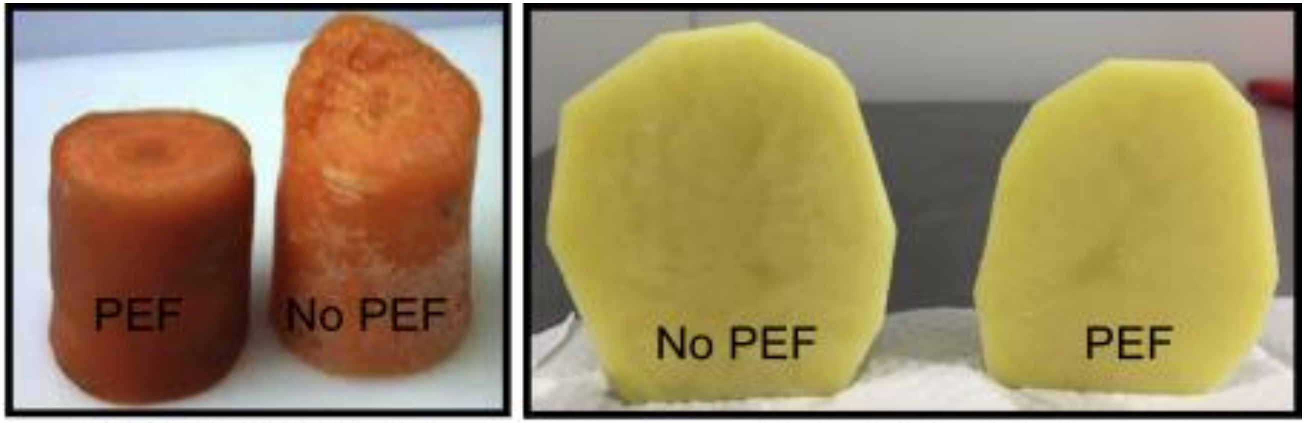
INNOVATIVE TECHNIQUES IN FOOD PROCESSING



Better cutting accuracy

Smooth cut surface

https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/plant-tissues

Smetanska

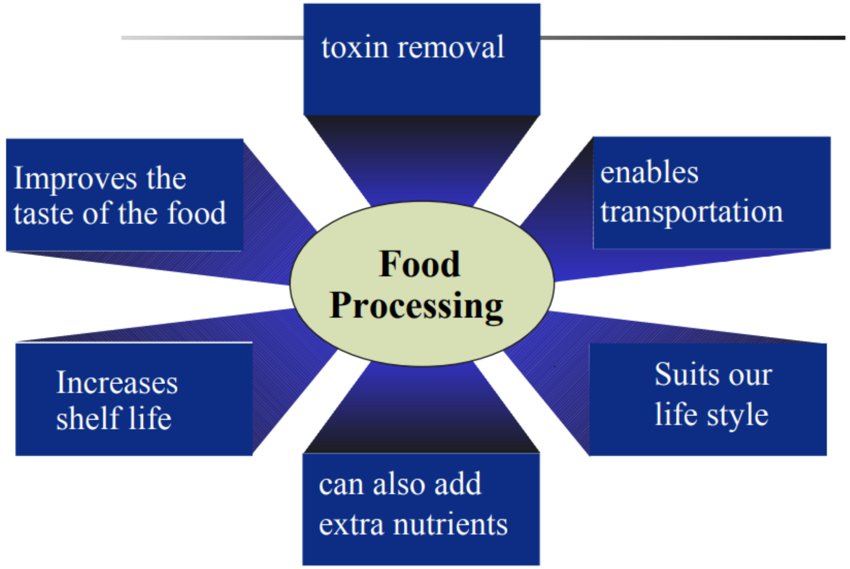
Innovative techniques in food processing

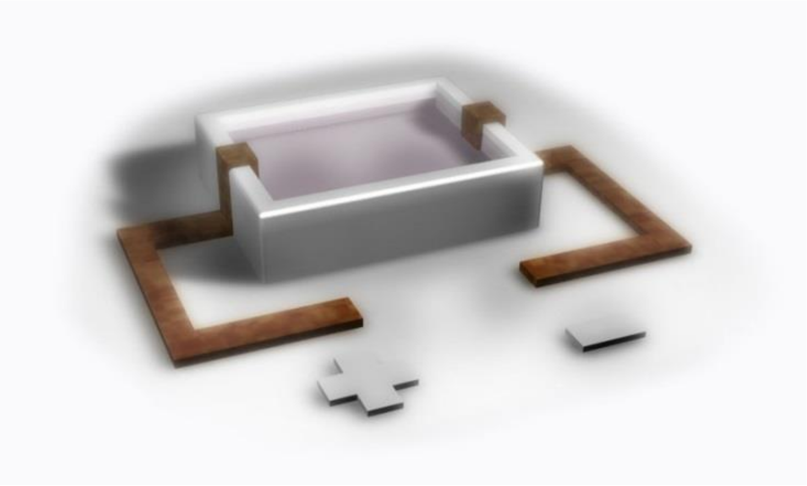
What is Food Processing?

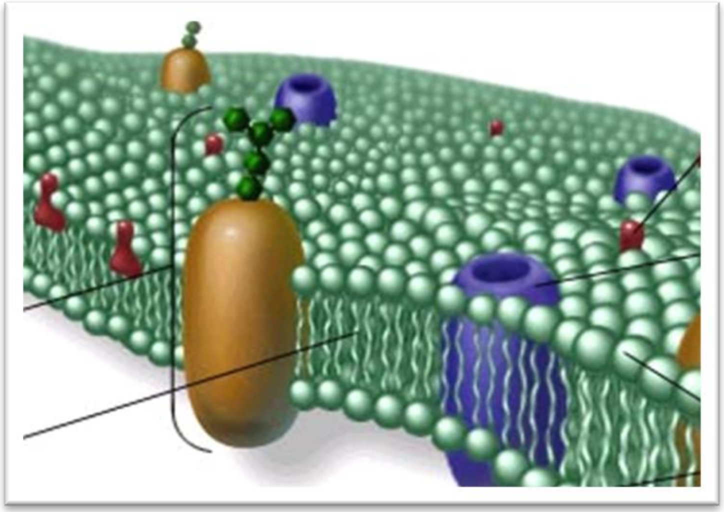
- **Food processing is the transformation of raw ingredients, by physical or chemical treatments into food.**

- **Food processing combines raw food ingredients to produce marketable food products that can be easily prepared and served by the consumer.**

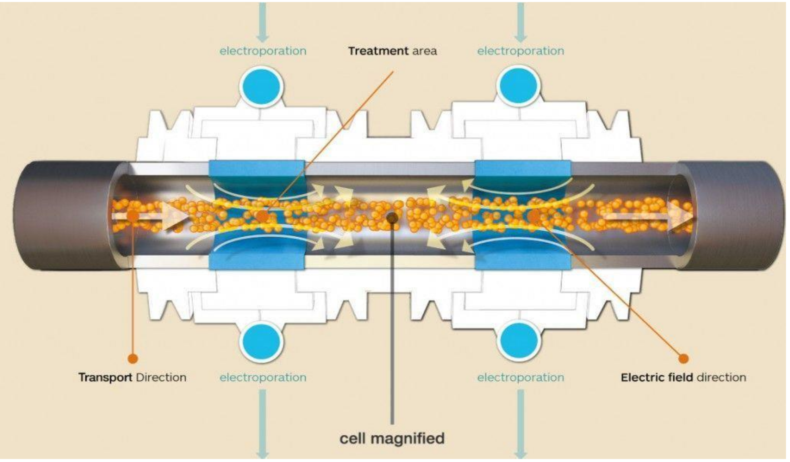
Why it should be processed ?



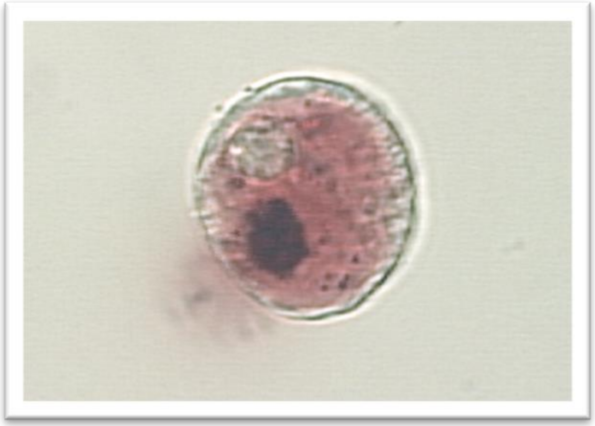




Pulsed Electric Fields in Food Preservation

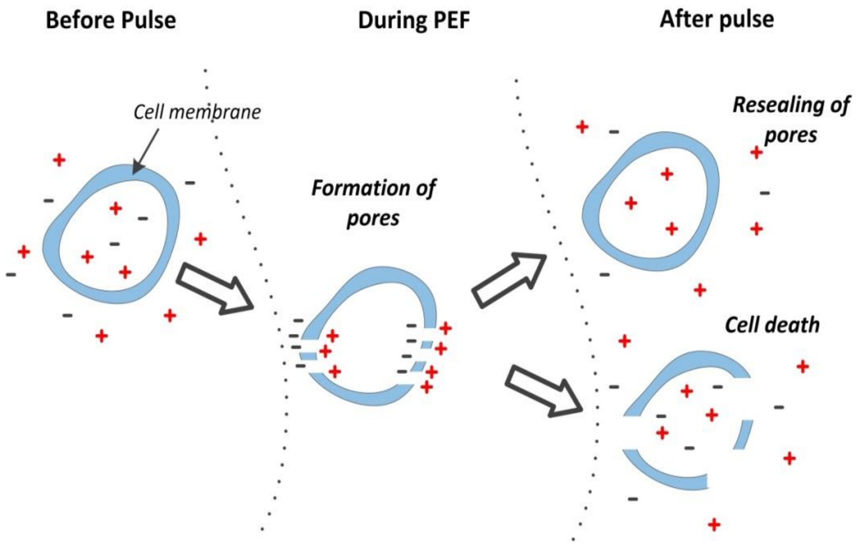


Smetanska



Pulsed Electric Fields (PEF)

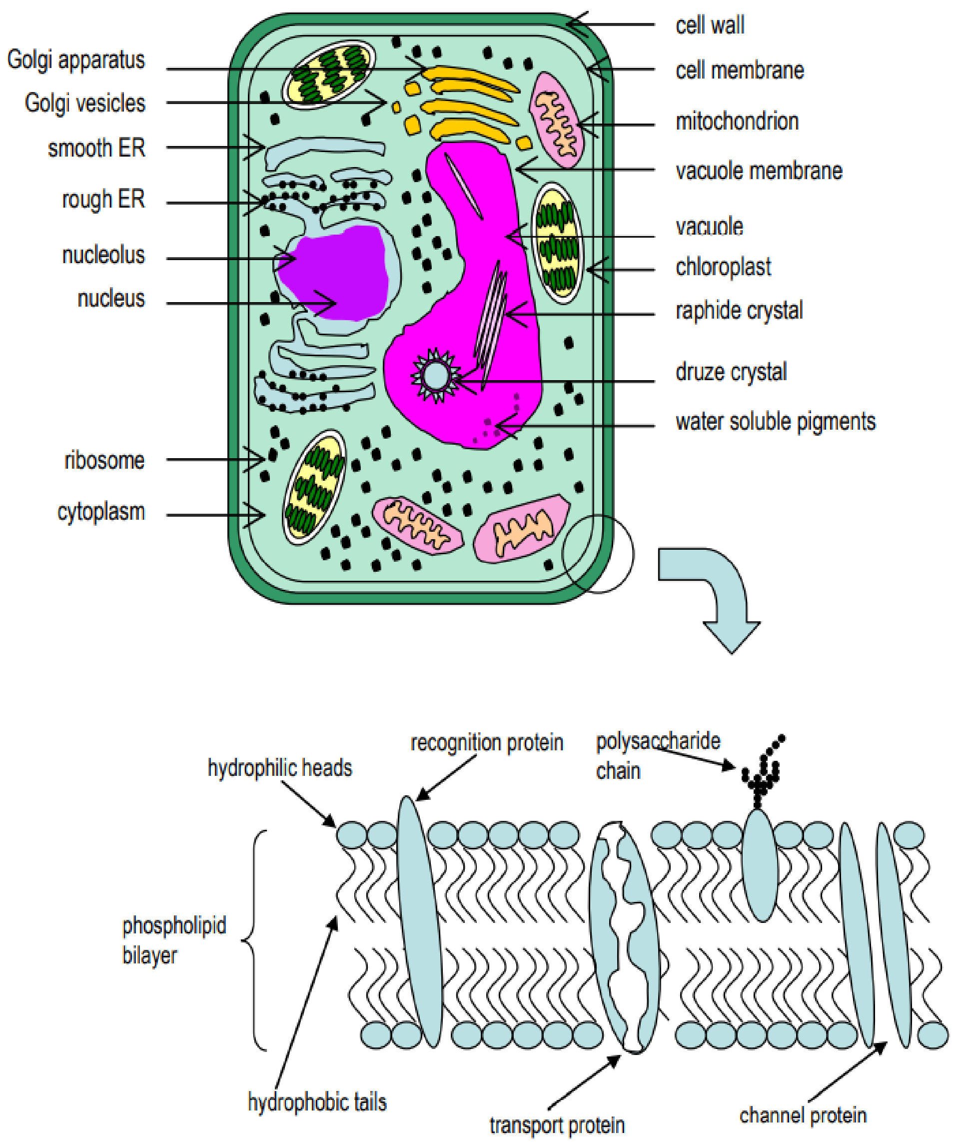
- PEF treatment is a non-thermal food processing method of food preservation
- Principle: cell disintegration
- Permeabilization of the cell membrane takes place when biological cell is exposed to the external EF since the conductivity of extracellular and intracellular media is several orders of magnitude larger than conductivity of the cell membrane
- PEF occurs within a very short time range (µs to ms) leading to temporary (reversible permeabilization) or permanent pore formation (irreversible permeabilization.



Mechanism of PEF induced permeabilization described through electromechanical model

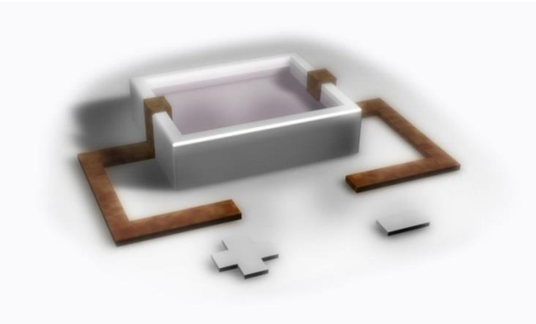
http://pef-technologies.nl/

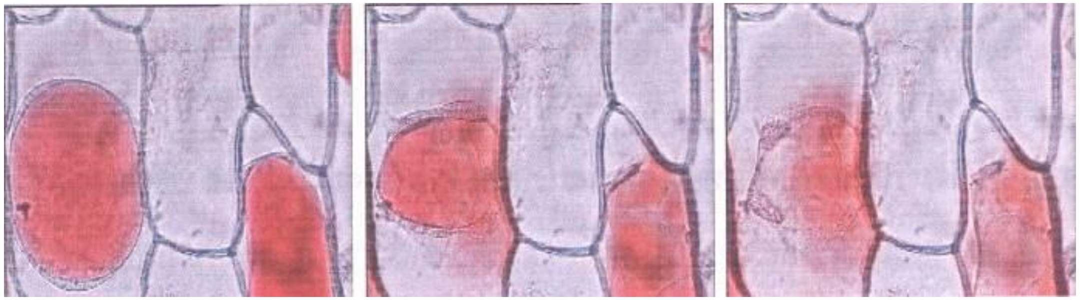
PEF: plant cell

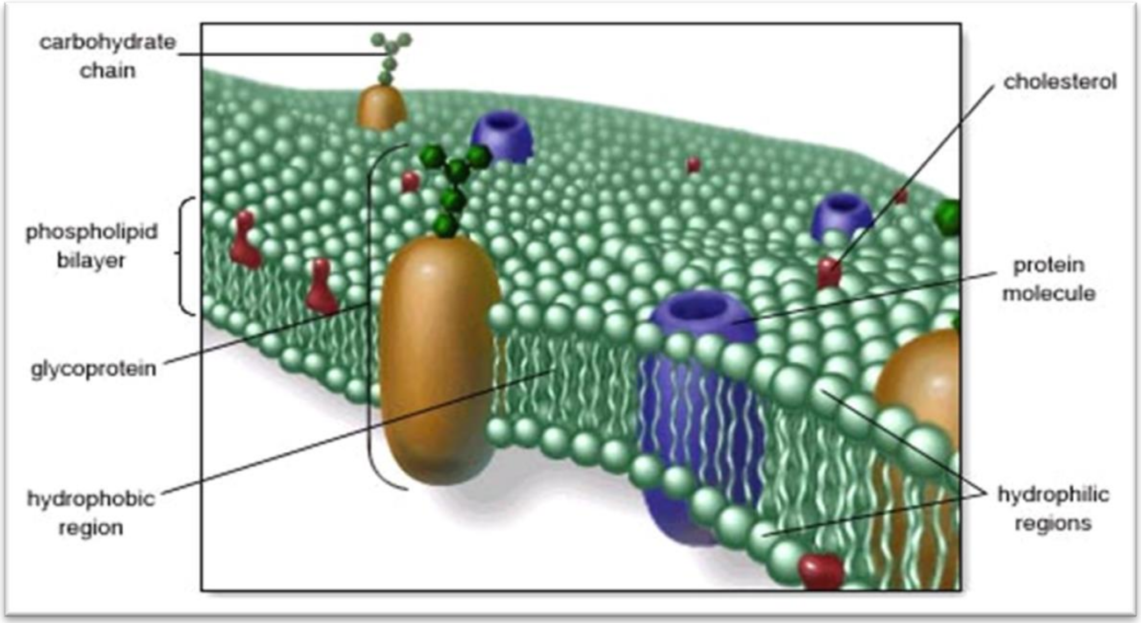


The plant cell and membrane structure

PEF: cell membrane

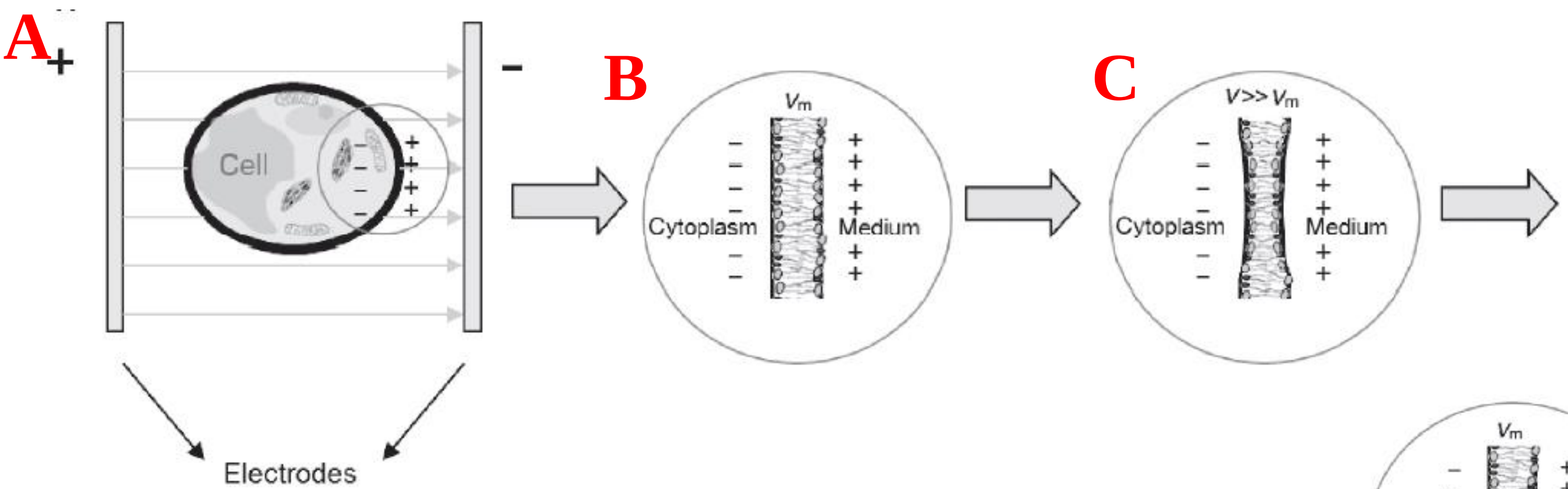




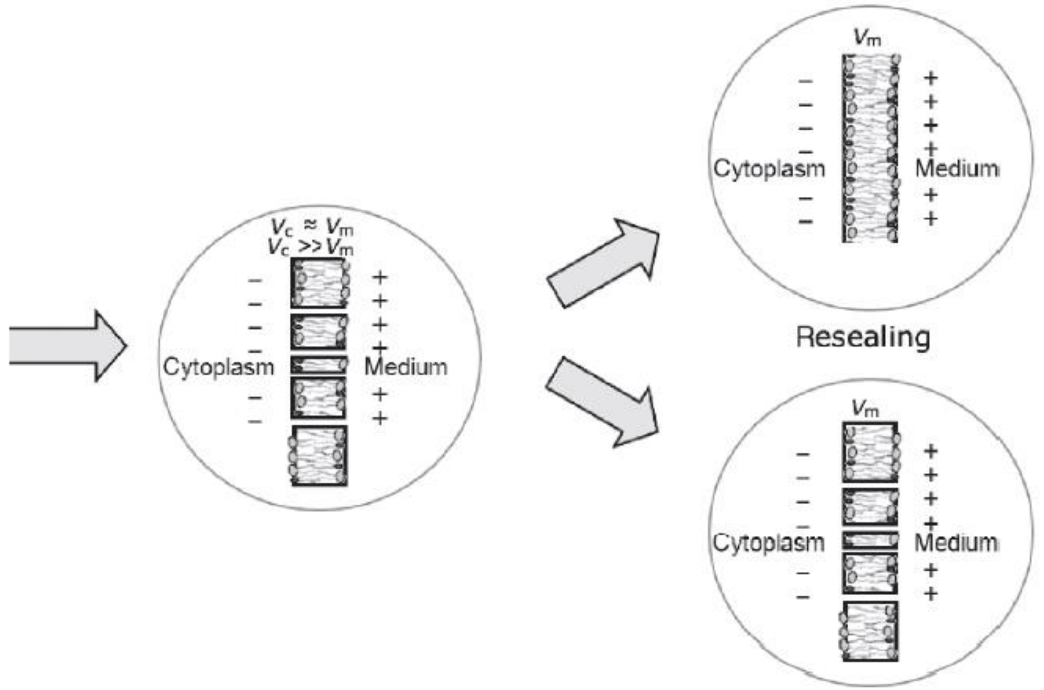


Intracellular and extracellular environment consists of a conductive media filled with free charges of opposite polarities that are separated by the cell membrane, constituting naturally occurring transmembrane potential of about 10 mV.

PEF: permeabilization



2,2kV/cm: starting permeabilization (pores 1nm)
10-15kV/cm irreversible permeabilization

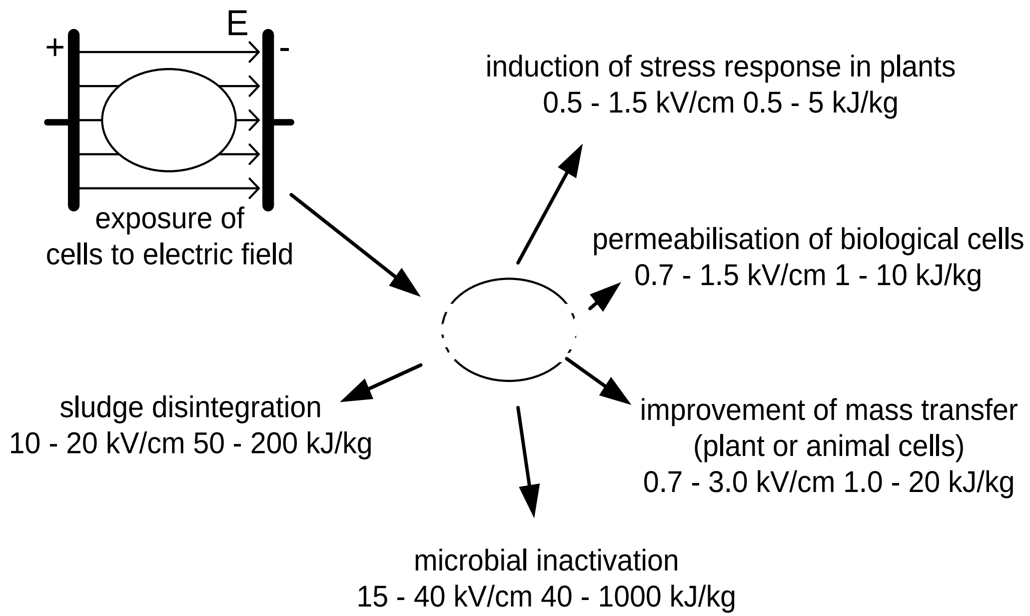


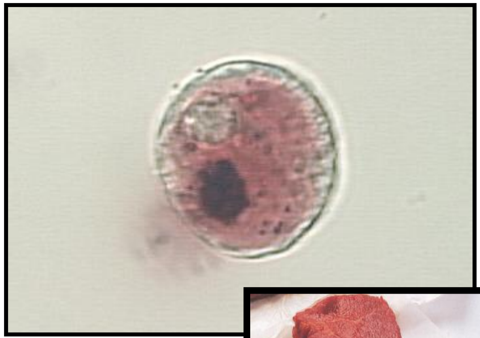
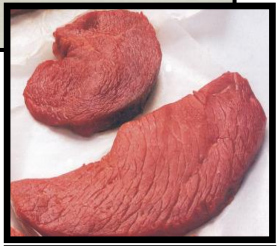
Zimmermann et al., 1974

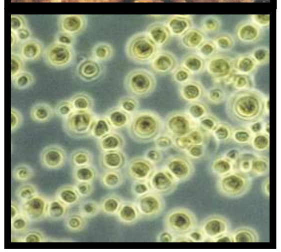
PEF: influencing factors

- Size and geometry of the cell
Plant cells (cell size 40 - 200 µm) 1 - 2 kV/cm
microbial cells (1 - 10 µm) and 10 - 14 kV/cm.

- **cell orientation and local cell density**
- **membrane fluidity**
- **cytoskeleton and presence of cell wall**
- **external medium composition**
- **osmotic pressure**





Toepfl et al., 2018

Zimmermann & Niel, 1996

PEF: principle of work

PEF generating system consists of:

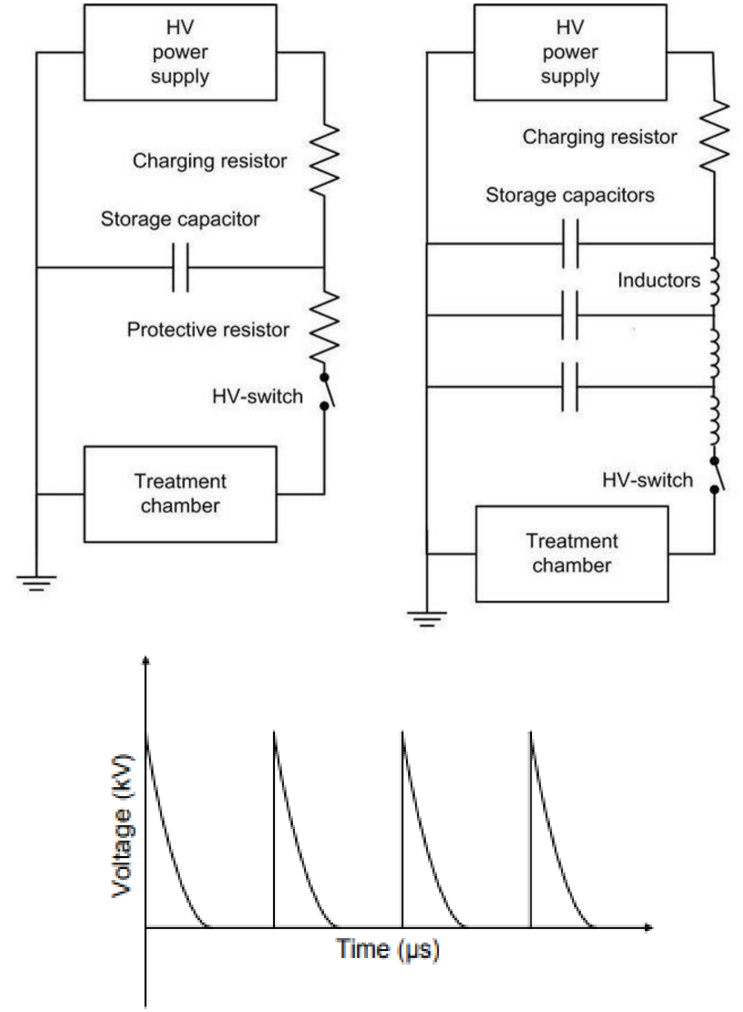
- **high voltage power supply,**
- **capacitor,**
- **high voltage switch.**

Treatment chamber, where generated high voltage pulses are applied to product, placed between electrodes.

High voltage generator transforms low voltage electric power (220 - 440 V alternating current) to a high voltage direct current power.

Once the high voltage has been generated, a capacitor is charged across a charging resistor to the required level. The power is released through a pulse forming network, resulting in a defined pulse shape, which is delivered to the electrodes in the treatment chamber.

The generation of high intensity electric field pulses is realized by repetitive charging and discharging of capacitor which accumulate electrical energy.

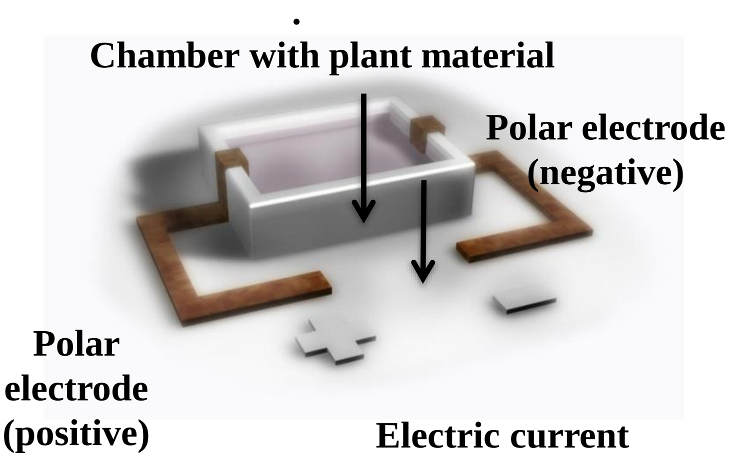


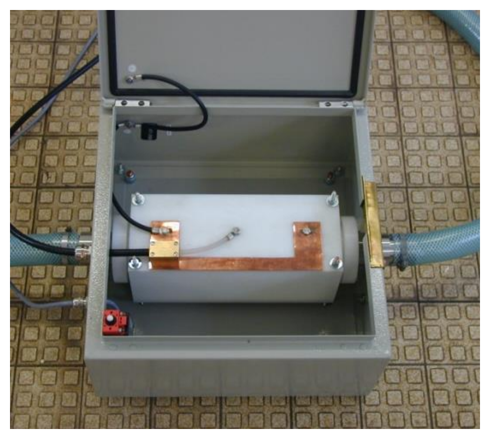
Simplified electrical circuits of impulse generation systems for exponential decay (left) and square wave pulses (right), generation of exponential decay monopolar pulses

PEF: construction

Batch or continuous treatment chambers consist of two electrodes, which are separated by electric insulating materials to ensure the electric potential between them.

The simplest alignment of electrodes to achieve most uniform electric field distribution and avoid electrical and thermal hot spots is a parallel plate electrode configuration.





PEF: application

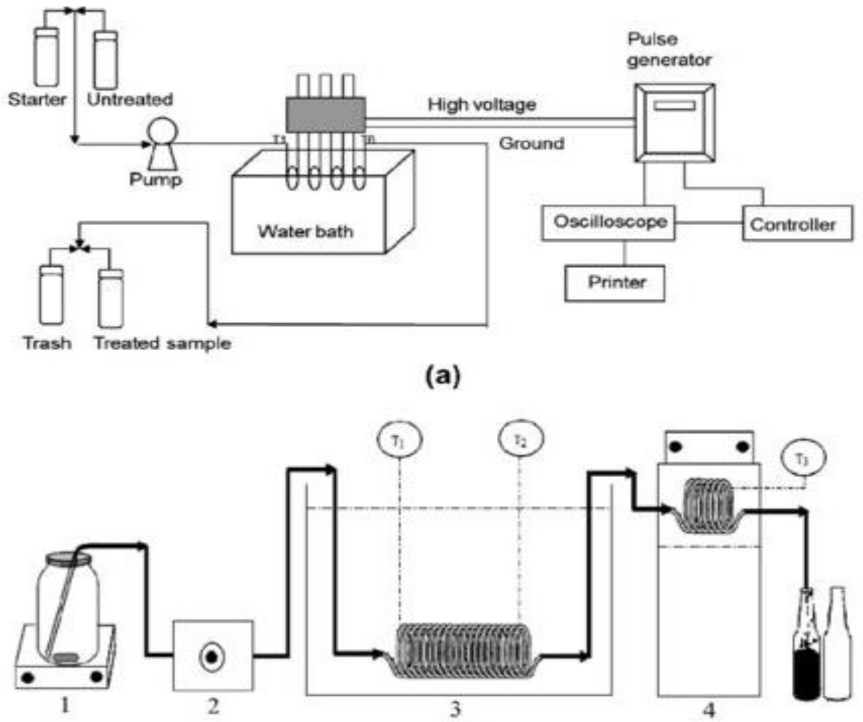
Due to its impact on a biological cell, PEF can be utilized in the food industry for:

- **stress induction in plant cells and tissues**
- **alternating nutritional value of food products**
- **changes in texture and moisture of raw materials**
- **inactivation of microorganisms at low temperatures**

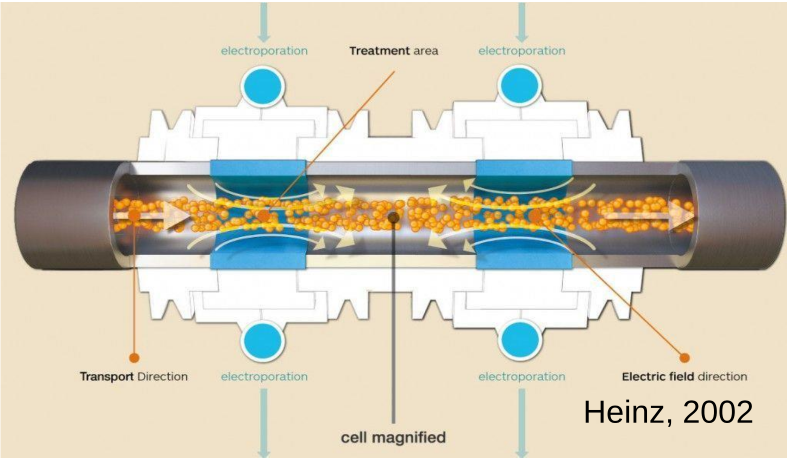
Processing intensity	*Electric field intensity*	*Electric pulse duration*	*Permeabilization*	*Application*
Low	0.1 – 1.5 kV/cm	1 – 400 µs	Reversible	Stress induction Nutritional value
Moderate	0.5 – 3 kV/cm	1 – 400 µs	Irreversible (plant and animal tissue)	Drying Expression Texture Extractability
High	15 – 40 kV/cm	1 – 400 µs	Irreversible (microbial cell)	Microbial safety

Heinz, 2003

PEF: heat pasteurization



Schematic diagram of PEF (a) and heat pasteurisation (b) systems (1: stirrer; 2: peristaltic pump; 3: heating coil; 4: cooler)

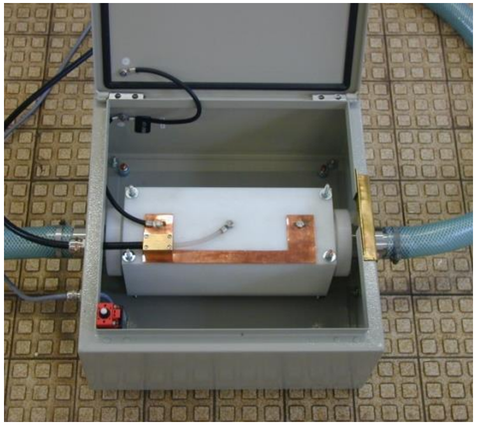


Heinz, 2002

PEF+ heat pasteurization

1. PEF as a Pre-Treatment
2. Enhanced Heat Transfer
3. Reduced Thermal Damage
4. Improvement of Overall Quality
5. Selective Microbial Inactivation
6. Extended Shelf Life

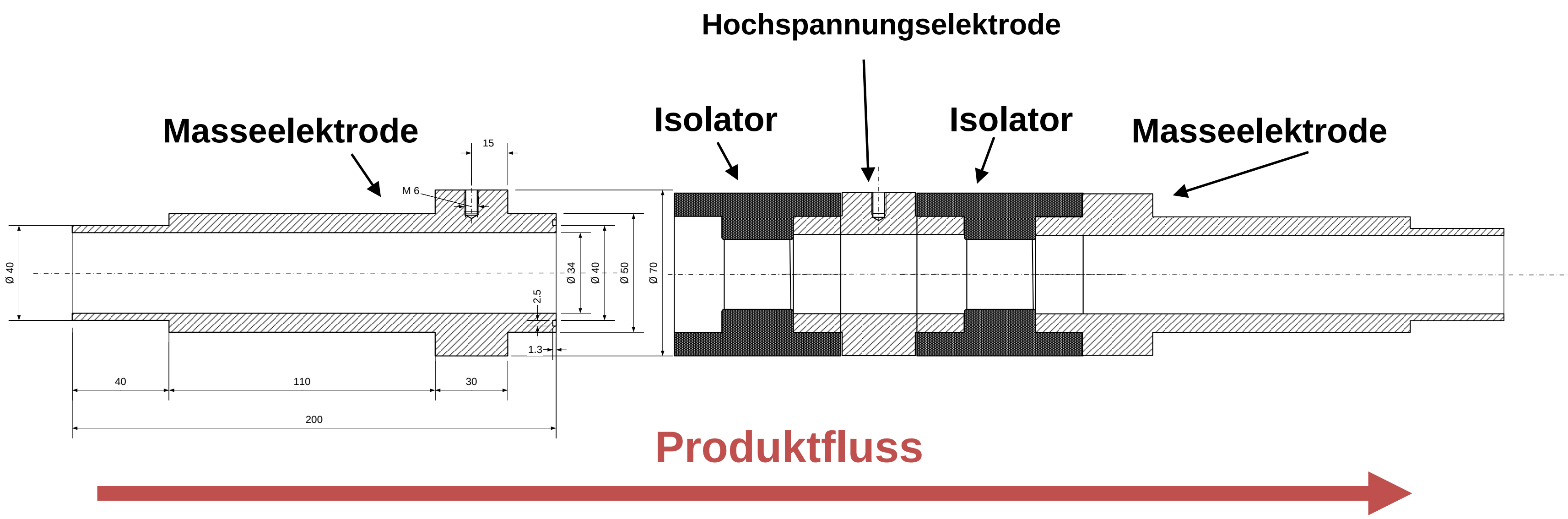
PEF: continuous system



For efficient treatment on an industrial scale continuous systems are proposed, with high flow rate capacity and easy integration in already existing processing lines.

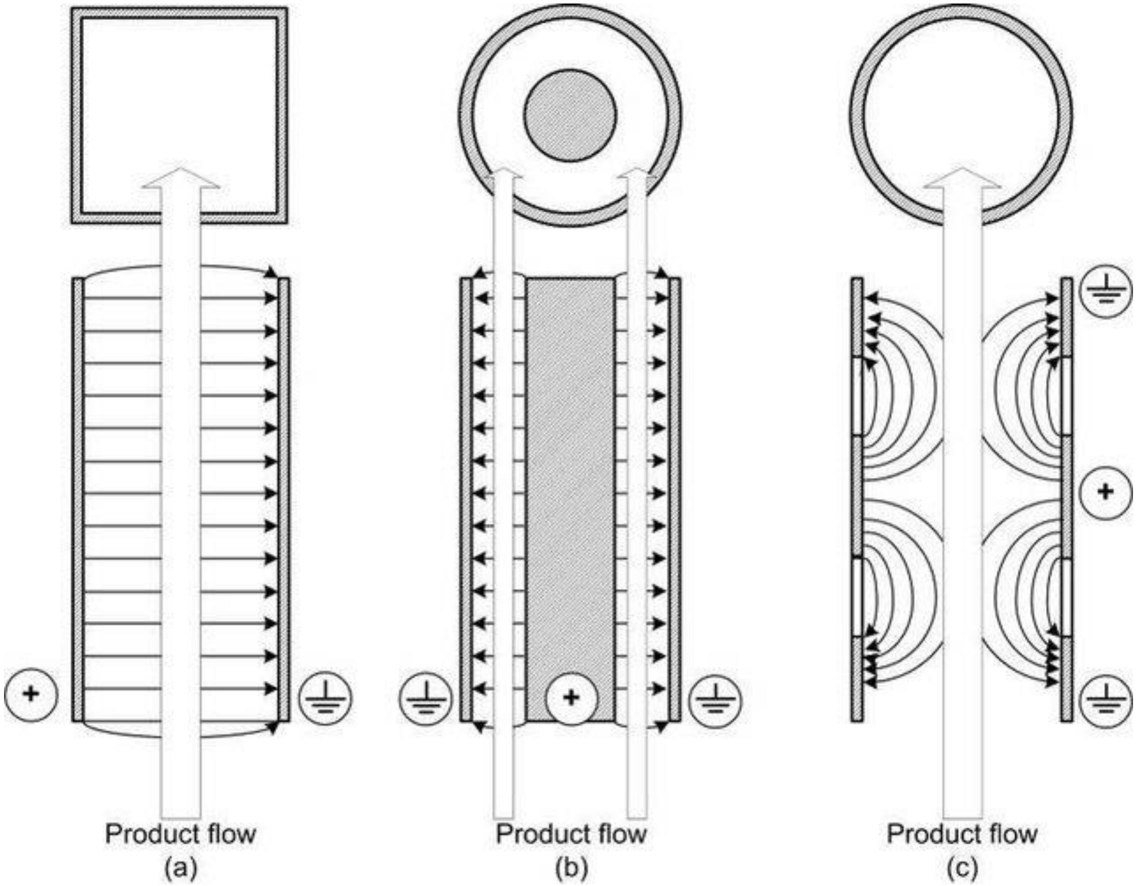
To allow successful industrial application the systematic process of scale up is necessary.

PEF systems for an industrial application of microbial decontamination:
equipment capacities of up to 10000 L/h,
cell disintegration up to 25 t/h



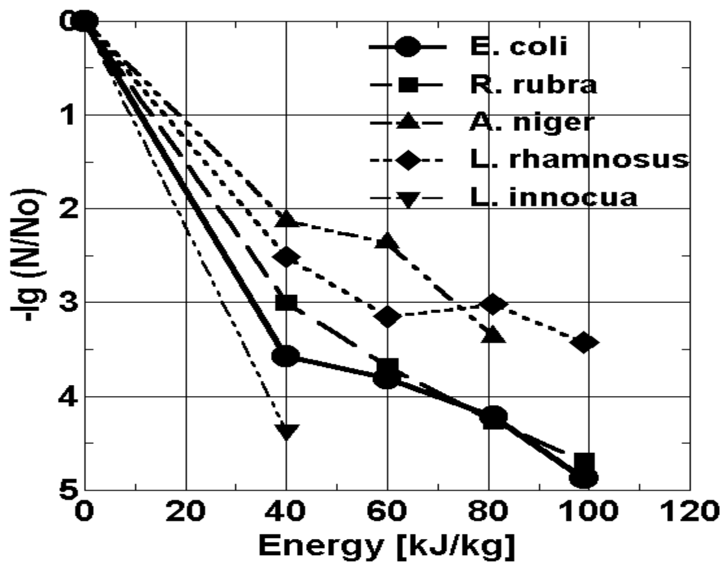
Heinz, Angersbach, Knorr, 1997

PEF: continuous system



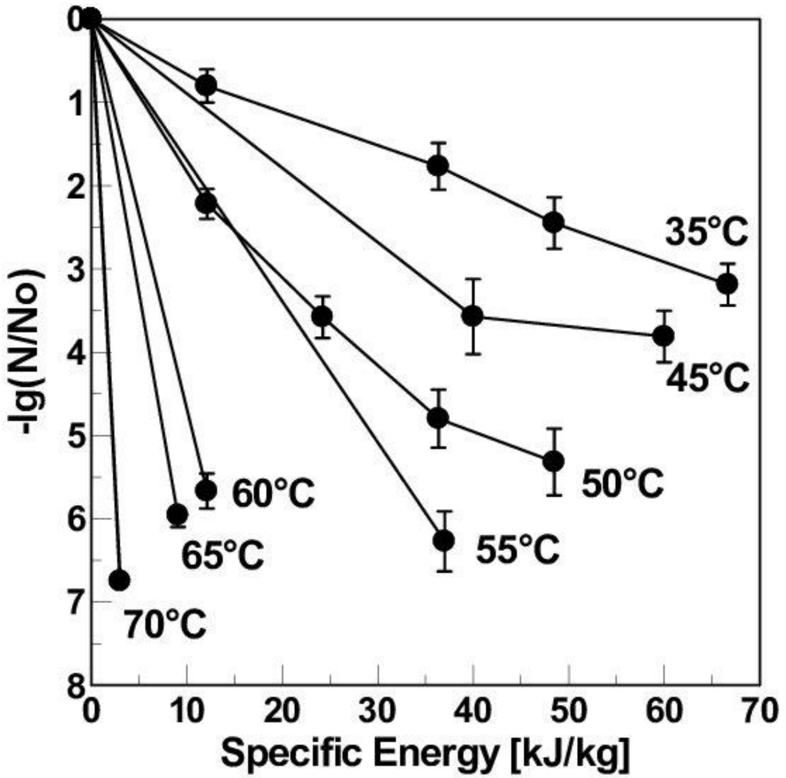
Configurations of treatment chambers for continuous PEF-treatment; (a) parallel plate, (b) coaxial and (c) co-linear configuration.

PEF: inactivation of MO



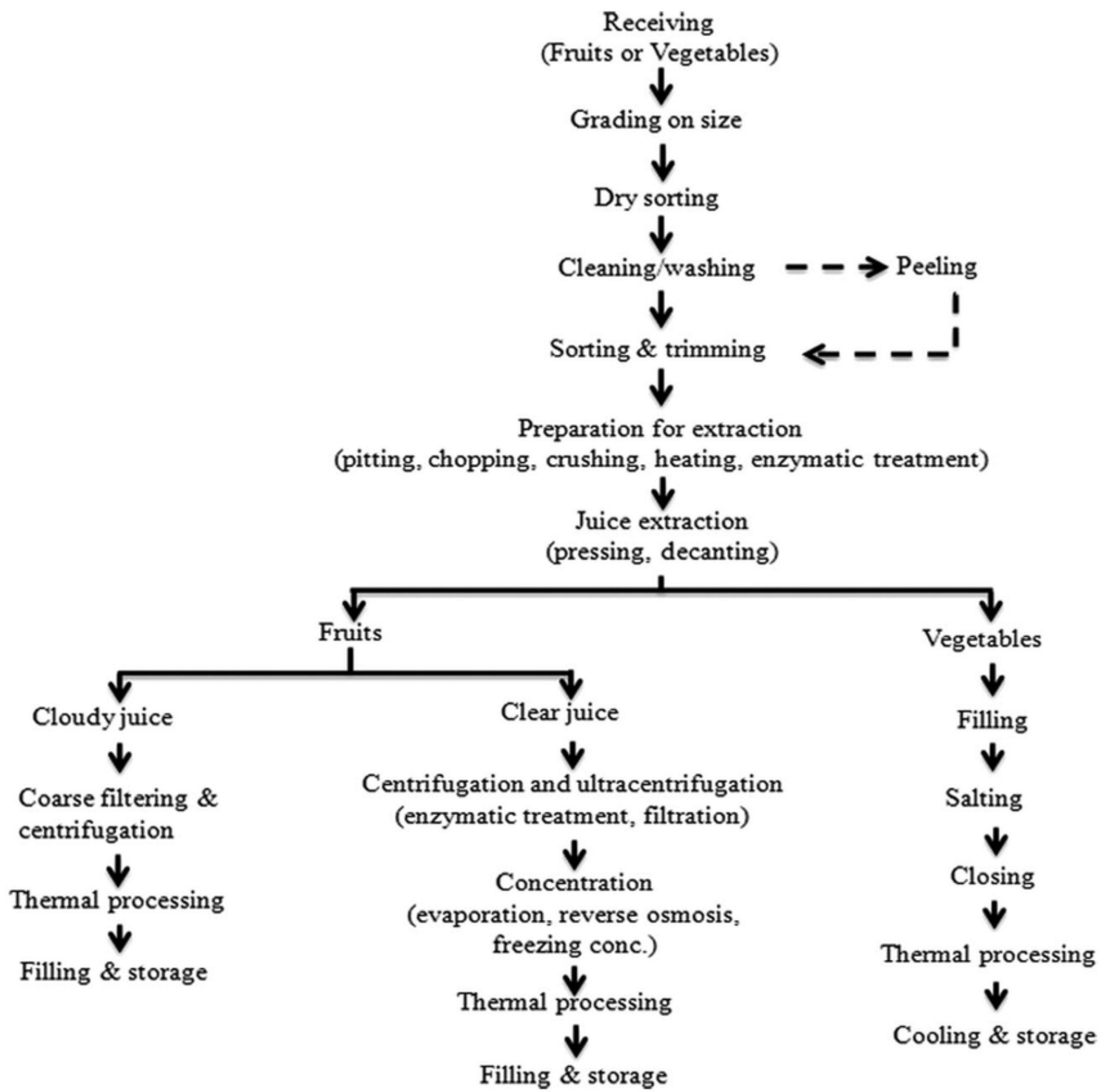
Inactivation of MO in apple juice.
Field strength 34kV/cm
Temperature 45°C,
Flow: 2 l/h.

Inactivation of E. coli in apple juice in relation to specific energy input at different treatment temperatures. Electric field strength: 36 kV/cm, flow rate 5 kg/h.



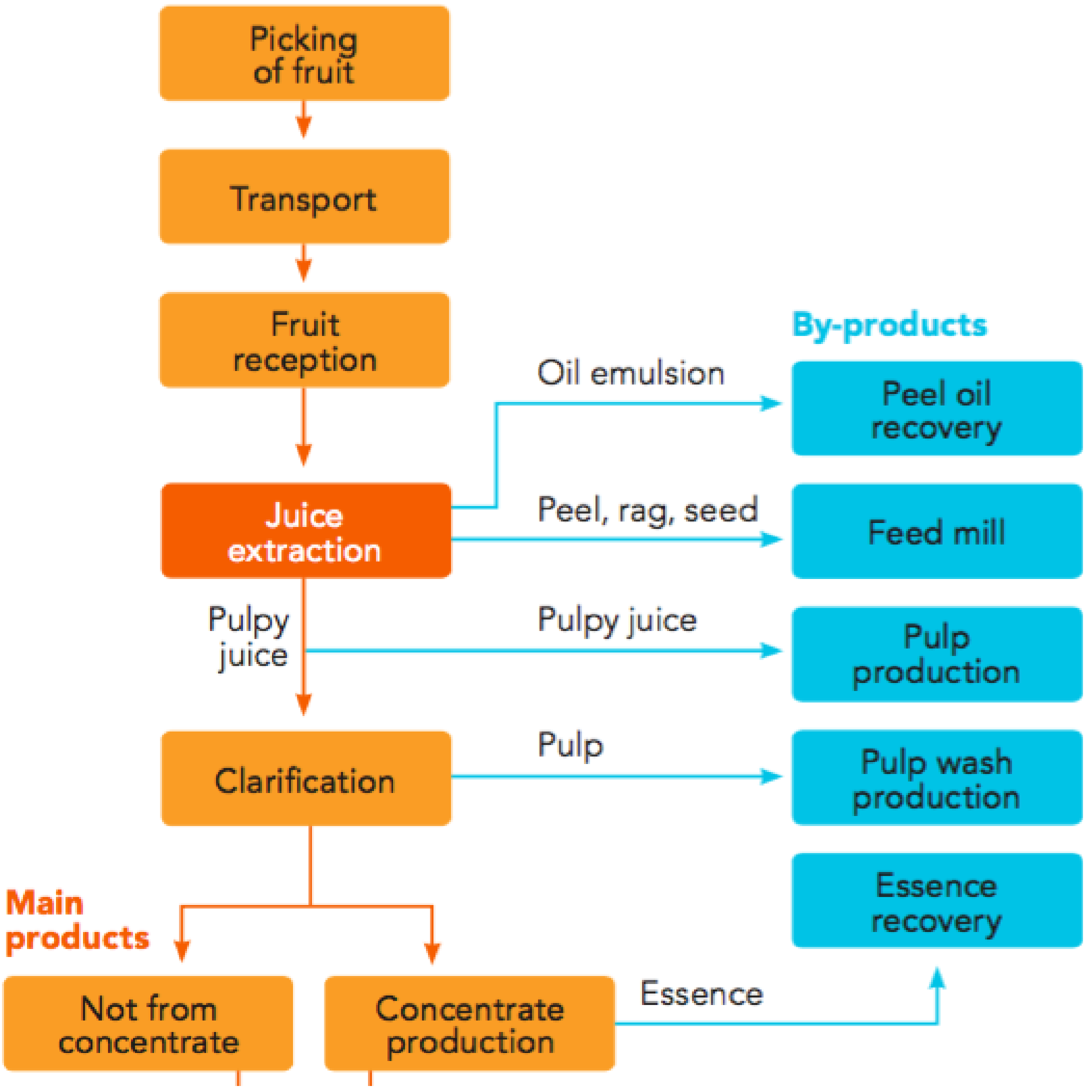
Toepfl S. 2006

PEF: juice processing



https://www.researchgate.net/publication/313264513_Functional_Applications_of_Lignocellulolytic_Enzymes_in_the_Fruit_and_Vegetable_Processing_Industries/figures?lo=1

PEF: juice processing



https://orangebook.tetrapak.com/chapter/fruit-processing

PEF: juice processing

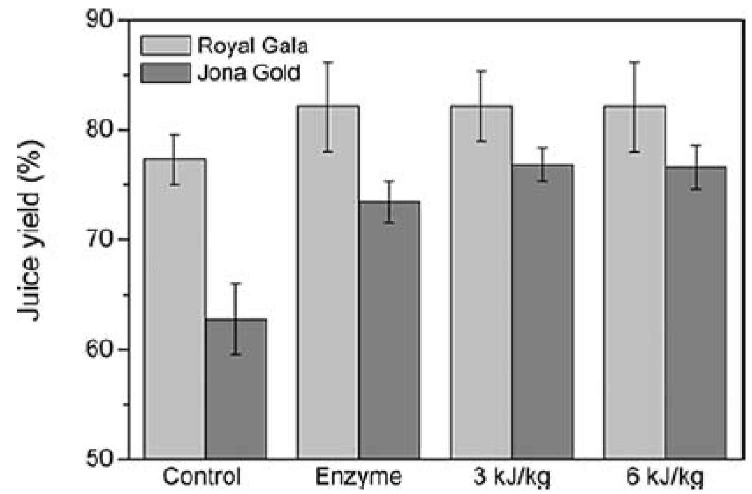


Fig. 9 Juice yield obtained in baling press from two apple varieties after PEF-treatment at 2 kV/cm and different specific energy input in comparison to enzyme treatment and untreated sample (adapted from Toepfl 2006)

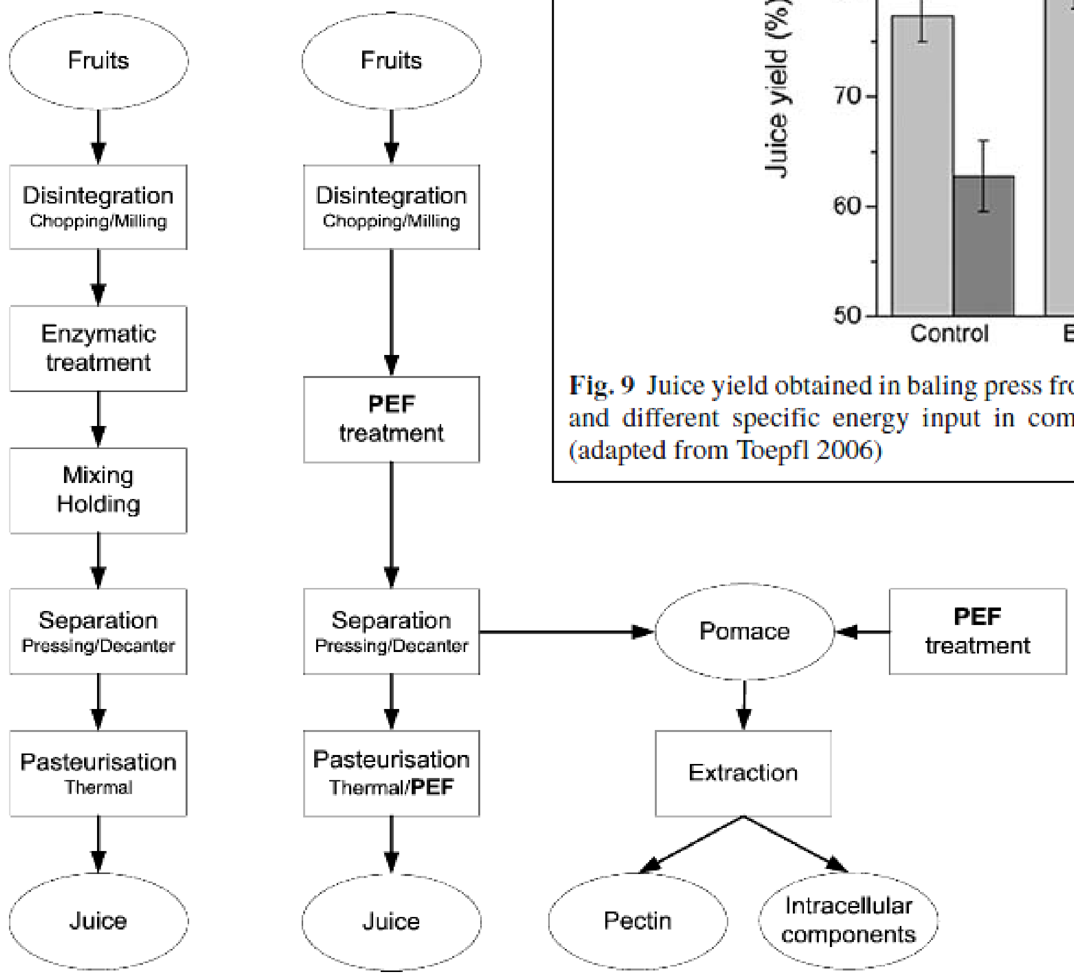


Fig. 8 Apple juice processing scheme. Comparison of conventional juice making process with electroplasmolysis treated apple mash and pomace

Jaeger, 2011

PEF: juice processing

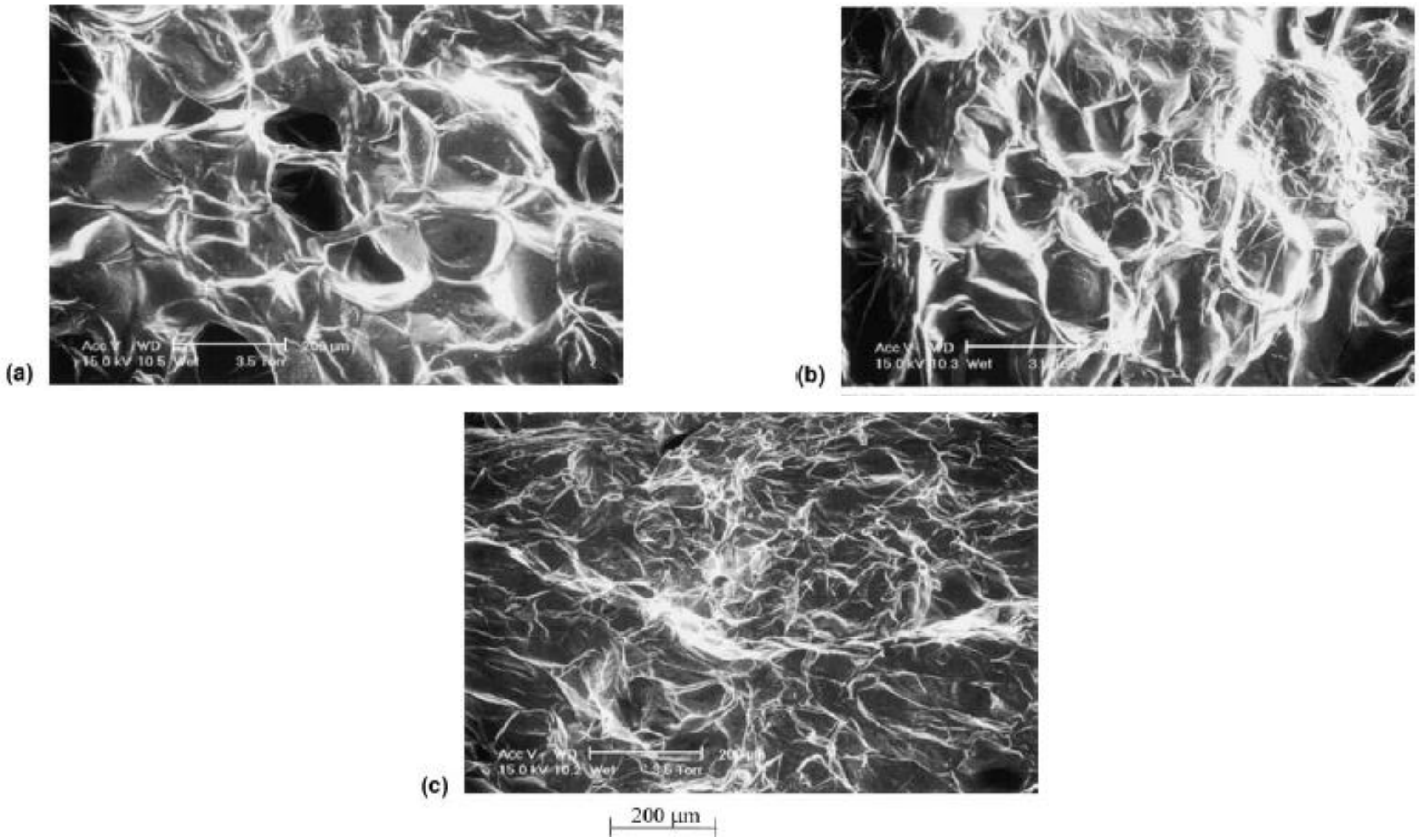
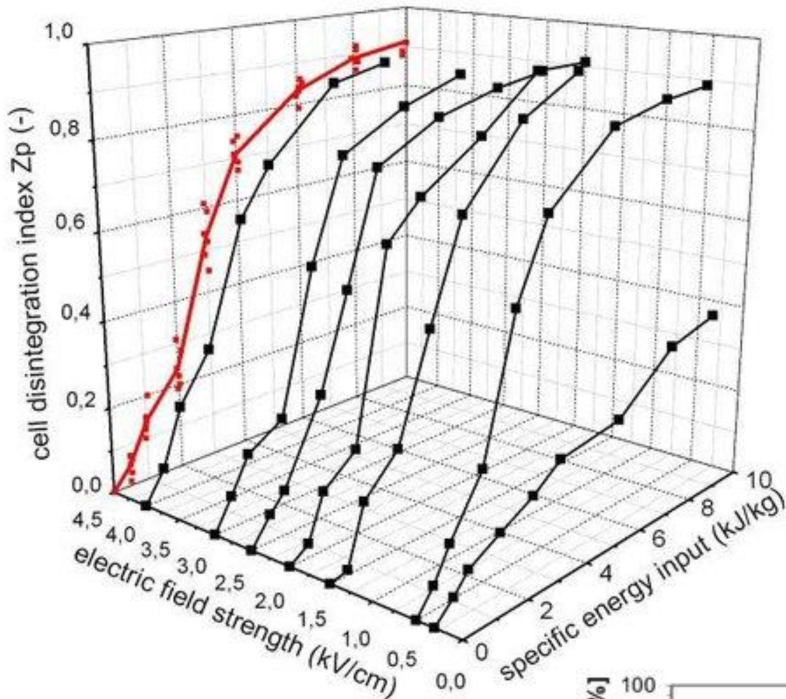


Fig. 3. ESEM micrographs of apple tissue: (a) before treatment; (b) after pressing ($P = 3$ bars, $t = 600$ s); (c) after simultaneous PEF and pressing treatment ($P = 3$ bars, $t_p = 330$ s, $E = 500$ V cm^{-1}, $t = 600$ s).

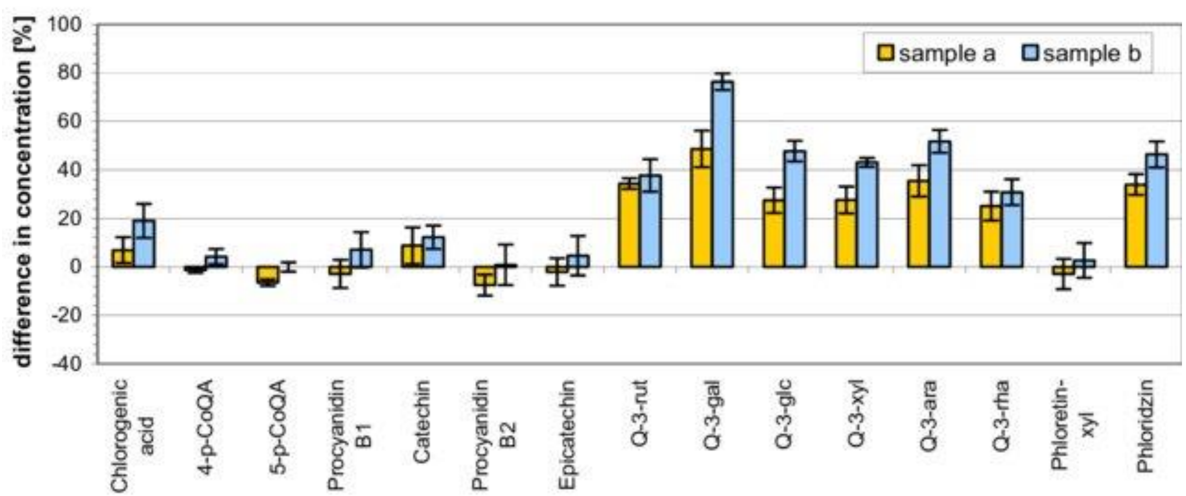
Jaeger, 2011

PEF: juice processing



Scatter diagram of cell disintegration index Z p of apple (Royal gala) samples after a PEFtreatment at a field strength of 0.3 to 4 kV/cm and a specific energy input of 0.5 to 10 kJ/g. The red line denotes the average of an YZ-projection of data points of the treatments at a field strength between 1 and 4 kV/cm.

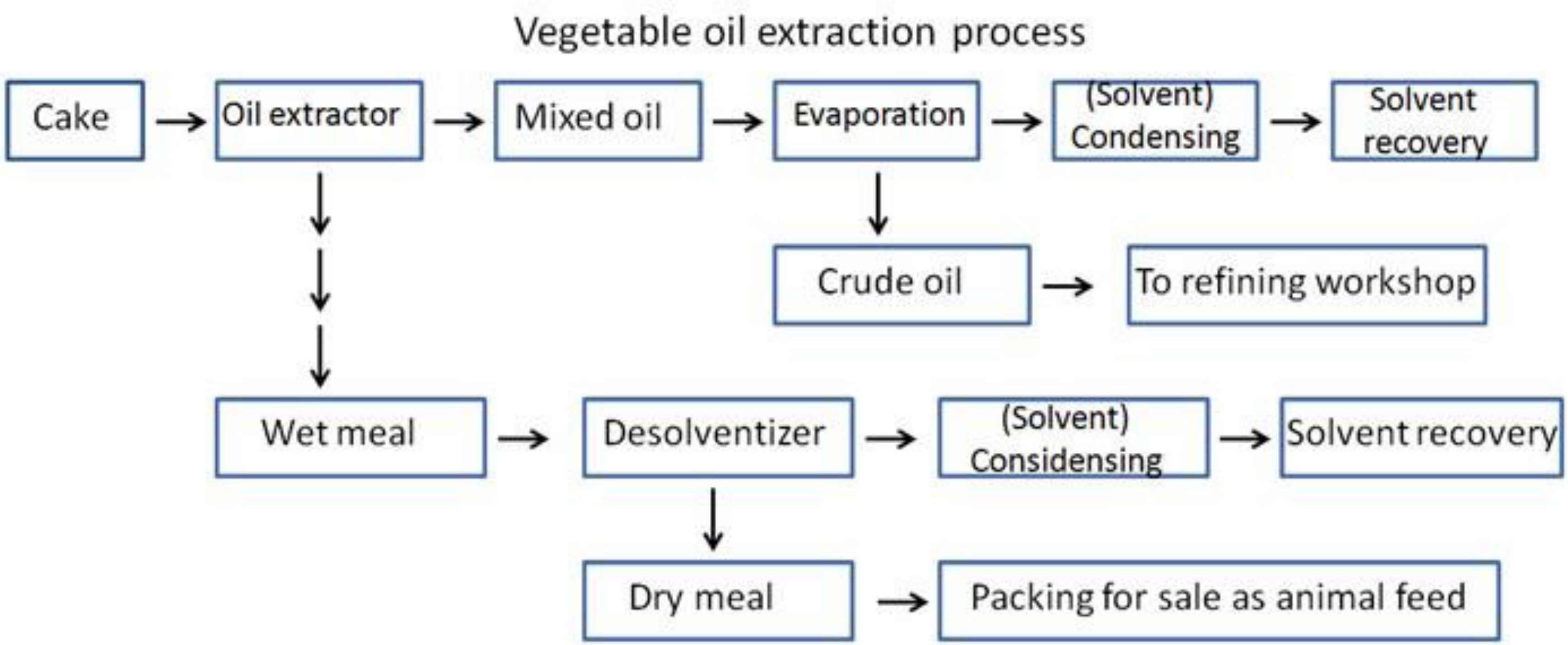
Difference in concentration of selected phenolic compounds in juice of Red Boskoop after a PEF-treatment at 3 kV/cm, 30 pulses (samples a and b) in comparison to untreated control



Toepfl S. 2006

PEF: oil extraction

Rapeseed oil extraction process



https://www.doingoilmachine.com/PRODUCTS/Oil_Extraction_Process/rapeseed_oil_extraction_process_479.html

PEF: oil extraction

Saatmais

↓

Quellung 48 h in Quellwasser bei 50°C

↓

Vermahlung in Prallmühle → Stärke, Schale

↓

Maiskeimlinge

↓

HSI-Behandlung

↓

Trocknung

↓

Extraktion mit überkritischem CO_2	Extraktion mit Hexan für 1 h bei Raumtemp.	Pressung in Schneckenpresse

PEF 5 kV/cm and 60 pulses; 7 kV/cm and 120 pulses; duration of each pulse 30 µs as a pre-treatment method before mechanical pressing or solvent extraction

Increase oil yield and concentration of tocopherols, polyphenols and phytosterols

Guderjan, Toepfl, Angersbach & Knorr, 2005

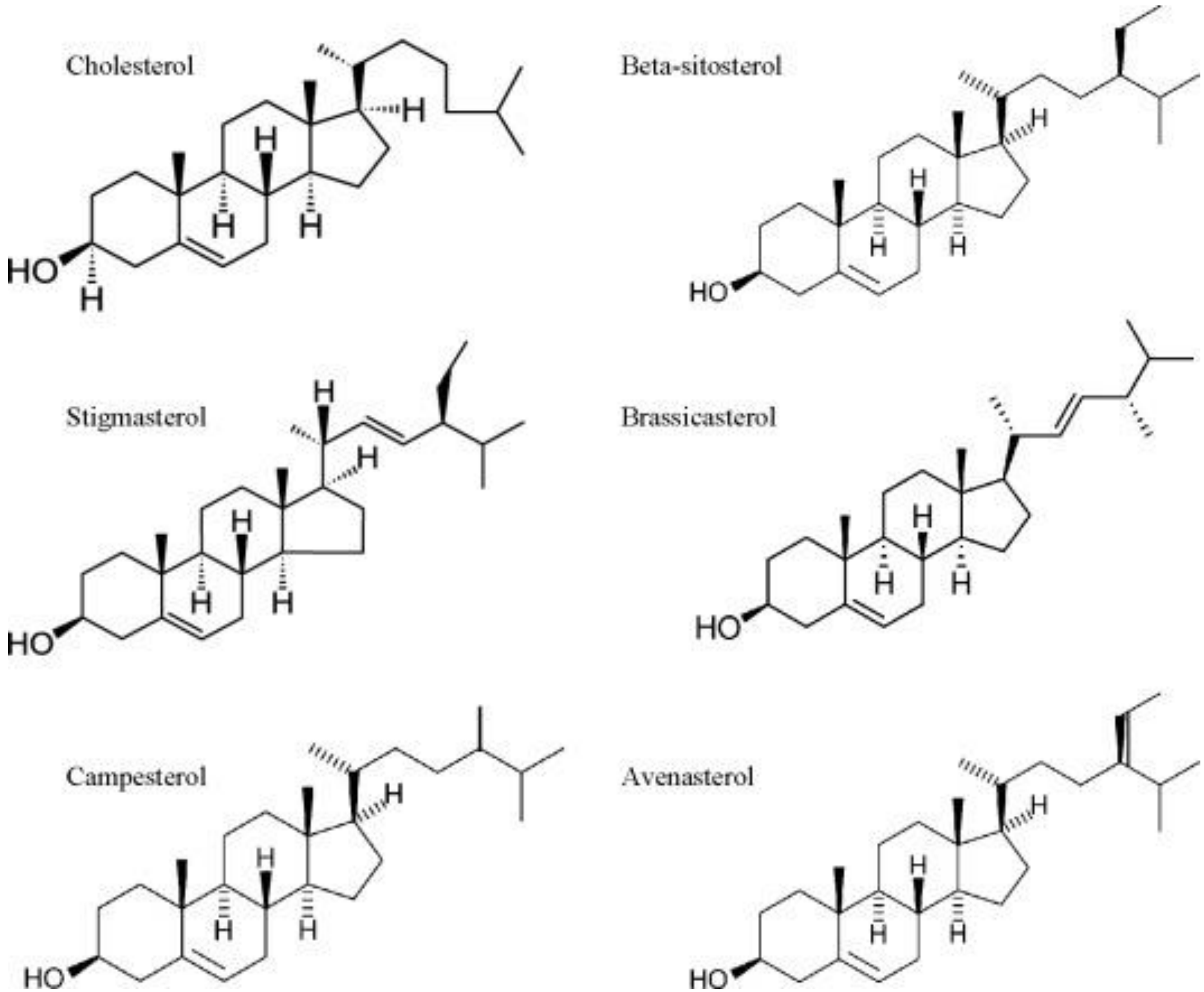
PEF: oil extraction

Pilot scale de-juicing systems. A) belt press; B) rack-and-cloth press; C) horizontal hydraulic filter press; D) decanter

Setup for a pilot plant to study the PEF assisted recovery of olive oil. A) pulse generator; B) Crusher feed hopper and screw; C) Crusher; D) PEF treatment chamber; E) malaxer; F) decanter

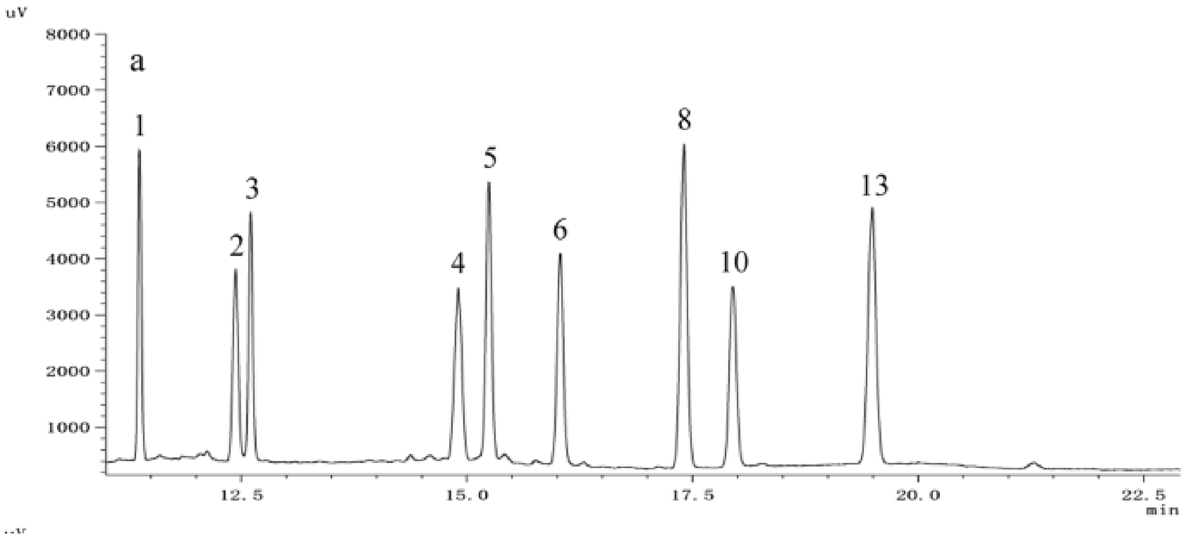
Jaeger, 2012

PEF: phytosterols



https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/phytosterols

PEF: oil extraction



HPLC Determination of Free Phytosterols and Tocopherols in Vegetable Oils

https://link.springer.com/article/10.1007/s12161-019-01649-7

Phytosterol composition of commercial corn oil determined by mass spectrometry

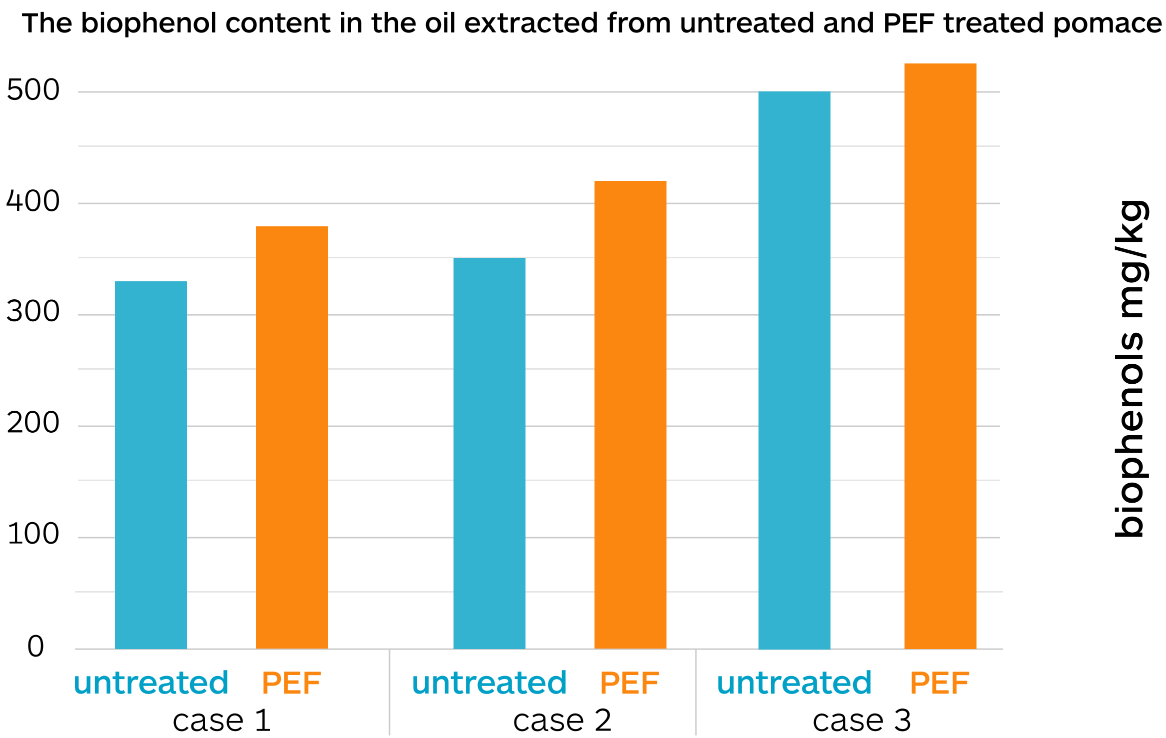
https://www.researchgate.net/publication/11335471_Phytosterols_that_are_naturally_present_in_commercial_corn_oil_significantly_reduce_cholesterol_absorption_in_humans/figures?lo=1

	Phytosterols	
	Weight	Amount
	% by weight	*%*
Sitosterol	0.593	76.7
Campesterol	0.147	19.0
Stigmasterol	0.014	1.8
Sitostanol	0.014	1.8
Campestanol	0.005	0.7
Total phytosterols	0.773	—

PEF: oil extraction, phytosterols

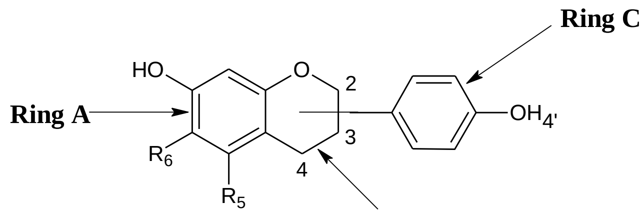
Benefits PEF

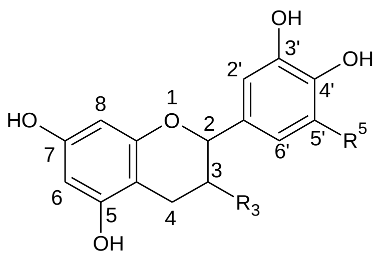
- **Increased oil extraction yield**
- **Higher process efficiency**
- **Improved oil quality**
- **Increased amounts of phytosterols**



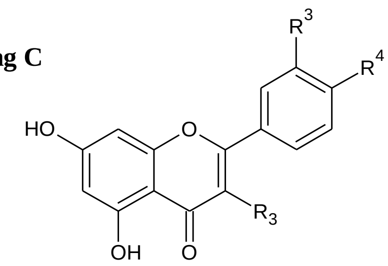
https://elea-technology.com/olive-oil/

PEF: Extraction of phenolics

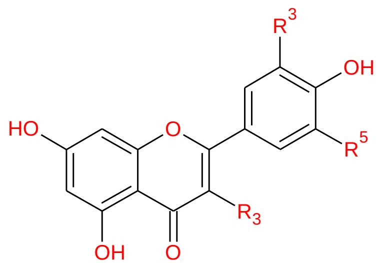




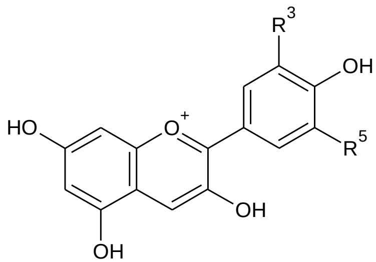
Flavanols	R_3	R^5
Catechin	OH	H
Epicathecin	OH	H
Epigallocathecin	OH	OH
Epicathecingallate	Gallate	H
Epigallocathecingallate	Gallate	OH



Flavanones	R_3	R^3	R^4
Naringenin	H	H	OH
Hesperetin	H	OCH_3	H
Flavanonols			
Taxifolin	H	OH	OH
Astilbin	O-rhamnosyl	OH	OH
Engeletin	O-rhamnosyl	H	OH



Flavonols	R_3	R^3	R^5
Kaempferol	OH	H	H
Quercetin	OH	H	H
Myricetin	OH	OH	OH
Isorhamnetin	OH	OCH_3	H
Flavones			
Luteolin	H	OH	H
Apigenin	H	H	H



Anthocyanins	R^3	R^5
Pelargonidin	H	H
Cyanidin	OH	H
Delphinidin	OH	OH
Paeonidin	OCH_3	H
Petunidin	OCH_3	OH
Malvidin	OCH_3	OCH_3

PEF: Extraction of phenolics

During Vine fermentation

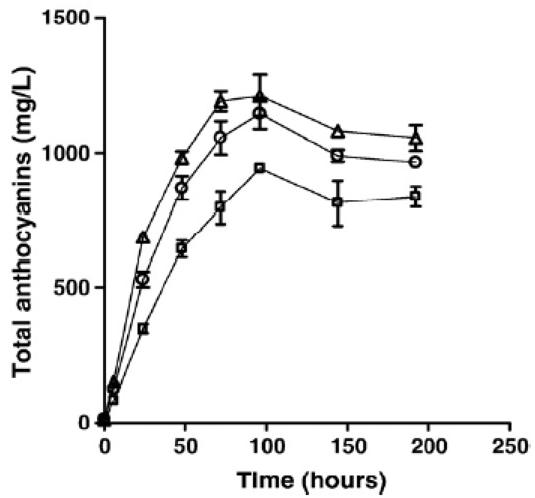


Fig. 2. Evolution of the anthocyanins along maceration time during vinification of untreated samples (control) and PEF treated samples at 5 and 10 kV/cm. (□) Control, (○) 5 kV/cm (Δ) 10 kV/cm.

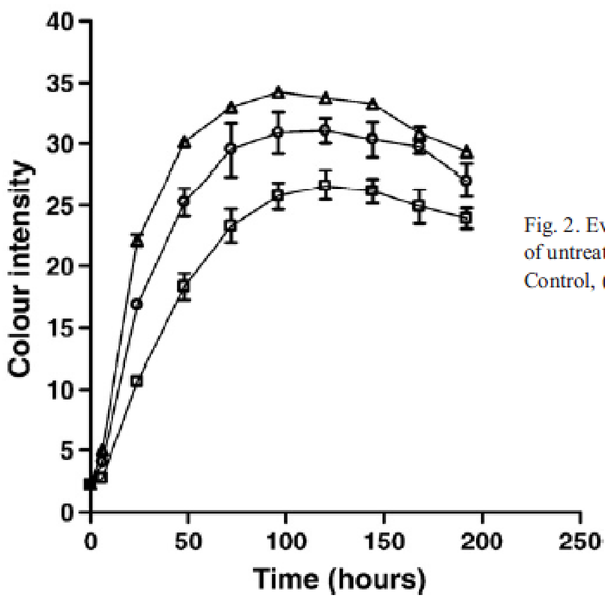


Fig. 1. Evolution of the colour intensity along maceration time during vinification of untreated samples (control) and PEF treated samples at 5 and 10 kV/cm.(□) Control, (○) 5 kV/cm (Δ) 10 kV/cm.

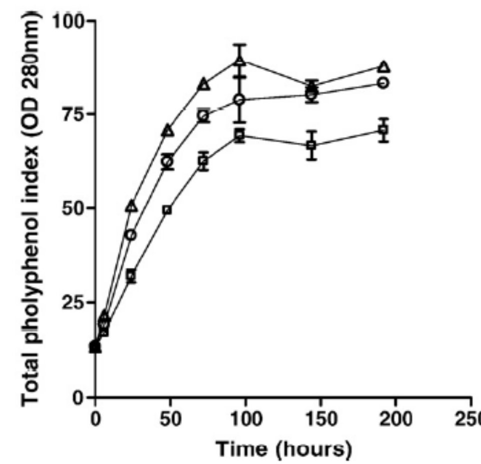


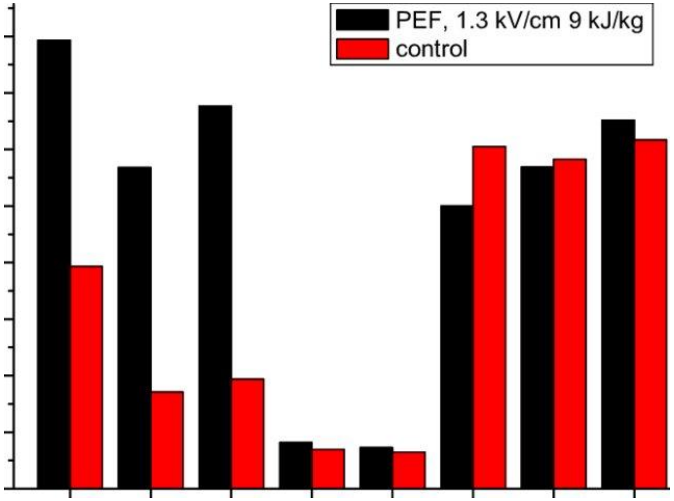
Fig. 3. Evolution of the index of total polyphenols along maceration time during vinification of untreated samples (control) and PEF treated samples at 5 and 10 kV/cm. (□) Control, (○) 5 kV/cm (Δ) 10 kV/cm.

Balasa, 2014

PEF: Extraction of phenolics

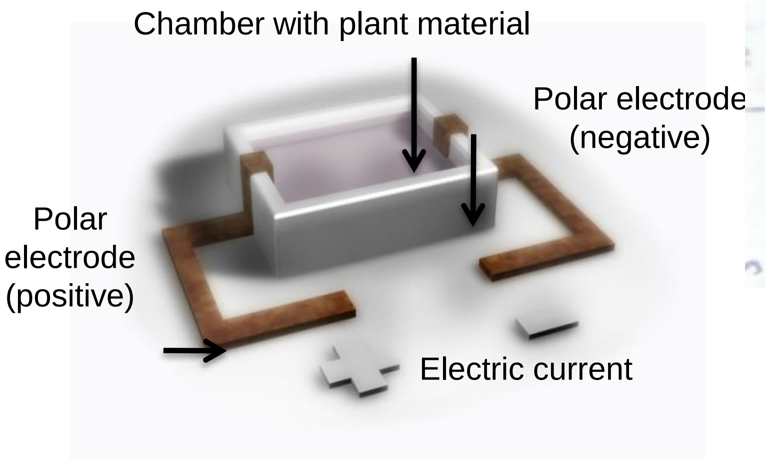
Solanum scabrum, also known as garden huckleberry, is an annual or perennial. In Africa it is cultivated as a leaf vegetable and for dye from the berries

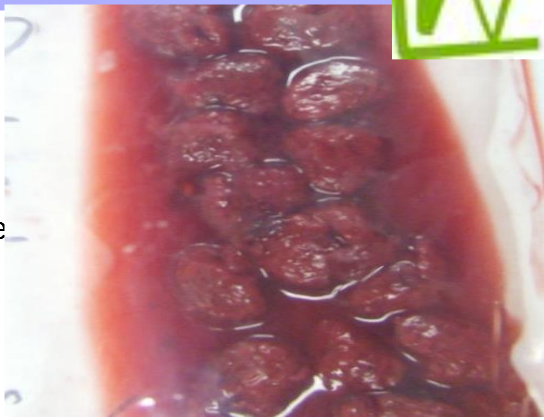
Anthocyanin concentrations of freshly extracted Solanum scabrum berries after Pulsed Electric Field (PEF) application in comparison to control. A pooled sample per accession was analyzed.



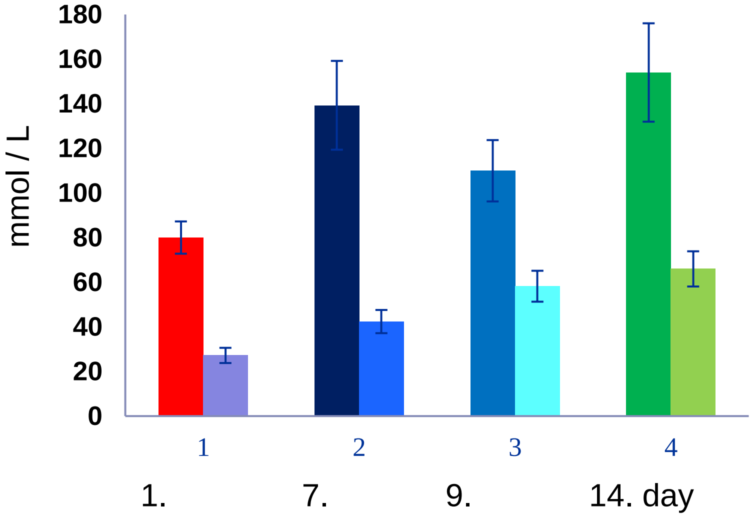
Toepfl S. 2006

PEF: Extraction



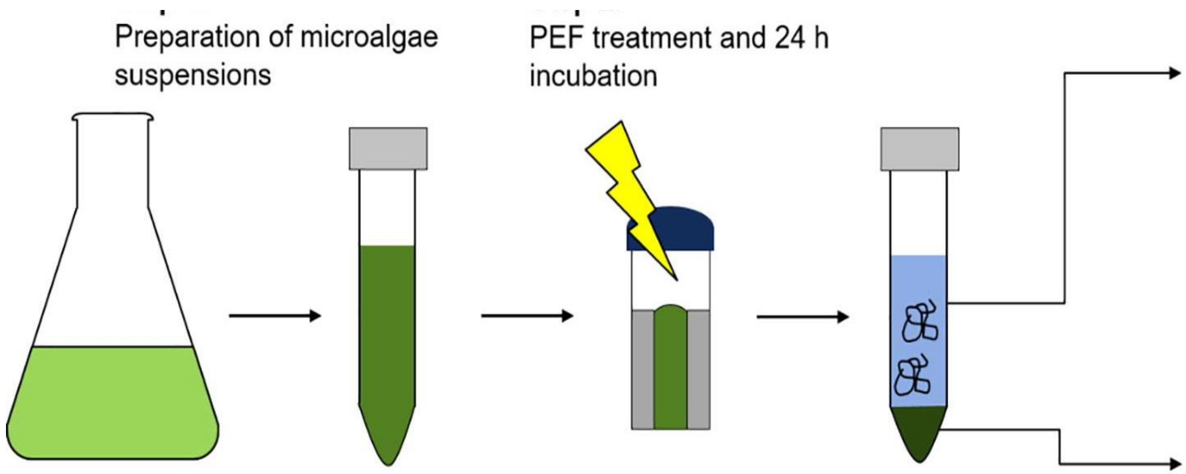


Anthocyanins in cell cultures of Vitis vinifera after PEF stress

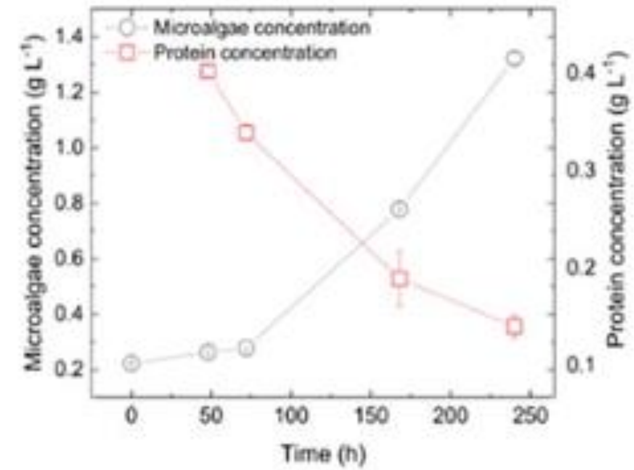


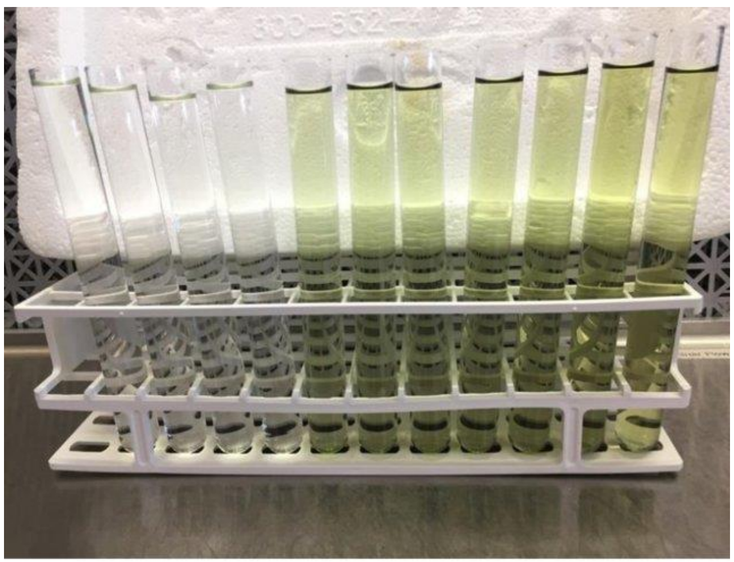
Smetanska et al, 2010, Appl Biochem Biotech

PEF: Algae



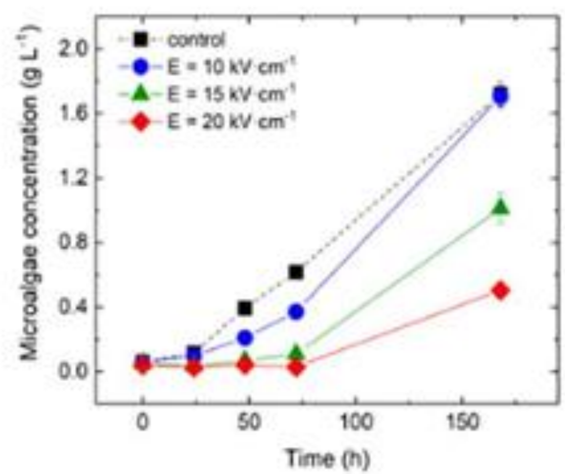
Step 3:
Determination of extracted proteins





PEF impact on *Chlorella vulgaris* at increasing field strengths from 0 kV/cm to 39 kV/cm. Chlorophyll release is first visible at 10 kV/cm, 20 mks treatment time (5 th from left), and increases with higher fields (up to 39 kV/cm). The algae samples in these tests were PEF treated at growth concentration and centrifuged, with no solvents

Step 4:
Revitalization



Mathys et al, 2019

PEF: Algae

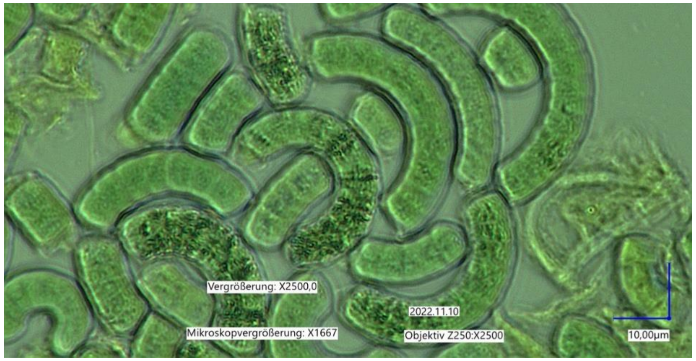
Chlorella and Spirulina

Increase in proteins 27%, chlorophylls 809% und carotenoids 525%

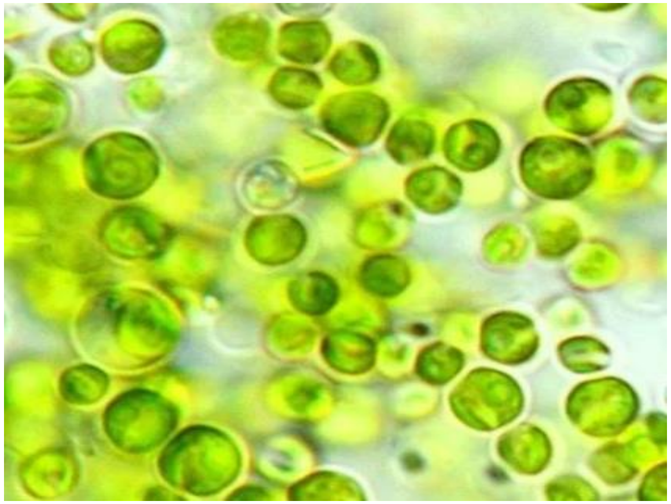
Extraction of functional compounds from microalgae

Component	*Chl.* dm BM	*Chl.* dm PEF BM	**Yield increase % Chlorella**	*Spir.* dm BM	*Spir.* dm PEF BM	**Yield increase %Spirulina**
Protein g/100g	5,48	6,98	**+ 27**	33,68	38,12	**+13**
Chlorophyll g/100g	0,011	0,1	**+ 809**	0,17	0,26	**+ 52,9**
Carotenoids g/100g	0,008	0,05	**+ 525**	0,044	0,11	**+ 150**
Protease Unit/100g	204,7	707,2	**+ 245,5**	864,2	812,5	**- 6**

Koehler, Toepfl et. al. 2006



Spirulina ***(Smetanska 2023, unpublished)***



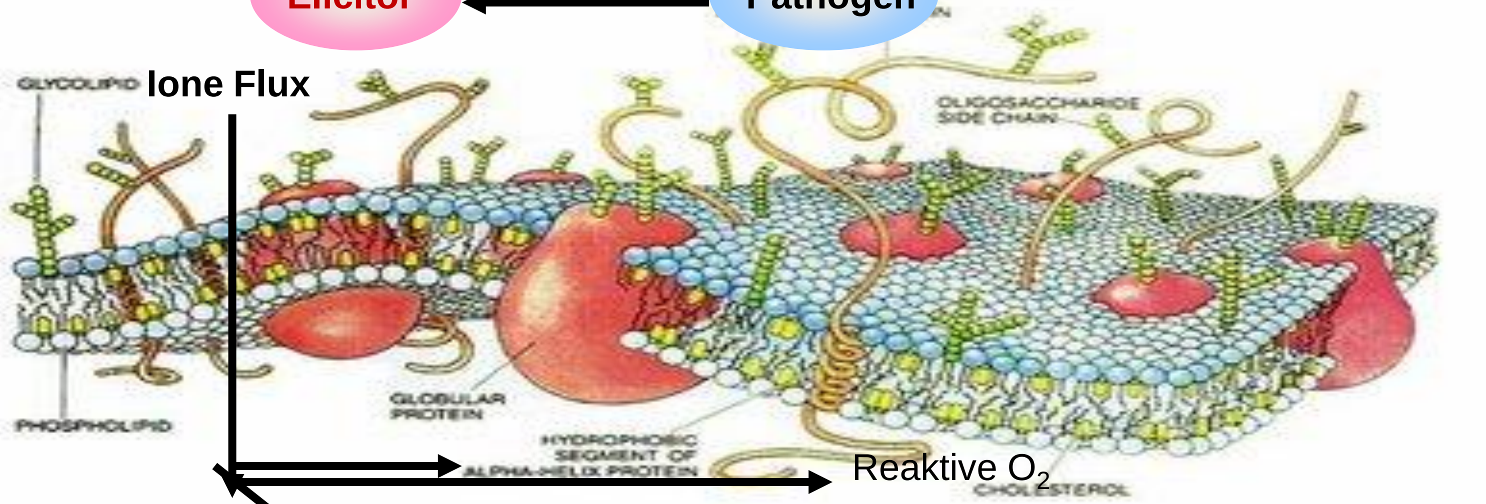
Chlorella ***(Smetanska 2023, unpublished)***

PEF: Stimulation of Synthesis

Answer on pathogen attack:
Recognition of pathogen,
Induktion of defence mehanisms
Synthesis of secondary metabolites

Elicitor ← **Pathogen**

Ione Flux



Reaktive O_2

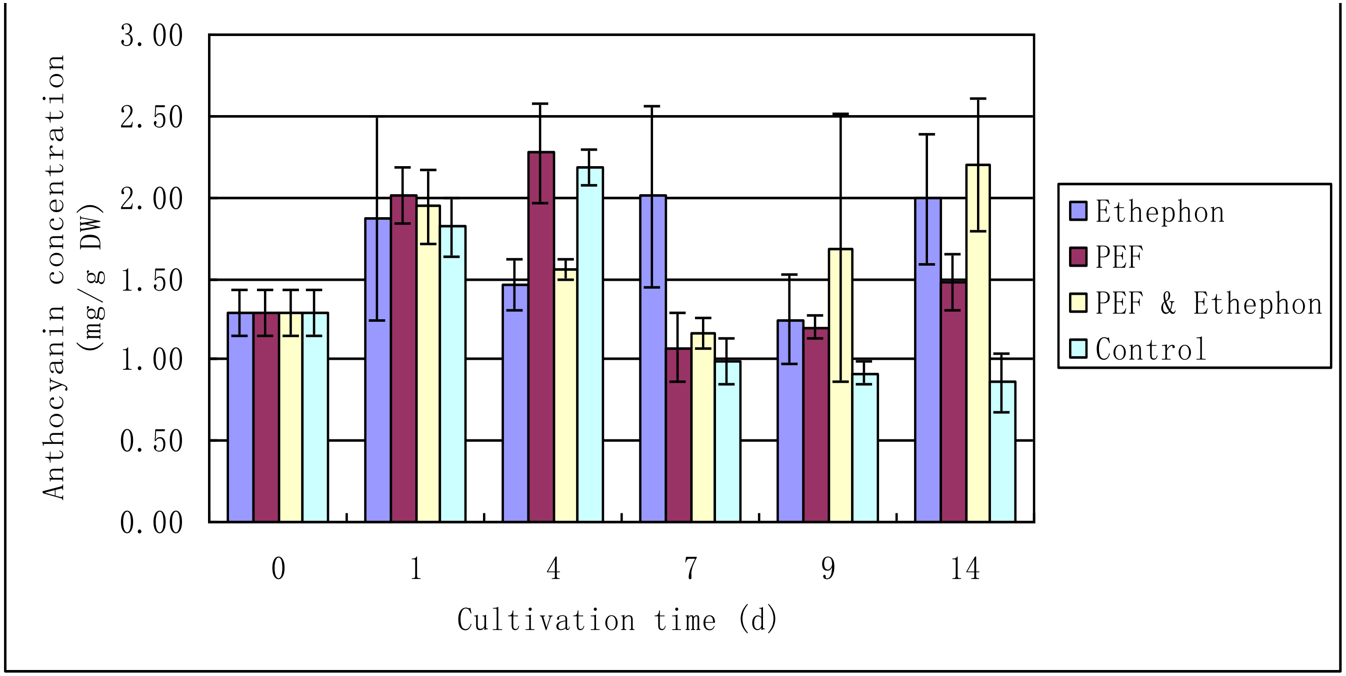
NADPH oxidase

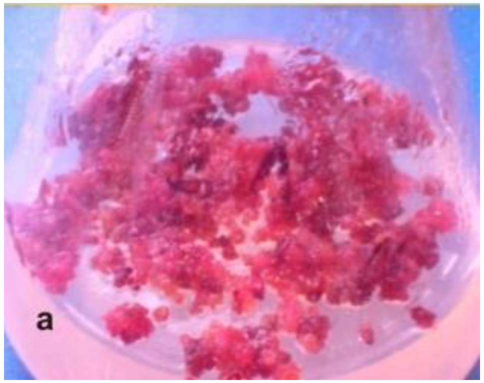
gen-activation, hypersensitive answer → **synthesis of secondary metabolites**

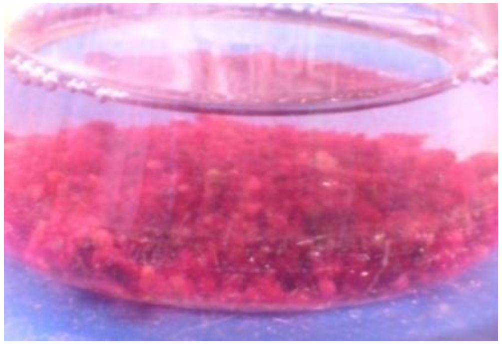
Cai,Saw, Riedel, Smetanska, 2009

PEF: Stimulation of Synthesis

Anthocyanin concentration in *Vitis vinifera* cell culture treated with electric field







300 V/cm electric field treatment

Cai, Saw, Riedel, Smetanska, 2009

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