




Fermentation

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History of Vegetable Fermentation

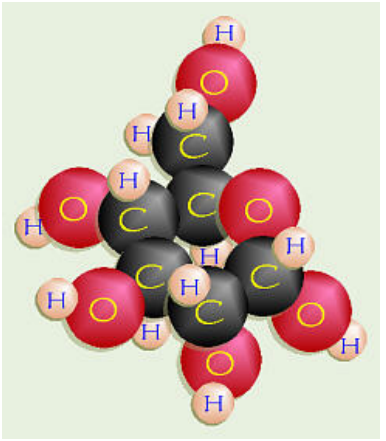
- First fermented foods were probably fermented fruits
- Recorded history of fermented drinks as early as 7000 years ago (Babylon)
- Fermented bread products in Egypt over 3500 years ago
- China thought to be birthplace of fermented vegetables (1112-256 BC)

Fermentation Value

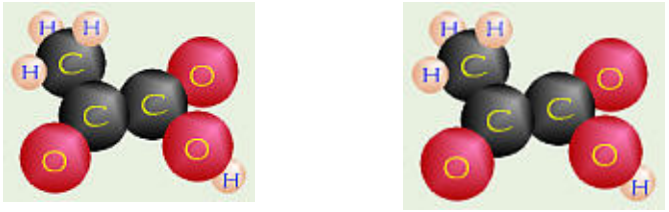
- Increase stability of food that would otherwise spoil
- Increases safety (makes product more acidic)
- Enhances nutrition (fermenting microorganisms produce B Vitamins)
- Increases digestibility (fiber broken down by fermenting microorganisms)
- Provide probiotic microorganisms which may benefit digestive health

Glycolysis

- There are two important ways a cell can harvest energy from food: **fermentation** and **cellular respiration**. Both start with the same first step: the process of **glycolysis** which is the breakdown or splitting of glucose (6 carbons) into two 3-carbon molecules called **pyruvic acid**.



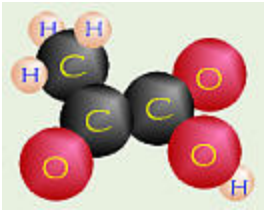
glucose



2 pyruvic acid molecules

Fermentation

- In **fermentation** these pyruvic acid molecules are turned into the “waste product” of lactic acid and energy.



Pyruvic Acid + 2 H+

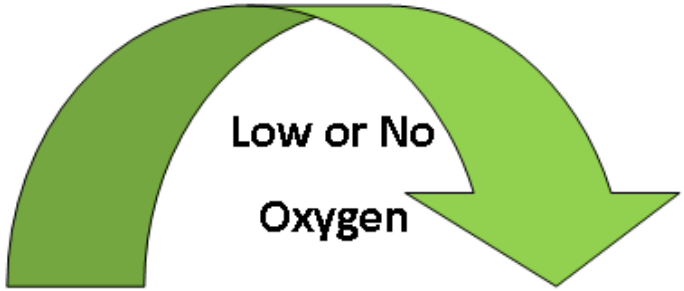
Lactic Acid + 2 ATP + CO2

Fermentation Reaction

Microorganisms

- **Lactic Acid Bacteria**
- **Yeast**

(Probiotics)



Vegetable Carbohydrates

- **Fiber**
- **Starch**
- **Sugars**

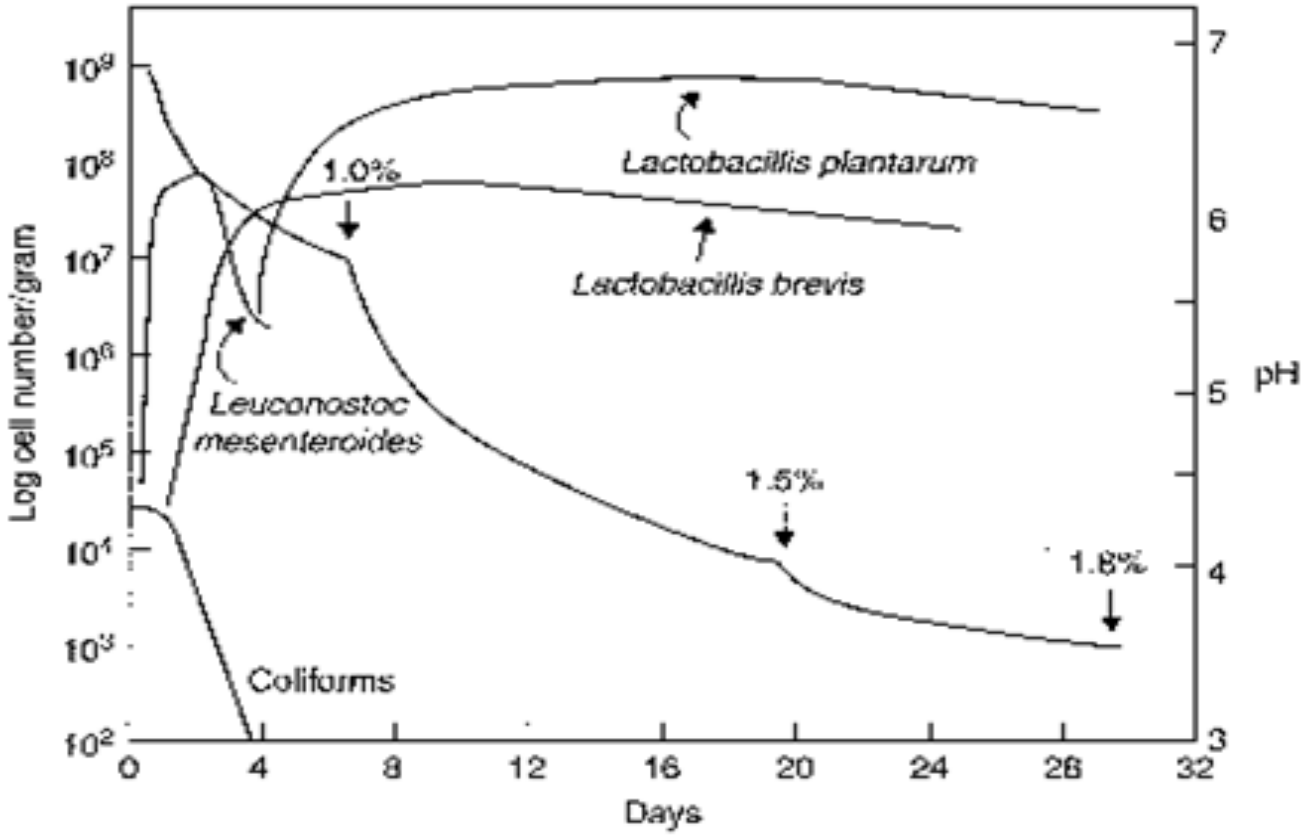
- **Lactic Acid**
- **Acetic Acid**

} **Tart/Sour**

- **Carbon Dioxide Gas—Bubbles**
- **Flavor Compounds**
- **Alcohol!**

Sequential Growth

Figure 1. Sequential Growth of Fermenting Microorganisms in Sauerkraut. (Adapted from Handbook of Vegetable Preservation and Processing 2010)



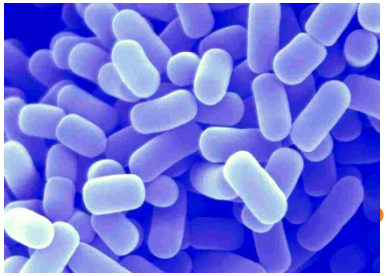
Symbiotic Starters

Yogurt

- *Streptococcus thermophilus*
  - Starts fermentation producing lactic acid; lowers pH to 5.0
  - Lowers pH favors growth of *Lactobacillus bulgaricus*
  - Produces carbon dioxide as by-product benefiting the facultative anaerobe *Lactobacillus*
- *Lactobacillus bulgaricus*
  - Breaks down lactic acid further into acetic acid; lowers pH further to 4.0
  - Produces peptides and amino acids which can be utilized by the Streptococcus
  - Produces acetaldehyde and diacetyl as by-products

Symbiotic Starters: Vegetable Fermentation

- Initiation Stage: Start fermenter growth
  - *Leuconostoc mesenteroides*: sauerkraut, kimchi, olives and low-salt pickles
  - *Pediococcus cerevisiae*: high-salt pickles and olives
- Primary Stage: Rapid growth of fermenters



  - Characterized by acid and carbon dioxide production
- Secondary Stage: More acid produced
  - Lactobacillus brevis and Lactobacillus plantarum

Symbiotic Starters: Kombucha

- SCOBY: Symbiotic Culture Of Bacteria and Yeast
- Resembles vinegar fermentation predominated by yeasts initially
  - Sucrose → Glucose + Ethanol + Carbon Dioxide
- Bacteria
  - Ethanol → Acetaldehyde → Acetic Acid
- Acetic acid and alcohol content should be less than 1% but can be higher
  - Consumer warning: Heathy consumers consume no more than 4 oz. per day
- Final pH approximately 2.5

Components of Fermentation: Culture

- Spontaneous or natural
  - Allow naturally containing fermenters to grow
  - Unpredictable
  - Complex flavor development
- Back-slopping/Mother Culture/SCOBY
  - Add live culture from other fermented products
  - Lowers unpredictability
  - Flavors may not be as complex
  - Acidity of back-slop can affect fermentation
  - Control of culture quality extremely important
    - **Keep culture below pH 4.2 for safety**

Components of Fermentation: Culture

- Culture Inoculation
  - Bacteria culture added (mixture or single species)
  - Substrate usually heat treated to get rid of other microorganisms
  - Flavor complexity can be low but will be more consistent
  - Recommended for first initial batch for Kombucha
  - Must follow directions for culture (i.e. growth temperature)

Components of Fermentation: Food Substrate

- Choose high quality products with no damage or spoilage
- Ensure that products are washed and purchased from a reliable source
- Ensure sanitary practices/cGMPs
- Size matters (Vegetables)
  - Chop/shred vegetables
  - Small pickles ferment better than large pickles

Components of Fermentation: Sugar

- Sugar concentrations usually range from 4-15%
- Alcohol production will naturally stop
  - Yeast enzymes (zymase) inhibited by alcohol concentration
- Yeast have alcohol tolerances
  - Brewer's yeast: 5-6% alcohol
  - Wine yeast: 10-15%
  - Other specialized yeasts: up to 21%
- Sugar substitutes are no substitute

Components of Fermentation: Salt (Vegetable Fermentation)

- Pulls water and sugars from vegetables
- Favors growth of fermenters
- Allows for crisper vegetables
- Decreases mold growth
- Gives flavor to final product

Components of Fermentation: Salt

- Important to fermentation process
- Follow ***validated*** recipe and measure carefully Consistency is important for commercial production.
- Salt concentrations depend on vegetable being fermented
  - Cabbage (sauerkraut): 2.25- 2.5% **by weight**
  - Low-salt pickles: 3-5% **by weight**
  - High-salt pickles: 5-16% **by weight**

Components of Fermentation: Salt

- Low Salt
  - Favor growth of more fermenters
  - Faster acid production/more acid production
  - Mold growth
  - Softer textured product
  - Off-flavors
- High Salt
  - Favor growth of only some fermenters
  - Flavor may not be as complex
  - Crisper vegetables
  - Reduces mold growth

Components of Fermentation: Salt Addition

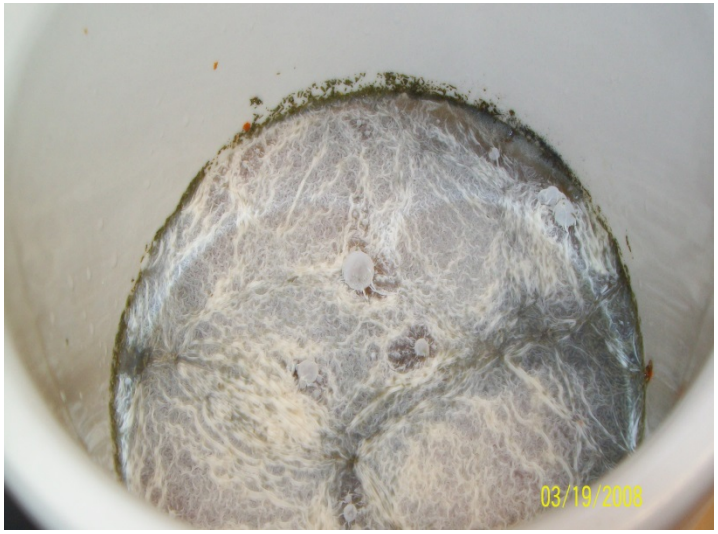
- Direct or dry-salting
  - May want to allow salted vegetables to stand to allow for liquid release
  - Chopping/shredding will help
- Brining
  - Mix salt and water to form brine before adding
  - Better coverage

Components of Fermentation: Salt Quality

- No additives
  - Anti-caking additives cloud brine
  - Iodine brown vegetables and cloud brine
- Avoid natural salts
  - Impurities can reduce acidity, cause bitterness
  - Variability in weight can alter brine strength
- Recommend using canning or pickling salt

Components of Fermentation: Spices

- Follow approved recipes that allow spice addition
  - If no spice addition in recipe, consider adding spices after fermentation complete
- Whole spices over dried/ground spices
- Use new spices (old spices may have mold spores)



Equipment of Fermentation: Containers

- Choose plastic, glass or ceramic
- Avoid metal
  - If using metal, must be high grade stainless (used in the wine/beer fermenting industry for instance)
- Choose container that is:
  - Easy to clean
  - Free from deep scratches, pits or cracks
  - **Lead-free**
  - **Food grade**
- Clean container with hot soapy water and rinse before using (bleach sanitation without not recommended)
  - Water sanitation: 160°F or greater held for 30 seconds or longer

Equipment of Fermentation: Crocks

- Lead-free
- Consider size and shape
  - Vegetable submersion important (1-2” below liquid line)
  - 1 gallon crock size = 5 pounds vegetables
- Covering crock is important

Equipment of Fermentation: Containers

- Plastic
  - High density polyethylene (HDPE)
  - Food grade
    - **Garbage cans and trash bags are not food grade!**
  - Phthalate and bisphenol free
- Glass
  - Ensure not broken, cracked or chipped
  - Wide mouth jars allow for better vegetable submersion
  - Use plastic lids (metal can rust and degrade)
  - Keep lids loose or use specialized fermenting lids

Equipment of Fermentation: Weights

- Used to keep vegetables submerged below liquid
  - Keeps oxygen out and favors fermentation
- Available in different sizes and styles
  - Should completely fill the inside of container and cover vegetables
  - Cleanable
  - Food-grade and lead-free
- **Do not use rocks (may contain impurities)**
- Inexpensive weights
  - Plate or glass pie plate weighted with jars filled with water
  - Food-grade plastic bags filled with brine (1 ½ TBS to every 1 quart water or 4 ½ TBS to every 3 quarts of water)

Equipment of Fermentation: Thermometer

Vegetable

- Fermentation temperature range: 60-78°F
  - Ideal temperature range: 68-72°F
    - 3-4 weeks time at ideal temperature
  - Lower temperatures
    - Slow fermentation time (5-6 weeks)
    - More complex flavors/higher quality
  - Higher temperatures
    - Fast fermentation time
    - Less complex flavor
    - Increase chance of spoilage
- When producing commercially, temperature monitoring is critical

Equipment of Fermentation: Thermometer/Temperature Control

Kombucha

- Usually fermented at room temperature (68-72°F)
  - Yeast best ferments at 64-75°F
- 7-10 days
- pH of product should be below 4.2 in 7 days
  - Fermentation temperature may be too cool
  - SCOBY may be contaminated
- Beyond 10 days acetic acid may accumulate to dangerous levels

Flavor Manipulation Using Temperature: Yogurt

- 44°C (111°F)
  - Favors *S. thermophilus* growth: lactic acid predominant by-product
  - *L. bulgaricus* does not grow well: acetaldehyde and diacetyl produced in low amounts
  - Yogurt is more milky and creamy in flavor
- 38°C (100°F)
  - Favors *L. bulgaricus:* acetaldehyde diacetyl and acetic acid by-products
  - *S. thermophilus* grows slowly producing lactic acid; does not utilize amino acids/peptides produced by *L. bulgaricus* (leaves bitter notes.)
  - Yogurt is more acidic (both lactic and acetic acid are produced) with sour notes of acetaldehyde; yogurt has more of a “bite”

Equipment of Fermentation: pH Measurement

- pH is measurement of acidity
- Fermented product should have a pH below **4.6**
- Use pH meter or pH paper (if product has pH below 4.o)
- Calibration of pH meter essential as part of verification

Components of Fermentation: Acidity Control (CCP)

- Follow recipe carefully
  - Measure salt/sugar carefully
- Keep anaerobic environment
- Watch for gas bubble formation (carbon dioxide)
- Follow appropriate time for temperature range
- Check for mold growth and remove
  - Mold can consume acid and raise pH
  - Best fermentations control mold growth to little or none
- Monitor pH with meter or pH paper
- Maintain pH log

Storing Fermented Products

- Refrigeration
  - Refrigeration (41°F or below) is recommended
  - Containers
    - Fermenting container
    - Kegs
    - Consumer container
  - Quality will suffer over time
  - Fermentation continues and acidity will increase and product will sour
  - Probiotic fermenters will die when acid accumulates to a point of intolerance
  - Danger – gas accumulation if stored in airtight container for too long
  - Airtight containers keep product anaerobic; prevents Kombucha bacteria from converting alcohol to acetic acid

Storing Fermented Products

- Shelf Stable
  - Pasteurization will destroy fermenters
  - Glass jars filled with fermented vegetables should be processed using boiling water bath/hot-fill hold procedure to make shelf-stable (held without temperature control)
    - Recommended in producing commercial shelf-stable product with no temperature control requirements
    - Canning method should be from reliable source validate by process authority
    - Last for at least one year at room temperature without quality loss

Fermentation: Specialized Process

- Food Code views as specialized process
- Requires variance
- Food safety plan needed/HACCP
- Process authority may become involved

Dangers of Fermented Products

- If not produced in sanitary manner, could contain pathogenic organisms
  - In general, low pH will render product unsuitable for pathogens to grow
    - Below 4.6 to eliminate risk of Clostridium botulinum
    - Below 4.2 to reduce risk of pathogenic *E. coli*, *Listeria monocytogenes* and Salmonella
  - Improper fermentations will not have enough acid and low pH
  - Process monitoring is critical
- Alcohol values in Kombucha have been found above 0.5% or **reach values above 0.5% in container**
  - If above 0.5% before or after bottling, tea is subject to TTB regulations and taxation

Dangers of Fermented Products

- Fermented foods are touted to boost immune system
  - If food is not fermented correctly or in an insanitary manner, pathogens (yeast, mold and bacteria) can be present and especially harmful to immunocompromised individuals
- Overeating or drinking fermented foods has led to acidosis (abnormal increase of acid levels in body fluids) – rare but serious and sometimes fatal
  - Cases mostly cited with excessive drinking of Kombucha tea
- Kombucha tea has been used as antiseptic on wounds
  - Can cause infection if pathogens present
  - Cutaneous anthrax case has been reported and linked to use of Kombucha tea placed on skin wounds
  - Allergic reactions have also been reported (mold)

Fermentation Control Points

- Consistency and monitoring is necessary
  - Follow validated process flow
  - Monitor **salt and sugar concentrations** (by weight), **fermentation temperature** and **pH (CCP)**
  - Recordkeeping is a must if wish to validate through process authority
    - Records should be throughout process and not just beginning and endpoint
- Proper sanitation important for both safety and quality
- Recommend running same fermentation for full year before submitting data (document seasonal changes)
- Scaling up (especially if ingredients are not by weight) may not be straight forward

Fermentation Recipe Validation

- Cucumber, kimchi and sauerkraut recipes have been validated and published from scientific sources
- No published Kombucha recipes are validated by scientific sources
  - Producer could generate data which could be validated by a process authority
  - Brian Nummer publication: *Kombucha Brewing Under the Food and Drug Administration Model Food Code: Risk Analysis and Processing Guidance*
- Colorado State is in process of producing information and recipes
  - Kimchi Information Sheet
  - Making Kimchi
  - Kombucha Information Sheet
  - Health Benefits of Kombucha
  - Making Kombucha Tea
- Dr. Fred Breidt (N.C. State and USDA ARS working on models for predicating pH in certain fermentations (will also pass along)
- Process authority associations and working groups

Questions?

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