

1.8: Fermented Vegetables

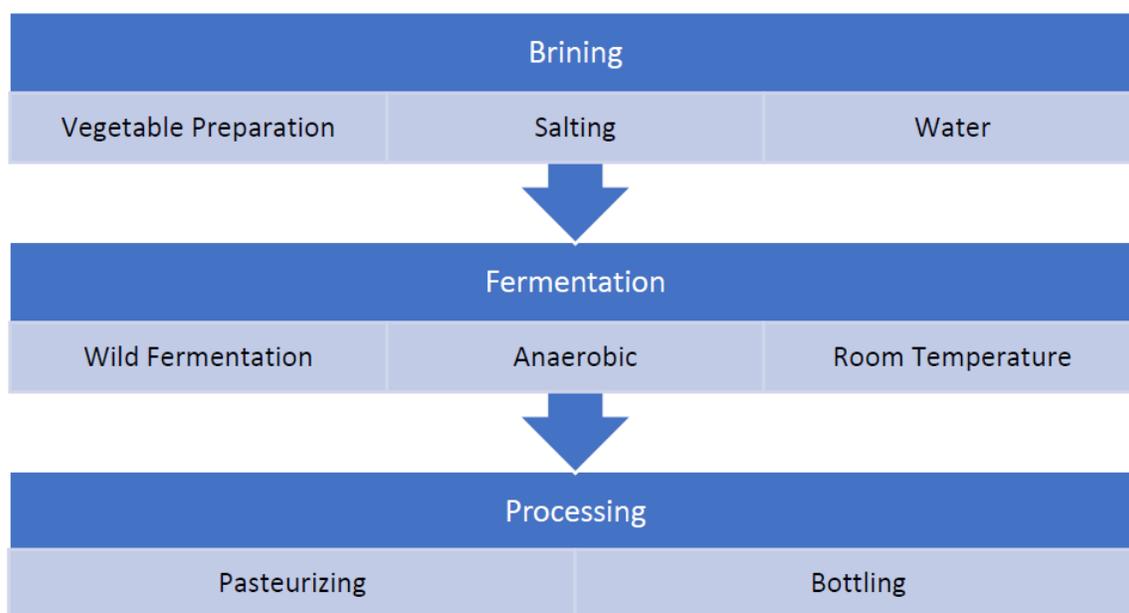
Pickled Vegetables Production

Vegetables may be preserved by fermentation or acidification. The most common commercial fermented vegetables include cucumbers, cabbage, and olives, but there are many other vegetables that have been used.

Definitions:

- **Fermented Vegetables:** vegetables that have been preserved with acid-producing microorganisms (additional acid may or may not be added to the process)
- **Acidified Vegetables:** vegetables that have been preserved the direct addition of acid
- **Pickles:** generic term that refers to either fermented or acidified vegetables but usually refers to the use of acetic acid as the primary acidifying agent

Typical Process for Vegetable Fermentation:



Vegetable Carbohydrates

Carbohydrates in Vegetables: Simple sugars

Fresh cabbage contains about 4-8% fermentable sugars: glucose, fructose, and sucrose. Cucumbers have much lower amounts of these fermentable sugars.

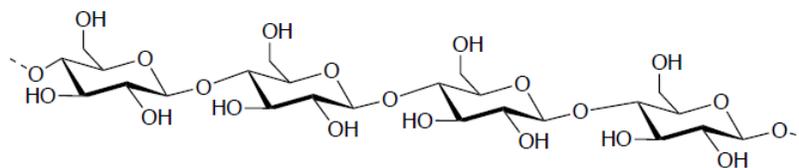
? Exercise 1.8.1

- Draw these three fermentable sugars.
- Cabbage fermentations reach much lower pH than cucumber pickles causing sauerkraut to be more sour than other fermented vegetables. Explain this observation

There are many complex polysaccharides in vegetables that are not fermentable or easily metabolized. This is often called fiber.

Carbohydrates in Vegetables: Cellulose

Cellulose is a linear chain of thousands of linked D-glucose units.



? Exercise 1.8.2

What type of linkages are used in this polysaccharide? Circle the correct designations.

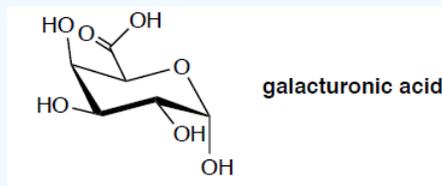
- α or β
- 1-2 1-3 1-4 1-5 1-6 2-4

Carbohydrates in Vegetables: Pectins

Pectin is a polysaccharide made from a mixture of monosaccharides. While many distinct polysaccharides have been identified and characterized within these 'pectic polysaccharide family', most contain stretches of linear chains of α -(1-4)-linked D-galacturonic acid.

? Exercise 1.8.3

- Draw a linear chain of linear chains of α -(1-4)-linked D-galacturonic acid.



Brining

Yeast and many microorganisms are usually present on surface of raw vegetables. Salt, either as a solid or as a brine solution, is added to the vegetable. Shredded cabbage or other suitable vegetables are placed in a jar. Salt, either as a solid or as a brine solution, is added to the vegetable so that is fully submerged. Mechanical pressure is applied to the cabbage to expel the juice, which contains fermentable sugars and other nutrients suitable for microbial activity.

Salt, primarily NaCl, serves several major roles in the preservation of fermented vegetables:

1. High salt concentration limits the growth of many spoilage organisms
2. Salt helps rupturing the membranes, releasing the fermentable sugars into the solution for the bacteria
3. Salt contributes to the flavor of the final pickle

? Exercise 1.8.4

In addition, the salt can prevent the pectinolytic or cellulolytic enzymes from working.

- How might salt impact an enzyme on a molecular level? Consider IMF.
- Why would you want to prevent the pectinolytic and cellulolytic enzymes from working? Consider texture of pickled cucumbers.

Fermentation Process

Fermentation organisms

The fermentation of vegetables usually involves naturally occurring lactic acid bacteria (LAB). This is considered to be a wild fermentation as the LAB bacteria are found naturally on the vegetables. At the start, there are many bacteria that colonize the fresh vegetable; these organisms will compete. As the LAB begin to excrete lactic acid, the pH will decrease, and most other organisms will die.

? Exercise 1.8.5

- Review: Outline the pathway for the formation of lactic acid.
- Some producers will add acetic acid to the brine at the start. Suggest a reason why. The first stage of vegetable fermentation involves anaerobic bacteria, *Leuconostoc* species, that ferments the sugars into lactic acid.
- This is a heterolactic fermentation. What are the other products produced in this process?
- It is important that the fermenting vegetables stay submerged in the brine/acid solution and the system not be exposed to air for the first week. Explain why.

As the pH drops, the environment becomes too acidic for these bacteria to survive and they die out. In the second stage, *Lactobacillus* species that are better adapted to acidic environments will begin to flourish. *Lactobacillus* will continue to anaerobically ferment the remaining sugars into lactic acid until the pH reaches about 3.

? Exercise 1.8.6

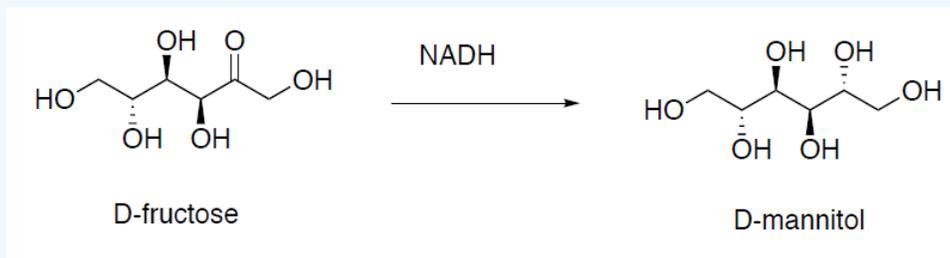
- This is a homolactic fermentation process. What are the products of this type of fermentation?

Fermentation Pathways and Flavor: Mannitol production

In sauerkraut, *Leuconostoc mesenteroides* converts the vegetable sugars, typically glucose, to lactic and acetic acids and carbon dioxide. *Lc. mesenteroides* also uses fructose as an electron acceptor, reducing it to mannitol. Fructose can be used as an electron acceptor being reduced to mannitol; this reaction contributes to the replenishment of the cells' NAD^+ pool.

? Exercise 1.8.7

- Draw a curved arrow mechanism for this process.



- What is the side product formed? How does that help the bacteria?

Given enough time, *Lc. mesenteroides* will continue to ferment mannitol to lactic acid.

- Why does this take time

Fermentation Pathways and Flavor: Mannitol as Contributor to Flavor

Sauerkraut consumption has decreased in the US. In taste comparisons of partially fermented European vs American sauerkraut vs fully fermented sauerkraut, most consumers preferred the flavors of the partially fermented European sauerkraut. The primary chemical differences were higher levels of remaining sugars, mannitol and ethanol (probably from post-processing addition of wine). Mannitol is sweet and has a desirable cooling effect often used to mask bitter tastes. However, 'partially fermented' sauerkraut can cause problems in bulk storage; remaining sugars allow spoilage organisms to thrive (and gas evolution). Fully fermented sauerkraut has no remaining sugars, so it does not need further processing.

? Exercise 1.8.8

- If you were a sauerkraut producer in the US, which process would you use? Defend your answer.

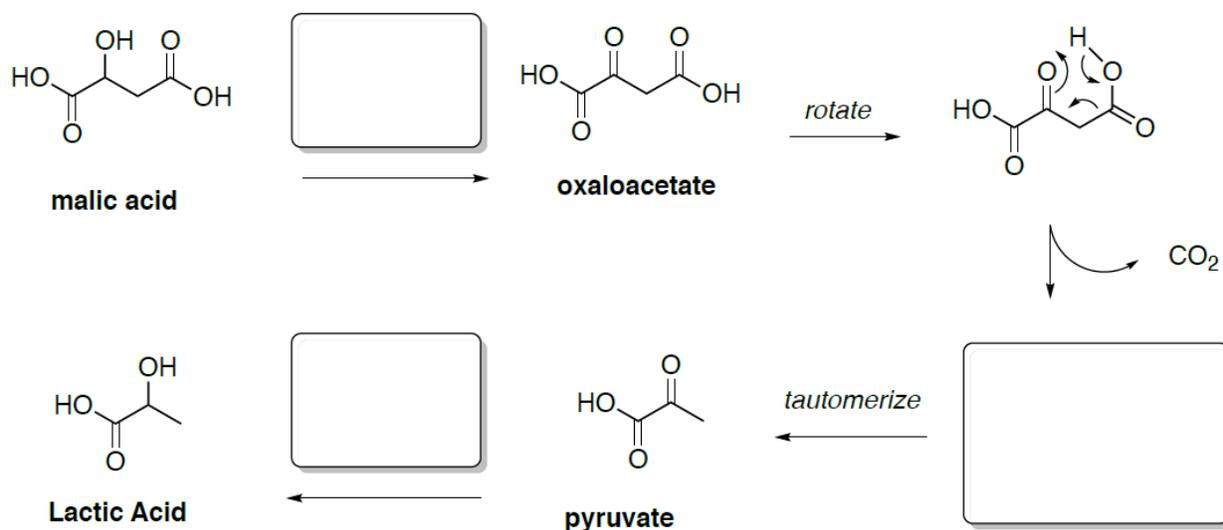
Fermentation Pathways and Flavor: Malolactic Fermentation

Many strains of *Lc. mesenteroides* and *Lactobacillus* can ferment malic acid (naturally found in vegetables) to lactic acid. The **malolactic fermentation** (MLF) involves the conversion of malic acid into lactic acid and carbon dioxide. Some LAB bacteria

convert the malic acid in one step; while others utilize these steps that include intermediates from the TCA cycle.

? Exercise 1.8.9

- Complete the steps in this biochemical pathway to convert malic acid to lactic acid.

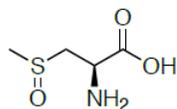


- In cucumber fermentation, this is a problem because the _____ production causes gas bubbles in the cucumbers, softens the pickle, and creates 'bloaters and floaters'.
- '**Heaving**' is a rapid increase in sauerkraut volume resulting in gas entrapment within the sauerkraut and a rise in brine level in the tank. This is a problem in industrial sauerkraut production. It is probably due to malolactic fermentation. Explain.
- Suggest a method for reducing malolactic fermentation in pickle and sauerkraut production.
- On the other hand, malic acid has a harsher and more aggressive flavor than lactic acid. High levels of malic acid decrease the flavor ratings of sauerkraut. How much should the MLF be suppressed?

Sauerkraut Flavor Profiles

Sulfur compounds

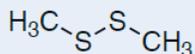
Sulfur aromas and flavors are strongly associated with cruciferous vegetables such as cabbage, radishes, kale, and broccoli. S-Methyl cysteine sulfoxide (SMCSO) naturally occurs in large quantities in fresh cabbage.



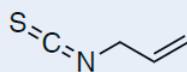
SMCSO
S-Methyl cysteine sulfoxide

Sauerkraut flavors are characterized mostly by salty, sour, and sulfur notes. The sulfur character of sauerkraut can lend both desirable flavors, as well as unfavorable aromas and flavors. This is often dependent upon concentration levels.

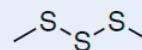
Many of the compounds (shown below) found in sauerkraut are derived from the enzymatic degradation of SMCSO.



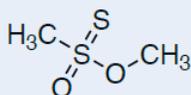
DMDS
Dimethyl Disulfide



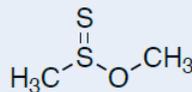
AITC
allyl isothiocyanate



DMTS
dimethyl trisulfide



MMTSO₂
methyl methanethiosulfonate



MMTSO
methyl methanesulfinothioate

DMTS and MMTSO₂ appear to be the most critical compounds for the sauerkraut sulfur flavor.

Caraway spiced commercial sauerkraut is known to be less sulfurous and milder in flavor than traditional sauerkraut, was found to contain no DMTS and the level of the DMDS was also lower. Caraway seeds appear to remove the precursor to these molecules, methanethiol.

? Exercise 1.8.10

- Propose a method for how caraway seeds might reduce the presence of methanethiol

Post-Fermentation

Spices, wines, and other ingredients may be added to the pickles to augment its flavor.

After fermentation and removal from brine storage, cucumbers may be desalted or rinsed to reduce acid content.

? Exercise 1.8.11

- What are some problems associated with decreasing salt or acid content?

Many pickle and sauerkraut products undergo pasteurization in their glass containers before they are sold.

- Why are these products pasteurized?
- What is the downside to pasteurization for vegetables?

Sources

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Johanningsmeier, et. al. Chemical and Sensory Properties of Sauerkraut, *J. Food Sci.*, **2005**, 70(5), 343-349.

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