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High Pressure Processing and Food Safety

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High pressure processing

- Non-thermal processing
- First commercialised in Japan in the early 1990s for pasteurisation of acid foods for chilled storage
- High pressure treated foodstuffs have been marketed in Japan since 1990 and in Europe and the United States since 1996
- Slow commercialisation
  - High investment and slightly higher processing costs
  - Low throughput

Commercial HPP products

- Food products that have been brought to market include raw oysters, fruit jellies and jams, fruit juices, pourable salad dressings, raw squid, rice cakes, foie gras, ham, chicken breast, beef steak, pork chops and guacamole.

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Commercial products

Crab meat

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Commercial products

Guacamole & Salsas, Avomex (Keller, TX)

Jams & Fruit Toppings - Meidi-ya (Japan)

http://grad.fst.ohio-state.edu/hpp/CommercialProducts.html

Suggested pressure range for fruits

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Food Item	Processing Pressure	
	MPa	Psi
Fruit		
Fruit juices		
Orange juice	100-800	14,504-116,030
Apple juice	150-621	21,756-90,068
Peach juice	600	87,023
Jam/Jelly	100-400	14,504-58,015
Apple cubes	400	58,015
Strawberry coulisse	200-500	29,008-72,519
Banana puree	500-700	72,519-101,526

http://www.hpp.vt.edu/HPPParams.html

Suggested pressure range for vegetables

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Food Item	Processing Pressure	
	MPa	Psi
Vegetables		
Fresh raw vegetables		
Lettuce	200-400	29,008-58,015
Tomato	200-400	29,008-58,015
Asparagus	200-400	29,008-58,015
Onion	200-400	29,008-58,015
Cauliflower	200-400	29,008-58,015
Green peas	400-900	58,015-130,534
Crushed/Liquid extract of vegetables		
Carrot	600	87,023
Tomato	335-600	48,588-87,023
Broccoli	600	87,023
Salsa	545	79,046
Tofu	400	58,015
Olive and seed oils	700	101,526
Sprout seeds	250-400	36,259-58,015

http://www.hpp.vt.edu/HPPParams.html

Main components of high pressure system

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- A pressure vessel and its closure
- A pressure generation system
- A temperature control device
- A material handling system

Main components

- Pressure vessel
  - Made from high tensile strength steel alloy ‘monoblocs’ (forged from a single piece of material)
  - For higher pressures, prestressed multi-layer or wire-wound vessels are used
  - Vessels sealed by threaded steel closure, a closure having an interrupted thread (that can be removed more quickly) or by a sealed frame that is positioned over the vessel

Main components

- Pressure generation system
  - Indirect compression:
    - After removal of air, a pressure transmitting medium (either oil or water) is pumped from a reservoir using a pressure intensifier until desired pressure is reached
    - Requires static pressure seals
  - Direct compression:
    - Piston to compress the vessel
    - Requires dynamic pressure seals between piston and internal vessel – subject to wear
    - Not commercially used

Main components

- Temperature control
  - Pumping heating and cooling medium through a jacket - Slow control for large vessels
  - Large vessels may require internal heat exchanger

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Main components

- Material handling system
  - In-container processing – automatic equipments, similar to that used to load/unload batch retorts
  - Bulk processing – simple, requires pumps, pipes and valves

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Hyperbaric HPP machine

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HPP processing steps

1. Packaged food items are placed in the pressure vessel.
2. Vessel is sealed and filled with water.
3. A pump (with intensifier) forces more water into the vessel, creating hydrostatic pressure. Pressure is isostatically transmitted by the fluid medium. A small temperature increase (~ 3° C per 100 MPa applied) may occur in the product,depending on the product composition.

HPP processing steps

4. Vessel pressure is maintained for a predetermined period of time (usually between 30 seconds and 15 minutes), during which time pathogens and spoilage bacteria are inactivated.
5. When the cycle is complete, the vessel is quickly depressurized, and temperatures return to the starting temperature.
6. Vessel is opened and product is removed.

http://www.hpp.vt.edu/downloads/HPP_Basics.pdf

What can HPP do?

- Inactivate food borne pathogens
- Inactivate spoilage organisms
- Activate or inactivate enzymes
- Germinate or inactivate some bacterial spores
- Marinate meats
- Shuck oysters
- Extend shelf life
- Reduce the potential for food borne illness
- Pressure-shift freezing or thawing
- Promote ripening of cheeses
- Minimize oxidative browning

http://www.hpp.vt.edu/downloads/HPP_Basics.pdf

HPP - Advantages

- Attractive for consumers as it meets demand for freshness and minimal processing as it does not require chemical additives or high temperatures
- No consumer negativity that is commonly associated with other food processing technologies (*e.g.* irradiation and GM).

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

HPP - Advantages

- Extended shelf life enables wider product distribution and results in fewer product returns
- High pressure also uses less energy (hence greenhouse gases) than other technologies and has the highest processing efficiency for pumpable foods

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

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HPP - Advantages

- Processing can be done in final packaging thus avoiding post-processing contamination and tempering
- Required processing times are also reduced and there are no by-products
- Permits the inactivation of microorganisms and enzymes at low temperatures, while valuable low molecular constituents, such as vitamins, colours and flavourings, remain largely unaffected.

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

Advantages over heat processing

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- High pressure avoids destruction of heat labile vitamins and bioactive components
- Pressure effect is more uniform to a food components than heat effect
- Heat-denatured proteins result in the formation or destruction of covalent bonds that may produce off-flavours while HPP denaturation is due to the disruption of hydrophobic and ion-pair bonds and retains flavours

Advantages over heat processing

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- Enzymatic reactions can be more easily controlled as the effects of 14,000 to 57,000 psi pressure on enzymes are reversible
- Product ability to retain freshness without ice crystals under sub-zero conditions (for frozen products)
- Significantly higher flavour and taste freshness over heated products

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Vitamins

- Water soluble vitamins, such as vitamin C, the vitamins B1, B2, B6 and folic acid, appear to be not or only little affected by pressure treatment under realistic production conditions. Changes are noticed in model systems rather than in the food matrix which exerts a protective effect. This holds also for fat soluble vitamins, such as vitamin A, vitamin E and vitamin K as well as provitamin A. Chlorophyll is stable under pressure at low temperatures

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

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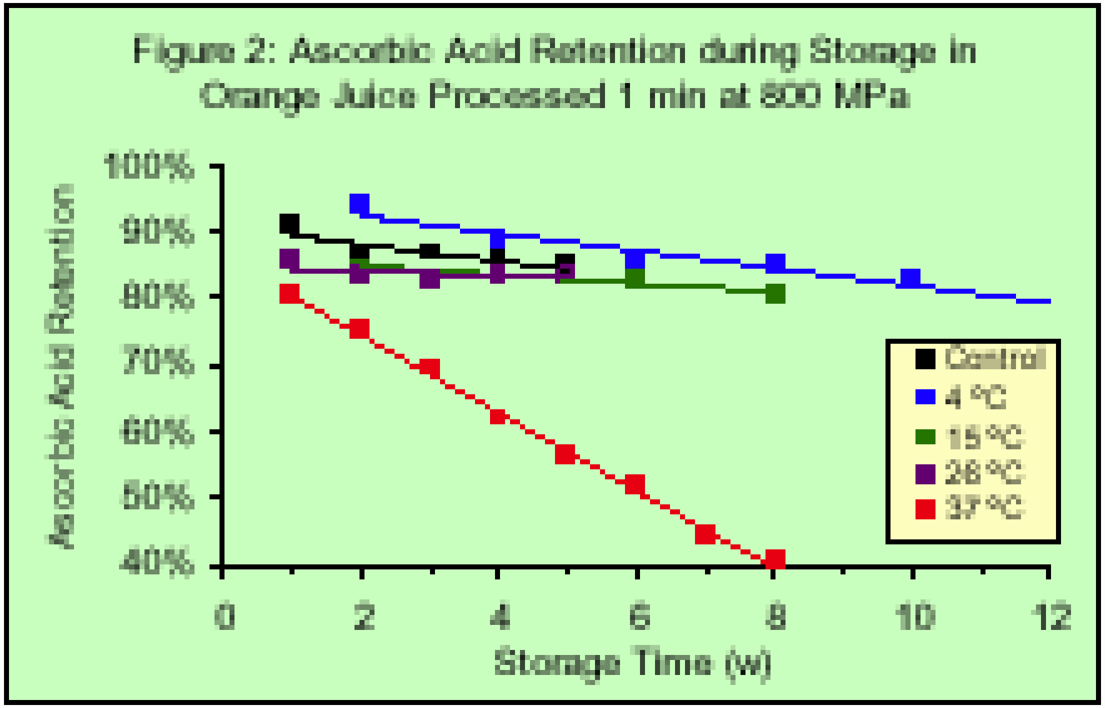
HPP juice – ascorbic acid



800MPa

More than 80% ascorbic acid was retained after 3 months storage at 4ºC or 2 months at 15ºC.

http://grad.fst.ohio-state.edu/hpp/83A-16.pdf

HPP effect on Vit A in orange juice

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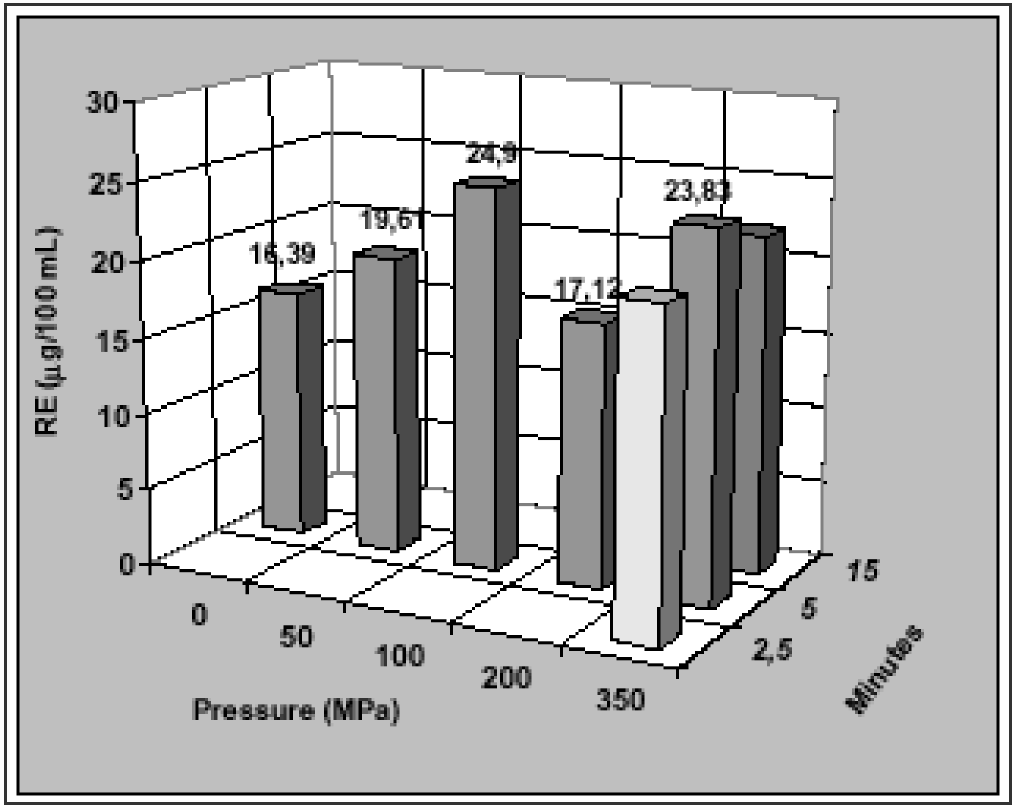

http://www1.unne.edu.ar/cyt/2001/8-Exactas/E-052.pdf

Orange juice - sensory

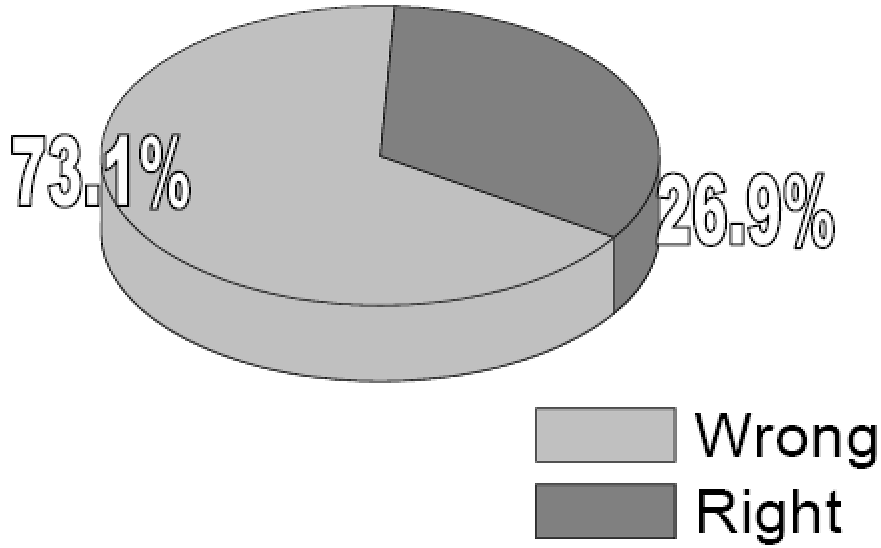

Fig.3.2.1.3 Triangle test on treated and untreated fresh squeezed orange juice stored at 4°C for 8days after pressure treatment at 600 MPa and 30 seconds. 79% of 29 panel testers preferred the treated juice.

Ardia, 2004

Antioxidant properties of fruits and vegetables

- Studies have shown that the antioxidative and antimutagenic potential of fruit and vegetable juices remains intact after high pressure treatment, although it is often lost through heat treatment

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

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Toxicology

- The toxicological studies needed depend on the nature of changes induced by the high pressure treatment, the expected magnitude of the consumption of these products, and the resulting exposure of the consumer to the ingredients concerned.
- High pressure treatment causes none or no significant changes in the chemical composition and/or the structure of the foodstuff ingredients, then the product may be judged to be substantially equivalent to the corresponding conventionally treated comparison product and therefore can be accepted without further investigations

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

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Toxicology

- From the investigations of high pressure treated foodstuffs so far carried out no evidence has appeared for an increased toxicological potential compared to unprocessed or thermally preserved foodstuffs.
- It must be ensured, that components of the packaging do not transfer into the foodstuff in concentrations relevant for health.

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

Allergenicity

- Many technological, particularly thermal, processes result in a partial inactivation of the allergenic potential. Studies of high pressure processes performed to date point in the same direction. Although the thermal treatment of foodstuffs causes drastic structural and chemical changes of food constituents, there is very little evidence for an increase in allergenicity from food processing

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

Allergenicity

- Another mechanism which might explain reduced allergenicity of a food after high pressure treatment has been described by Kato et al. It was shown, that the major allergens of rice are released from the grains after high pressure treatment at 500 Mpa in a liquid medium. Presently attempts are being made to use this observation for industrial production of hypoallergenic rice.

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

HPP and Microbial food safety

HPP & Food Safety – FDA comments

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- Experience with acid foods suggests that shelf-stable (commercially sterile) products, having a water activity close to 1.0, and pH values less than 4.0, can be preserved using a pressure of 580 MPa and a process hold time of 3 min. This treatment has been shown to inactivate 10^6 cfu/g of *E. coli* O157:H7, *Listeria* spp., *Salmonella* spp., or *Staphylococcus* spp. in salsa and apple juice

http://www.cfsan.fda.gov/~comm/ift4-5.html

HPP - Mechanism of Microbial action

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- Breakdown of non-covalent bonds
- Puncturing or permeabilisation of the cell membrane
  - Vegetative cells – 300 MPa (room temp)
  - Spore formers - >600 MPa (at 60-70° C)
  - Some enzymes – 300 Mpa
- Little effect below 40% food moisture

Aerobic bacteria & *E.coli* - Raw milk

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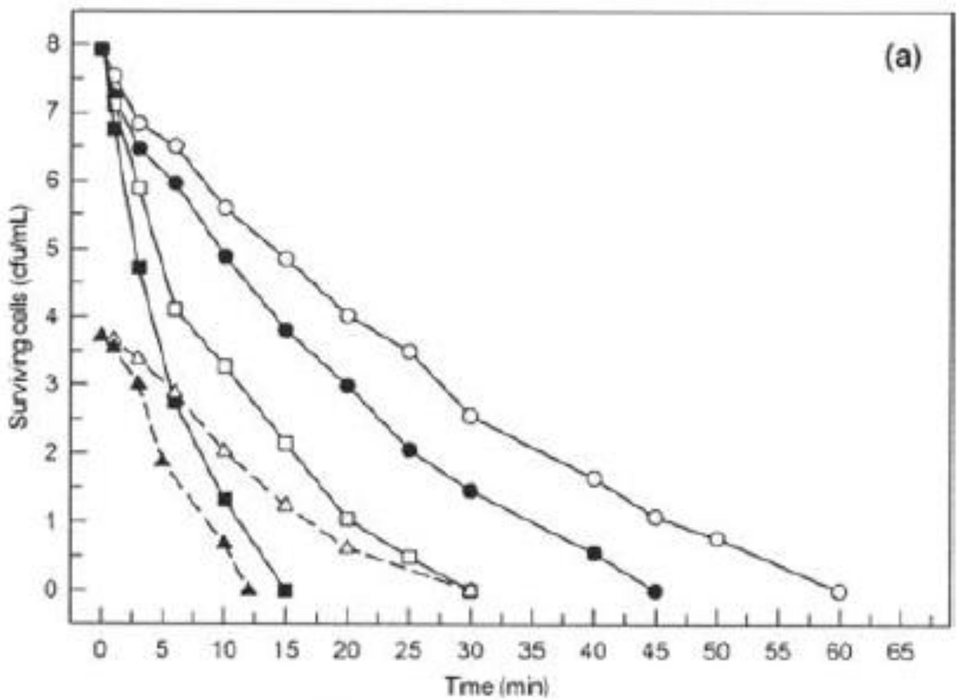
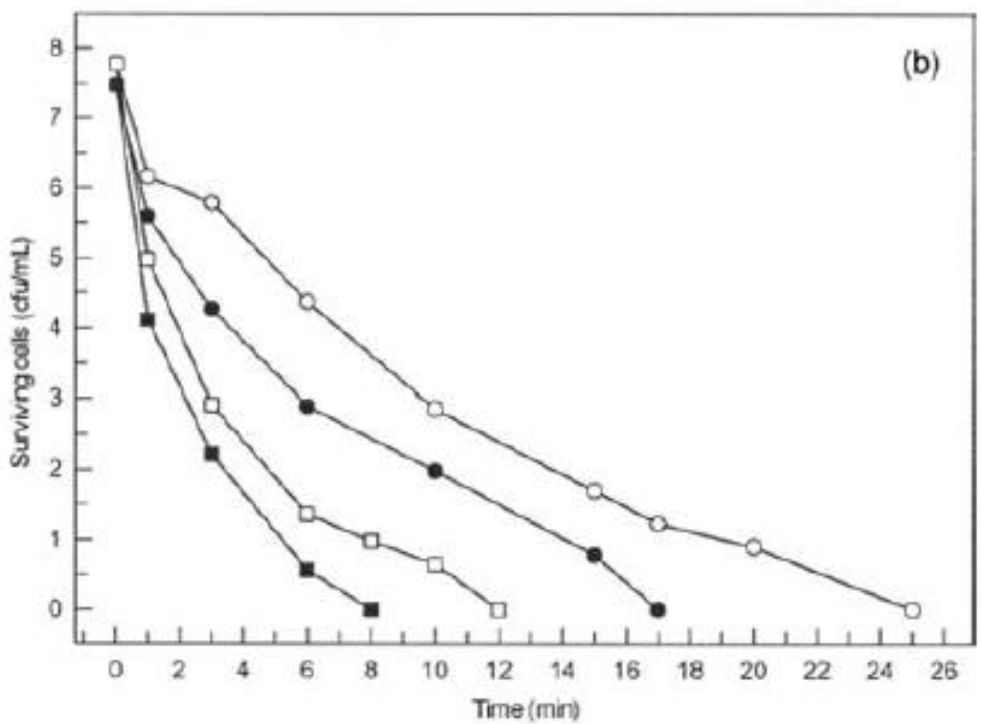


Raw milk

Figure 3. The effect of high hydrostatic pressure at 400 and 600 MPa on aerobic bacteria and *E. coli* at different times. (a) Raw milk; (b) fresh peach juice; (c) fresh orange juice; (○) 400 MPa (APC); (●) 400 MPa (*E. coli*); (□) 600 MPa (APC); (■) 600 MPa (*E. coli*); (△) 400 MPa (milk natural flora); (▲) 600 MPa (milk natural flora).

Dogan & Erkmen (2003)

Aerobic bacteria & *E.coli* - Peach juice



Peach juice

Figure 3. The effect of high hydrostatic pressure at 400 and 600 MPa on aerobic bacteria and *E. coli* at different times. (a) Raw milk; (b) fresh peach juice; (c) fresh orange juice; (○) 400 MPa (APC); (●) 400 MPa (*E. coli*); (□) 600 MPa (APC); (■) 600 MPa (*E. coli*); (△) 400 MPa (milk natural flora); (▲) 600 MPa (milk natural flora).

Dogan & Erkmen (2003)

Aerobic bacteria & *E.coli* - Orange juice

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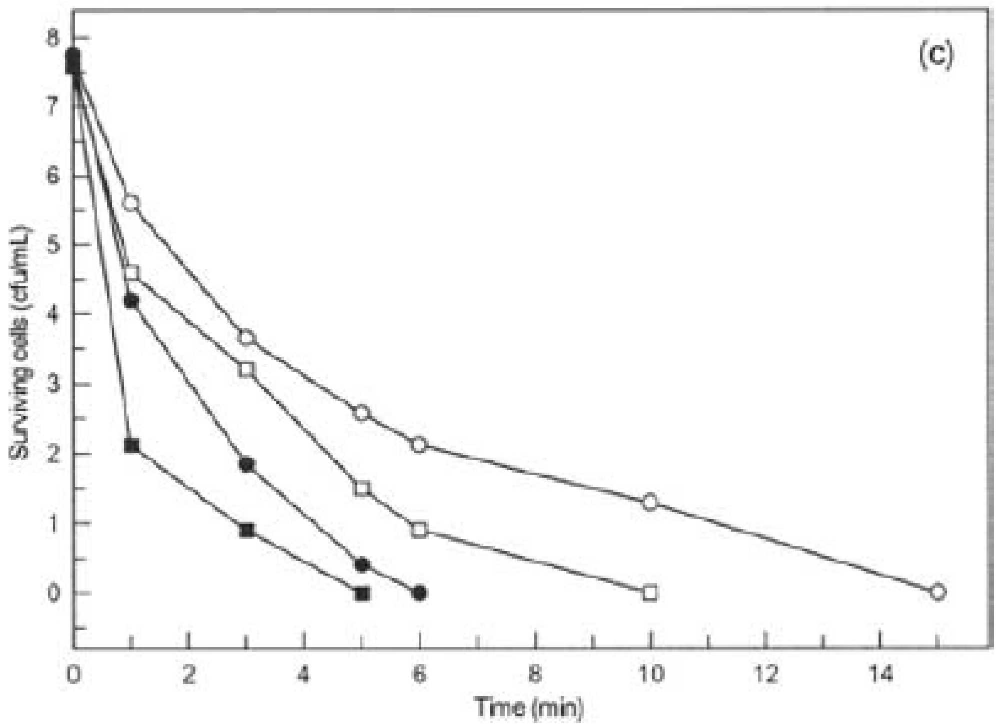

Orange juice

Figure 3. The effect of high hydrostatic pressure at 400 and 600 MPa on aerobic bacteria and *E. coli* at different times. (a) Raw milk; (b) fresh peach juice; (c) fresh orange juice; (○) 400 MPa (APC); (●) 400 MPa (*E. coli*); (□) 600 MPa (APC); (■) 600 MPa (*E. coli*); (△) 400 MPa (milk natural flora); (▲) 600 MPa (milk natural flora).

Dogan & Erkmen (2003)

Enterobacteriaceae – cooked ham, stored at 4C

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Time (days)	Enterobacteriaceae	
	NT	HPP
0	<1	<1
After HPP	NA	<1
30	1.66±1.22	<1
60	<1	<1
90	3.71±2.91	<1
120	3.08±3.68	<1

NT: nontreated; HPP: treated at 600 MPa; NA: nonapplicable.
Values are mean of triplicate ± standard deviation.
Data are expressed in log CFU g^{-1}.

Garriga et al 2004

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E. coli –in buffer

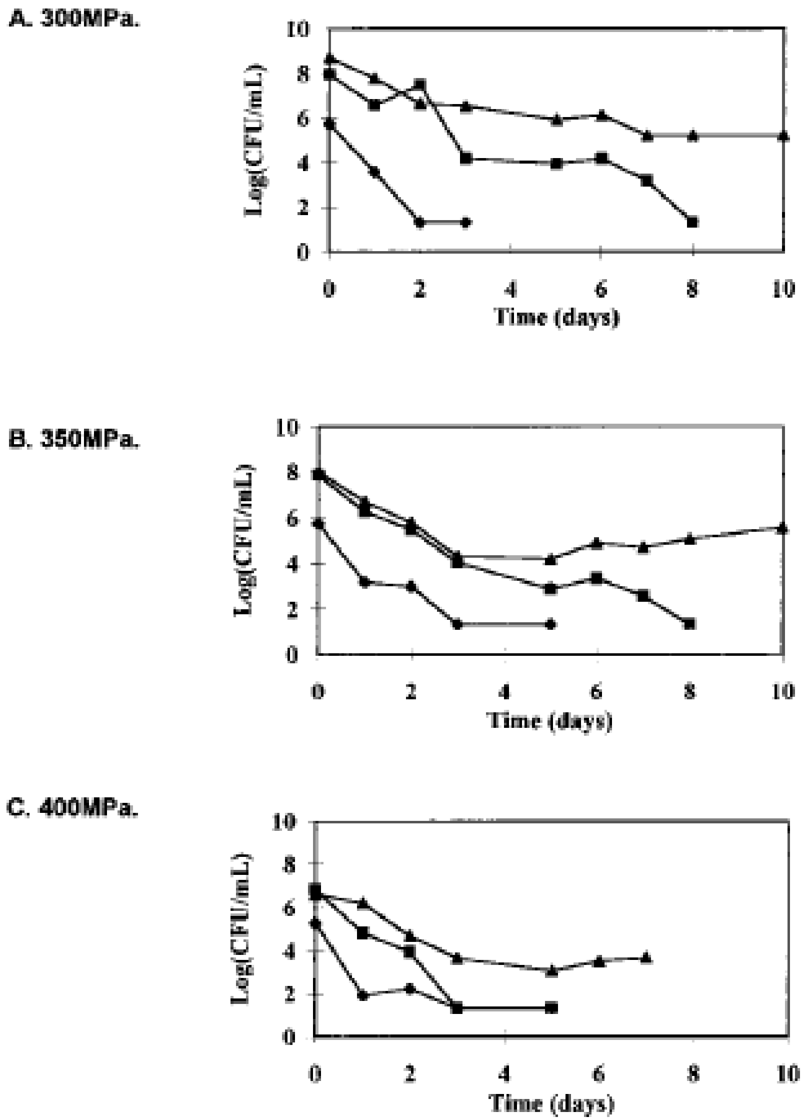

FIG. 3. Survival of *E. coli* LMM1010 in pH 3.0 (◆), pH 3.5 (■), or pH 4.0 (▲) HEPES buffer upon storage at 8°C for up to 10 days after pressure treatment for 15 min at 20°C and 300 MPa (A), 350 MPa (B), or 400 MPa (C). The initial number of cells in each case was between 0.35×10^9 and 1.8×10^9 CFU/ml, and the detection limit was 20 CFU/ml. Inactivation in non-pressure-treated controls was always <1 log after 10 days of incubation.

Garcia-Graells etal 1998

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E. coli - in culture broth

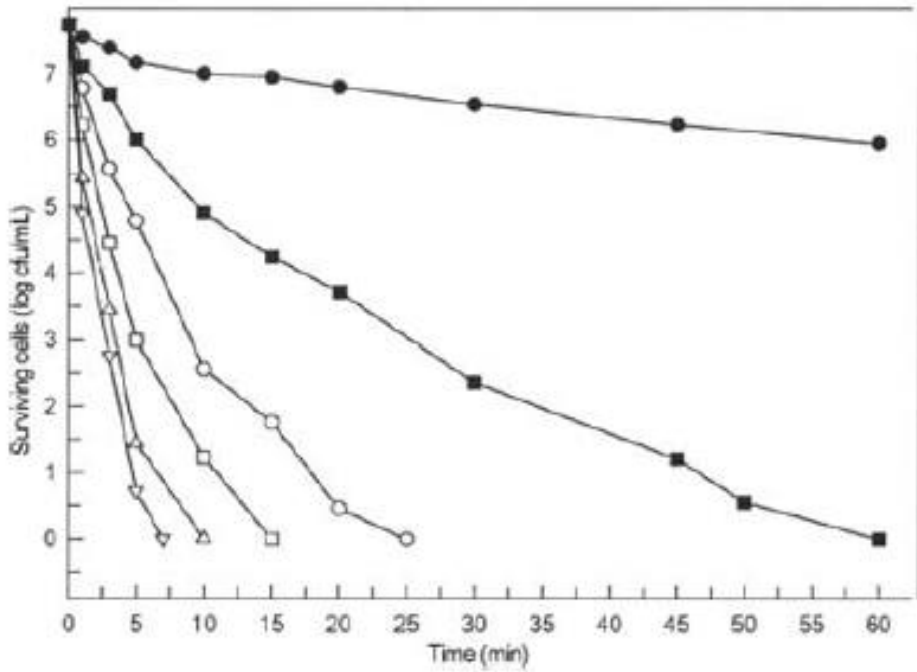

Figure 1. The effect of high hydrostatic pressure from 200 and 700 MPa on *E. coli* in BHIB vs. time.(●) 200 MPa, (■) 300 MPa, (○) 400 MPa, (□) 500 MPa, (△) 600 MPa, (▽) 700 MPa.

Dogan & Erkmen (2003)

E. Coli - in buffer, apple and orange juices

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TABLE 1. High-pressure inactivation of *E. coli* parental strain MG1655 and three pressure-resistant mutant derivatives in HEPES buffer and in apple and orange juices

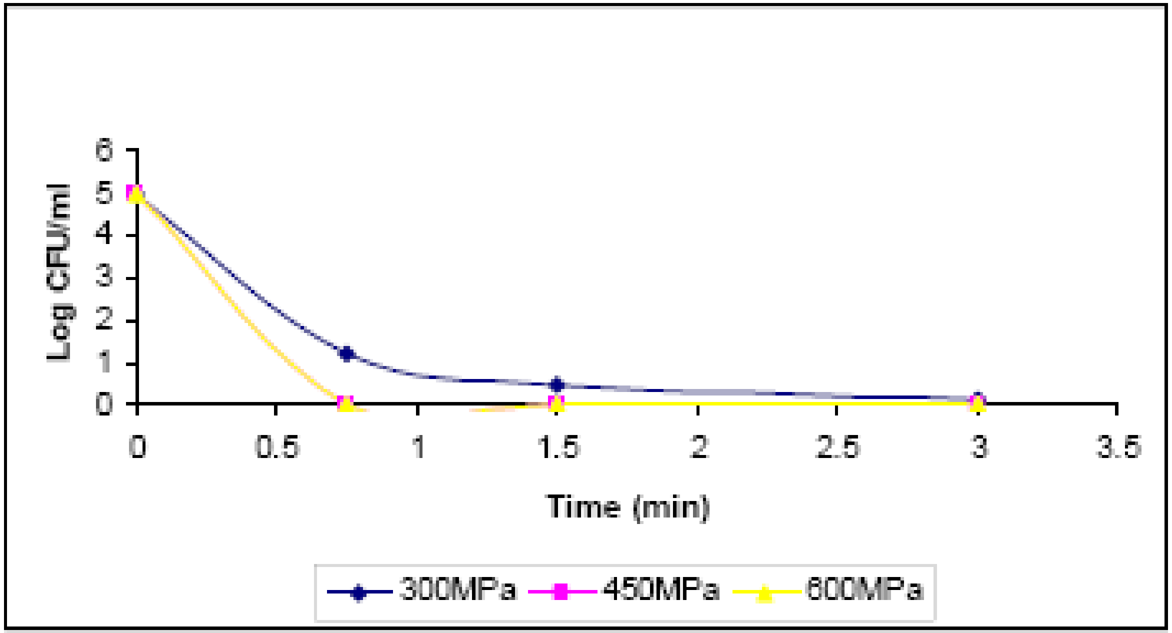
Pasteurization medium and pH	Inactivation of strain at pressure of[a]:							
	300 MPa				400 MPa			
	MG1655	LMM1010	LMM1020	LMM1030	MG1655	LMM1010	LMM1020	LMM1030
HEPES buffer								
pH 7.0	4.9	0.4	0.6	0.4	7.0	0.6	2.1	0.8
pH 4.0	ND[b]	0.5	ND	ND	ND	2.6	ND	ND
pH 3.5	ND	1.2	ND	ND	ND	2.3	ND	ND
pH 3.0	ND	2.9	ND	ND	ND	3.3	ND	ND
Apple juice, pH 3.3	>4.4	1.1	2.0	>3.4	>4.4	>4.7	>3.4	ND
Orange juice, pH 3.8	3.5	0.8	0.4	1.6	>4.4	1.5	2.4	>3.4

[a] Inactivation performed for 15 min at 20°C and is expressed as $\log(N_0/N)$, with N_0 and N being the counts for the untreated control and the pressure-treated sample, respectively.
[b] ND, not determined.

Garcia-Graells etal 1998

Yeast - Diced apple

Fig. 1 High pressure (300, 450 and 600 MPa) inactivation of *Saccharomyces cerevisiae* on diced apples



Chauvin 2004

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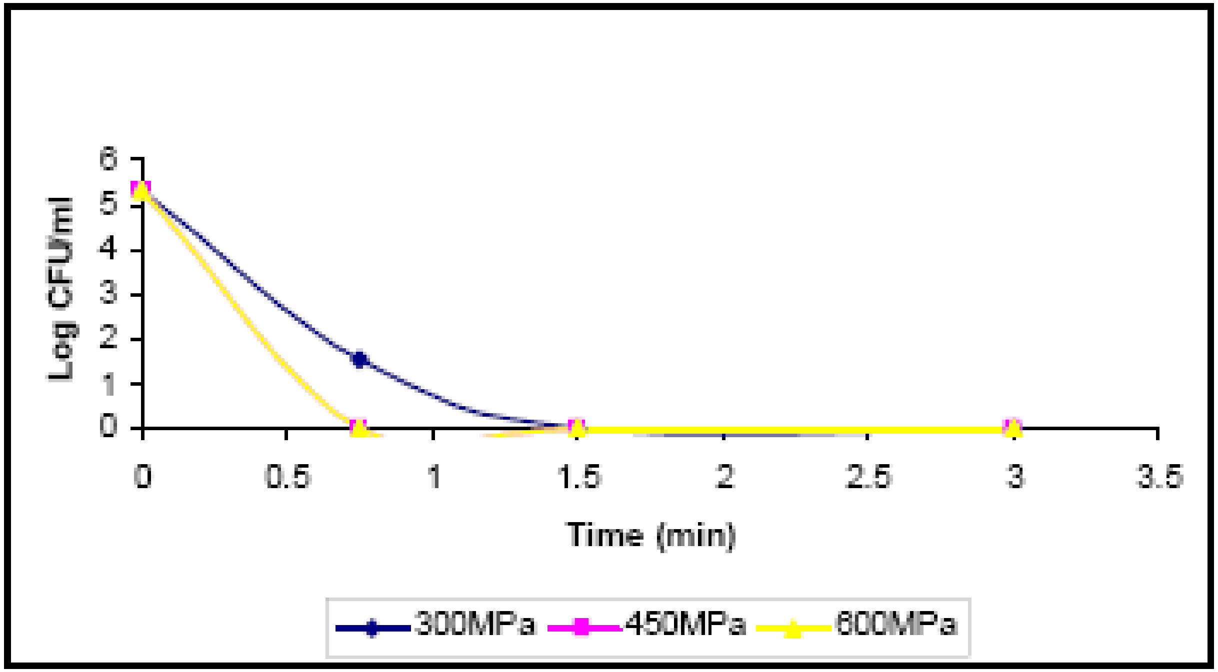
Yeasts - Grapes

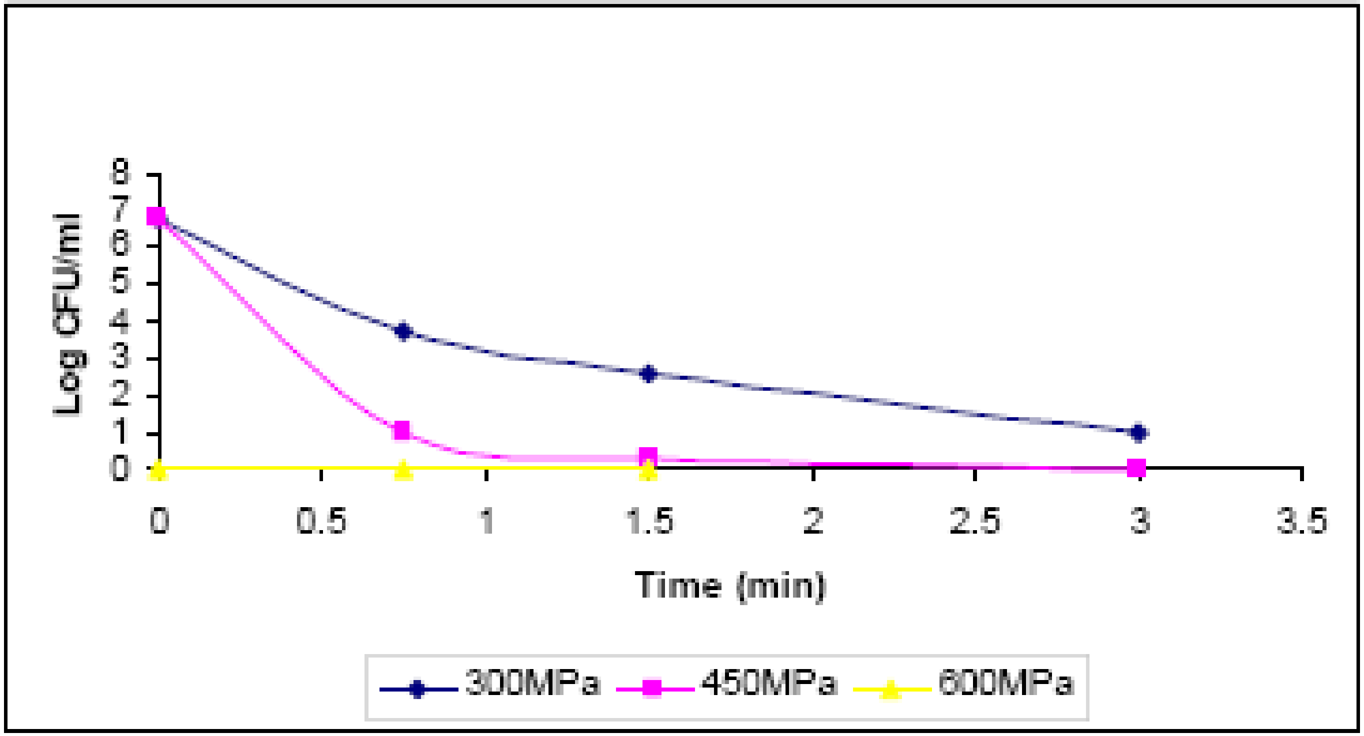
Fig. 2 High pressure (300, 450 and 600 MPa) inactivation of *Saccharomyces cerevisiae* on grapes



Chauvin 2004

Yeasts - Blueberries

Fig. 4 High pressure (300, 450 and 600 MPa) inactivation of *Saccharomyces cerevisiae* on blueberries



Chauvin 2004

Yeasts - Strawberries

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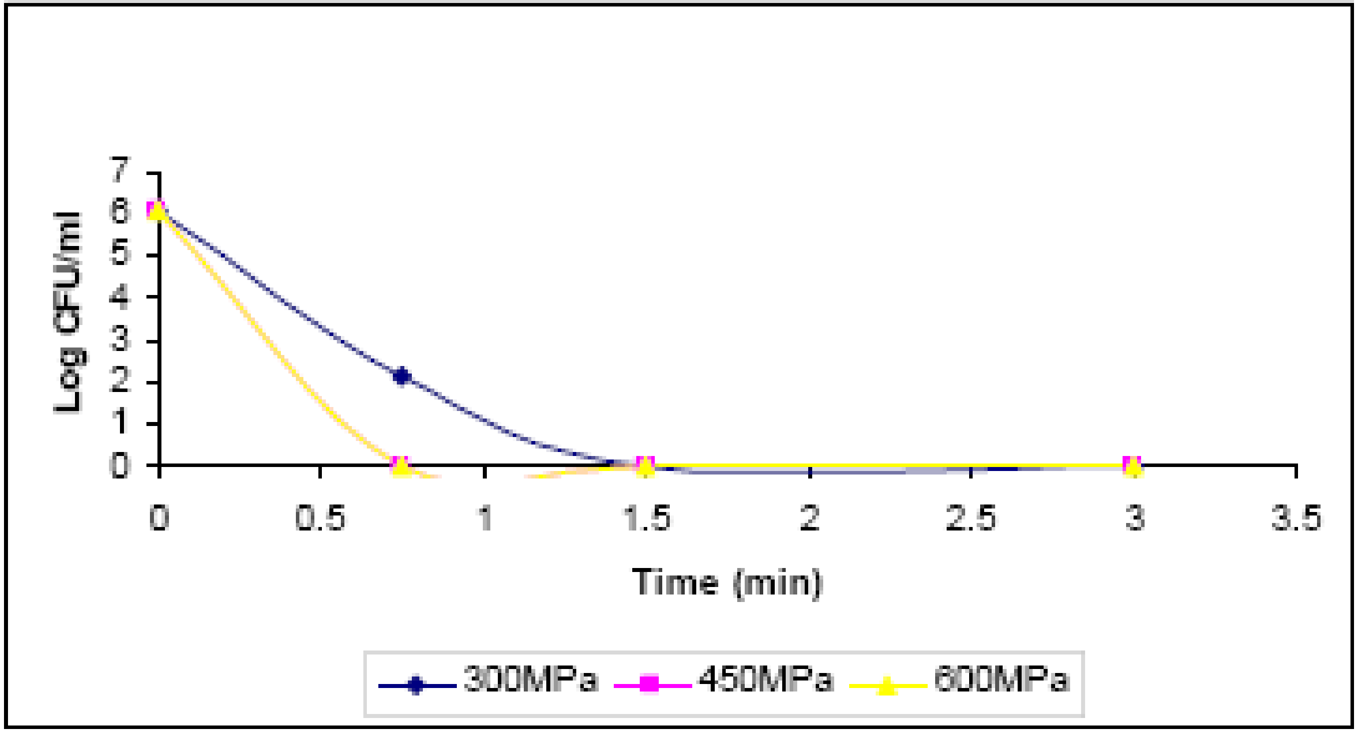
Fig. 3 High pressure (300, 450 and 600 MPa) inactivation of *Saccharomyces cerevisiae* on strawberries



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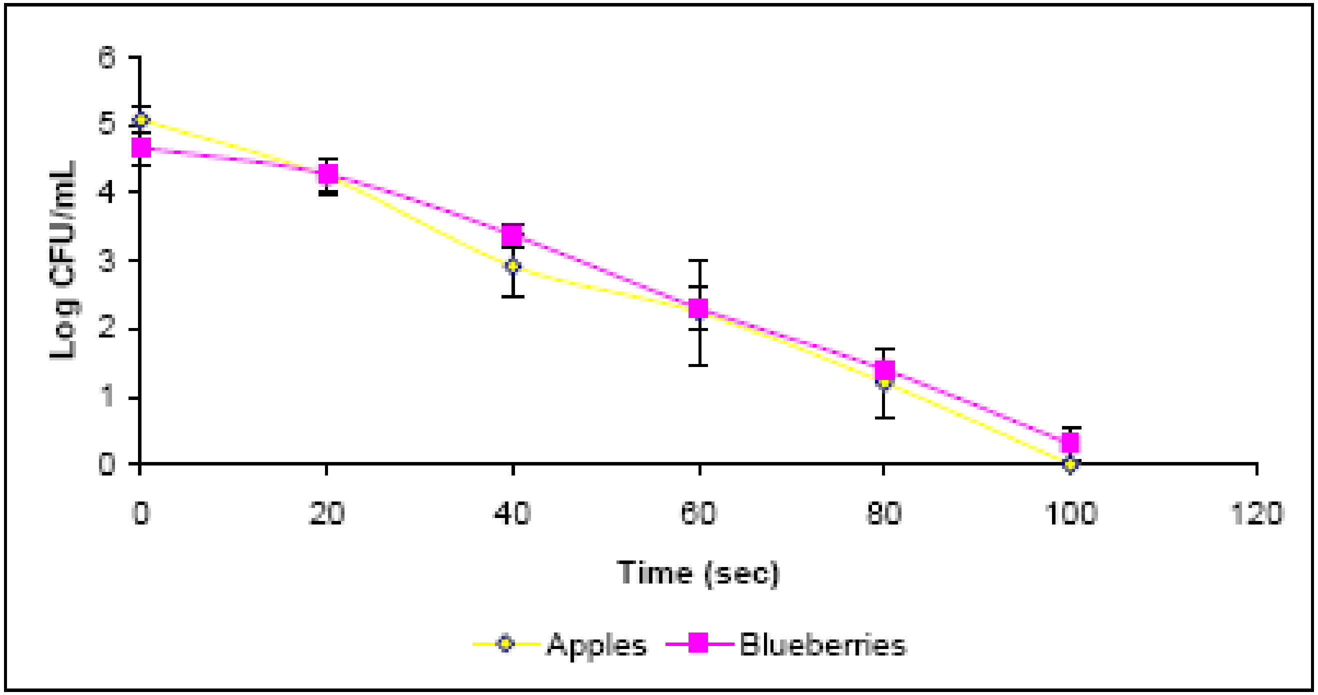
Yeasts - Diced apples and blueberries

Fig. 9 High pressure (300 MPa) inactivation of *Saccharomyces cerevisiae* on diced apples and blueberries



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Yeasts – cooked ham, stored at 4C

Time (days)	Yeasts	
	NT	HPP
0	<1	<1
After HPP	NA	<1
30	2.43±0.75	<1
60	3.00±1.74	<1
90	2.86±0.77	<1
120	3.27±1.21	<1

NT: nontreated; HPP: treated at 600 MPa; NA: nonapplicable.
Values are mean of triplicate ± standard deviation.
Data are expressed in log CFU g^{-1}.

Garriga et al 2004

Listeria, Aeromonas, Enterococcus - D-Value

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Table 1. D-values-time required for decimal reduction (minutes) of *Listeria monocytogenes, Aeromonas hydrophila* and *Enterococcus hirae* at given pressure

UHP (MPa)	*L. monocytogenes* (ham)	*L. monocytogenes* (apple juice)	*A. hydrophila* (cheese)	*E. hirae* (cheese)
100	31.80	11.54	32.05	–
200	28.30	6.37	12.97	–
300	5.80	2.60	2.43	33.67
400	2.40	1.56	–	17.83
500	–	–	–	16.03

Fonberg-Broczek, et al 2005

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Listeria – in pure culture

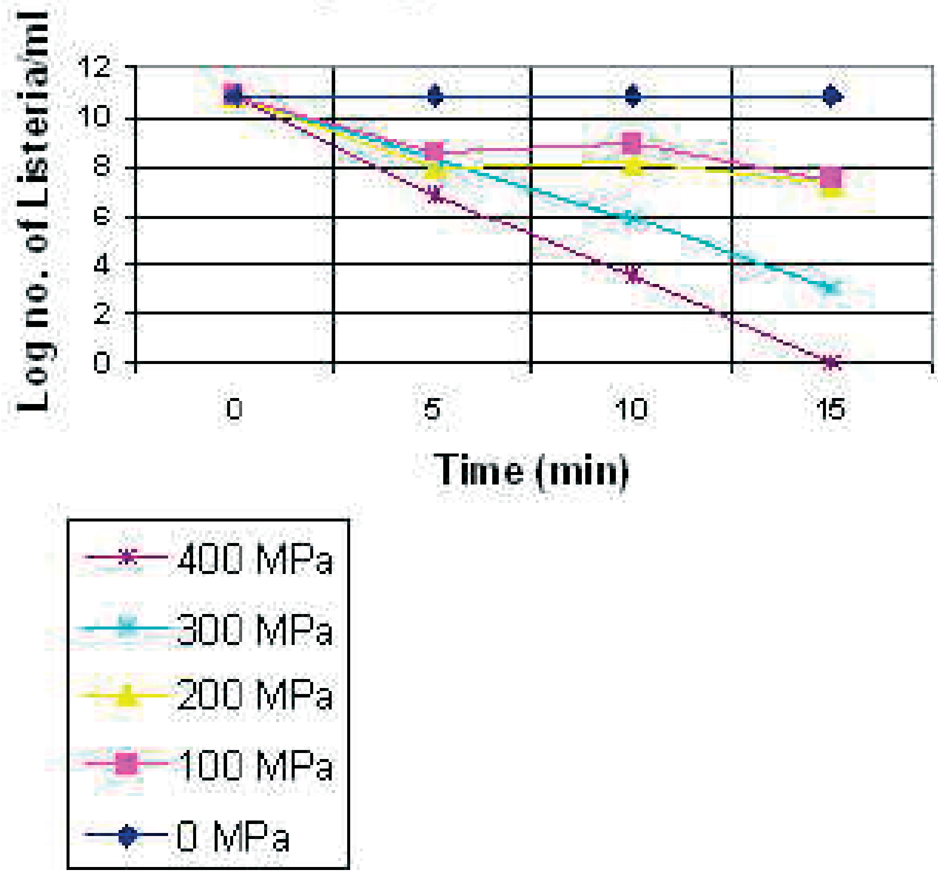

Figure 1. effect of pressure and treatment time on survival of *Listeria monocytogenes* (pure culture).

Fonberg-Broczek, et al 2005

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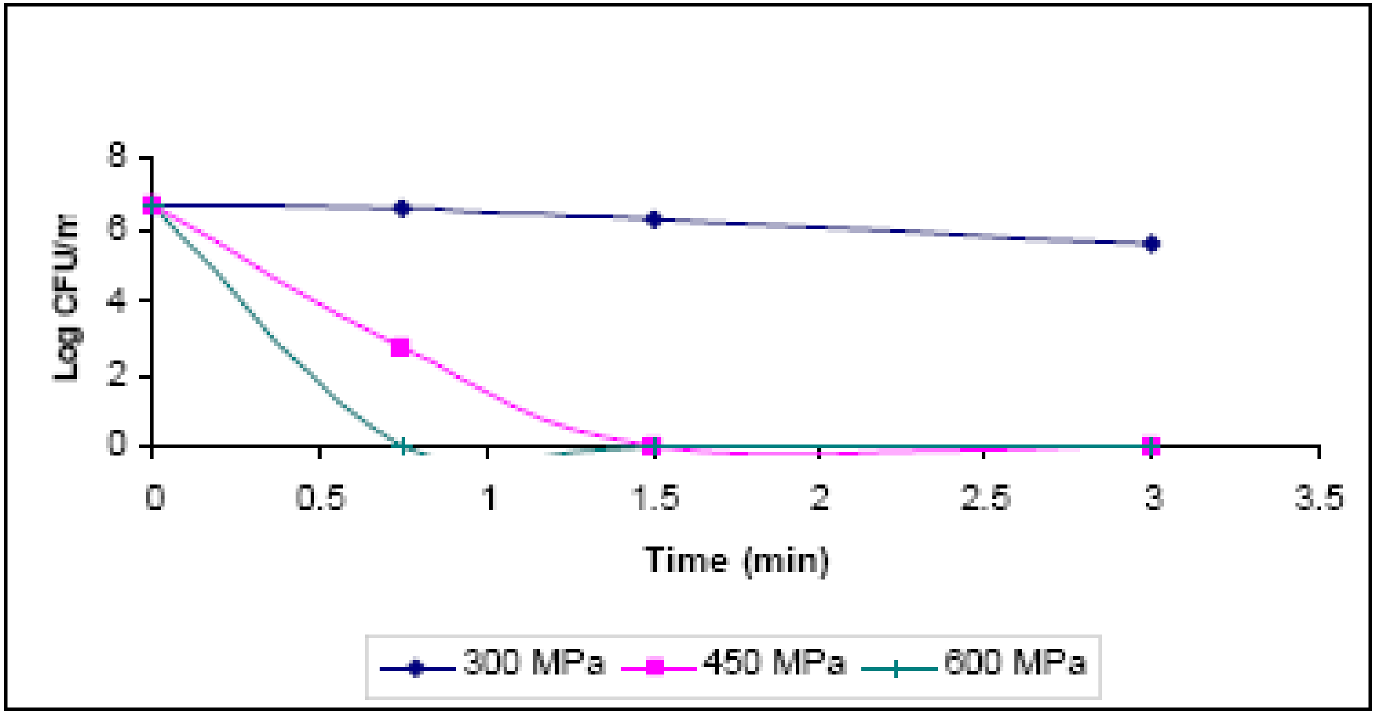
Listeria - Apples

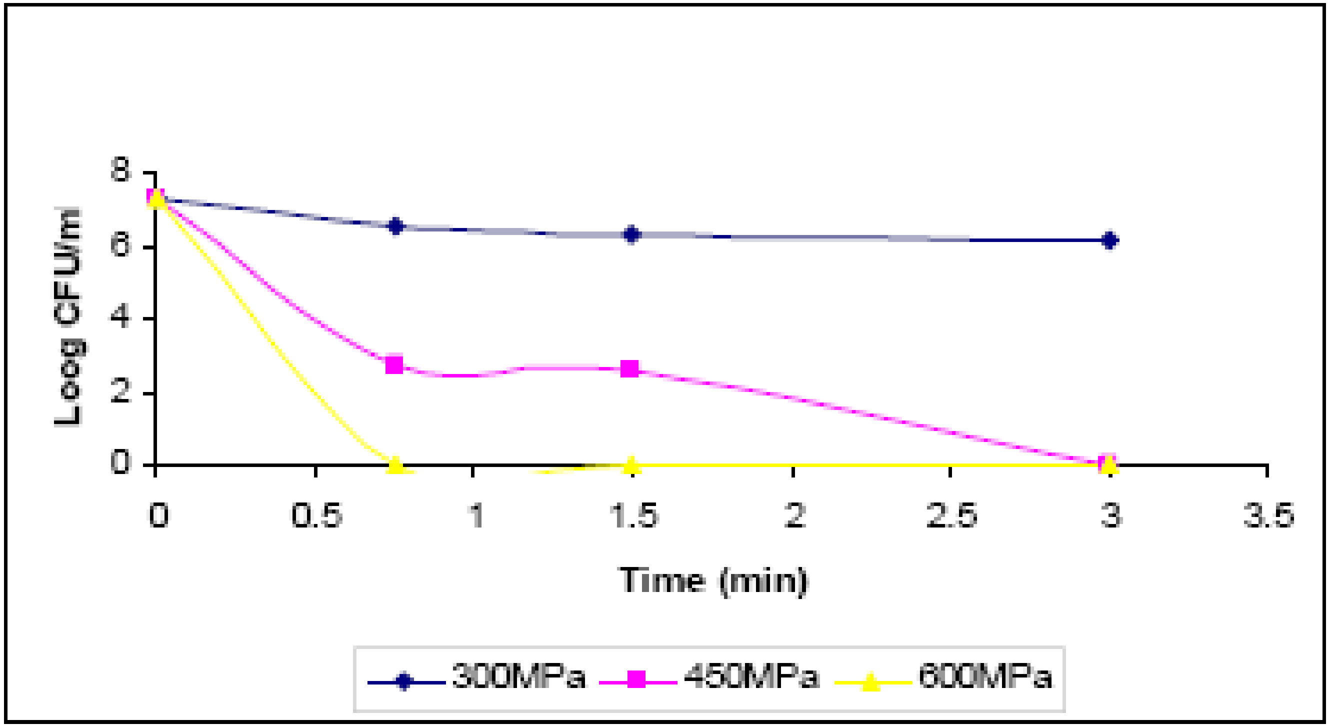
Fig. 5 High pressure (300, 450 and 600 MPa) inactivation of *Listeria innocua* on diced apples



Chauvin 2004

Listeria - Grapes

Fig. 6 High pressure (300, 450 and 600 MPa) inactivation of *Listeria innocua* on grapes



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Listeria - Strawberries

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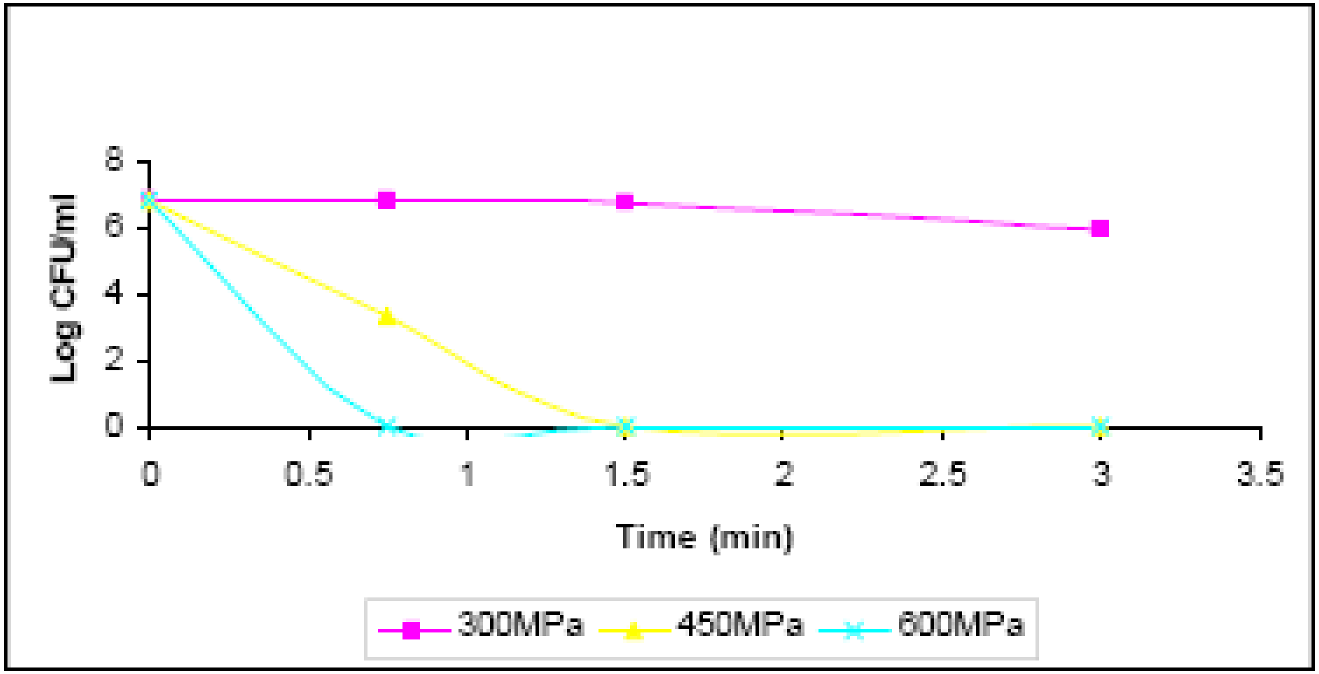
Fig. 7 High pressure (300, 450 and 600 MPa) inactivation of *Listeria innocua* on strawberries



Chauvin 2004

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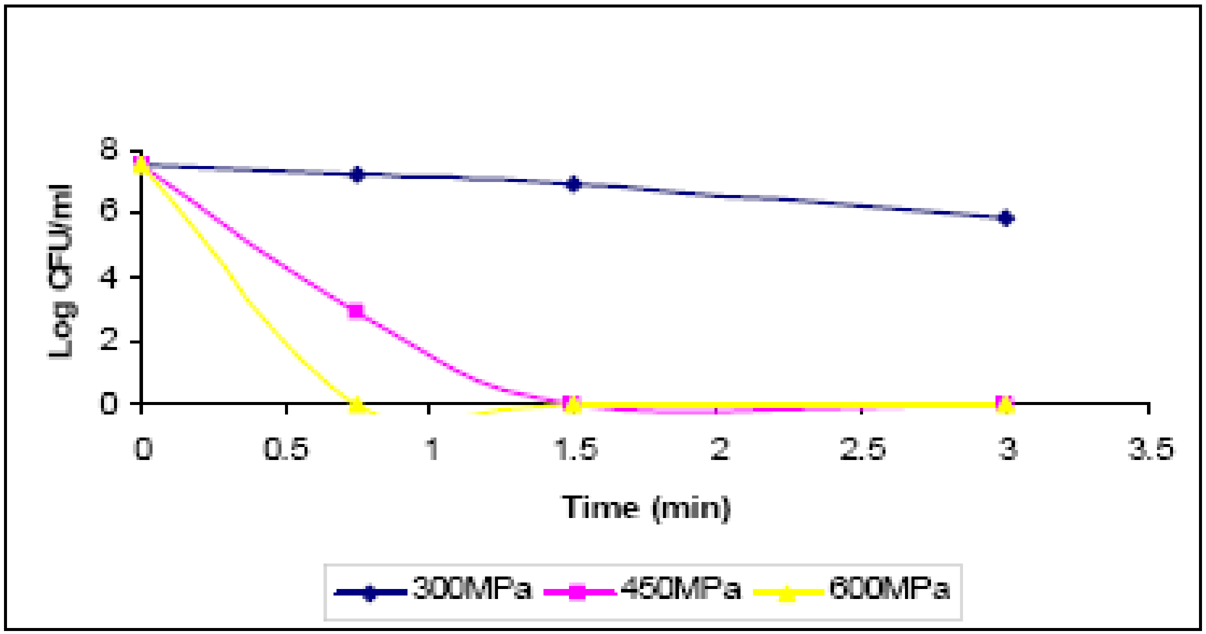
Listeria - Blue berries

Fig. 8 High pressure (300, 450 and 600 MPa) inactivation of *Listeria innocua* on blueberries



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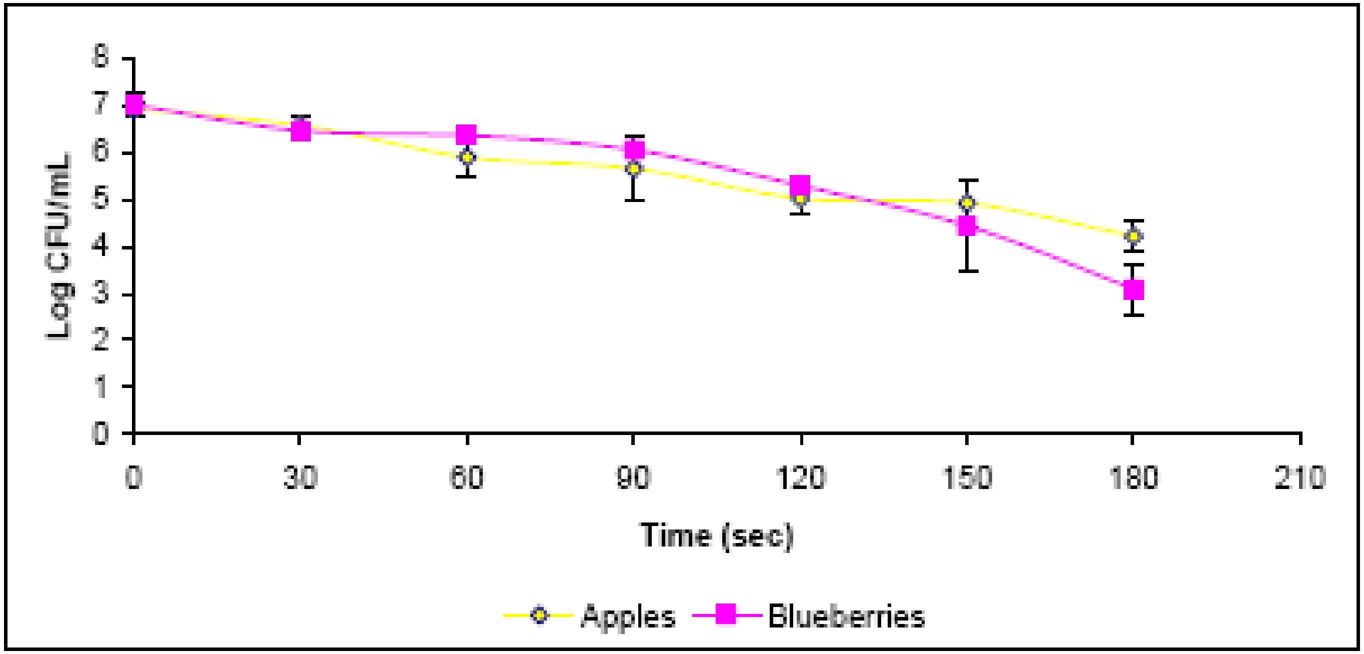
Listeria - Diced apples and blueberries

Fig. 10 High pressure (375 MPa) inactivation of *Listeria innocua* on diced apples and blueberries



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Viruses

- In principle, viruses can also be inactivated by high pressure. The multiplicity of virus types and their structures is, however, so large as to make it impossible to formulate a general statement at the present time.

http://www.dfg.de/aktuelles_presse/reden_stellungnahmen/2005/download/sklm_high_pressure_2005_en.pdf

Toxins - fresh crab meat inoculated with *B.cereus* (103 spores/g) on storage at 4 & 12C

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550 MPa, 40C, 15 min

Treatment/Day	0	3	7	12	17	24	31
Positive control	+	+	+	+	+	+	+
Negative control	-	-	-	-	-	-	-
Control 4° C	-	-	-	-	-	-	-
Control 12° C	-	-	-	-	-	-	-
Treated 4° C	-	-	-	-	-	-	-
Treated 12° C	-	-	-	-	-	-	-

\+ is positive for toxin detection
\- is negative for toxin detection

Source: Virginia Tech

Microbial safety - summary

Pathogen	HPP effects
Salmonella	Inactivation by HPP
Listeria mono-cytogenes	Inactivation by HPP, avoid post processing contamination as it can grow at refrigeration temperatures
Staph aureus	Inactivated by heat and HPP; bacteria does not grow well under refrigeration
B. cereus	Vegetative cells destroyed but spores may survive (similar to heat pasteurisation)
E. coli	Inactivation by HPP, avoid post contamination
Enterobacteriaceae	Inactivation by HPP

Key message: Start with high quality raw materials and avoid post-processing contamination

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