Fermented Food

Traditional fermented foods and beverages

sauerkraut

kimchi

tempeh

natto

kefir

kombucha

Soy sauce

Novel fermented foods and beverages

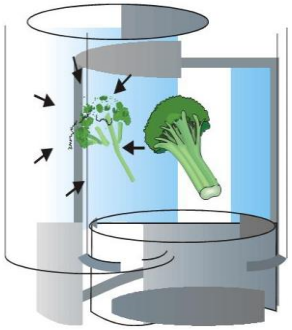
Beverages fermented by kefir and kombucha starters

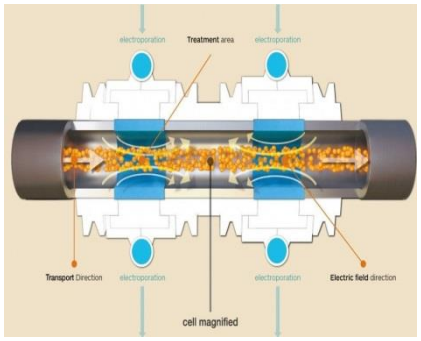
Lactic fermented vegetable mixes

Encyclopedia of Food Microbiology (Second Edition), 2014

Prof. Dr. agr. habil. Dr.-Ing. Dr. Iryna Smetanska

Fermented food





Up to 30% of all foods are fermented!

Fermentation is the transformation of food with the help of various bacteria and the enzymes they produce.
People use these transformed powers to make food more durable, more digestible, less toxic and tastier.
Fermentation is a natural phenomenon that is much more comprehensive than human preparation processes.

Humans did not invent fermentation, fermentation created us.

Food preservation

Reasons :

1. Extending shelf life
2. Preventing foodborne illness
3. Reducing food wastes
4. Improving food security
5. Enhancing nutritional value and digestibility
6. Diversity
7. Economic savings

Common methods of food preservation

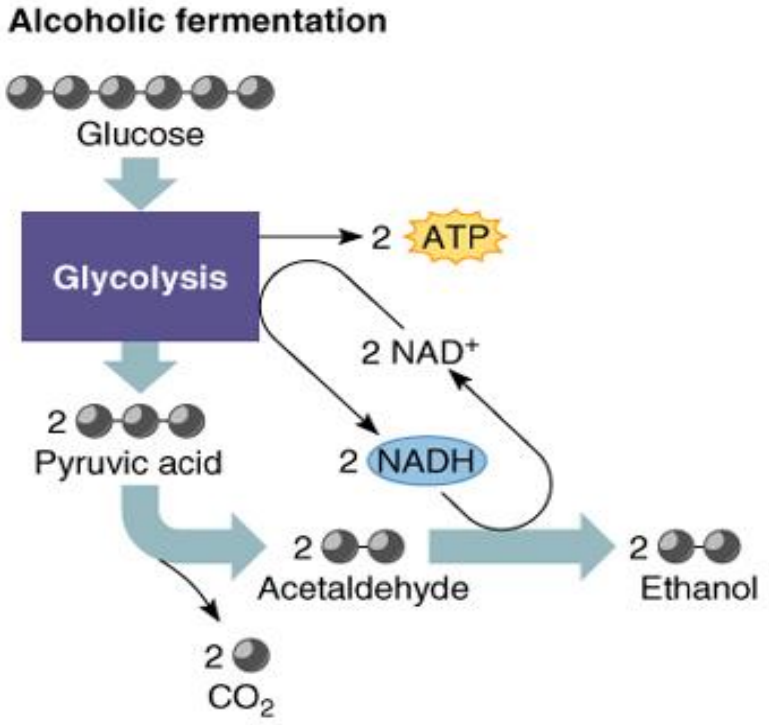
- Freezing
- Canning
- Drying/Dehydrating
- Salting/Smoking
- **Fermentation**

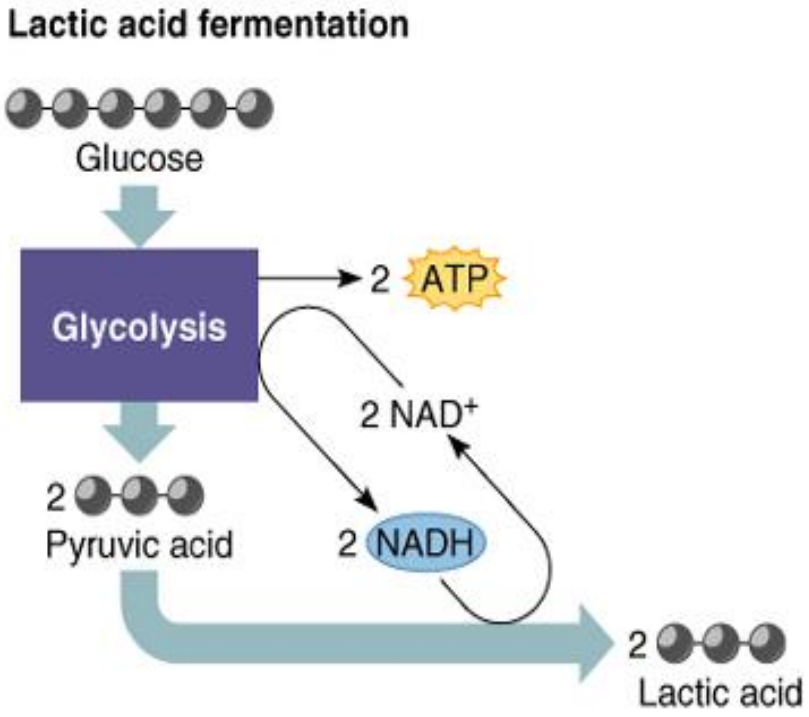
Each method offers specific benefits and is chosen based on the type of food, the desired shelf life, and the flavor profile.

Food preservation

microbiological	chemical	physical
Acids/ alcohol	Osmosis	Temperature
Fermentation: - Lactic acid - Alcoholic - Acetic acid -Propionic acid (Emmentaler) - Malolactic (wine) - Formic acid - Butyric acid - Homoacetate	- Salting - Sugaring - Chemical additives	- Pasteurisation - Sterilisation - Deep- Freezing - Drying

Microbiological preservation methods





Alcoholic fermentation

Carbohydrates are converted into ethanol and CO_2 by yeasts; in the production of alcoholic beverages, bread

$$C_6H_{12}O_6 + 2\,ADP + 2\,P_i \rightarrow 2\,C_2H_5OH + 2\,CO_2 + 2\,ATP$$

D-glucose, 2 ADP and inorganic phosphate are fermented to ethanol, CO_2 and ATP.

Lactic acid fermentation

Sugar is converted into lactic acid; in the production of yogurt, sauerkraut .

$$C_6H_{12}O_6 + 2\,ADP + 2\,P_i \rightarrow 2\,C_3H_6O_3 + 2\,ATP$$

D-glucose, 2 ADP and inorganic phosphate are fermented to lactic acid and ATP.

Schmidt K-H

Microbiological preservation methods

Fermentation is a metabolic process in which energy (in the form of ATP) is obtained through the oxidation of energy-rich compounds (carbohydrates, amino acids).

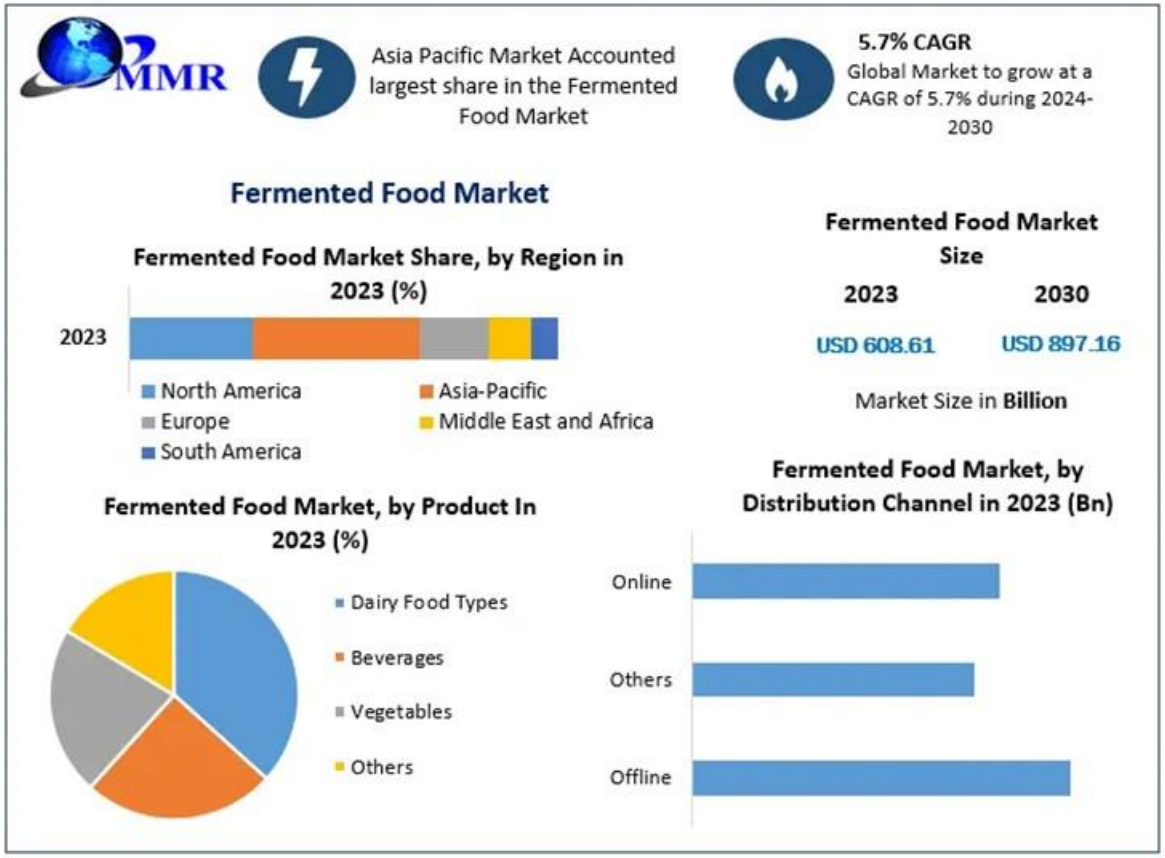
	Lactic acid fermentation	Acetic acid fermentation	Alcoholic fermentation
MO	Lactic acid bacteria	Acetic acid bacteria	Yeasts
Process	Sugar → Lactic acid	Sugar / alcohol → Vinegar	Sugar → Alcohol
Fermentation stop	-at 2-9 % -pH value drops		at 12.5-23 %
MO	Inhibition of MO growth		
Food	Yogurt, kefir, sauerkraut, pickled cucumbers	Apple, wine, Brandy vinegar	Beer, wine

MO excrete fermentation products from the cell.

Primary fermenters: MOs that carry out fermentation
Secondary fermenters: MOs that absorb the fermentation products of primary fermenters and ferment them further to CO_2 , acetate or H_2

Fermented food market

Global market size expected to reach USD 897.16 Bn by 2030, growing at a CAGR of 5.7%



https://www.maximizemarketresearch.com/market-report/fermented-food-market/213506/

Nation's Restaurant News: *As the consumption and variety of sour vegetables has grown in recent years, fermented foods are now among the innovative products.*

Fermented vegetables

Lactic acid fermentation is not only used to preserve perishable food, but also to expand the product range.

Raw materials

Cabbage - white and red cabbage, broccoli, cauliflower, kohlrabi
Root vegetables - carrots, celery, radish
Fruit vegetables - zucchinis, peppers, pumpkin, tomatoes
Onion vegetables - onions, leeks, garlic
Soy, beans, mushrooms.

Duration of fermentation: 6 days - 3 weeks - 2 years

Benefit	Raw material	Fermented food
Preservation	Cabbage	Sauerkraut
Enhancement of safety • Acid production • Acid and alcohol production	 Fruit Barley, Grapes	 Vinegar Beer, Wine
Enhancement of nutritional value • Improved digestibility • Retention of micronutrients • Synthesis of probiotic compounds	 Wheat Leafy vegetables Milk	 Bread Kimchi, sauerkraut Yakult, yoghurt
Improvement of flavour	Coffee beans Tee	Coffee Kombucha

https://www.picuki.com/tag/completeorganics

Lactic acid fermentation

During fermentation, under the direction of lactic acid bacteria, several biochemical and physiological changes take place. This creates various organic acids, aromas, flavors and vitamins in the product.

Carbohydrates
Hexoses (glucose)
Disaccharides (lactose)
Alcohols (mannitol)
Acids (malic acid)

Lactic acid bacteria

are not included in the vegetables

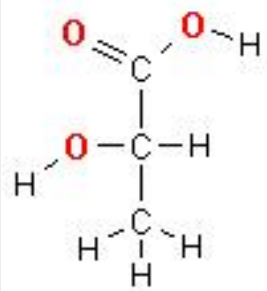
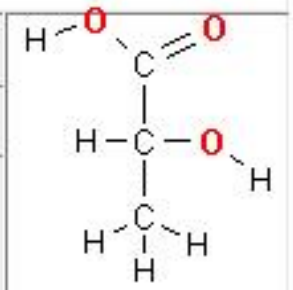
Lactic acid

Lactic acid:

- **Preservation - Shelf life**
- **pH value reduction**
- **Inhibition of harmful and pH-sensitive MO**
- **Prevention of alcoholic fermentation**
- **Salt facilitates the release of cell sap - air is prevented from entering and the formation of lactic acid is promoted**
- **Preservative E270**

What is lactic acid?

- Discovered in 1780 by Carl Wilhelm Scheele in sour milk
- Metabolic product of plant and animal organisms
- L (+) - Lactic acid is formed in the muscle as a product of glycolysis

$C_3H_6O_3$ Milchsäure			
	(+)-Milchsäure L-Milchsäure	(-)-Milchsäure D-Milchsäure	
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www.carl-roth.de

- IUPAC- Name: 2- Hydroxypropanoic acid
- Colorless, syrupy, hygroscopic and odorless liquid
- Hazard symbol: X - Irritant
- Preservative in the food industry (E 270)

What is lactic acid?

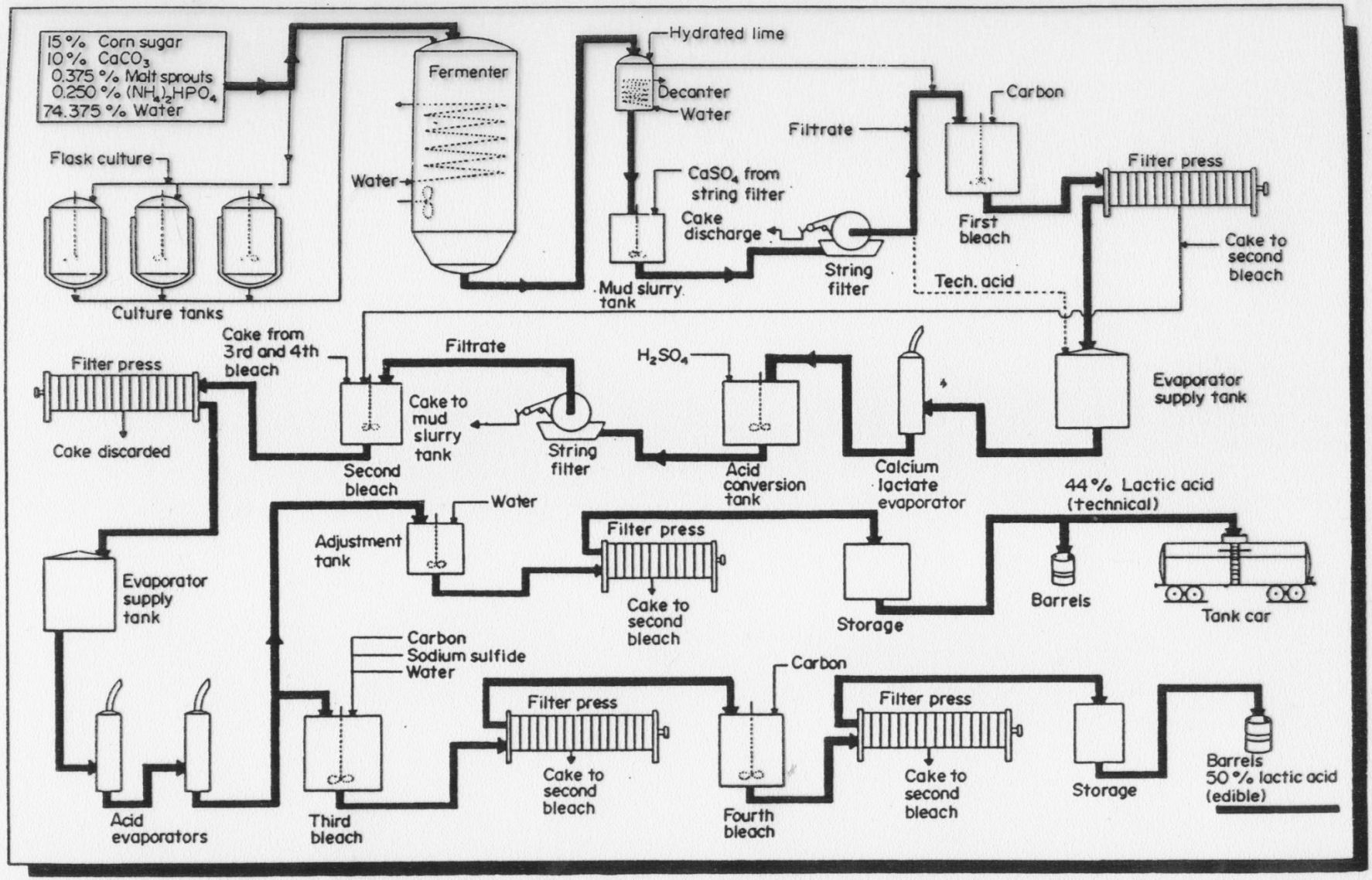


Figure 2 Lactic acid process used by the American Maize-Products Co. Reprinted with permission from Inskeep *et al.*

Knorr D

History and origins of some fermented foods

Food	Time	Region
Fermented milk products Soy sauce	5000 BC 3000 BC	Mesopotamia China, Korea, Japan
Wine	3000 BC	North Africa, Europe
Fermented milk, cheese	3000 BC	Middle East
Beer Curd	2000 BC	Egypt, Europe India
Bread KimChi	1500 BC	Europe, Asia, North Africa Korea, China
Pickled vegetables Cheese, fermented olives	1000 BC 500 BC	China, Europe Greece and Rome

Sauerkraut

is the product with characteristic flavor, obtained by lactic fermentation of shredded cabbage in the presence of 2-3% of salt.

This can be achieved with or without the use of a probiotic culture starter as cabbage has naturally occurring beneficial MOs present on its leaves.

The end products of a normal kraut fermentation is lactic acid and a mixture of aromatic esters.

The acidity helps to control the growth of spoilage organisms and contributes to the extended shelf life of the product.

Duration of fermentation: 4 days – 6 months

Suerkraut (upasteurized) is known for its diverse array of beneficial lactic acid bacteria and enzyme content, properties of which became especially popular in the U.S. in 1990's with the introduction of the Body Ecology Diet. This diet promotes the use of naturally fermented sauerkraut for improving digestion and boosting immune health.

Sauerkraut: History

220 BC - Sauerkraut production in China

1.White cabbage was preserved in brine in ancient Rome

1210 - Genghis Khan invades China; migrating Mongol tribes bring the recipe to Central Europe.

17th century - only made by monks (fasting food)

1775 - Sailor Cook - in shipping against scurvy (6% salt in the brine)

James Cook (1728-1779)

Scurvy: ***(also known as Möller-Barlow disease) is a disease caused by a vitamin C deficiency*****.**

Symptoms: Bleeding gums and tooth loss / susceptibility to infectious diseases / exhaustion and fatigue / poor healing of wounds / skin problems and skin inflammation / joint inflammation / muscle atrophy / high fever

Main cause of death among seafarers

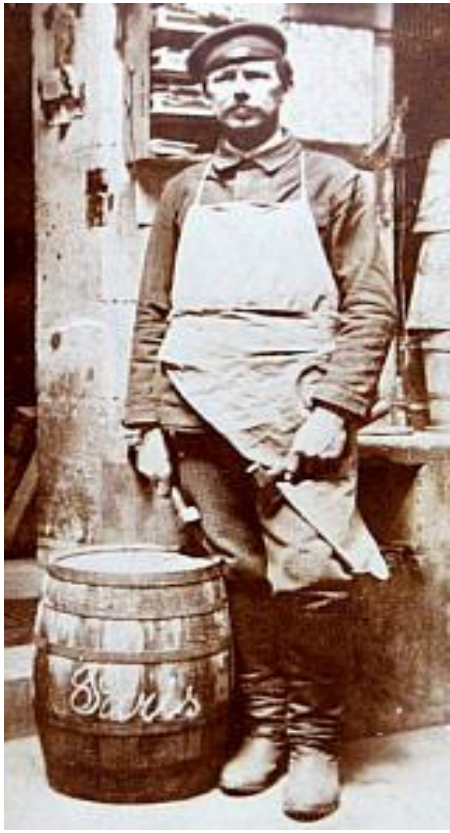
Sauerkraut: History

18th century - Sauerkraut production in private households

19th century - industrial sauerkraut processing

1882 - 1st special machine factory for sauerkraut production (Plieningen, near Stuttgart)

1916 - Ordinance on the quality assurance of sauerkraut



1883 - first sauerkraut factory in Plieningen

Filderkraut

Cabbage slicer

http://www.heimat-museum.de/03_kraut/index.html

Sauerkraut

Harvest:

Cabbages are harvested, cleaned and hard outer leaves are removed. Quality control: 5-8 kg, rot, pests, soiling.

Storage and delivery :

Storage in CA storage at < +1 to +2 °C in a pressurized atmosphere with increased CO2 content

Warm up refrigerated goods to ~18 °C 2 days before processing

Source: Sauerkraut production welsh.lk5.com

Sauerkraut

White cabbage

Cleaning and cutting:

Clean away outer leaves that are not connected to the stalk

Drill out the stalk

Cutting with cutting machine, 1 mm cut

Core drill

Source: Sauerkraut production welsh.lk5.com

Knife of a cabbage slicing machine, 1 mm cut

Sauerkraut

Source: Sauerkraut production welsh.lk5.com

Salting :

Salt and a mixture of spices (including paprika, caraway, dill, apples or carrots) are added.
Salt in layers (sodium chloride), add water if necessary until the optimum salt content of 2.25 % is reached; compact (remove air)
Lactic acid fermentation at 18 to 21 °C
Fermentation time 7 to 10 (21) days

The containers - up to 120 tons.

Fermentation

Cabbage is tamped down in layers (to promote the release of cell sap, remove air) and sealed with a water-filled plastic bladder, weighted stones or wood.
Fermentation starts by itself or with the addition of starter cultures.
6 days- 3 months

Sauerkraut

Trade fairs:

Control of temperature and fermentation time, measurement of lactic acid by titration and pH value measurement

Filling

Lactic acid content 0.9 -1.1 % and pH < 4.0
Water bag is removed. Sauerkraut is lifted out of the silo with a crane and transferred into smaller containers for further processing.

Source: Sauerkraut production welsh.lk5.com

Sauerkraut

Source: Sauerkraut production welsh.lk5.com

Packing

Sauerkraut is packaged (raw / cooked) in cans, jars, bags and reweighed.

At a lactic acid concentration of 1.5-2.5% and pH 3.6-3.8 at 5-10°C up to 48 mo in cans and 18 mo in aluminum bags.

Wine, grated pineapple, sugar, ascorbic acid, sorbic acid can be added to the end product

Pasteurization

at 80°C: is briefly heated and then immediately cooled down again.

- **Transport to the cold store**
- **Cold store temperature +1 °C**

Labeling:

Label best before date; can be kept refrigerated for at least 6 months
Packing on Euro pallets
Delivery in a refrigerated truck

Source: Sauerkraut production welsh.lk5.com

Sauerkraut: Preservation

- to protect food from spoilage for a certain period of time.

Spoilage

1. enzymatic
2. microbiological

Heat treatment

Enzymes and MO can be inactivated.
However, each enzyme and each MO has its own behavioral characteristics with regard to an increase in temperature.

Pasteurization - the aim is to achieve a limited shelf life. Only the vegetative germs are eliminated.

Sterilization - all vegetative germs and all spores should be destroyed.

Conflict:

As a rule, it is not possible to sterilize a product using heat treatment without undesirable effects occurring.
Vitamins are destroyed and/or the texture becomes too soft.

Sterilization, pasteurization

	Sterilization	Pasteurization
Temperature	115°C.....130°C	Below 100 °C
Duration	10 - 90 min depending on product	Duration and temperature depend on the product types
Goal	Killing all MO	Partial destruction of the MO
Result	Stable product	Limited shelf life product
Durability	1-5 years	Approx. 21 days
Storage	At room temperature in dry rooms	In the refrigerator compartment (+6- +3°C) depending on the product

Production of sauerkraut

Production of sauerkraut

Execution

- remove the outer leaves with a knife
- Cut the cabbage into thin strips
- Salt after each layer.
- Mash until the juice comes out.

Recipe:

1. Chop 625 g white cabbage
2. Peel and grate 150 g carrots
3. (Mix in 125 g sauerkraut as a starter culture)
4. Put all the ingredients in the casserole and

Mix in 2% salt

5. Seal pot with air bubble airtight

Sauerkraut: Quality

Quality regulations for sauerkraut according to the "Guidelines for vegetable production"

- **Sauerkraut is sufficiently fermented, has a sufficiently firm consistency, a bright appearance and a strong aroma and taste typical of the species, without any foreign notes such as mustiness.**
- **Sauerkraut consists of at least 90% solid sauerkraut substance and, if necessary, solid ingredients and a maximum of 10% fermentation brine and liquid ingredients.**
- **Free from other impurities and components not suitable for consumption, e.g. weeds, straw or pests**
- **Free from mineral components such as soil or sand**

Destinations: Pressed brine (pressed brine is the mixture of drained and then pressed brine from the cabbage):

- **The pH value is below 4.1**
- **The acid content, calculated as lactic acid, is at least 0.75g/100ml.**
- **The salt content is between 0.5 and 3g/100ml**

Sauerkraut specialties

- 80% pasteurized
- 20 % fresh
- Barrel sauerkraut (in the fermentation process)
- Wine sauerkraut (with white wine)
- Organic fresh food L(+) sauerkraut (probiotic)
- Delicatessen sauerkraut (gently pasteurized)
- Diet sauerkraut (low sodium)
- Alsatian sauerkraut (with pineapple, apple sauce)
- Sauerkraut juice

Fermented cucumbers : History

Vats of fermenting cucumbers covered with plastic and water to prevent atmospheric oxidation.

Knorr D.

Fermented cucumbers (pickles)

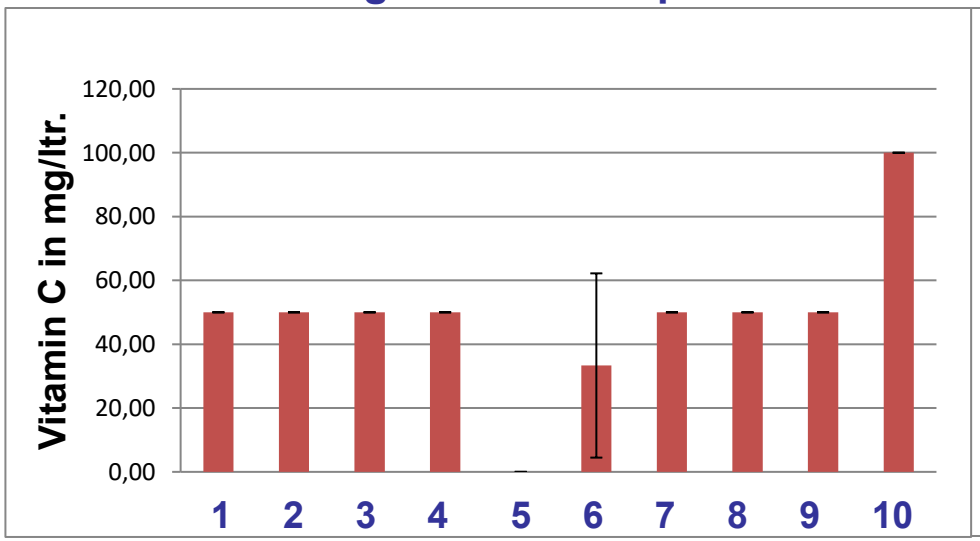
are cucumbers that have undergone a process of fermentation in a brine solution.

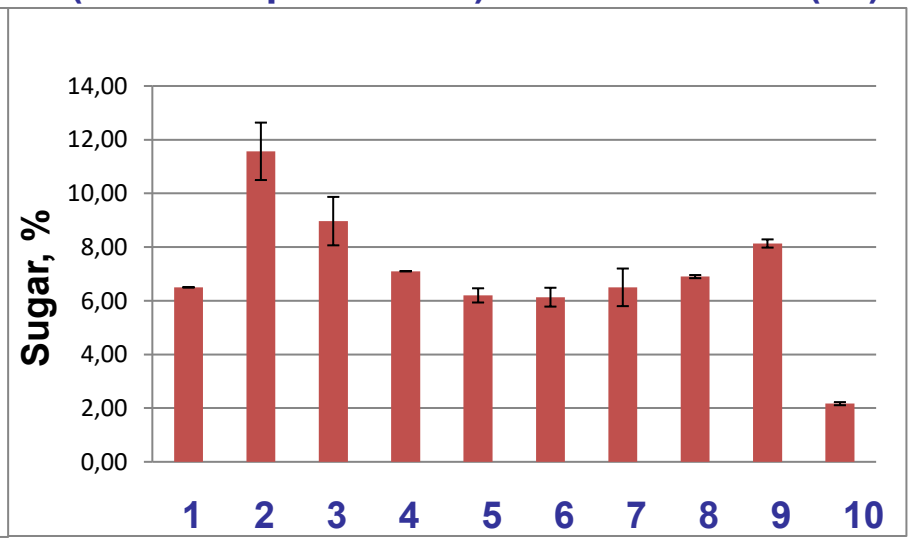
Brine Solution:

1. **chlorine-free water.**
2. **non-iodized salt**
3. **flavorings: garlic, dill, mustard seeds, peppercorns, herbs.**

The strong brine draws the sugar and water out of the cucumbers, which simultaneously reduces the salinity of the solution.
Acids are produced as a result of the fermentation.
The color of the cucumber surface changes from bright green to a dark olive green as acids interact with the chlorophyll.

Vitamin C and sugar content in pickled cucumber (different producers) and fermented (10)

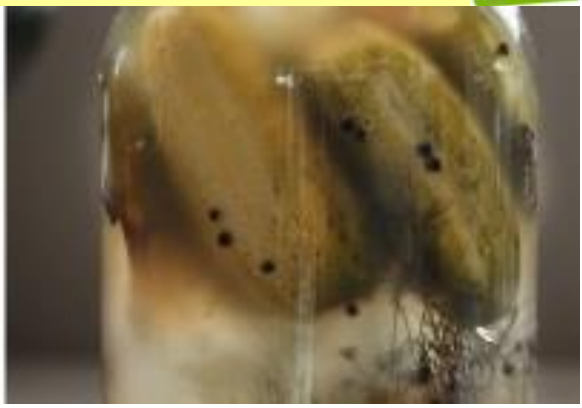




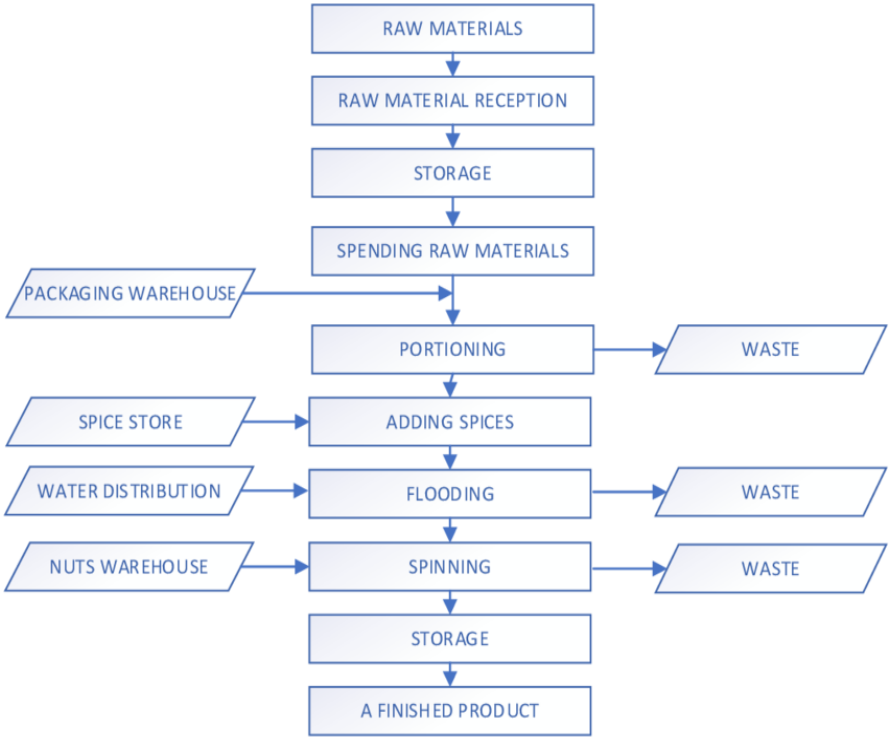
Smetanska et al, 2017, unpublished

Sour vegetables: Cucumbers





Flow diagram for the production of pickled cucumbers



Process stage	Type and source of the threat	Control	CCP
Raw material reception	Infected raw materials	approvals, visual assessment of packaging tightness	CCP 1
	Incorrect composition of raw materials	approvals, System procedure	
	Foreign bodies in raw materials	approvals, System procedure	
Storage	Development of microorganisms caused by pest activity	System procedure	CCP 2
	Growth of microorganisms caused by inappropriate temperature and humidity	System procedure	CCP 3
	Pests and their droppings	System procedure	CCP 4
Spending raw materials	Undefined threat	-	-
Portioning	Secondary human infection	GHP Code	-
	Incorrect amount/weight of cucumbers	Weighing instructions	CCP 5
Adding spices	Secondary human infection	GHP Code	-
Spinning	Secondary human infection	GHP Code	-
Storage	Development of microorganisms caused by pest activity	System procedure	-
	Growth of microorganisms caused by inappropriate temperature and humidity	System procedure	CCP 6

SZCZYRBA, A.. (2023). Good Manufacturing Practices for Quality and Safety Management in the Food Industry. 288-297. 10.21741/9781644902691-34.

Production of pickled cucumbers and tomatoes

- The preserving jar is washed out

- Wash the cucumbers (cut into pieces if necessary, approx. 4 cm long).
- The 2-liter preserving jar is washed out.
- A mixture of 2.5% salt and 2.5% sugar (% per 2 l) is balanced and mixed with a little water.
- Place the cucumbers, the mixed solution, dill, pepper, garlic, bay leaf, etc. in the preserving jar and fill with boiling water.

- The tomatoes are washed
- A mixture of 2% salt and 2.5% sugar is balanced and mixed with a little water.
- Put the tomatoes, the mixed solution, pepper, dill, garlic, bay leaf, etc. into the preserving jar and fill with boiling water.

Production of fermented tomatoes

Ingredients:

- Ripe tomatoes, garlic, chili pepper, salt

Implementation:

- Wash the tomatoes
- Quarter the tomatoes and remove the green stalk
- Finely dice the garlic and chili
- Puree everything finely and season with salt
- Pour into jars and leave to ferment for 2-3 days

Key Differences in Fermented and Modern Ketchup

Aspect	Fermented Ketchup	Modern Ketchup
Preservation	Fermentation (natural lactic acid)	Vinegar, sugar, and pasteurization
Flavor	Tangy, umami-rich, complex	Sweet, smooth, and mild
Texture	Chunkier or liquid-like	Smooth and uniform
Health Benefits	Probiotics and natural enzymes	Lacks live cultures

Kim Chi

- is a brine salted fermented Chinese cabbage with radishes, turnips, onions, chili, etc.

- one of the most popular fermented foods, 2500 years, 200 varieties.

Korean people consume 50-500 g/day of kimchi

Nowadays: hot dogs, pizzas, burgers, tacos, soups for a different flavor experience

Fermentation:
Can be fermented for several months to several years. Because the ingredients do not contain so much sugar, the final pH is 4.2-4.5 (sauerkraut pH is 3,8).

Production of Kim-Chi

Ingredients

➢Chinese cabbage, carrots, champignons, ginger, chili peppers, dried shitake mushrooms, salt and soy sauce

Implementation:

➢Outer leaves gone

➢Chop, salt, mash and fill into jars

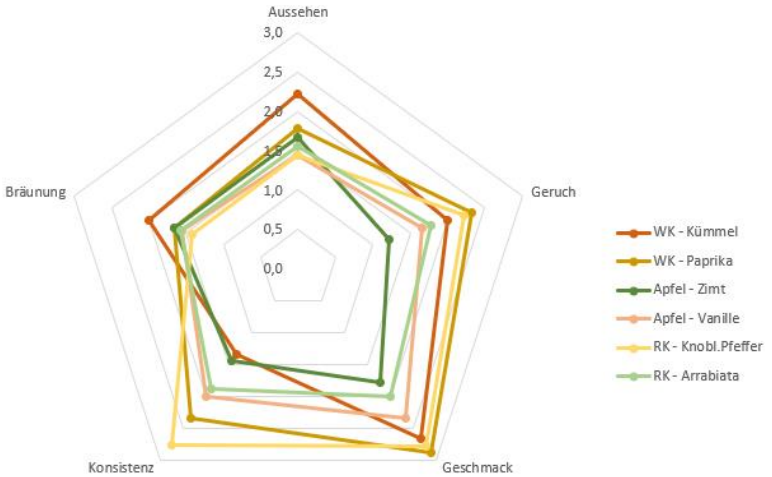
➢Weigh down with a water-filled bag

➢Fermentation takes approx. 2-3 days depending on taste

Production of crackers with fermented content

Crackers can be used to pick up on various trends

- **Convenience**
- **Reduced in calories**
- **Vegetarian**



Types of conditions for lactic acid fermentation :

1. Dry salted

the vegetable is treated with dry salt (approx. 3%). The salt extracts the juice from the vegetable and creates the brine.
Sauerkraut, dry salted pickled cucumbers

2. Brine Salted

Brine is used for vegetables which contain less moisture. A brine solution is prepared by dissolving salt in water (15 - 20% salt solution)
Pickled cucumbers, Kimchi, Olives, Radish

3. Non-salted

Vegetables are fermented by lactic acid bacteria, without the prior addition of salt or brine
Fermented tea leaves, kombucha

Sinki (pickled Radish)

Sinki is a non-salted fermented sour pickle from radish.

It is consumed traditionally in India and Nepal, where it is used as a base for soup or eaten as a pickle.

Fresh radish roots are harvested, washed, sun-dryed for one day.
Afterwards they are then shredded and packed tightly into a jar, which is sealed and left to ferment.

Fermentation: 12 days at 30ºC, pH drops from 6.7 to 3.3.

After fermentation, the radish is sun-dried.

Consumption: sinki is rinsed in water for 2 minutes, then fried with salt, tomato, onion and green chili.

Changes in finely acidic vegetables

Taste, smell, color, nutritional value
Fermentation and chemical/thermal post-treatment

1. biochemical

- Sugar breakdown
- pH value
- Aroma and flavor substances (acids, biogenic amines)

2. physiological

- Texture - Salt - Removal of water
- Color - degradation or conversion of pigments

3. nutritional-physiological

- Nutritional value - breakdown of carbohydrates, synthesis of vitamins

4. Microbiological changes

- *Lactobacillus, Lueconstoc* (lactic acid)
- Inhibition of yeasts, fungi
- Starter cultures

Biochemical changes-1

1. Breakdown of sugar

Breakdown of carbohydrates
→Energy content decreases

Degradation products: mainly lactic acid, acetic acid, ethanol and CO_2 (from glucose) and mannitol (from fructose)

Some of the resulting acids are esterified with ethanol
→Flavors and odors

2. pH value

Preservative effect
→Sinks into acidic range during fermentation due to lactic acid formation (inhibits undesirable MO)

drops from pH 6.2 at the beginning to 3.4 - 3.8 (sauerkraut)

Biochemical changes - 2

3. Degradation of proteins

Formation of *biogenic amines*

→By-products of vegetable fermentation
→Primary amines
→Formed by *decarboxylation* of amino acids

4. Vitamin content

Vitamin B_{12}

→The only plant-based food that contains vitamin B_{12} (microbial)
→is only formed by bacteria
→accumulates in animal products

5. Flavorings

Acids of lactic acid fermentation: *formic acid, lactic acid, acetic acid, succinic acid*

Esterified acids

Biogenic amines

Physiological changes

Osmotic processes

1.5 to 2 % **salt**

→ **Deprivation of *water* and *carbohydrates***

→ **Sagging of the tissue**

→ **Purpose:**

- **Expel the trapped air by forming the brine**
- **Leaking carbohydrates form nutrients for the MO**
- **Salt serves as a preservative until the preservative effect occurs due to the lactic acid formed**

Structural changes

Desired structure of the sauerkraut

- **→juicy firm**
- **→easy to chew**
- **→not soft, limp or leathery tough**

Exclusion of air

has a selective effect on MO flora

- **→Aerobes are inhibited, anaerobes can develop**

Implementation by using a water bubble

- **→Spatial separation from the ambient air**
- **→Pressing pressure is exerted on crushed cabbage**

Physiological changes: Texture

Osmotic processes

1,5 - 6 % Salt

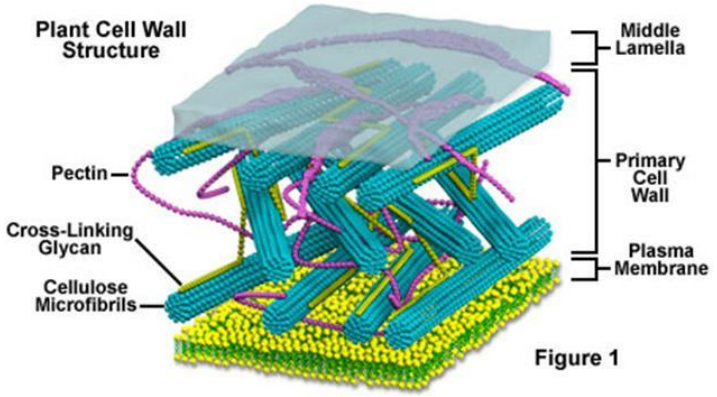


Figure 1

Salt withdraws water from vegetative tissues ►

- **enables LAB grow,**
- **inhibits the growth of undesirable microorganisms**
- **delays enzymatic spoilage.**

- **Proper concentration of salt (2.5% for sauerkraut) favors LAB**
- **low salt results in tissue softening, because not enough water is pulled form the tissues**
- **high salt (over 3.5% for sauerkraut) inhibits all LAB, including the desirable ones, slows anaerobiosis, and results in undesirable yeast growth.**

Air affects fermentation negatively (LA-fermentation is anaerobic):

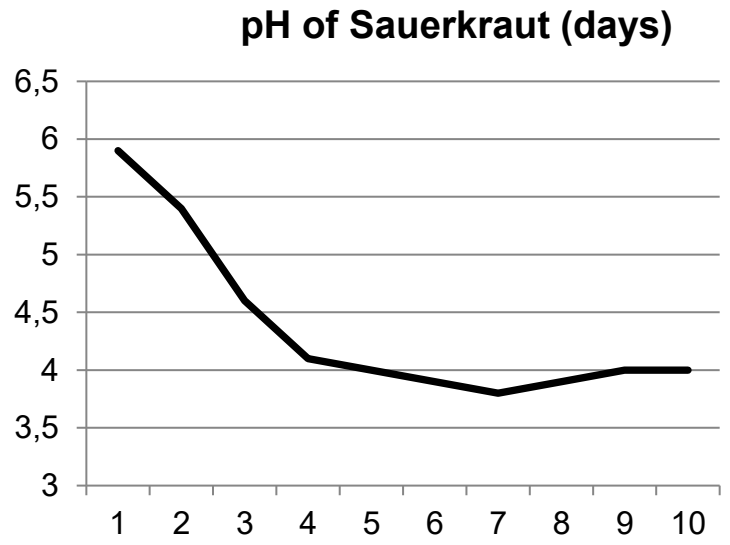
- **promotes yeast and mold growth**
- **causes softening, off flavors and darkening of the product.**

**** LAB – lactic acid bacteria***

Acidity (pH)

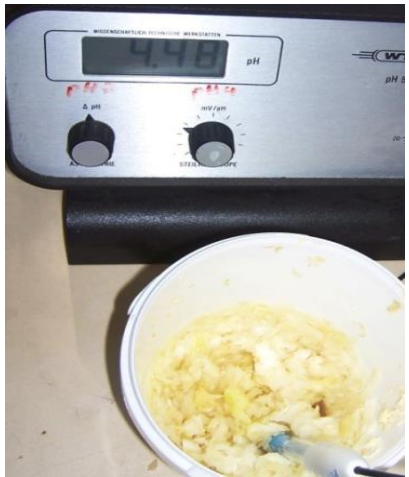
Lactic bacteria produce acids. When the acidity reaches 0.25 % (pH 3,8), these bacteria slow down and begin to die off.

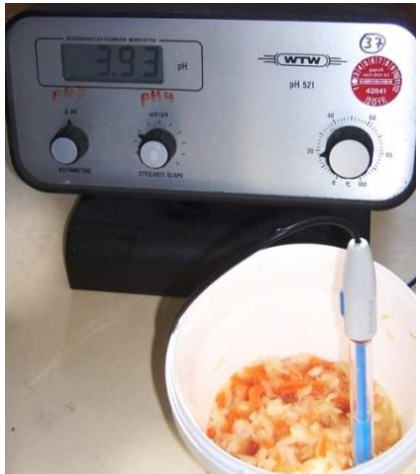
Sauerkraut
3 days ► pH falls from 6,5 until 4,2, which makes impossible for mold and yeast to survive
3 weeks ► pH 3,8 ► the product is sterilized and preserved in a natural way
Traditionally - 6 months (Chinese traditional kitchen - eggs, fermented for hundreds of years).



Smetanska, practical trainings, 2009-2016

pH of sauerkraut (4,48), sauerkraut with carrots (3,93), red cabbage (4,26), Kim Chi (4,21) on 4th day of fermentation (Smetanska, practical trainings, 2009-2016)





Physiological changes: Dyes

Chlorophylls

- in chloroplasts

- Chlorophylls a and b

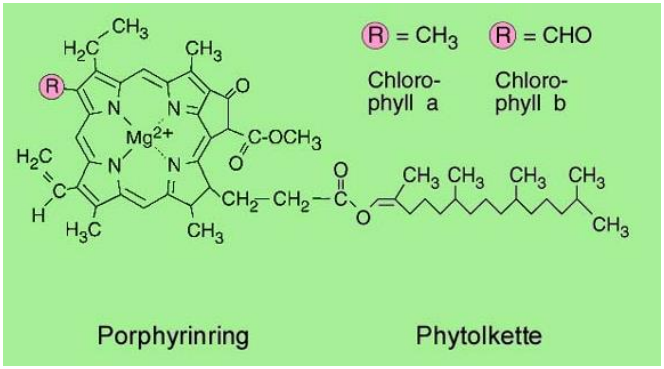
- Organic complexes with a Mg^{2+} ion as the central ion

- not resistant to pH and heat

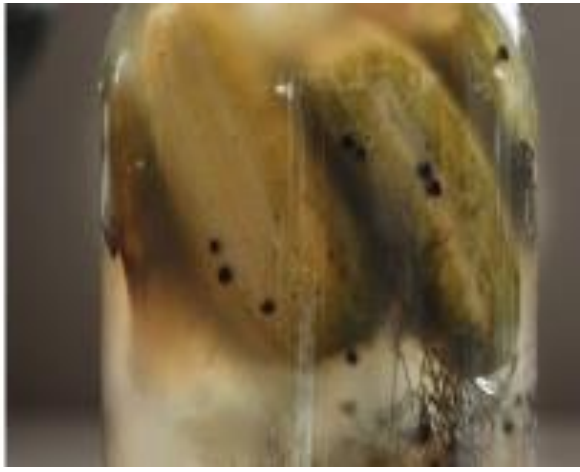
Prevention of degradation:

Chemical: due to sulfites;

Physical: due to low temperature



www.uni-duesseldorf.de

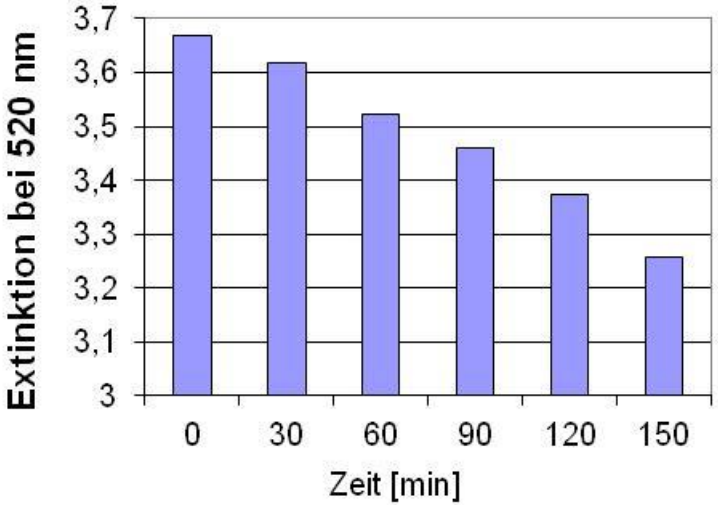


Physiological changes: Dyes

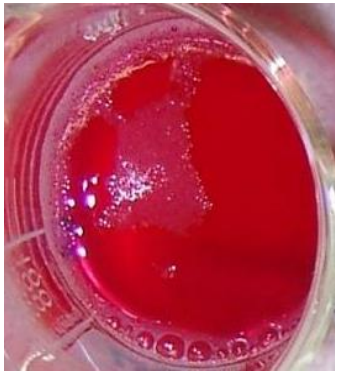
Vacuole: anthocyanins, betalains

® Smetanska

Anthocyanins under the influence of heat (95



Anthocyanins under pH influence (red cabbage)



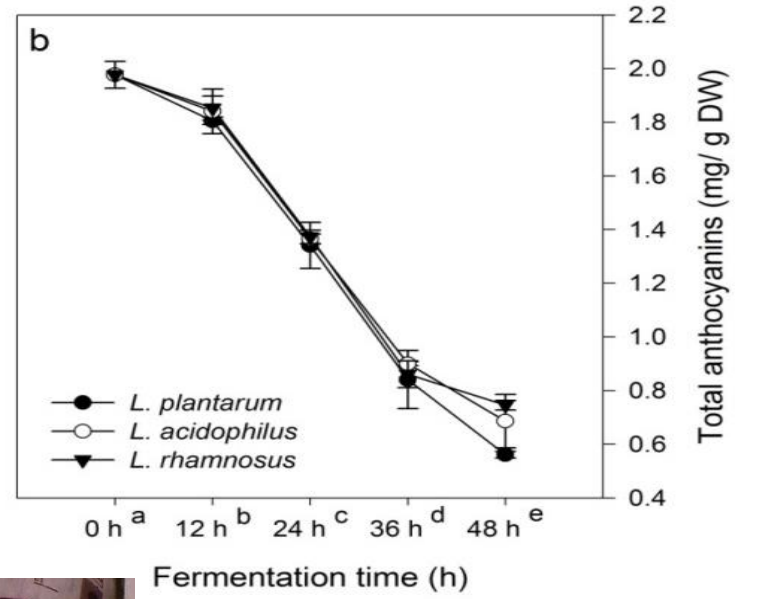
pH 3 7 9

Bethalaine (beet) and anthocyanins (red cabbage)

HSWT, May 2011, "Food Technology"

Physiological changes - Dyes

Praktika : Juice from fermented cabbage was added in various concentrations from 0.5 to 5 ml to 50 ml each of tap water, mineral water and milk to achieve optimal coloration.



Paramithiotis S.

Physiological changes: Dyes

Carotenoids

-in chloroplasts, chromoplasts

- not resistant to pH

- Resistant to heat

Carotenoid content, mg/ g

Food	α-Carotene	β-Carotene	Lutein + zeaxanthin
Carrots (heated)	980	370	-
Carrots	790	360	26
Spinach (heated)	550	-	1260
Spinach	410	0	1020

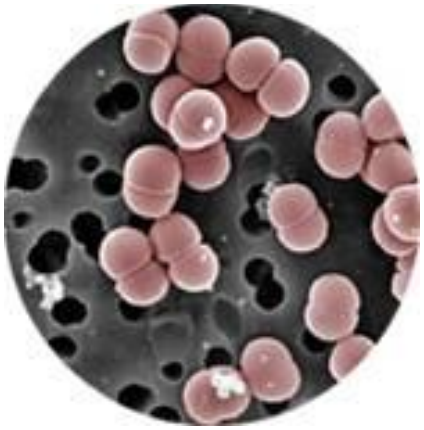
Lactic acid fermentation

Phase	1 Hetero-fermentative	2 Homo - fermentative	3 Hetero-fermentative	4 Homo-fermentative
Glucose to	Lactic acid, formic acid, succinic acid, acetic acid, ethanol, CO_2	Lactic acid	Lactic acid Ethanol Acetate, CO_2	Lactic and acetic acid Ethanol, Mannitol
Microflora	*Lactobacillus brevis;* Bacteria, yeasts	Obligate aerobic *Pediococcus cerivisae*	*Lactobacillus plantarum; Leuconostoc mesenteroides*	killed
Conditions	20 (35° C), NaCl	25 C°	20 C°	
Lactic acid	-	1%	2.0 % (intensive)	2,5%
pH	6,5	4,5	4,0	3,6 - 3,8
Features	Foam formation	Oxygen deficiency	Esterification of carbohydrates; taste, odor, aroma formation	

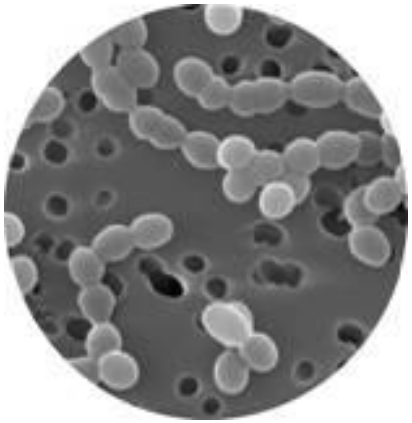
Microbiological changes

Phase	1	2	3	4
Glucose to	Lactic acid, formic acid, acetic acid, ethanol, CO_2	Lactic acid	Lactic acid Ethanol Acetate	Lactic acid (and acetic acid)
Microflora	*Lactobacillus brevis,* yeasts, Molds	*Pediococcus cerivisae*	*Lact. plantarum; Leuconostoc mesenteroides*	killed

Lactobacillus brevis



Pediococcus damnosus

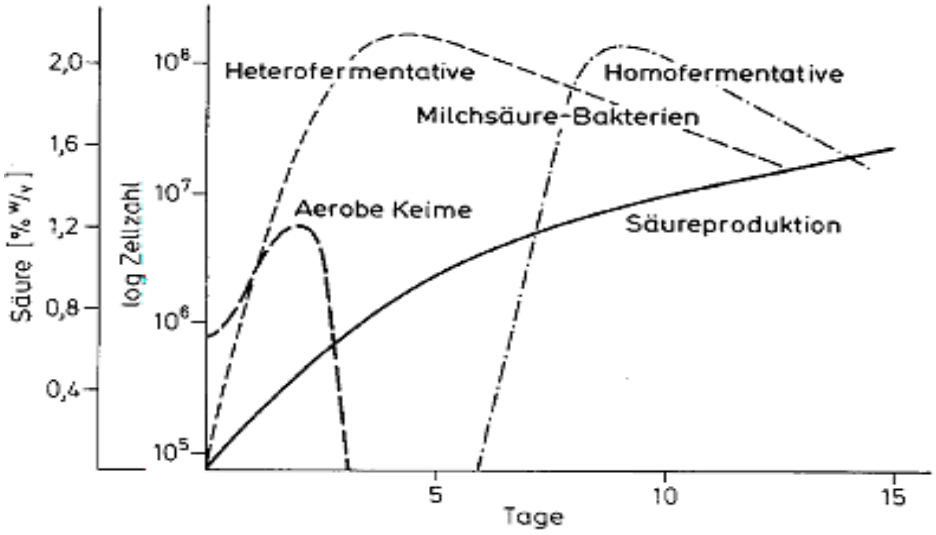


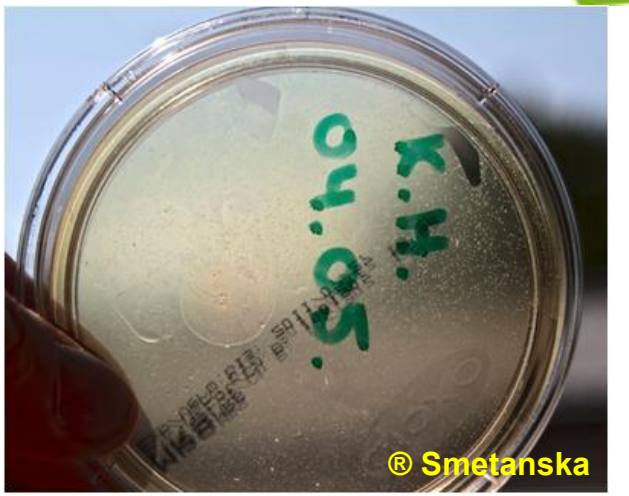
Leuconostoc mesenteroides

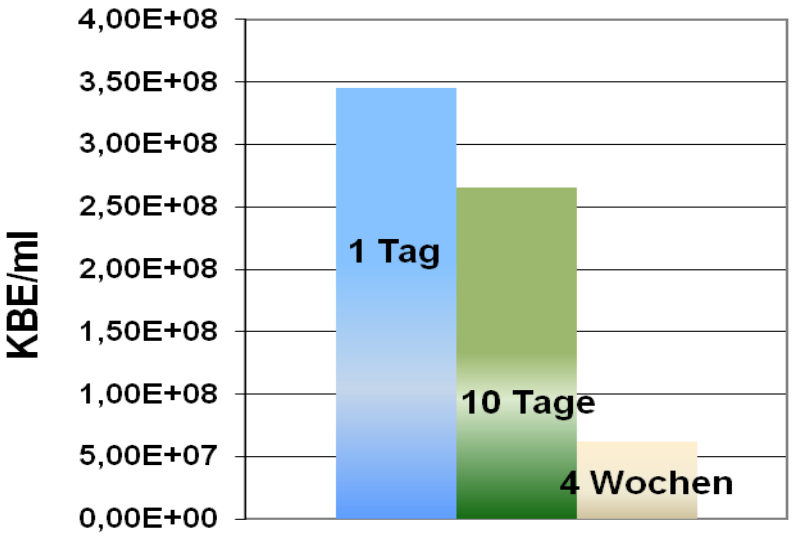
Lactobacillus plantarum

Microbiological changes

Comparison of the bacterial count of sauerkraut juice at different stages of ripeness







HSWT, 2010-2019

Starter cultures

- Traditionally the fermenting organisms came from the natural microflora or a portion of the previous fermentation.
- In many cases the natural microflora is either inefficient, uncontrollable, and unpredictable, or is destroyed during preparation.
- A starter culture can provide particular characteristics in a more controlled and predictable fermentation.
- The primary function of lactic starters is the production of lactic acid from sugars.
- Other functions of starter cultures:
  - flavor, aroma, and alcohol production
  - proteolytic and lipolytic activities
  - inhibition of undesirable organisms
- Instead of starter cultures it is possible to use back-slopping.

Starter cultures

What are starter cultures?

Definition: "Starter cultures are cultivated pure cultures of bacteria, yeasts or molds that are cultivated from undefined, empirically obtained species in order to achieve predictable and reproducible product quality and quantity."

Tasks of starter cultures

Lactic acid fermentation (homofermentative, heterofermentative)

Flavor formation e.g. by MSB in butter (diacetyl) and in yoghurt (acetaldehyde)

Hole formation in the cheese

Acidification ►▼ pH ► Protection against MO (preservation)

Starter cultures

Advantages:

Avoidance of economic losses
- Less incorrect fermentation
- Shortening production processes in terms of time
- Better raw material conversion

Production of better products in terms of
- Flavor
- Safety (microbiological, toxicological)
- Homogeneity

Culture	Food
Lactobacillus	Cheese, bread, sauerkraut, raw sausage
Pediococcus	Raw sausage, vegetables, soy sauce
Micrococcus, Streptococcus	Raw sausage
Lactococcus, Leuconostoc	Milk, butter, cheese, wine
Saccharomyces	Alcoholic drinks, bread, soy sauce
Penicillium	Raw sausage, cheese

Starter cultures

Genetic engineering

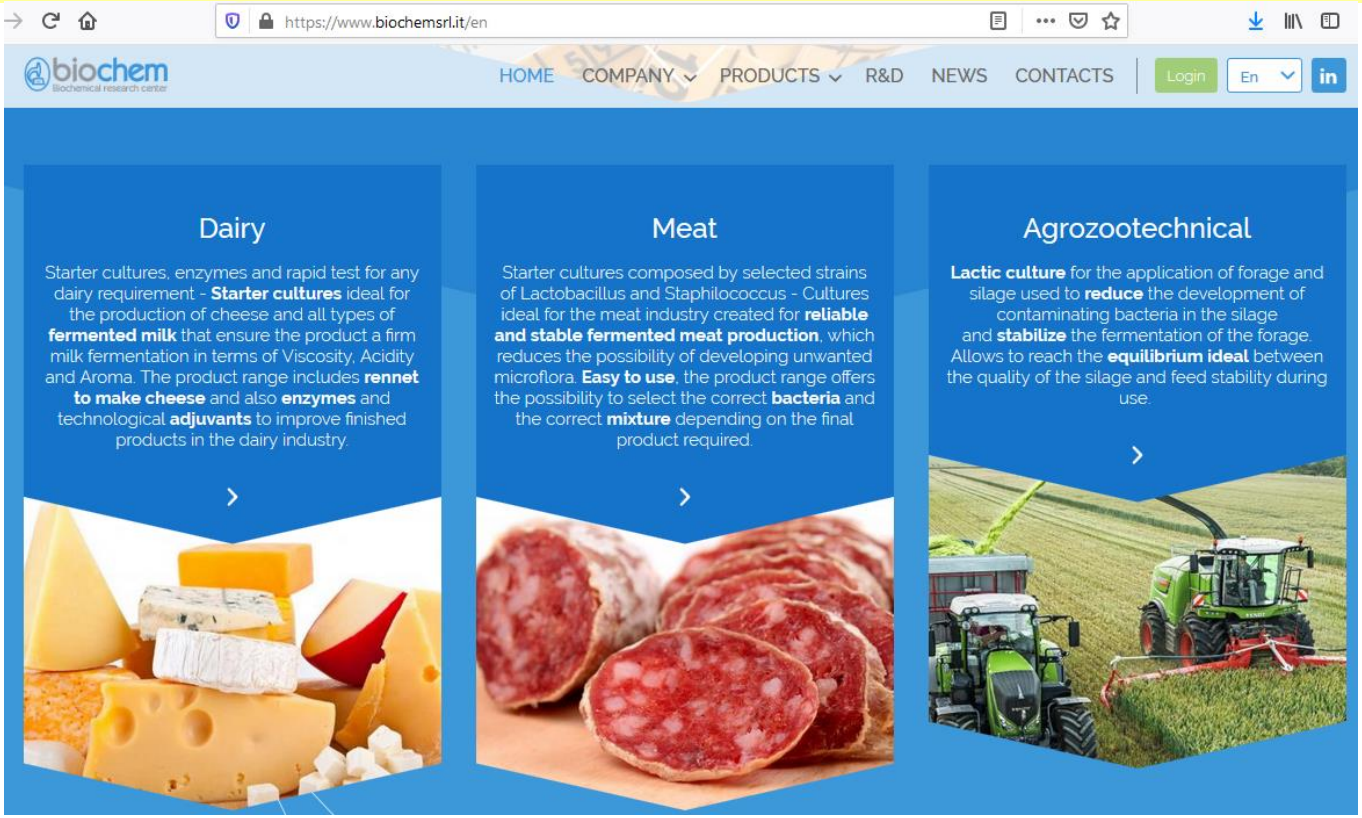
There are currently no approvals in the industry
Several strains have already been genetically modified in science

Goals of change:

- Change in product properties
- Increasing the nutritional and physiological value
- Increase in hygienic product and process safety

Properties	Donor organism	Conception organism
Catalase	*Lactobacillus (Lb.) sake*	*Lb. casei, Lb. curvatus*
α-Amylase	*Bacillus stearothermophilus, Clostridium thermocellum*	*Lb. casei, Lb. lactis, Lb. plantaurum, Lactococcus (Lc.) lactis*
Protease	*Lc. lactis*	*Lb. plantarum*
Lysozyme	*Chicken egg white*	*Lc. lactis*
Lipase	*Staphylococcus hyicus*	*Lb. curvatus*

Starter cultures



Application for economic reasons → more cost-effective

Nutritional expectations of the consumer → mild taste

Guaranteed standardized activity in terms of growth and aroma formation,

Freedom from foreign germs is guaranteed

Product safety/ process safety

Pure starter cultures (Single or Mixed)

Nutritional and physiological changes

- **Low in calories**

Breakdown of carbohydrates, 17 kcal/100g

- Sugar broken down ⇒ good for diabetics

- regulate peristalsis (against stomach ulcers; acetylcholine - activates the pancreas)

- Dietary fiber (satiety, cholesterol-lowering)

- **Minerals**

Synthesis through MO
Fe - improved absorption, against anemia

- **Secondary plant substances**
- Anticancer (isothyocyanates)

- **Dietary fiber**

Feeling of satiety
cholesterol-lowering
regulate peristalsis (against stomach ulcers)
Acetylcholine (activates the pancreas)

Substance group	in 100 g white cabbage	in 100 g sauerkraut
Protein	1,3 g	1,5 g
Glucose	2040 mg	420 mg
Fructose	1760 mg	210 mg
Sucrose	310 mg	140 mg
Calorific value	22 kcal	17 kcal
Potassium	208 mg	288 mg
Zinc	210 µg	320 µg

Nutritional and physiological changes

Vitamins

- Synthesis through MO

Vitamin C
- Antioxidant

- Retention during acidification with pure cultures: 90-100%; spontaneous fermentation: 50-80%
- The faster fermentation begins, the more vitamin C is retained: CO_2 produced during fermentation displaces O_2 (destroys vitamin C)
- after fermentation is complete - vitamin C loss during storage in the air

Vitamin B_{12} - the only source in plant-based foods

Vitamin K - blood formation

Vitamin B_6 - nerve function

Ingredients	1 portion (200g), daily requirement
Vitamin C	40 %
Folic acid	15 %
Potassium	29 %
Calcium	10 %
Iron	12 %
Dietary fiber	17 %

Errors in lactic acid fermentation

Taste, smell, texture	
soft texture	Fermentation temperature too high, salt concentration too low, Absence of anaerobic conditions
Sliminess	*Candida validia, Hansenula anomala* with the formation of a creamy skin
Butyric acid	*Clostridium butyricum* at low pH value
Discoloration	
gray -green	Mold - Insufficient acid formation
White layer on the surface	Mold - harmless layer - can be removed
Black	Hydrogen sulphide-producing bacteria
Red	*Rhodotorula spp.*
Brown	autolytic processes
Other	*Aspergillus spp., Penicillium spp.*

Miso

- traditional Japanese seasoning produced by fermenting soybeans (rice, barley, etc.) salt, koji (Aspergillus oryzae) + “natural” lactic acid bacteria.

Steps in Miso Making:

1. Soaking and Cooking:
2. Inoculation with Koji:
3. Mixing with Salt:
4. Fermentation:
5. Aging:
6. Grinding and Packaging

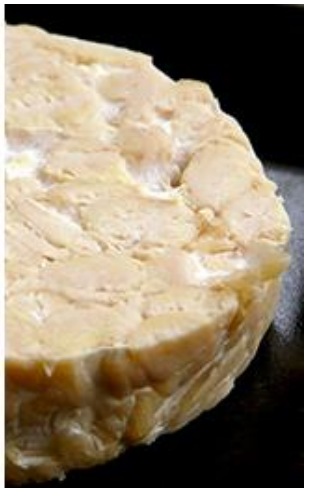
Types of Miso:

- White Miso (Shiro Miso): Light in color, mild and slightly sweet.
- Yellow Miso (Shinshu Miso): Medium in color, balanced flavor.
- Red Miso (Aka Miso): Darker, bold and salty flavor.
- Mixed Grain Miso: Includes other grains besides soybeans.

https://miso-jfoodo.jetro.go.jp/en/recipes/miso-marinated-air-fryer-chicken-kebabs-with-spicy-peanut-sauce/

Tempeh

- **Fermented Asian food produced from soybeans with the help of *Rhizopus oligosporus***
- **Origin: Indonesia**
- **Firm, white cake made from mushroom mycelium with a nutty aroma**
- **is a good source of protein, dietary fiber, and various nutrients (vegetarian or vegan diet, provides a significant amount of plant-based protein).Contains vitamin B12, isoflavones, saponins, all essential fatty acids**
- **High fat content (10%) and protein content (20%)**
- **Free from cholesterol**



Tempeh: Processing

1. Soybeans soaking
2. Cooking
3. Inoculation with *Rhizopus oligosporus*
4. Fermentation

- inoculation with *Rhizopus oligosporus* ► production of ammonia, *L. plantarum*
- incubation at 25-35°C and RH 70-85% for 1-2 days
- ►compact cake in which the beans are held together by the fungal mycelium

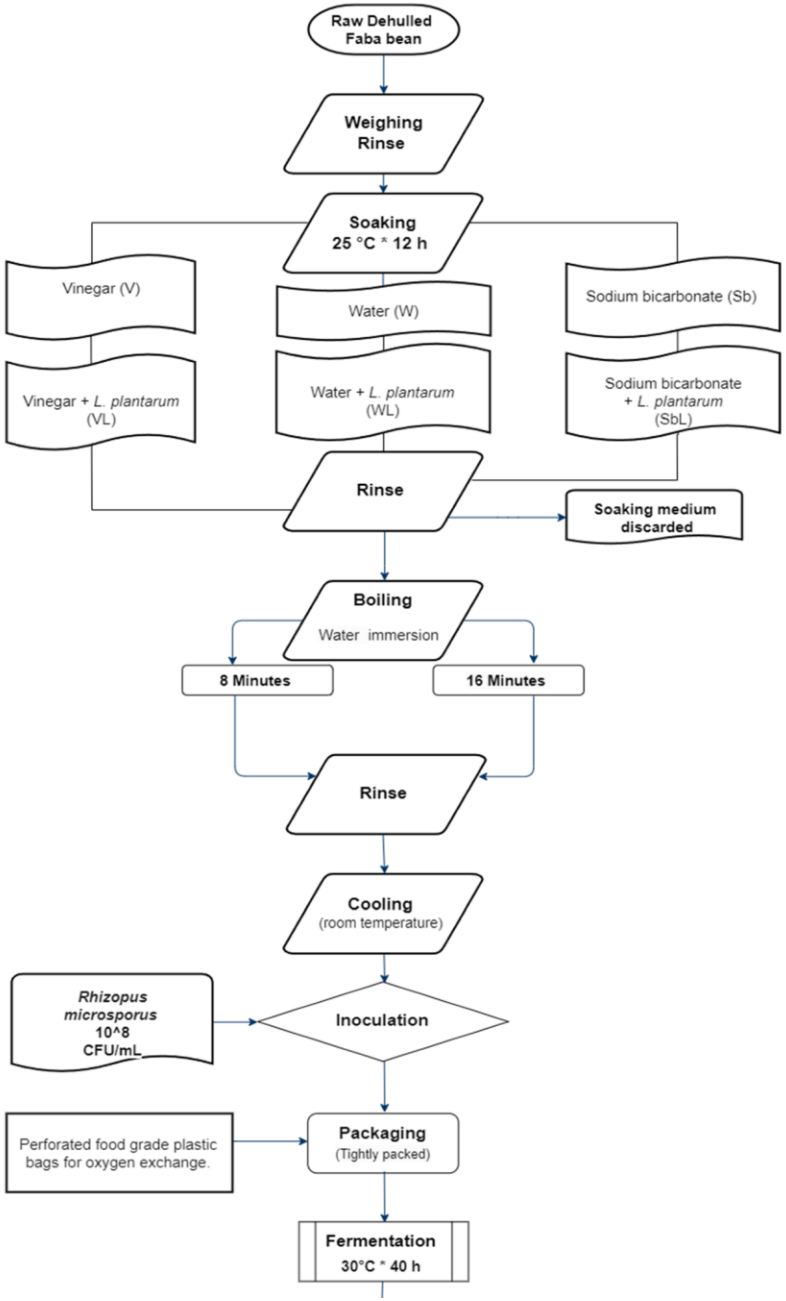
5. Harvesting

• can be kept refrigerated for at least one week, pasteurized longer

• can be sliced, cubed, or crumbled

• can be marinated, stir-fried, grilled, used in soups, stews, and sandwiches

•can also be made with other legume seeds, cereal grains, peanut or coconut press cake



Fernandez Castaneda, L.A.; Auer, J.; Leong, S.-l.L.; Newson, W.R.; Passoth, V.; Langton, M.; Zamaratskaia, G. Optimizing Soaking and Boiling Time in the Development of Tempeh-like Products from Faba Bean (*Vicia faba* L.). *Fermentation* **2024**, *10*, 407. https://doi.org/10.3390/fermentation10080407

Fermented red rice

= red yeast rice or red rice koji

- not to be confused with the red-skinned rice varieties

Fermentation:

- with the mold *Monascus purpureus*
- 3-6 days
- grains turn bright red at the core and reddish purple on the outside

- Available as dried grains, wet paste, or fine powder
- Chinese cuisine and medicine

Health Impact

- Contains monacolin K, similar to cholesterol-lowering medications
- May help reduce cholesterol levels
- Potential benefits for metabolic syndrome and inflammation
- Risk of citrinin contamination, a potentially harmful mycotoxin

Noble rot

Desirable infestation of ripe grapes with the mold *Botrytis cinerea*

- **the mold dissolves the skin enzymatically, causing moisture to escape and evaporate in warm weather ► the sugar content increases**
- **the fungus prefers to break down acids instead of sugar, which favors the high sugar content**
- **Metabolic products of Botrytis lead to the typical aroma of noble sweet wines**
- **Botrytis infestation only desirable in certain grape varieties and at certain times of the year**

https://www.weinco.at/inspiration/ausbruch-43554

Soy sauce

Water + soybeans + grain + salt.

History

-Originated in ancient China
-Made from chi (salted, fermented soybeans) and
- **jiang (fermented soybean paste)**

-Brought to Japan in the 6th century
-The preservative effect contributed to its popularity
-Japanese manufacturing was developed in the 16th century

Chinese soy sauce - light / dark, thick and salty,
Indonesian - thin and sweetish, with palm sugar is called Ketjap Manis
Japanese - Shoju / Tamari, thin and salty
Korean soy sauce

Soy sauce

Traditional production:

1. Beans - ground, cooked + swollen rice or wheat meal mixed with noble mold (*Aspergillus oryzae*).
- Fermentation - 2-year fermentation period - dark, translucent and aromatic liquid.
- Presses
- Weaning
- Heating

Industrial manufacturing process

-Starting product: Soy flour

-Hydrolyzed by hydrochloric acid

-Lactic acid bacteria and yeast are added for fermentation

- ⇨ This reduces the maturing time to a few days
- ⇨ As the taste is very different, naturally brewed soy sauce is often blended with it

Soy sauce

Traditionally brewed soy sauce:

-High in protein, low in fat and calories
-Rich in antioxidants
-High salt content
-No added sugar, colorings or preservatives

Advantages:
-Better taste
-No harmful ingredients

Disadvantages:
-Long, cost-intensive brewing process

Industrially produced soy sauce:

-No antioxidants
-High salt content
-Often with added sugar, coloring and preservatives
-Hydrolysis produces substances such as: Furfural, dimethyl sulfide, hydrogen sulfide and levulinic acid

Advantages:
-Production only takes a few days
-More cost-effective

Disadvantages:
-No health-promoting substances
-Contains by-products of hydrolysis
-Inferior taste

Soy sauce

- Standard soy sauce - 50 % soybeans + 50 % grain
- dark soy sauce - made from 100 % soy
- light soy sauce - saltier, shorter maturing time
- double-processed soy sauce - very strong, for sushi
- Sweet soy sauce - with a high grain content

Use of soy sauce

-Condiments

-Sushi

-Soups, broths

-For marinating meat

-In the industry as a flavor enhancer

⇨ **Not subject to declaration**

Fermented raw sausages

- uncooked meat products that undergo controlled fermentation and drying.
- ▼ pH, harmful microbes
- ▲ flavors, preservation.

Ingrediens :

- pork or beef, fat 20–30% to ensure proper texture and flavor.
- Starter Cultures: *Lactobacillus* spp., *Pediococcus* spp., *Staphylococcus* spp.
- Salt, Sugar, Spices and Additives

Fermentation :

- Conditions: 18–26°C, RH 85–95%
- Lactic acid bacteria ferment sugars to lactic acid, reducing pH to 4.6–4.8.
- Acidification preserves the sausage and gives a tangy flavor

Drying and Aging:

- RH 60–80% at 12–15°C for weeks to months, aw < 0.85

Sour milk products

Yoghurt is derived from the Turkish "yoghurmak" ≙ "to thicken"

Originally from the Balkans

Milk not pasteurized or flash pasteurized (72°C - 75°C, 15- 30 sec)

►Homogenization at 65°C

►Heat to 95°C for approx. 5 minutes ► Formation of homogeneous, smooth yoghurt mass

►Cooling to approx. 40°C

Addition of starter cultures *Lactobacillus bulgaricus* and *Streptococcus thermophilus*

►Fermentation 2-3h, 45°C, up to pH value 4.5

Produced as drinking yoghurt or spoonable yoghurt in various fat content levels:

- **from skimmed milk with max. 0.3 % fat**
- **from low-fat milk with 1.5 to 1.8 % fat**
- **made from whole milk with 3.5 to 4 % fat**
- **as cream yoghurt made from cream with at least 10 % fat**

Sour milk products

Yogurt:
Lactobacillus delbrueckii subsp. bulgaricus and *Streptococcus thermophilus*.

Buttermilk:
Lactococcus lactis and *Leuconostoc* species.

Kefir:
Kefir grains (*Lactobacillus* spp. and yeasts like *Saccharomyces*).

Sour Cream:
Lactococcus lactis.

Cheese

Milk + starter cultures ►acid (preservation) and flavor formation

Curd cheese, sour milk cheese:
Coagulation of casein by lactic acid bacteria
mesophilic acidification cultures (*Lactococcus* 20 - 30 °C)
thermophilic acidification cultures (*Streptococcus, Lactobacillus* 32 - 45 °C)

Sliced, hard cheese:
Coagulation of casein by rennet ferment (proteolytic enzymes)
Parallel acidification by lactic acid bacteria
additional microorganisms:
Camembert, Roquefort: molds
Emmental: Propionibacteria

Lactic acid fermented drinks

- **"Berliner Weiße" is produced using a mixed culture of top-fermenting yeast (*Brettanomyces*) and lactic acid bacteria (*lactobacilli*)**
- **During fermentation, hard malic acid is converted into gentler lactic acid**
- **A slightly sour beer is produced, which can be stored for several years due to the lactic acid formed**

Kombucha

Kombucha is a fermented drink made by fermenting sweetened tea with the Kombucha fungus (tea fungus). The Kombucha fungus breaks down the sugar into carbon dioxide (alcohol content 0.5-2%).

The Kombucha fungus is a symbiosis of lactic acid bacteria, acetic acid bacteria and yeasts. They form a whitish, gelatinous layer on the surface of the tea, with new layers constantly replicating on top.

- **is a natural refreshing, non-caffeinated energy drink (amino acids, polyphenols, vitamins C and B)**

- **is helpful detoxification aid (glucuronic acid, a compound that binds with toxins in the body and safely removes them)**

- **shows immune boosting effects (antioxidants like epigallocatechin gallate, gluconic, glucuronic and acetic acids).**

https://www.about-drinks.com/voelkel-kombucha-vier-sorten-fermentierte-erfrischung-fuer-den-sommer/

Production of Kombucha

- **Kombucha is a fermented drink made by fermenting sweetened tea with a kombucha culture.**
- **Through alcoholic fermentation, the Kombucha fungus breaks down the sugar into carbon dioxide and ethanol (alcohol content: 0.5 - 2 %).**
- **However, the Kombucha fungus is not an independent pliz, but a symbiosis of various yeasts and acetic acid bacteria**
- **Kombucha fermented tea tastes a little sweet and sour and fermented. The drink is drunk cold.**

- Ingredients:
  - Black tea
  - Sugar
  - Scoby (Kombucha mother or mushroom)
  - possibly additives such as raisins

Kombucha made from tea (with dried fruit)

•Tea boiled from 1.5 liters of water: 2 packets of tea bags

•Tea was sweetened with 105g cane sugar and chilled

•Approx. 10 raisins were added to the tea to add flavor

•Part (1/2) of the "kombucha mother" was added to the tea and covered with paper

Future Outlook

Diversity of fermented products :

Indigenous Fermented Vegetables:

Adapted Asian or African recipes

Because of the tremendously important role indigenous fermented vegetables play in food preservation and their potential to contribute to the growing food needs of the world especially in Africa, Latin America, it is essential that the knowledge of their production is not lost and various improvements are made.

Sprouts

Natural colorants

Non-alcoholic drinks

Surface decontamination (Fresh-Cut)

Perspectives

Product variety:

Sprouts

Food colorings

Encapsulation

Drinks

Surface disinfection

Manufacture:

Controlled fermentation: tempering, etc.

Starter cultures

Enzymatic preservation

Beautifying pasteurization:

Physical: UV, O_3

Mechanical: Ultrasonic

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