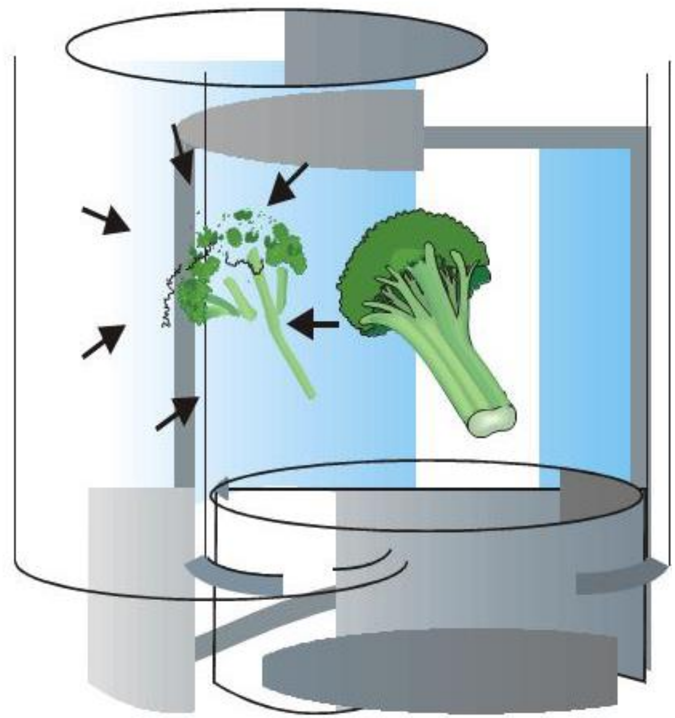
High pressure processing
High Pressure Pascalisation



https://www.wvxu.org

Smetanska

High pressure processing

By subjecting foods to high pressure (HP), microorganisms and enzymes can be inactivated without the degradation of flavour and nutrients associated with traditional thermal processing.

HPP is one of the novel techniques utilizing pressure at high level to achieve food safety and stability. It is helpful in maintaining the quality attributes and suitable especially for heat sensitive food.

Can be used in combination with other techniques as:

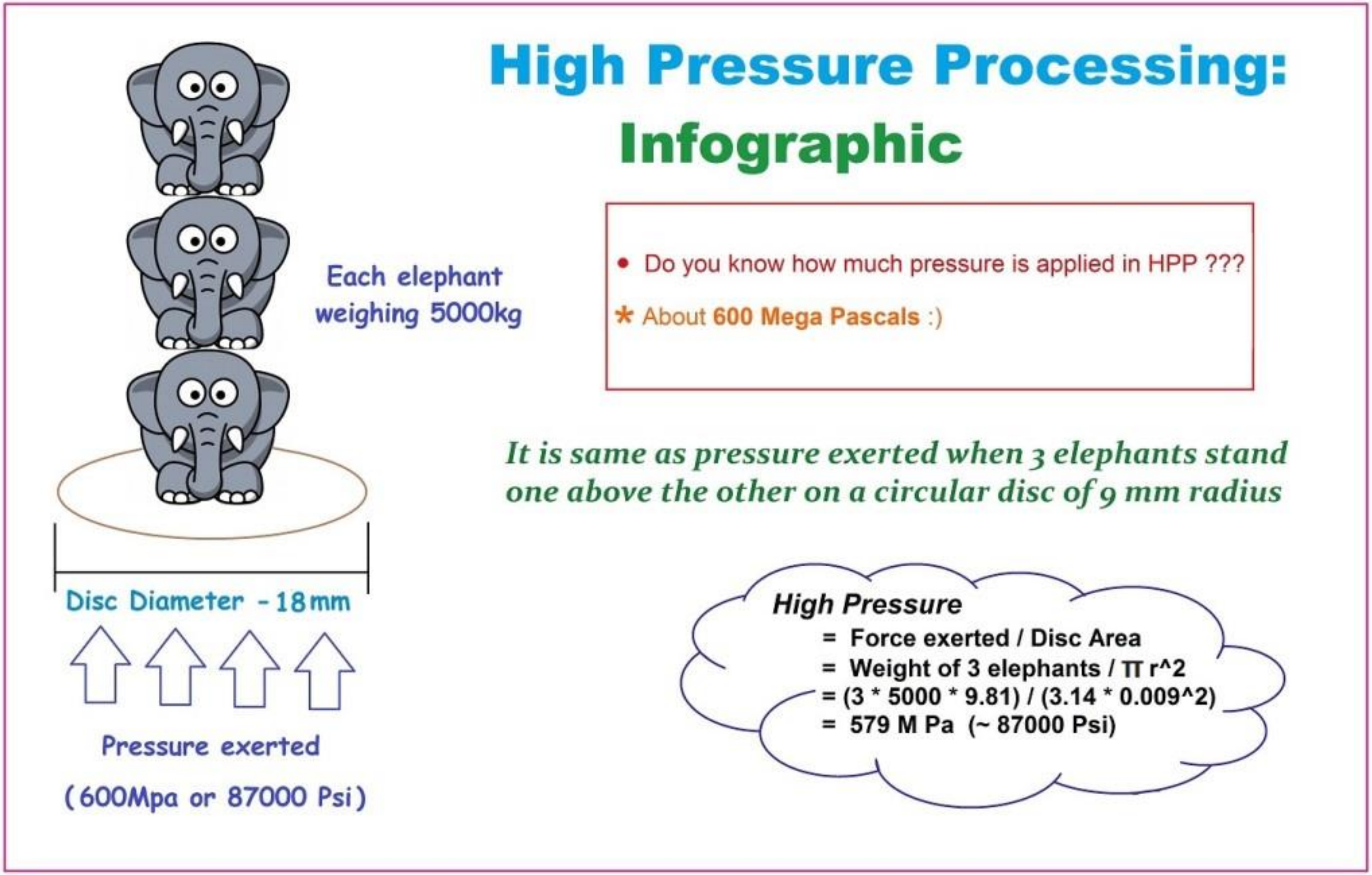
- **packaging**
- **irradiation,**
- **ultrasound filtration,**
- **oscillating magnetic fields,**
- **pulsed light,**
- **pulsed electric field.**

HPP is also offers modification of functional characteristics.

HP affects all reactions and structural changes where a change in volume is involved, as in the gelation of proteins or starch.

Front page of Hite's report describing the effect of HPP in the preservation of milk and HPP equipment used to pressurize milk samples (Hite, 1899)

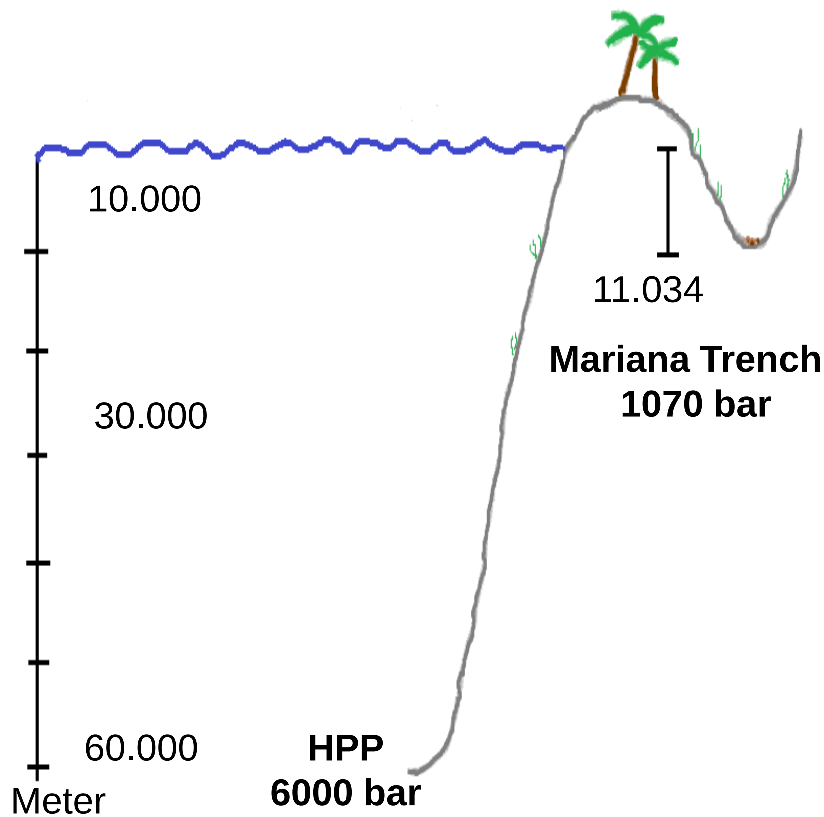
High pressure processing



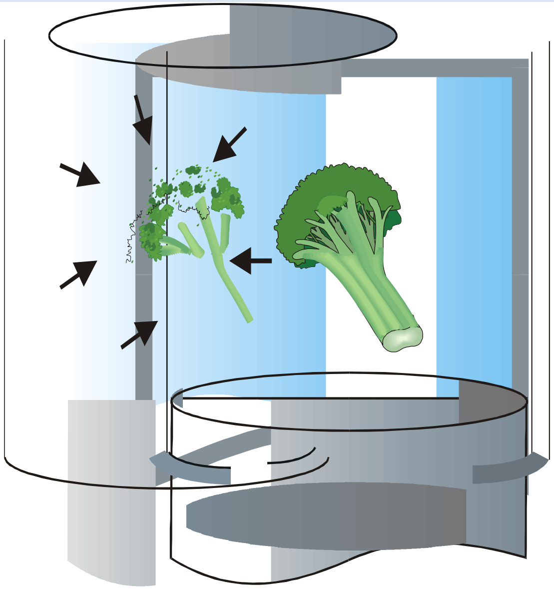
http://www.foodsciencesblog.com/wp-content/uploads/2013/05/High-Pressure-1024x657.jpg

HPP

HPP lower limit is 100 MPa, upper limit 1000 MPa for food processing.
How high is this pressure range? 10 times higher than the pressure in the deepest ocean.
60 kg person on an area of 1 cm2 => 5 MPa.
The pressure ranges between 100 and 800 MPa (106 Pascal) ≅ 8,000 atm!
1 MPa ≅10 atm



HPP



Pressures used in the HPP of foods appear to have little effect on covalent bonds.

HPP acts instantaneously and uniformly throughout a mass of food independent of size, shape, and food composition. Thus, package size, shape, and composition are not factors in process determination.

HPP may be combined with heat to achieve an increased rate of inactivation of microbes and enzymes.

The work of compression during HPP treatment will increase Temp. of foods through adiabatic heating of ca. 3°C/100 MPa, depending on the composition of the food

Foods decrease in volume as a function of the imposed pressure. An equal expansion occurs on decompression. For this reason the packaging used for HPP-treated foods must be able to accommodate up to a 15% reduction in volume, and return to its original volume, without loss of seal integrity and barrier properties.

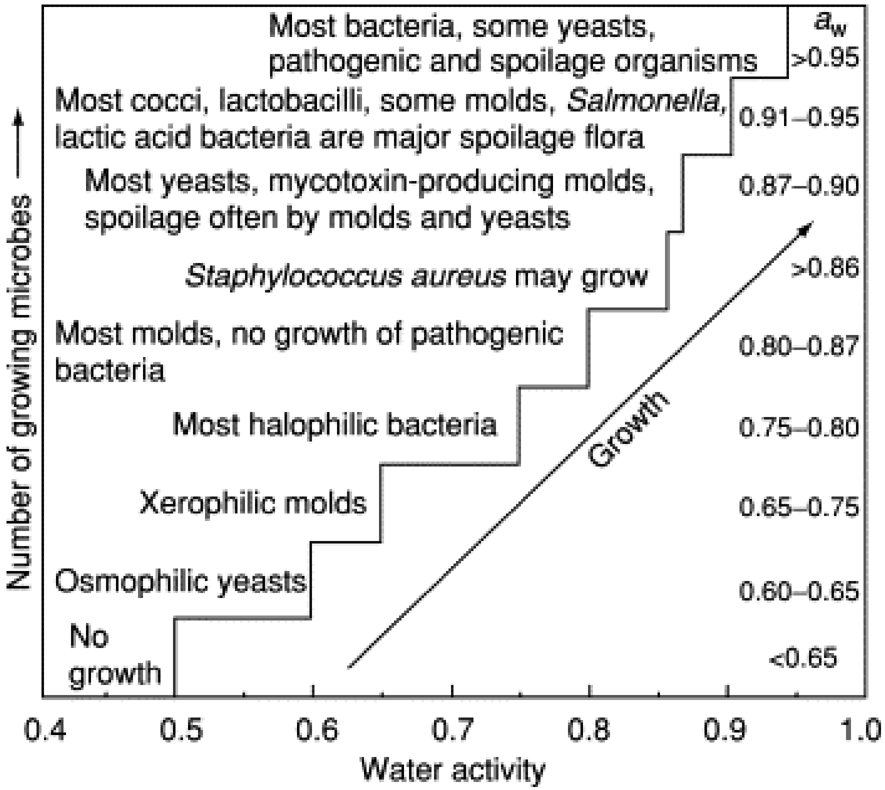
The greater the pressure level and time of application, the greater the potential for changes in the appearance of selected foods.

HPP History: Freezing

Freezing food slows down decomposition by turning residual moisture into ice, inhibiting the growth of most bacterial species

Water activity (a_w) is the partial vapor pressure of water in a solution divided by the standard state partial vapor pressure of water.

Bacterial growth correlates with water activity, not water content.



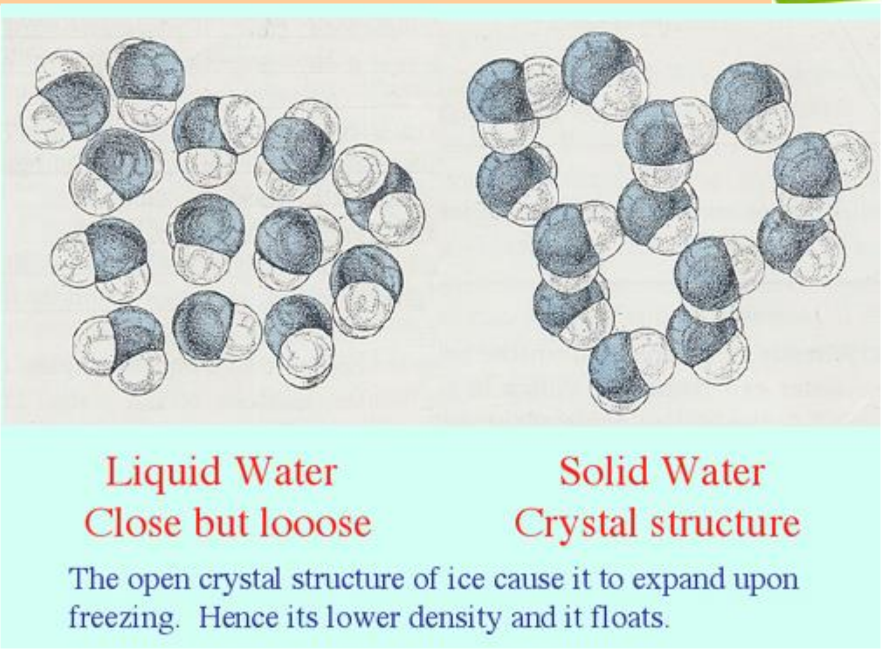
https://www.sciencedirect.com/topics/immunology-and-microbiology/microbial-growth

<u>Minimal growth temperatures:</u>

Bacteria -10 °C
Yeast -12 °C
Mold -15 °C

Freezing

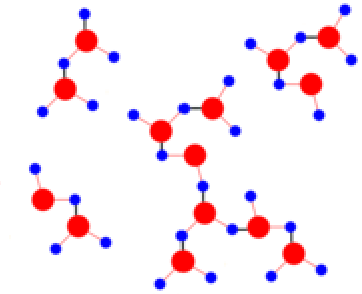
Mechanical and cryogenic (flash) freezing



The freezing kinetics is important to preserve the food quality and texture. Quicker freezing generates smaller ice crystals and maintains cellular structure.
Cryogenic freezing is the quickest freezing technology (−196 °C)

Formation of water clusters from the beginning of freezing process

at -5 °C 50.000 molecules
at -40 °C 70 molecules



Freezing

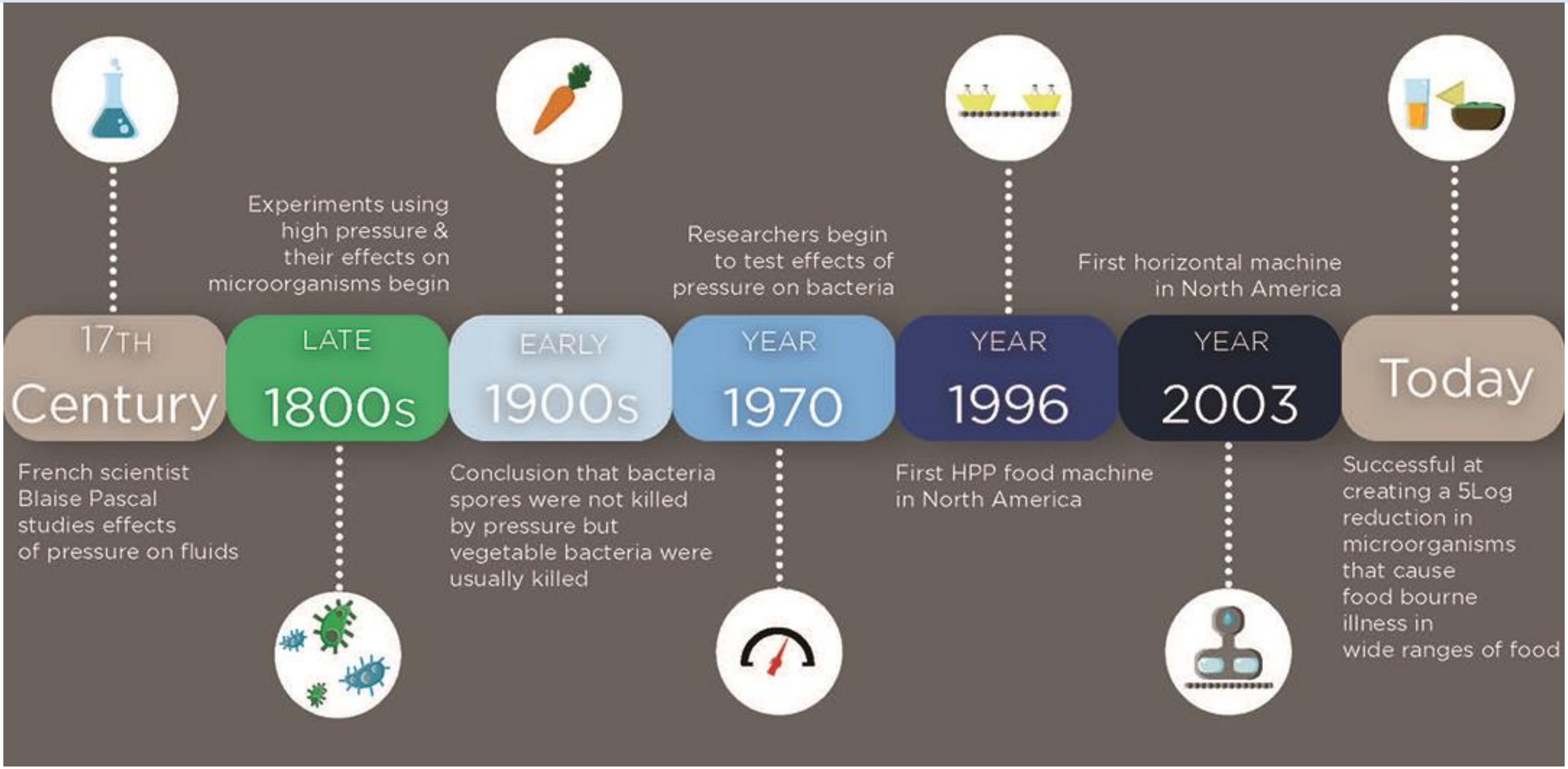
The speed of the freezing has a direct impact on the size and the number of ice crystals formed within a food product's cells and extracellular space.

Slow freezing leads to fewer but larger ice crystals

Fast freezing leads to smaller but more numerous ice crystals.

Large ice crystals can puncture the walls of the cells which will cause a degradation of the texture of the product as well as the loss of its natural juices during thawing.

HPP: History



https://hydrofreshhpp.com/what-is-hpp/hpp-technology/

1899 - Hite conducted first experiment: 6,800 kg/cm2 on milk ►6-7 D reduction in MO.

1914 - Bridgmann used pressure of 6,000 kg/cm2 on egg albumin ► coagulation.

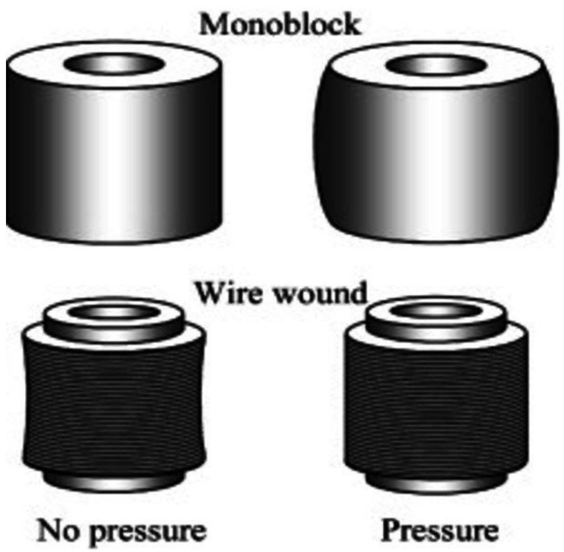
1980s - Research and applications of HP restarted, HP processed foods.

HPP: Application

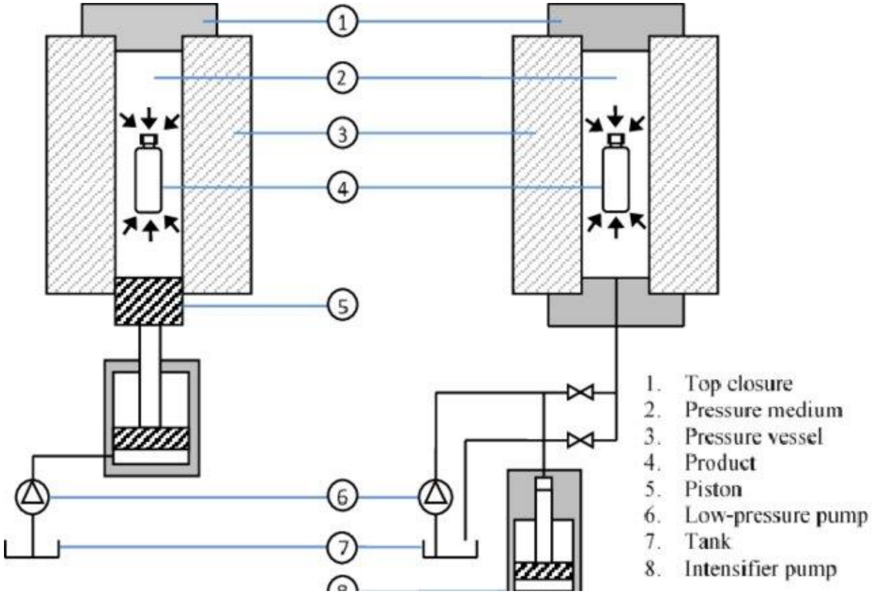
Recent examples of HP processing of fruit products (adapted from Cheftel, 1997)

Company	Product	Pressure/temperature/time combination	Role of HP
Japan			
Meidi-ya	Fruit-based products (pH < 4.5); jams (apple, kiwi, strawberry); jellies; purees; yoghurts; sauces	400 MPa, 10–30 min, 20°C	Pasteurisation, improved gelation, faster sugar penetration; limiting residual pectinmethylesterase activity
Pokka Corp. (ceased in 1998)	Grapefruit juice	200 MPa, 10–15 min, 5°C	Reduced bitterness
Wakayama Food Ind.	Mandarin juice (winter season only) (only about 20% of HP juice in final juice mix)	300–400 MPa, 2–3 min, 20°C	Reduced odour of dimethyl sulphide; reduced thermal degradation of methyl methionine sulphoxide; replace first thermal pasteurisation (after juice extraction) and final pasteurisation before packing: 90°C, 3 min
Nisshin fine foods	Sugar-impregnated tropical fruits (kept at −18°C without freezing) for sorbet and ice cream	50–200 MPa	Faster sugar penetration and water removal
QP corp	Ice-nucleating bacteria (for fruit juice and milk)	/	Inactivation of *Xanthomonas*, no loss of ice nucleating properties
Ehime Co.	Japanese mandarin juice	/	Cold pasteurisation
Takansi	Fruit juice	/	Cold pasteurisation
Pon (test market in 2000)	Orange juice	/	/
Europe			
Pampryl (France)	Fruit juice (orange, grapefruit, citrus, mixed fruit juice)	400 MPa, room temperature	Inactivation of microflora (up to 10^6 cfu g^{-1}), partial inactivation of pectinmethylesterase
Orchard House Foods Ltd (UK)	Squeezed orange juice	/	Inactivation of microflora and enzyme, keeping natural taste
United States			
Avomex	Avocado paste (guacamole, chipotle sauce, salsa) and pieces	700 MPa, 10–15 min, 20°C	Microorganism inactivation, polyphenoloxidase inactivation, chilled process

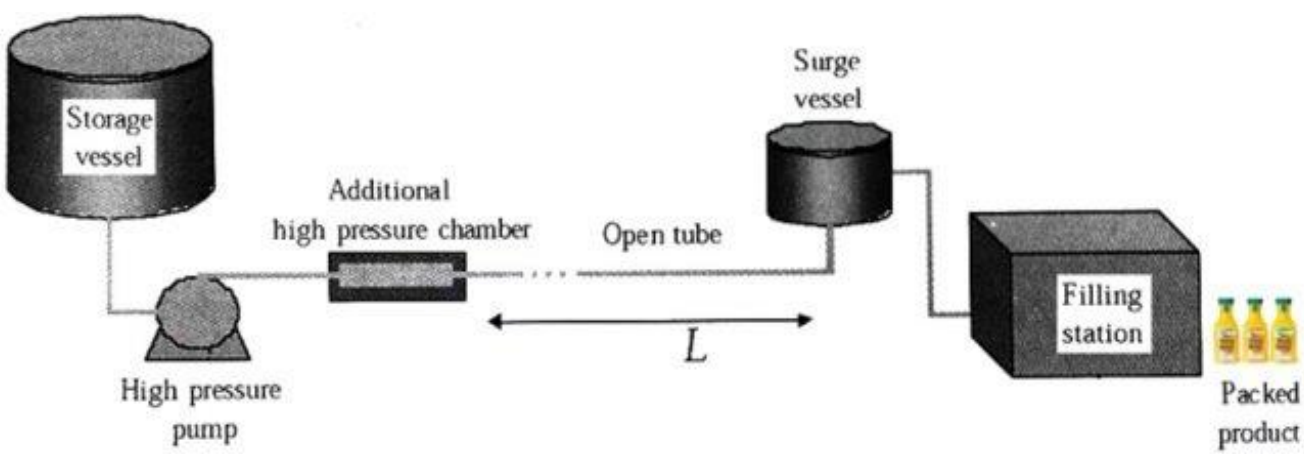
HPP: Technique



Shows a possible reduction in pressure vessels wall thickness achieved by using a different pre-stressed design



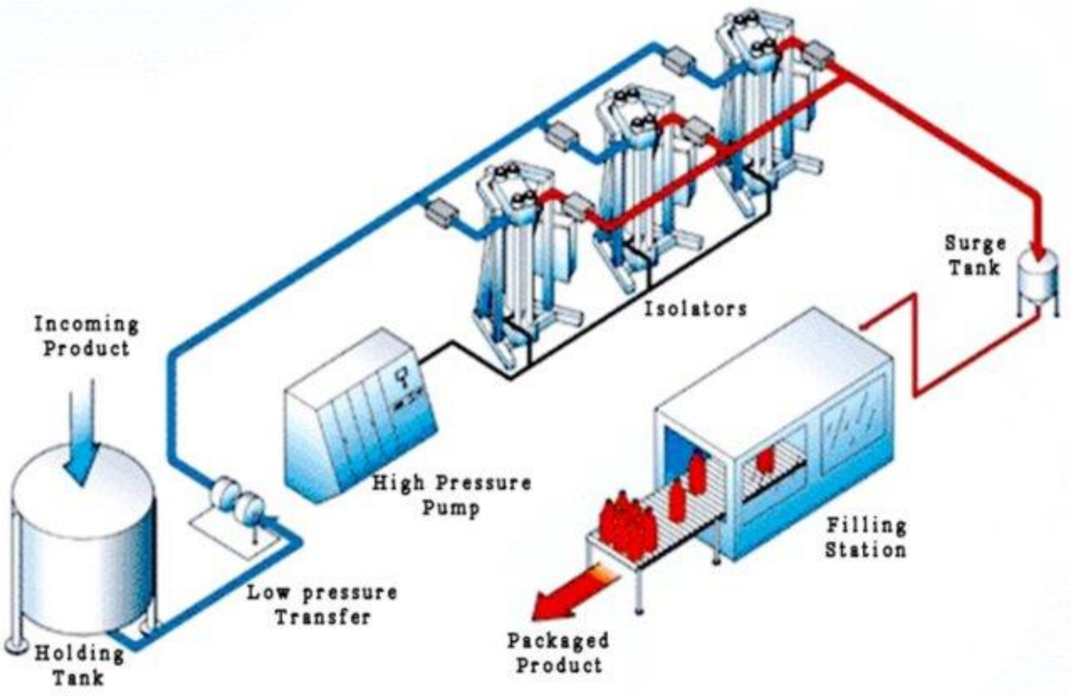
Schematics of high-pressure food processing techniques direct (left) and indirect (right) compression.



Continuous high-pressure processing system

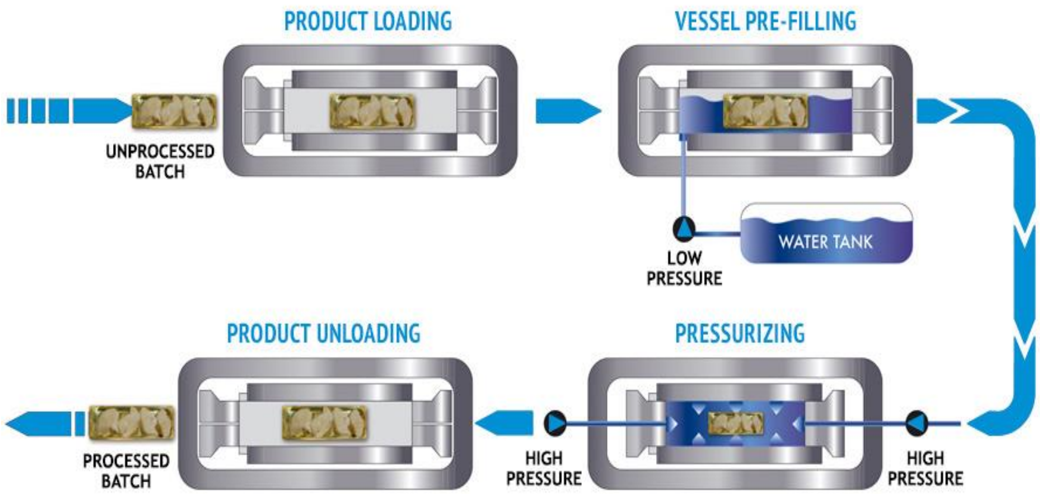
Wael M. Elamin

HPP: Prozess



Semi-continuous high-pressure processing system

Wael M. Elamin



http://www.hiperbaric.com/media/uploads/contenido/ficha/high-pressure.jpg

HPP: Color

Anthocyanins, chlorophylls and carotenoids

•polyphenoloxidase (PPO) which is responsible for enzymatic browning
•lipoxygenase (LOX) which induces changes in flavour, colour and nutritional value
•peroxidase (POD) which gives rise to unfavorable flavours.

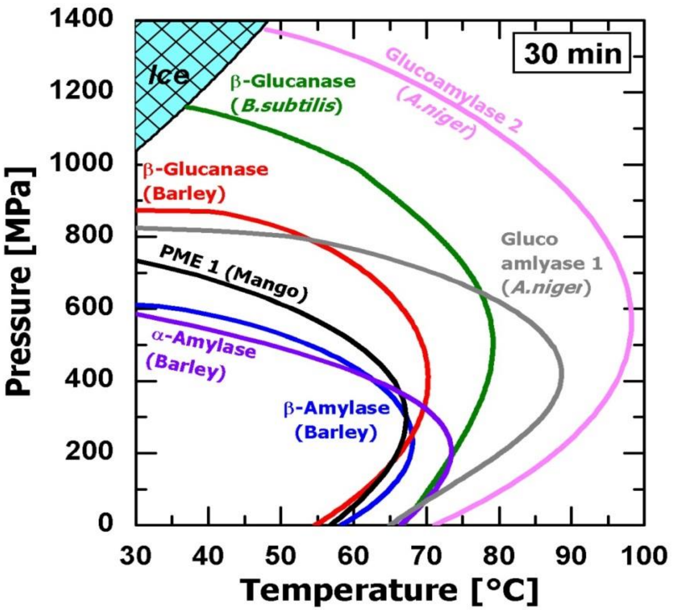
Polyphenoloxidase (PPO) and peroxidase (POD) catalyze the oxidative degradation of polyphenols into brownish degradation products.

β-glucosidase catalyzes the conversion of anthocyanins into their aglycones making them liable to PPO and POD catalyzed degradation.

Lipoxygenase (LOX) can cause the degradation of carotenoids through a co-oxidation mechanism ► decrease in color intensity.

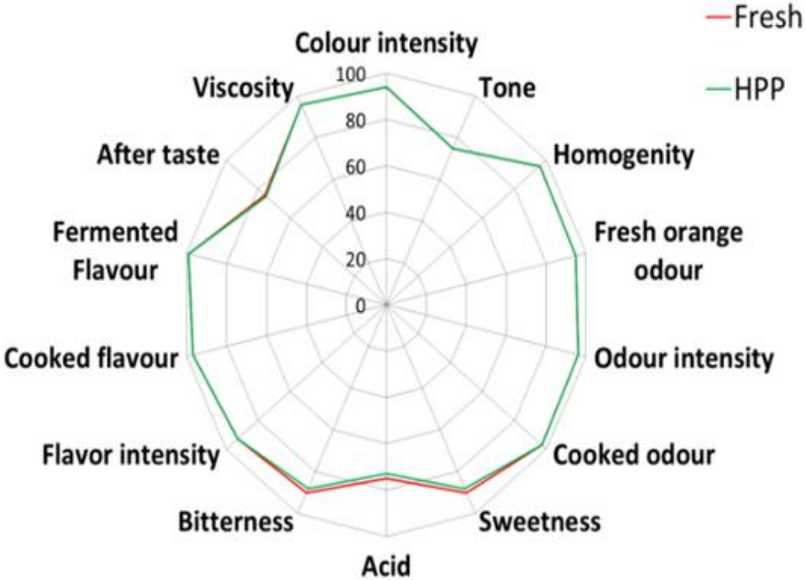
20 enzymes including chlorophylase are involved in the degradation of chlorophyll ►change in color from brilliant green to olive brown. POD and LOX have been reported to catalyze the co-oxidative degradation of chlorophyll.

Enzyme inactivation (95%) under pressure

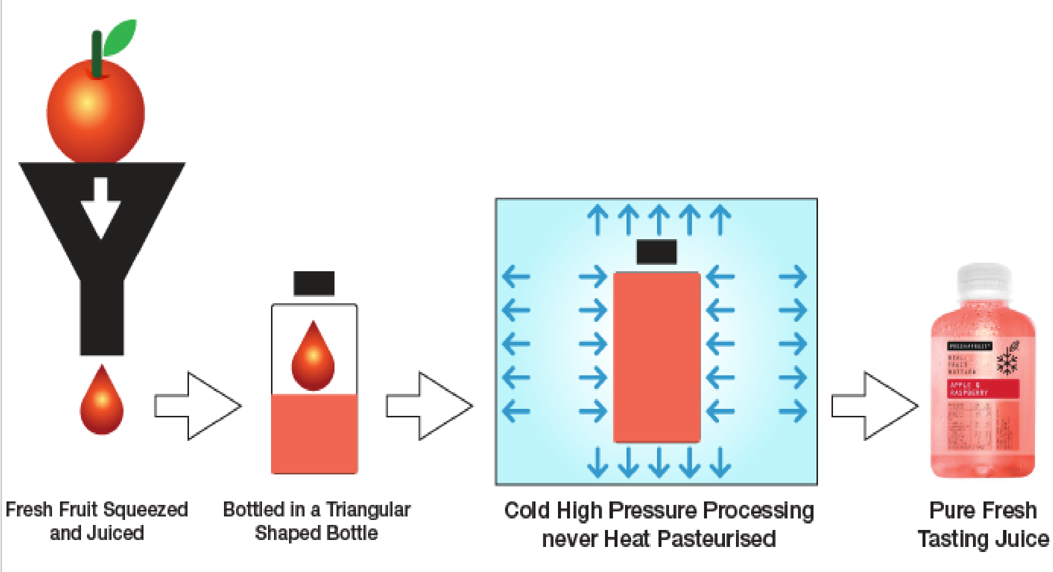


Buckow R

HPP: Color and taste



Difference between HPP and non- HPP-Juice



http://sskleena.blogspot.com/2016/12/high-pressure-processing-food-final.html

HPP: Color and taste

https://sokihpp.pl/en/

https://www.nutritioninsight.com/news/ganedenbc30-adopted-in-first-probiotic-launched-in-hpp-juice.html

by Juice Warrior November 10, 2015

HPP: Color and taste

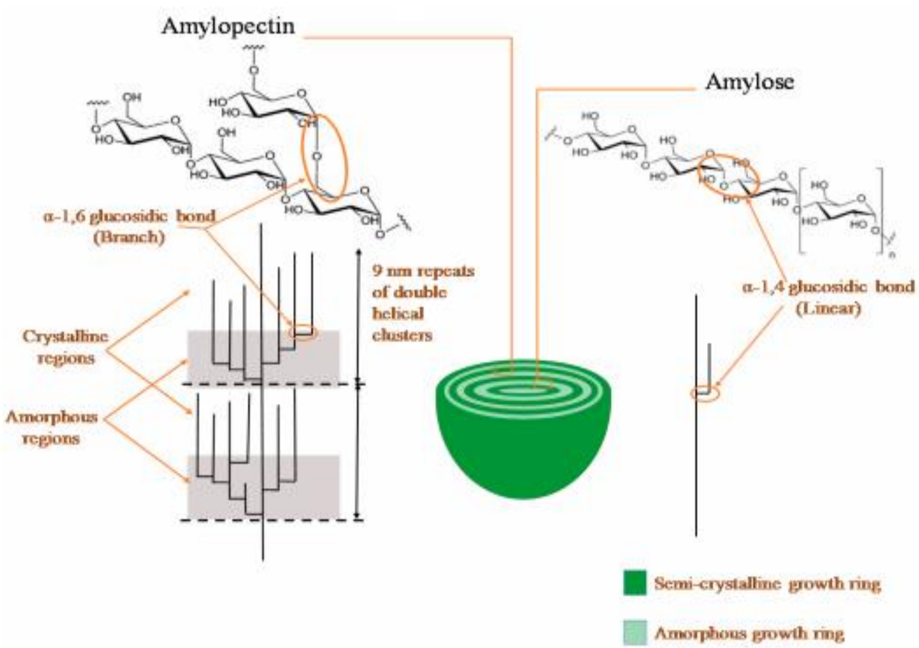
Summary of Relevant Studies on the Effect of HPP on Endogenous Enzymes in Apples and Pears

Product	Enzyme	Conditions Investigated	Results
Cloudy apple juice (pH 3.8) from cv. Boskop	PPO	0.1–700 MPa, 20–80°C, kinetic	65% activity increase at 400 MPa, 20°C, 5 min. Antagonistic effect at P[a] < 300 MPa and T[b] ≥ 60°C for pressure–temperature inactivation after initial PPO activation.
Cloudy apple juice (pH 3.5) from cv Amasaya	PPO	250–450 MPa, 25–50°C, 0–60 min	~50% activity increase at 450 MPa, 25°C, 15 min; 90% inactivation at 450 MPa, 50°C, 60 min.
Royal Gala apple puree	PPO	600 MPa, 34°C, 0–60 min	90% activity increase after HPP for 5 min. Approximately 10% activity reduction after HPP for 60 min.
Golden Delicious apple juice	PPO	430–570 MPa, 1–8 min	50% activity increase after HPP for 1 min irrespective of applied pressure.
Taylor's Gold pear puree	PPO	600 MPa, 34°C, 0–60 min	30% activity increase after HPP for 5 min.
Packham pears	PPO	600 MPa, 20–100°C, 5 min	78% and 90% inactivation at 20°C and 80°C, respectively. HPP at 40°C and 60°C resulted in significant higher residual enzyme activity.
Packham pears	POD	600 MPa, 20–100°C, 5 min	26% and 92% inactivation of this enzyme at 20°C and 100°C, respectively.
Apple pieces	POD	600–1000 MPa, 20°C, 15 and 30 min	Twofold increase in activity at 600 MPa, ~40% inactivation at 1000 MPa, no effect of treatment time.
Cloudy apple (Golden delicious) juice	PME	200–600 MPa, 15–65°C, 0.5–10.5 min	Activity increase up to 40°C at all conditions, some inactivation at higher temperatures.
Packham pears	PME	600 MPa, 20–100°C, 5 min	49% and 78% inactivation at 20°C and 60°C, respectively.

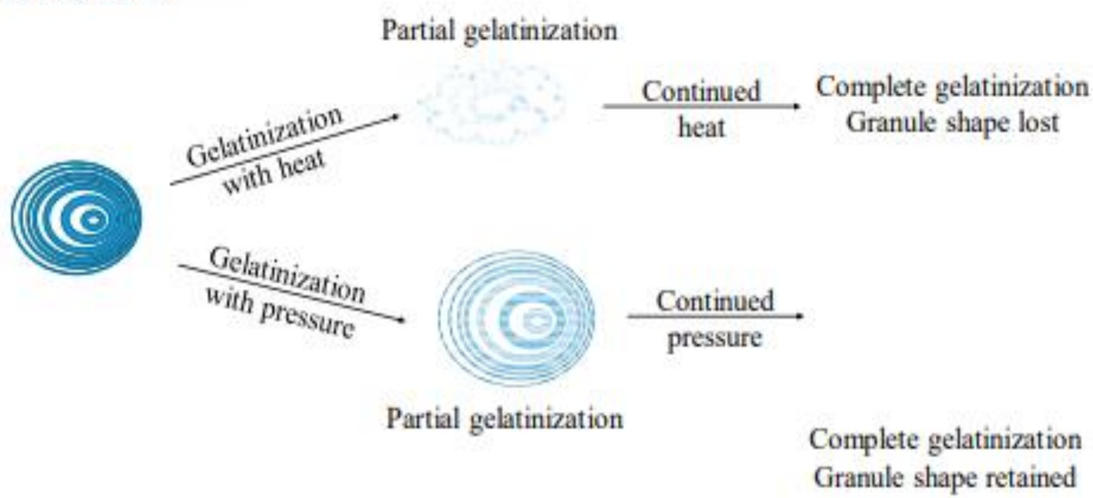
Netsanet Shiferaw Terefe and Roman Buckow

HPP: Starch

Starch is a polymeric carbohydrate that consists of two types of molecules, amylose and amylopectin.



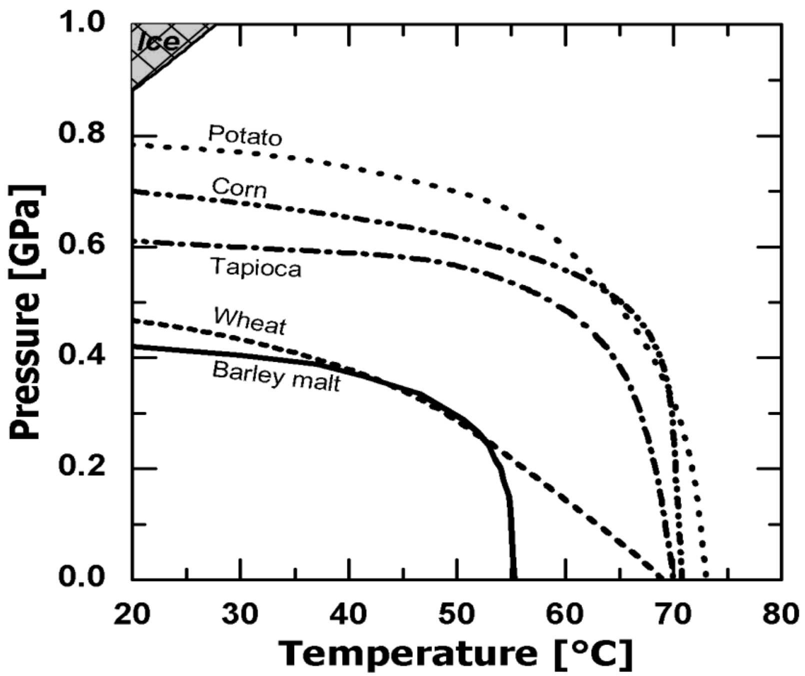
The gelatinization caused by heat results in disruption (structure loss) of the granules, whereas the pressure treated ones undergo distortion (structure change).



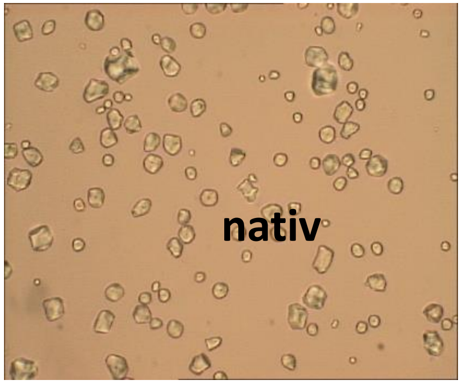
Balakrishna, 2020

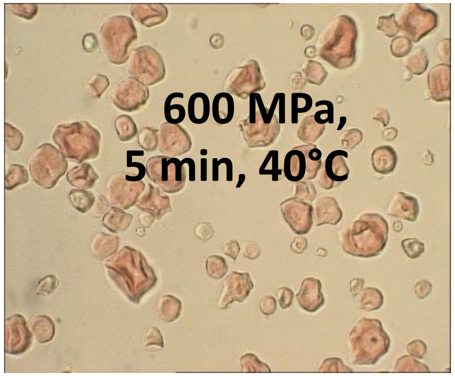
HPP: Starch gelatinisation

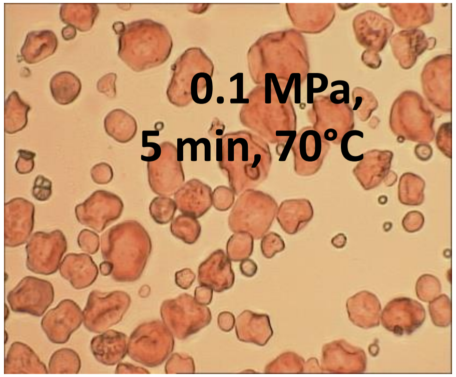
Starch gelatinization under pressure



The lines indicate a 100% loss in birefringence of different starch suspensions (5% w/w) after 15 min:´barley malt (—), wheat (--), tapioca (-·-), corn (-··) and potato (·····).







Buckow R

HPP: Starch gelatinisation

Table 1. Important highlights of the studies on different HPP treated starches.

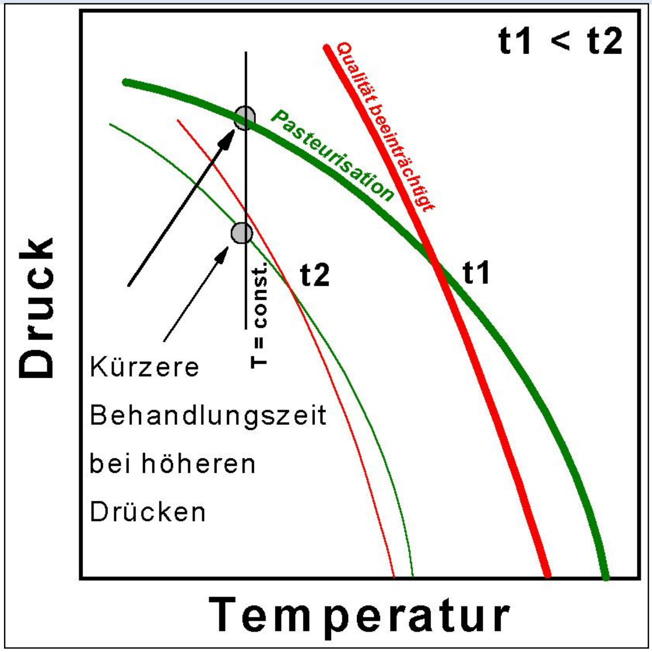
Type of Starch	Pressure	Temperature	Time	Property Assessed	Outcome
Tapioca	600 MPa	30–80 °C	10–30 min	• Hardness • Post storage changes in hardness • Comparison with thermally treated starch	• Harder gels at low temperatures. • Long treatment led to a slight decrease in hardness • Higher starch-starch and starch water interactions • Better storage efficiency
Wheat	600 MPa	25 °C	15 min	• Hardness • Retrogradation rate • Comparison with thermally treated starch	• Greater hardness in gels • Lower rate of retrogradation
Wheat	300–600 MPa	25 °C	10 min	• Hardness • Gumminess • Chewiness • Comparison with thermally treated starch	• Hardness, gumminess and chewiness were high only till gelatinization <40%
Potato	400 MPa (3 cycles) followed by 600 MPa (6 cycles)	21 °C	Each cycle 10 min	• Cyclic pressure treatments • Post retrogradation analysis	• Eruptions, abrasions and disruptions of starch granules • Highly compact gel • Post retrogradation, gel was more compact and dense
Maize	300 MPa	20 °C	5–60 min	Moisture adsorption-desorption analysis	• Upward shift of the MSI • Ability to higher moisture at the same water activity
Waxy rice	100–600 MPa	25 °C	20 min	• Lamellar repeat distance in starch granules • Crystallinity	With increase in pressure • Lamellar repeat distance increased • Crystallinity decreased
Chestnut	400–600 MPa	35–38 °C	10 min	• Degree of gelatinization • Granule particle size or hydration properties	• Pressure resistant • No change in granule particle size or hydration properties
Sorghum	120–600 MPa	Room temperature	20 min	• Gelatinization • Water absorption capacity and thermal stability • Oil absorption capacity, swelling power and viscosity	• B type crystalline pattern at 600 MPa • Increase in water absorption capacity and thermal stability • Decrease in oil absorption capacity, swelling power and viscosity
Mango kernel	300–600 MPa	38 °C	10 min	• Retrogradation • Structural analysis of the starch granules	• Lower aggregation and retrogradation tendencies • Insignificant structural changes in the starch granules, however significant changes in the smoothness of the granule surfaces

Balakrishna, 2020

HPP: Decontamination

Mode: **breakdown of non-covalent bonds and permeabilisation of the cell membrane**

HPP MO-inactivation involves:
Cell envelope-related effects.
Pressure-induced cellular changes.
Biochemical aspects – protein.
Effects on genetic mechanisms.
Cellular morphology.
Slowing cell division.



HPP of 100-300 MPa can induce spore germination ► higher sensitivity to environmental conditions.

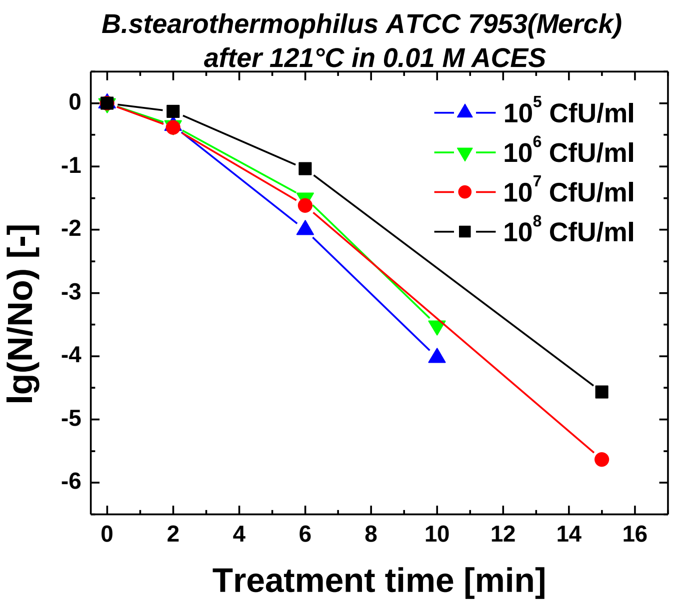
Vegetative MO cells are inactivated at 300 MPa at ambient temperature, while spore inactivation requires much higher pressures (600 MPa or more) +Temp. 60–70°C.

Certain enzymes are inactivated at 300 MPa, while others are very difficult to inactivate. Moisture level is extremely important, little effect being noticeable below 40% moisture content.

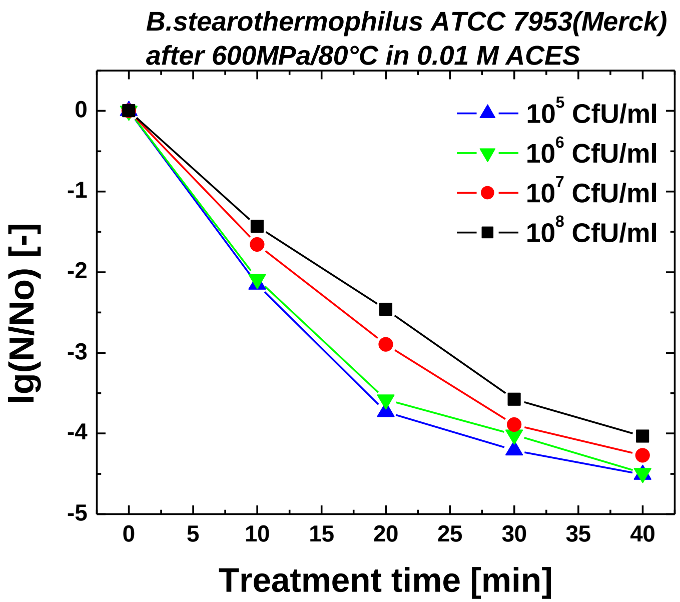
Pulsed or oscillating pressurisation is more effective in spore inactivation than continuous pressure.

HPP: Sterilisation

Thermal treatment (Capillary, 121°C)



Pressure treatment (600 MPa,80°C)



Similarities:

Dependence of the initial spore concentration to the inactivation

→Higher concentration = Higher resistance

Differences:

Different inactivation mechanisms → "Shoulder" and "Tailing"

Töpfl S.

HPP: Extraction

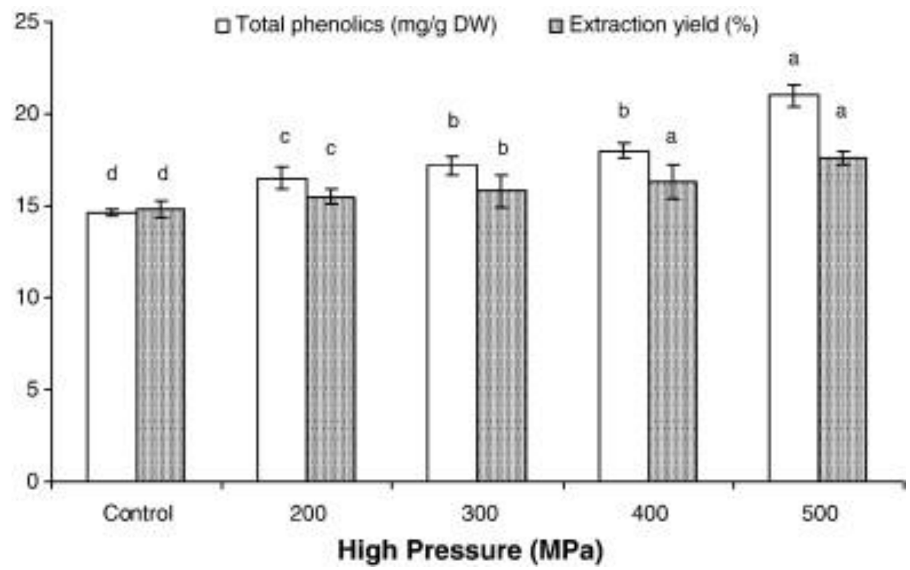
https://www.superfoods-online.org/longan-frucht/

Table 1. A comparison of scavenging activities of superoxide anion radical and DPPH radical of HPE and CE extracts from longan fruit pericarp

	Superoxide scavenging activity (%)		DPPH scavenging activity (%)	
	50 μg/mL	100 μg/mL	50 μg/mL	100 μg/mL
CE extract	48.6 ± 2.9a	56.6 ± 2.3b	50.1 ± 0.2c	76.6 ± 0.5b
HPE extract	50.4 ± 0.9a	61.6 ± 1.1a	75 ± 0.2 b	77.7 ± 0.2a
Ascorbic acid*	30.7 ± 2.7b	42 ± 2c	80 ± 2 a	80.4 ± 0.6a
BHT*	20 ± 3.5c	23 ± 1.7d	77.4 ± 2 a	80 ± 1a

Conventional extraction (CE): 50% ethanol, 1:50 (w/v) solid/liquid ratio and 12 h of extraction time at 30 °C and high pressure extraction (HPE): 50% ethanol, 1:50 (w/v) solid/liquid ratio, 500 MPa pressure and 2.5 min of extraction time at 30 °C. For each treatment means within a column followed by different letters were significantly different at the 5% level.

Effects of high pressure extraction on the extraction yield and total phenolic content of longan fruit pericarp



Prasad NK et al, 2009

HPP: Advantages and Limitations

Advantages:

 - **Decontamination:** Elimination the requirement of heat, while killing harmful microbes. It makes possible to treat heat sensitive products.
- **Extension of shelf-life** of the product from 3 to 10 times.
- **Sensory Quality:** The products remains with fresh like characteristics of sensory and nutrition. HPP doesn’t affect flavour, vitamins and pigments of the product in contrast to thermal processing and thereby retains freshness. It doesn’t produce any off-flavour as in case of heat treatments. Products retain the original shape as it is subjected to uniform pressure at every point.
- **Novelty:** HPP can create novel texture of protein or starch based foods through forming protein gels or increasing viscosity without application of heat.
- **Safety:** Cross contamination with untreated product is not possible because treatment is performed in batch wise operation.
- **Environmental friendly:** water is used as the most common fluid.

Limitations:

- HPP is insufficient to control enzymes resistant to pressure.
- Spores are not sure to be inactivated with the treatment itself.

Economics: The technology installation needs initial investment. Operating cost is greater than the same for corresponding thermal processing. Costs will decrease with increase in the rate of production.

HPP

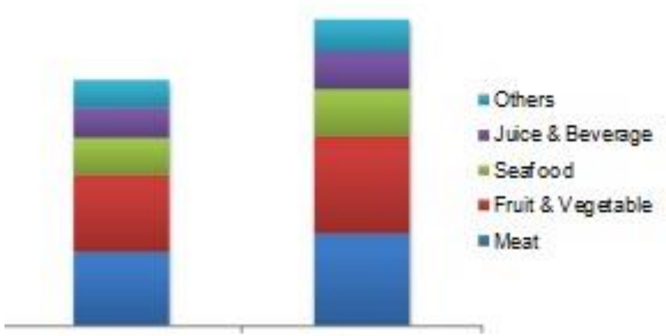
HPP of bioactive compositions (Fonterra, NZ)

Fonterra has developed a way to make colostrum health drinks by using pressure equal to five times that generated by the deepest oceans to preserve the beverages.

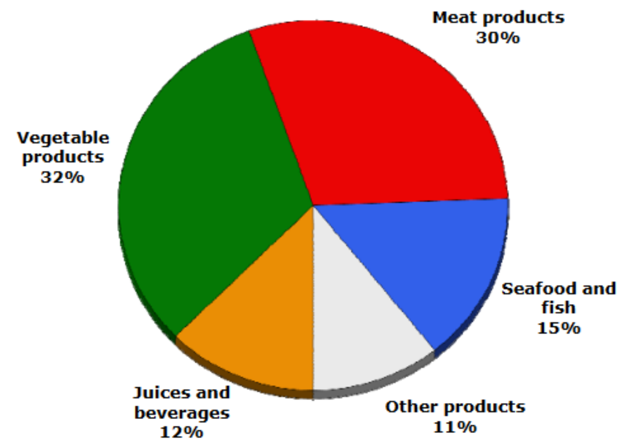
www.nzherald.co.nz www.fonterra.com

HPP

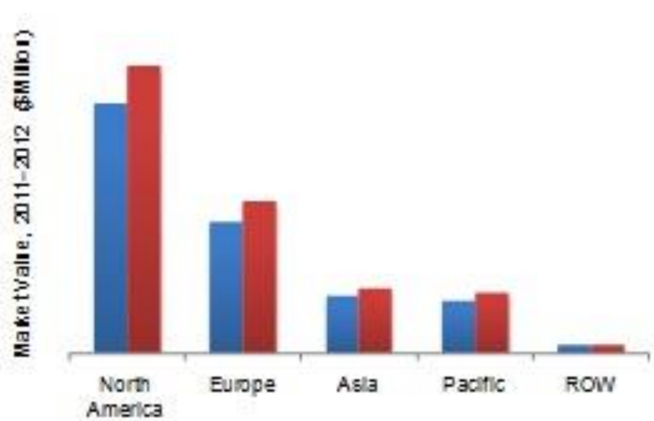
HPP Equipment: Market Value, By Applications, 2011-2020

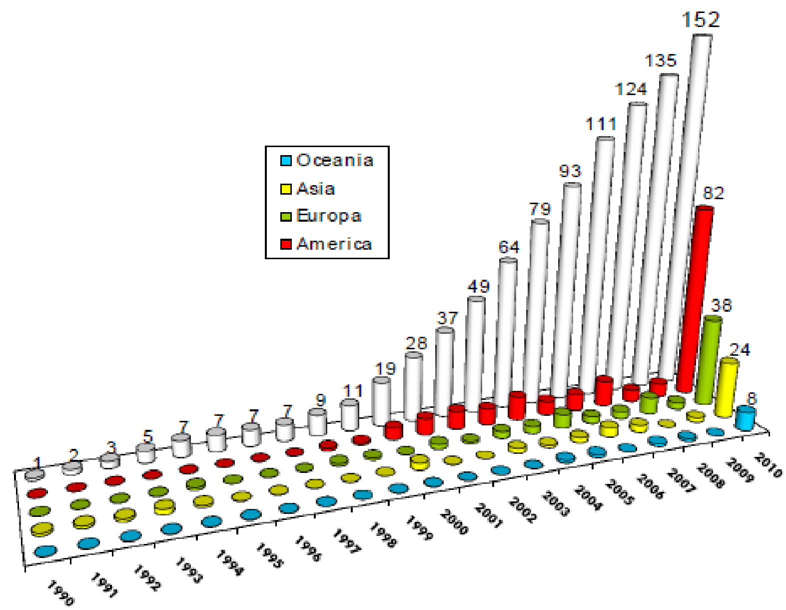


Distribution of HPP equipment in food industry



HPP Products: Market Value, By Region, 2011-2016 ($Million)





http://www.marketsandmarkets.com/Market-Reports/hpp-market-1274.html

Evolution of high pressure processing units installed on continents

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