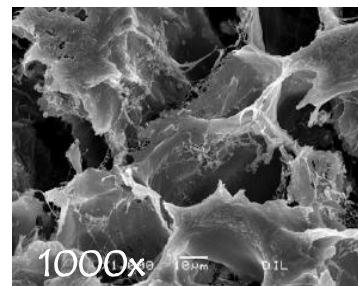
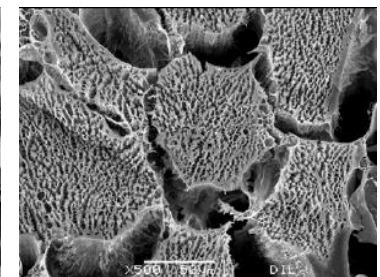
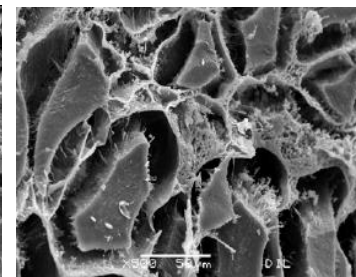
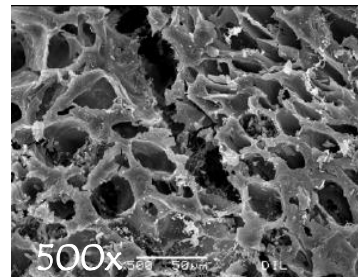
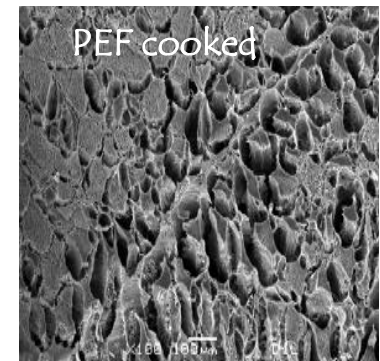
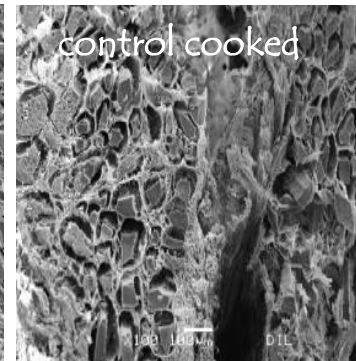
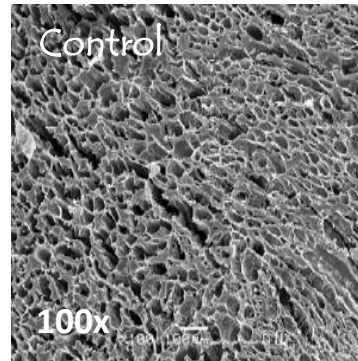
**Abbildung 17:** Vergleich der RNA-Gehalte in den abzentrifugierten Überständen nach einer PEF-Behandlung ( $E = 15 \text{ kV/cm}$ ,  $W = 50 \text{ kJ/kg}$ ) von *Candida utilis* mit den Werten für die unbehandelten Proben (UB) bei unterschiedlichen Suspensionskonzentrationen.

# PEF Treatment of Meat Products – REM Micrographs

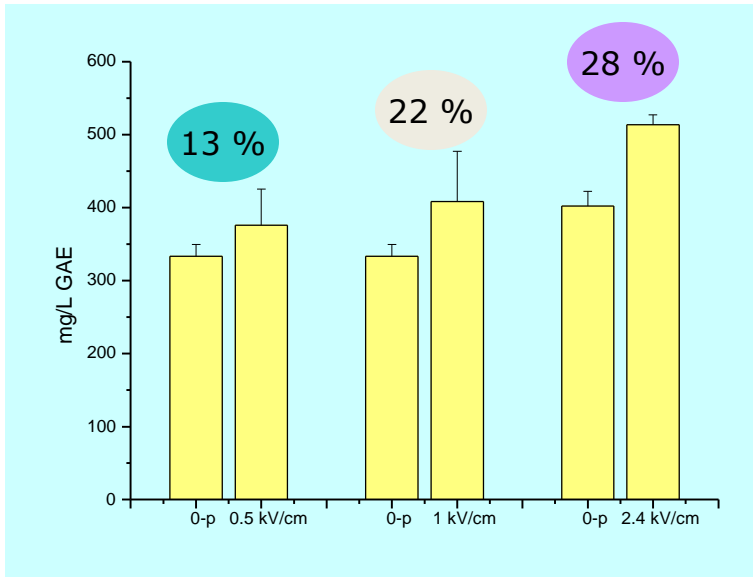
**Improvement of water binding indicated by swollen, sponge-like tissue structure**

**Improved micro-diffusion of brine**

**Improved water binding due to interaction between protein/salt/phosphate**

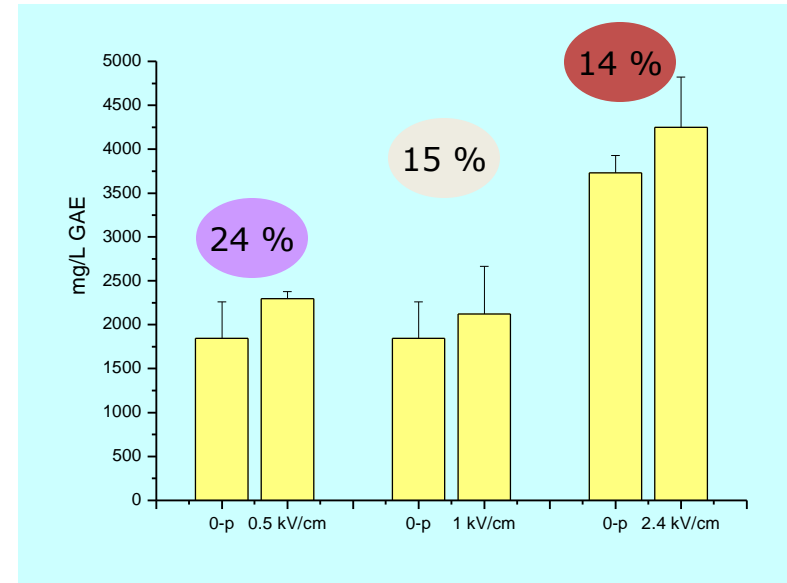


# Influence of PEF treatment on wine grapes



- Total polyphenolic content of fresh pressed **grape juice** obtained from grapes treated with different PEF strengths: 0.5kV/cm, 1 kV/cm and 2.4 kV/cm (0-p: reference value).

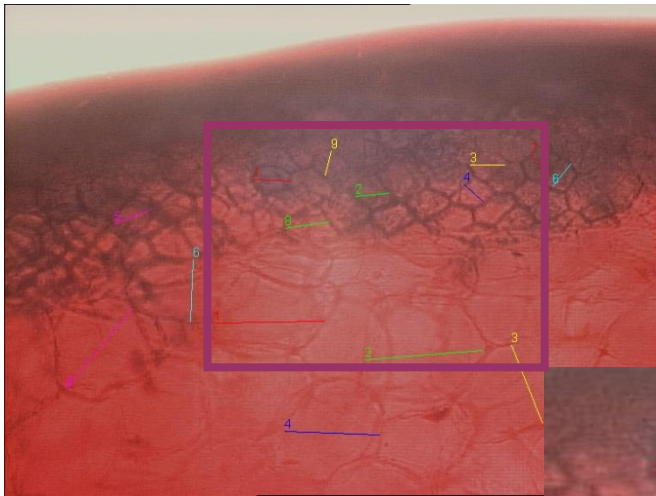
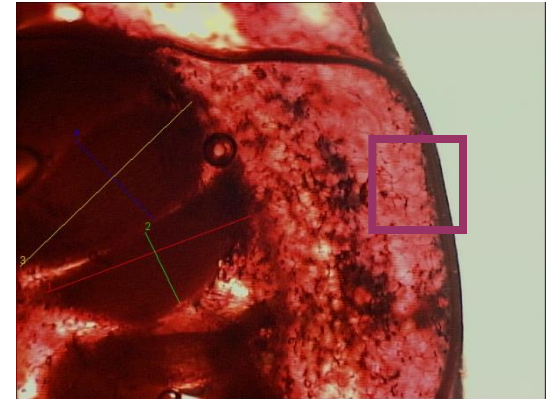
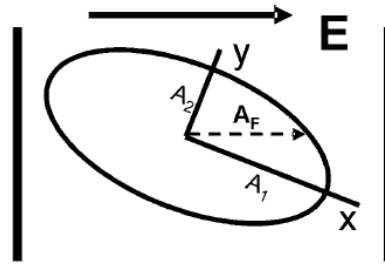
→ Enhanced mass transfer out of the cells  
→ Increased diffusion  
→ Increased release of phenolic compounds in juice



- Total polyphenolic content extracted from **grape pomace** obtained from grapes treated with different PEF strengths: 0.5kV/cm, 1 kV/cm and 2.4 kV/cm (0-p: reference value).  
(Results were calculated as mg/L GAE on 1g of dry matter).

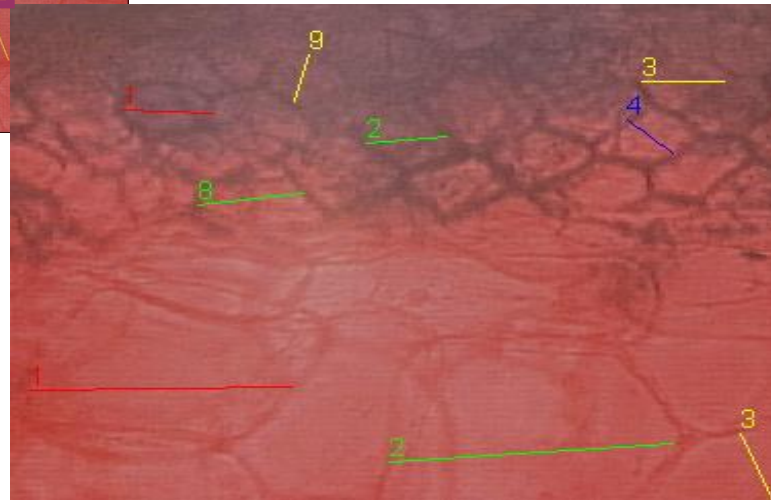
→ Stress induction of the cells  
→ Reversible pore formation  
→ Additional production of polyphenolics

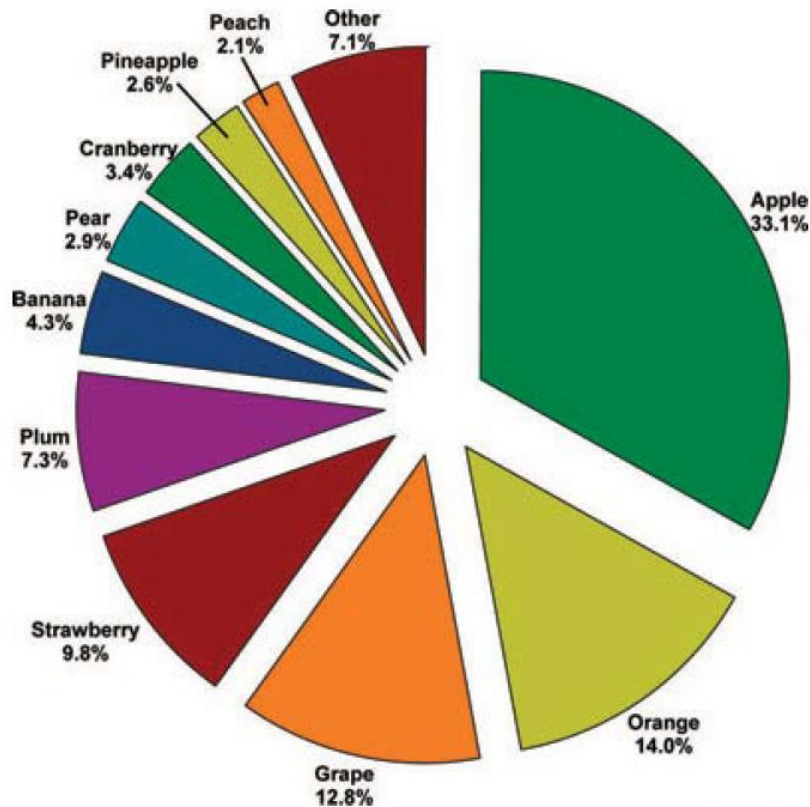
**Stress induction – cell size**



**Cell size 30 $\mu$ m (skin) - 140 $\mu$ m (flesh)**

**Reversible permeabilisation of skin cells  $\rightarrow$  irreversible permeabilisation of flesh cells**





This chart from one of Liu's recent papers shows the percentage of phenolics (phytochemicals) that Americans get from various fruits.

Provided

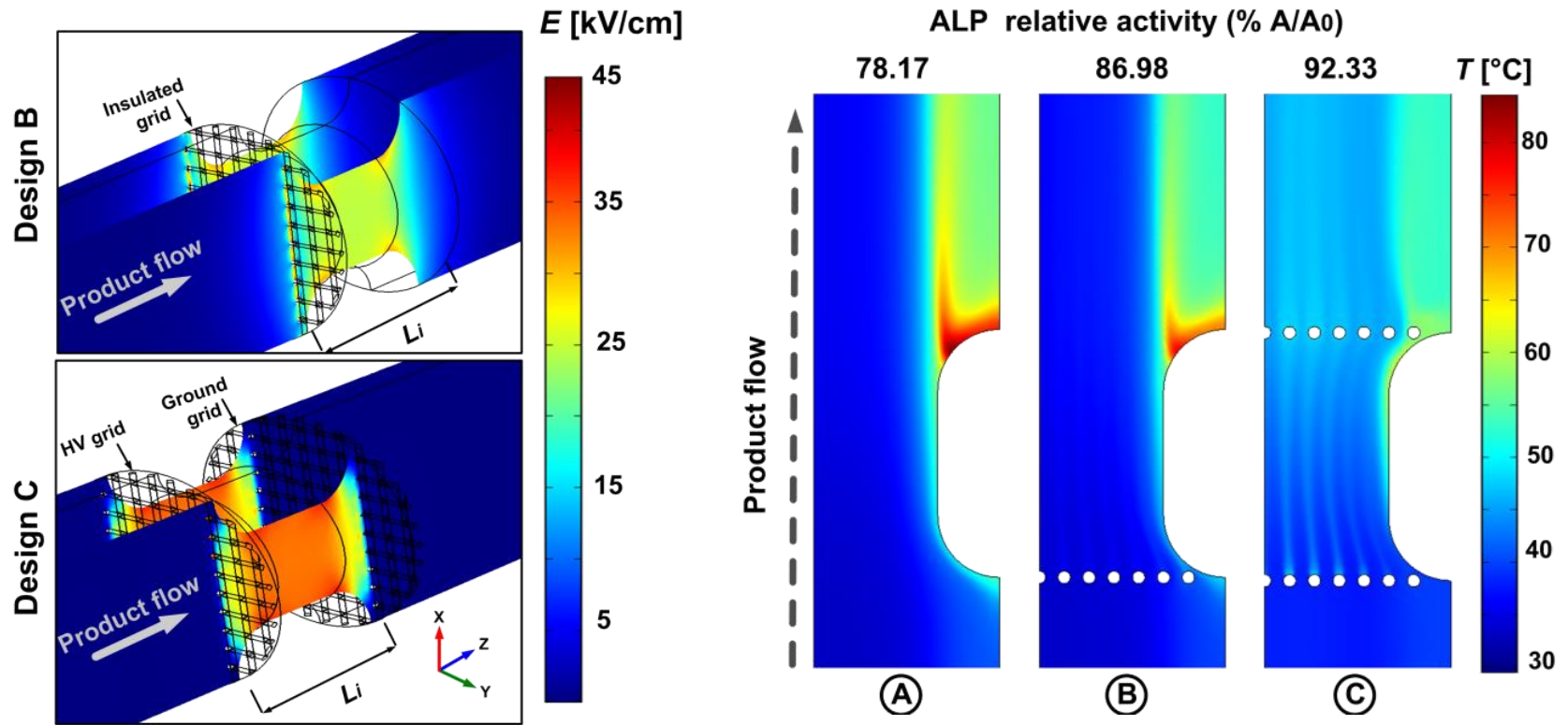
In a study of apple peel published in the same journal (56:21), Liu reported on a variety of new phenolic compounds that he discovered that also have "potent antioxidant and anti-proliferative activities" on tumors. And in yet another study in the same journal (56:24), he reported on his discovery of the specific modulation effects that apple extracts have on cell cycle machinery. Recently, Liu's group also reported the finding that apple phytochemicals inhibit an important inflammation pathway (NFkB) in human breast cancer cells.

Breast cancer is the most frequently diagnosed invasive cancer and the second leading cause of cancer deaths in women in the United States, said Liu.

<http://www.news.cornell.edu/stories/Feb09/apples.breastcancer.sl.html>



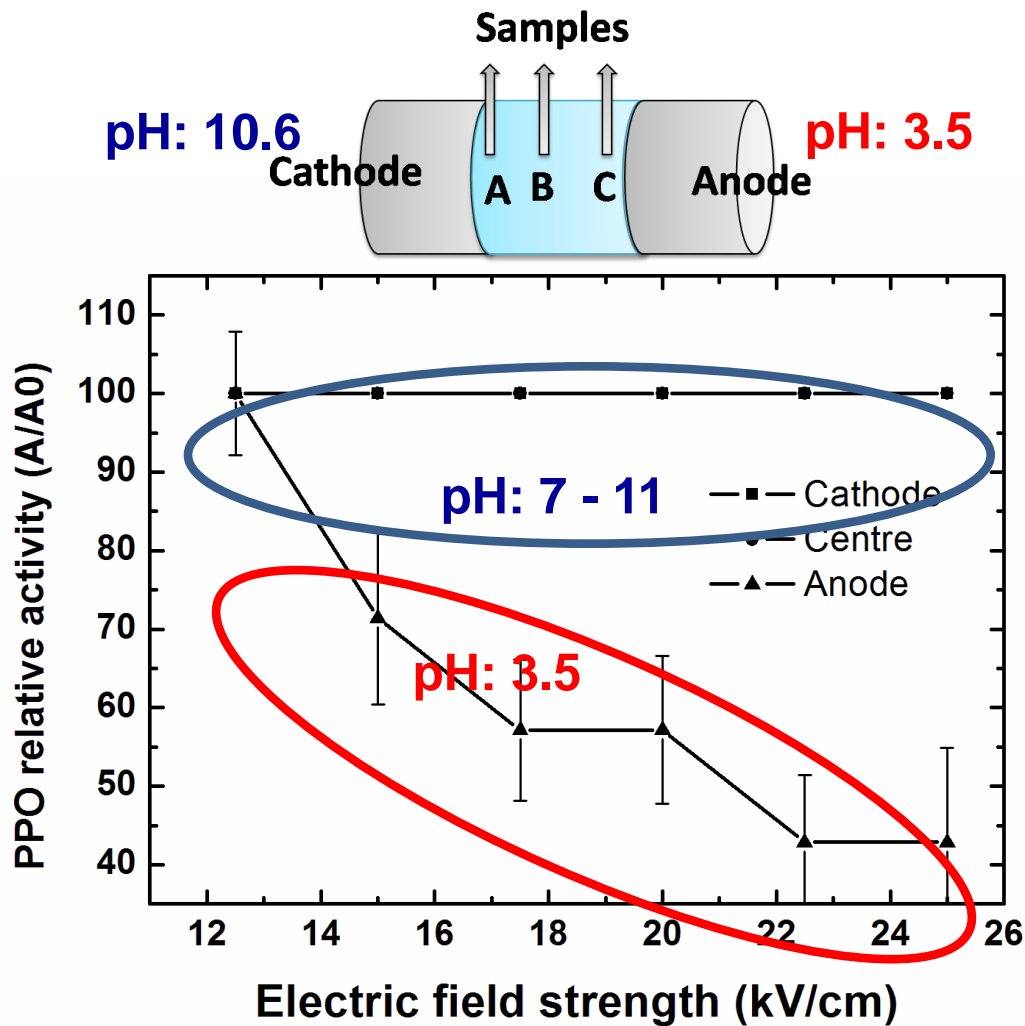
- Treatment chamber design – insertion of grids



- Increase of electric field strength up to 32%
- Higher homogeneity
- Increase on microbial inactivation up to 1.5 Log

- Reduction of temperature peaks
- Homogeneity of thermal load
- Better retention of heat sensitive compounds

# Enzyme inactivation due to pH-shifts



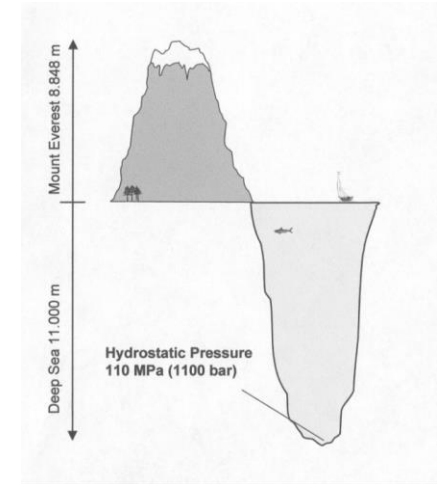


## New electric spoon can zap tongue with extra flavour

Scientists have created a spoon studded with electrodes that uses electricity to generate certain tastes on your tongue.

## High Pressure – Function and Mechanism

- Pressure range 100 - 600 MPa
- Pressure distribution homogenous and with out delay
- Le Chatelier Prinzip
- Compression heating (3-9 °C per 100 MPa)
- Minor influence on ingredients



Hiperbaric 420



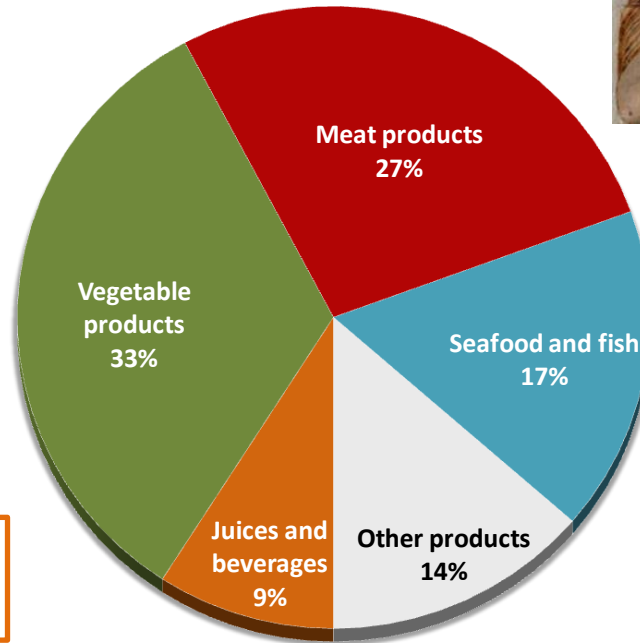
# Commercial Use of HP (HP-Pasteurization): Overview

Production 2014: ~350,000 T (ca. 252 systems) HPP products market value to reach about \$14 million by 2018

Guacamole dips



Juices / Smoothies



Ham



Fish- and Shellfish

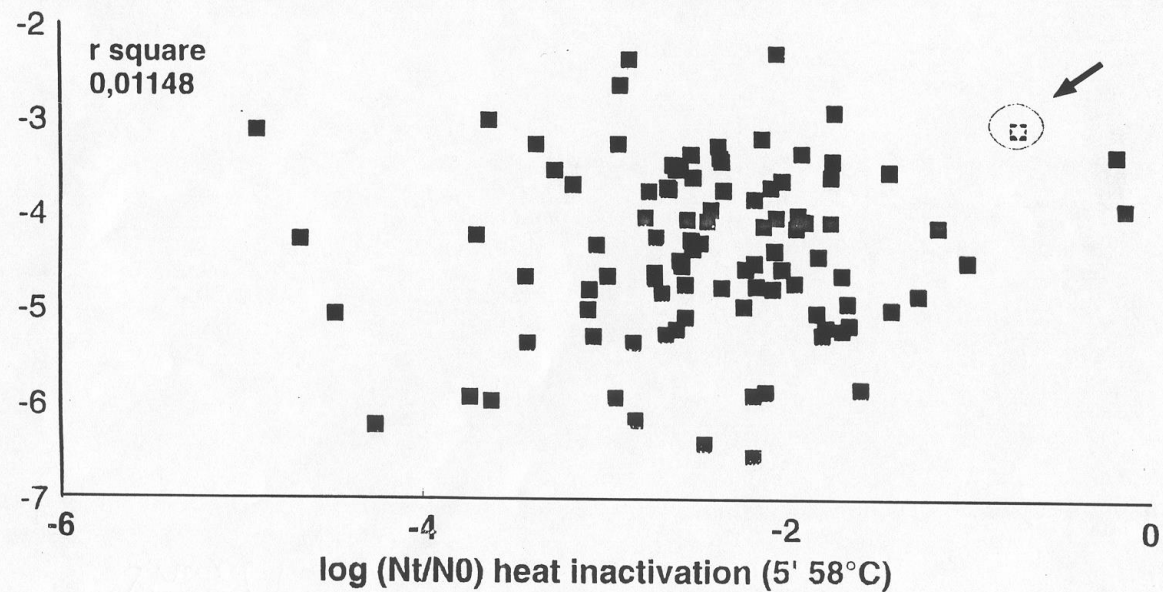




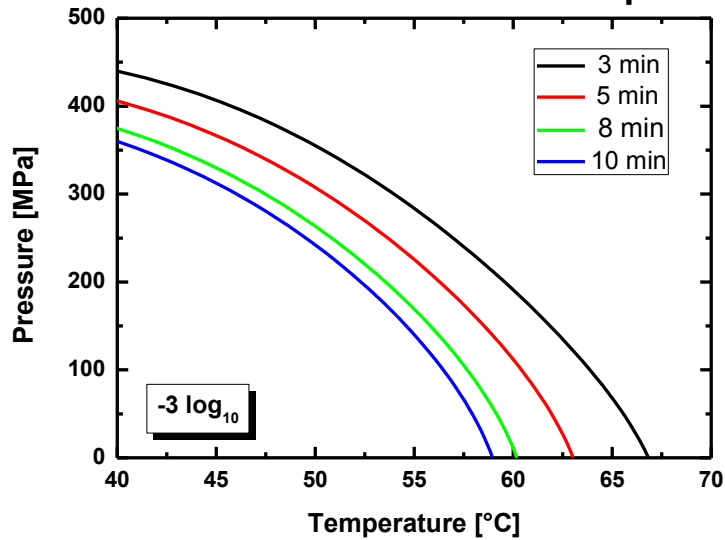


Pressure resistance vs heat resistance of 98  
Salmonella strains  
(5 min 58 °C)

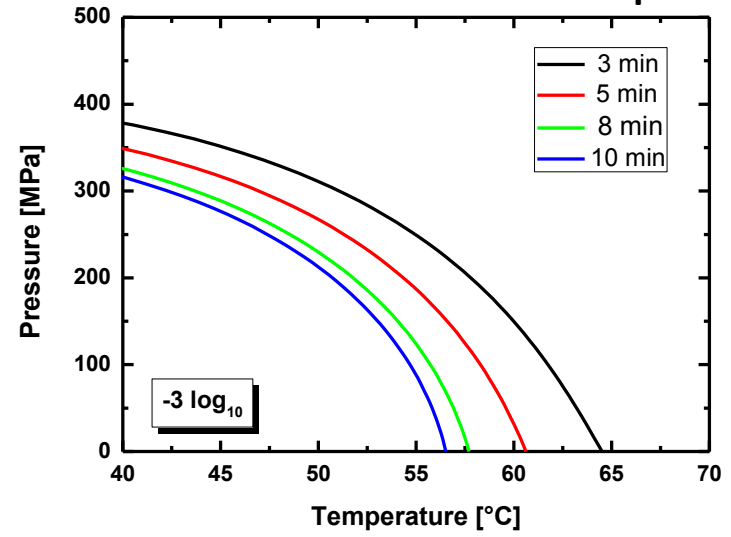
log (Nt/N0) pressure inactivation (10' 275 MPa)



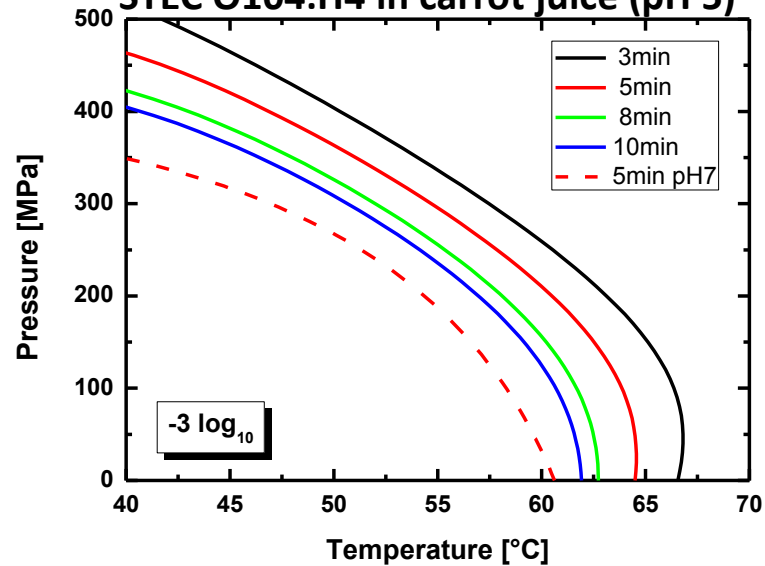
**STEC O157:H7 in ACES Buffer pH 7**



**STEC O104:H4 in ACES Buffer pH 7**

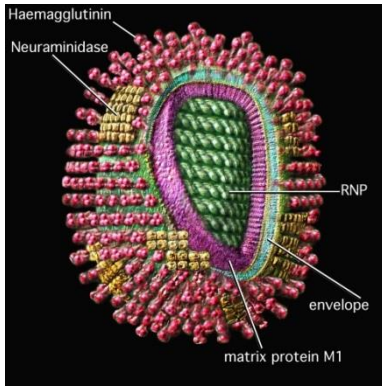


**STEC O104:H4 in carrot juice (pH 5)**

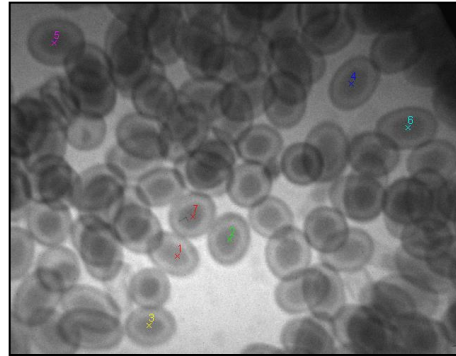


# MECHANISMS

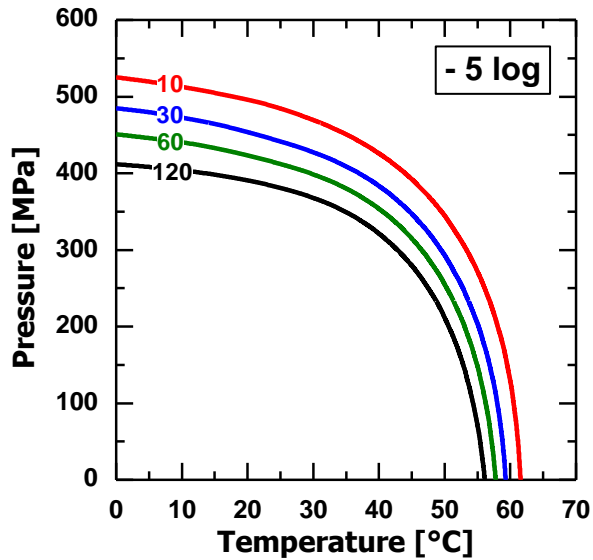
## Viruses



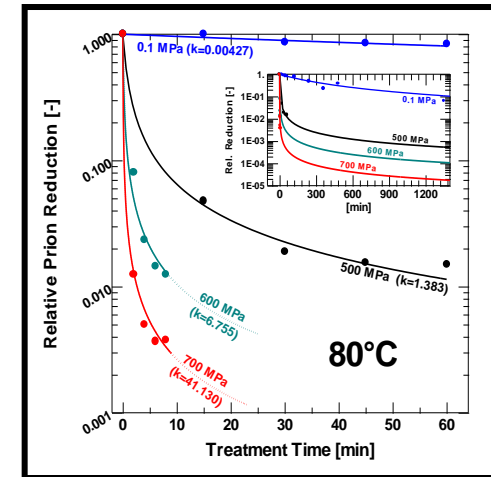
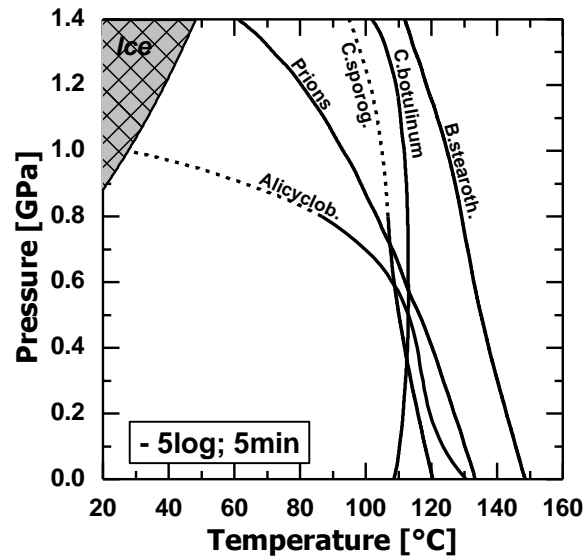
## Spores



## Prions

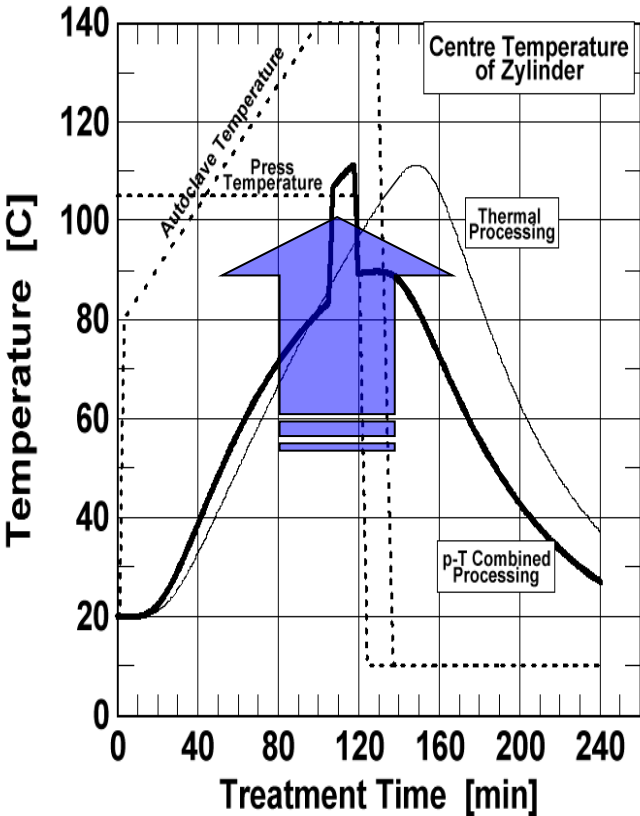
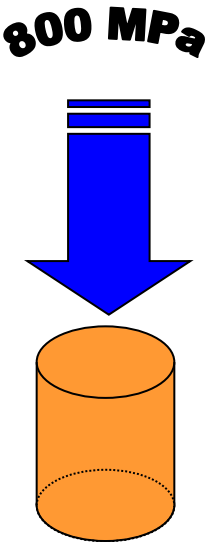


H7N7

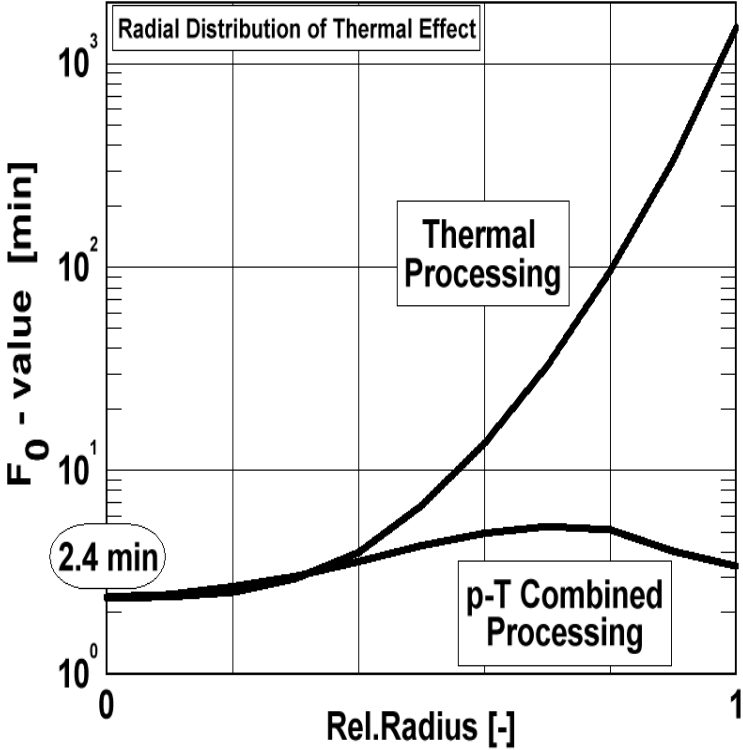


# Pressure Assisted STERILISATION

Centre Temperature in Cylindrical Package (10 cm Diameter)

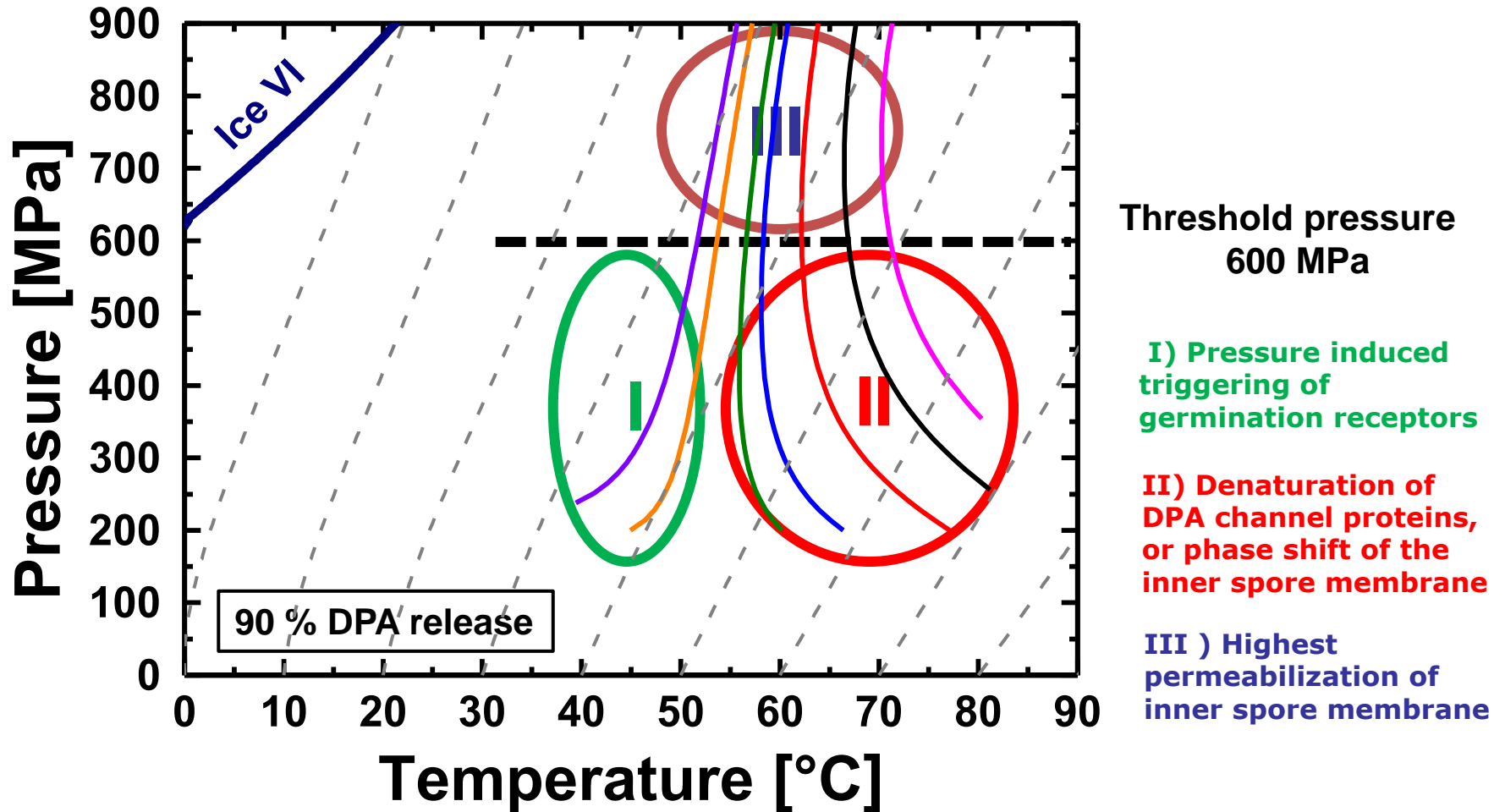


$$F = \int 10^{\frac{T(t)-T_{Ref}}{z}} dt$$



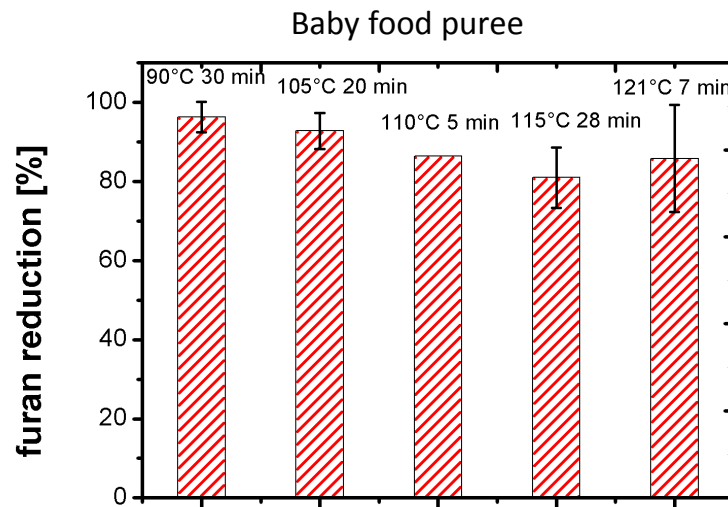
# MECHANISMS

Released dipicolinic acid – immediately after decompression (wild-type *B. subtilis*)

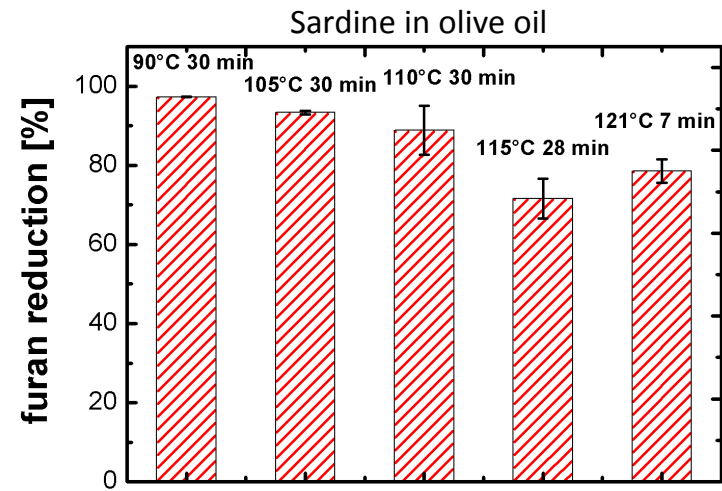




## HPTS vs. thermal treatment: Reduction of Food processing contaminants (Furan)



- Furan in autoclaved samples (115°C, 28 min)  
 $30.1 \pm 1.6 \mu\text{g kg}^{-1}$
- Reduction between 86 - 97 % to initial content



- Furan in autoclaved samples (115°C, 28 min)  
 $57 \pm 3.6 \mu\text{g kg}^{-1}$
- Reduction between 71-97 % to initial content

- HPTS offers: Double benefit in terms of food safety and reduction of toxicological potential
- HPTS: New principle of application for high pressure processing e.g. high value and high quality foods e.g. foods with medical purposes, baby food etc.

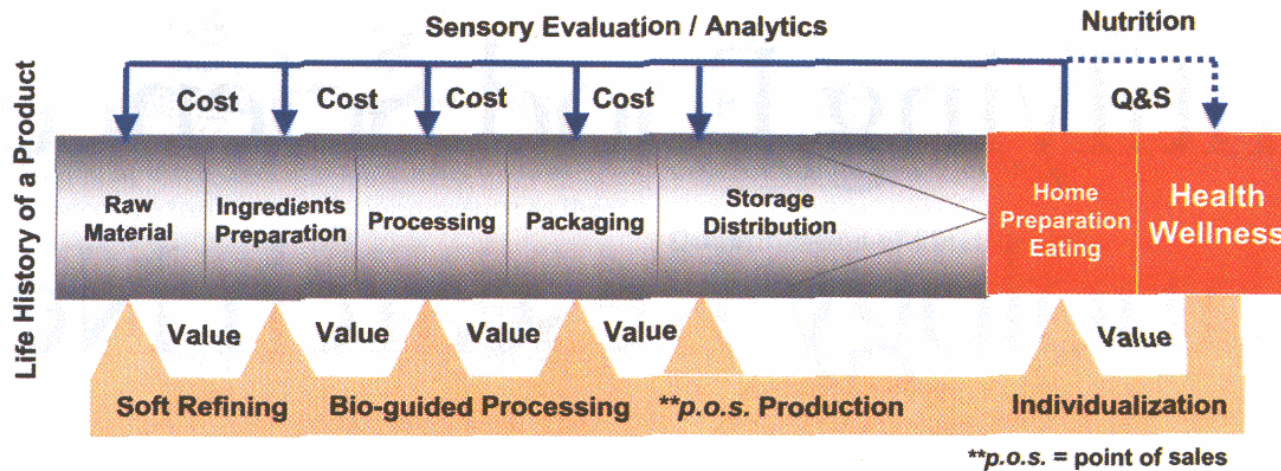


Fig. 1—The food process chain from agricultural raw materials to the final health effects of products. In more traditional processing, engineering is dominated by added functionalities for sensory and acceptance criteria and renovations designed to minimize cost throughout the production chain. Nutrition and health are properties added on as an isolated part of quality and safety to meet mandated general product compositions. As food products take on a more intimate role in the management of personal health, the wellness of the consumer becomes a key value driver, and various features of the health of the consumer will “bioguide” all of the stages of food processing, from softer refining to point of sale production and individualized benefits to the consumer.

(German et al 2004)

# Changes of interest within Unilever R&D

2000

2010

**Health**

**Health + Naturalness**

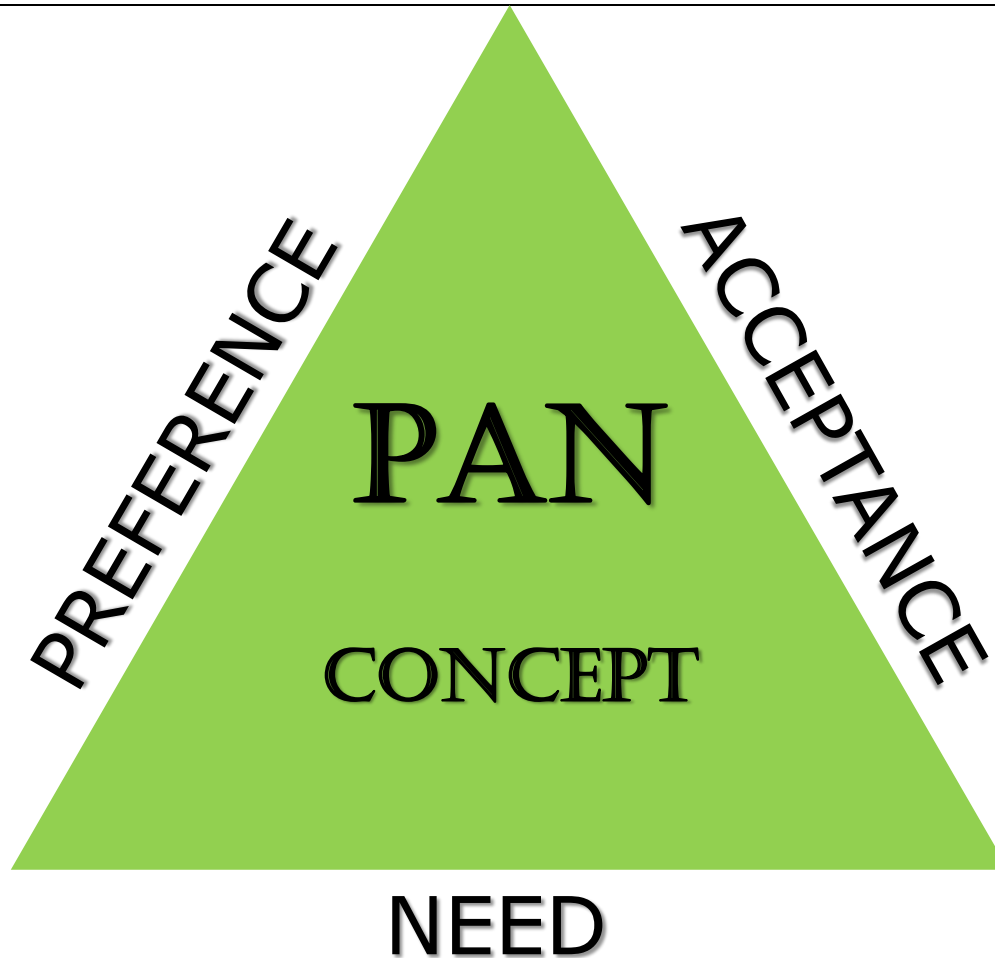
**Health + Naturalness + Taste**

**Health + Naturalness+  
Taste + Sustainability**

Cost reduction



Hans Hoogland

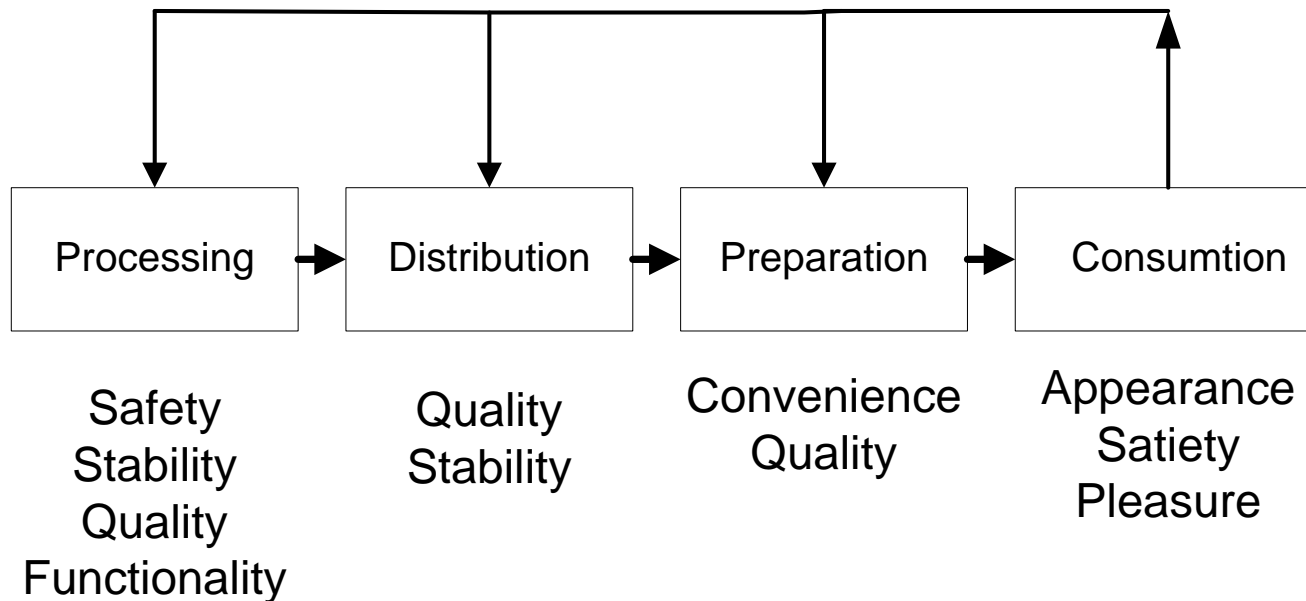


Appearance  
Sensory  
Convenience  
Origin

Safety  
Freshness

Energy  
Nutrients

# REVERSE ENGINEERING KEY CRITERIA





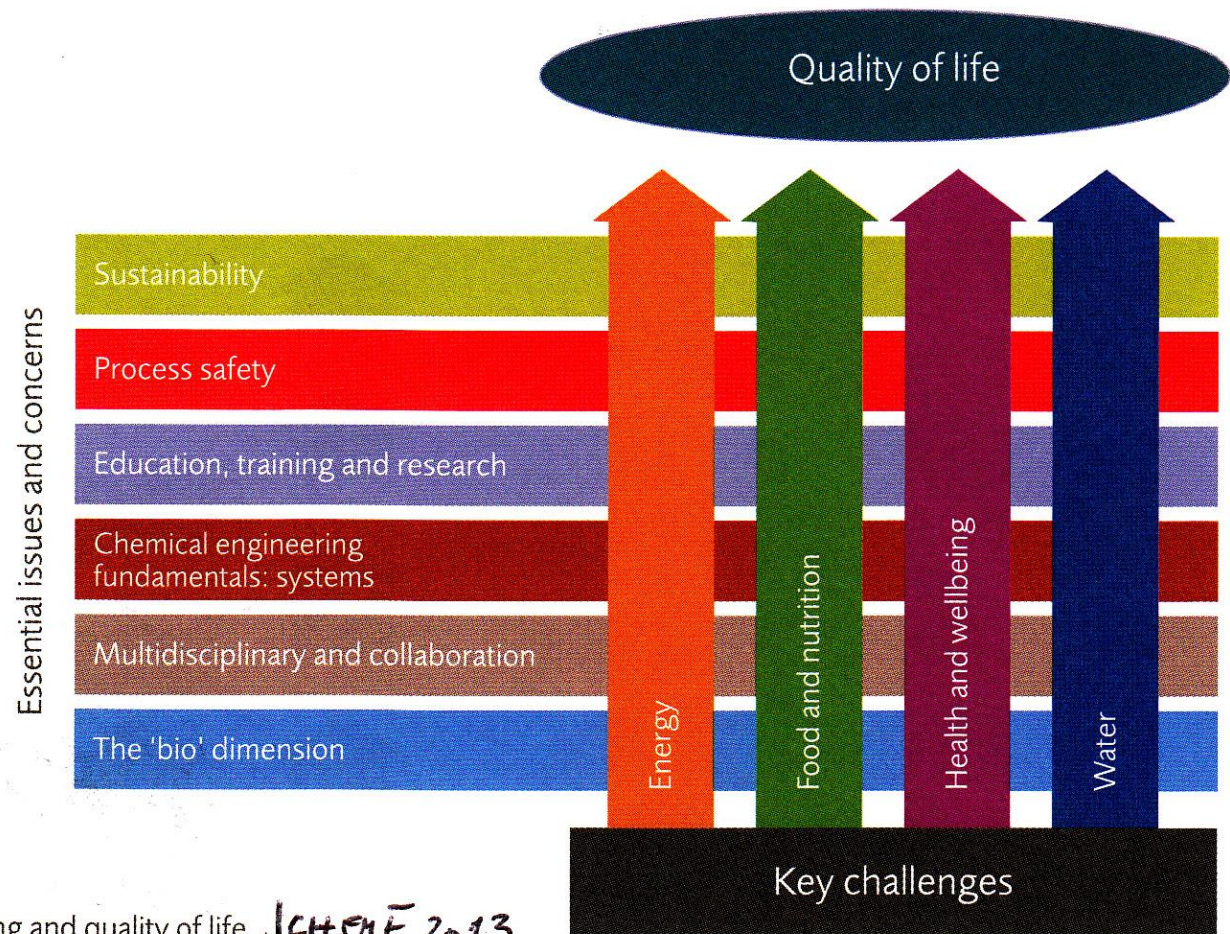


Figure 1: Chemical engineering and quality of life, ICHERE 2013

← Archive

SPECIALTY GRAND CHALLENGE ARTICLE

Front. Nutr., 07 April 2014 | doi: 10.3389/fnut.2014.00004

# Grand challenges in nutrition and food science technology



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