Produce Fermentation

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Opening

There is an increasing interest with food entrepreneurs and processors making non-heated-processed fermented food. Part of the increased interest in selling these types of products has to do with the passage of SD HB 1322 which allows processors to sell non-heated-processed fermented foods under the cottage food laws as long as they adhere to the laws by taking the state-certified online training and ensuring the food is consistently maintained and sold at a temperature that is at or below 41°F. In this article, we will explore the science and food safety of produce fermentation in the hope that processors will understand the process and risks with making naturally fermented vegetable products. For the purposes of this article, I will only address fermentation of fruits and vegetables and exclude other fermented products such as kombucha, sourdough bread, cheese and other products.

What is Fermentation

First, we must start with an understanding of what fermentation is. Fermentation can simply be understood as a process where microorganisms such as bacteria and yeasts will convert carbohydrates (sugar and starches) into acid, carbon dioxide, and other compounds under anaerobic conditions. Thus, fermentation requires carbohydrates, bacteria which will convert the carbohydrates to lactic acid, and an anerobic environment with optimal salt/brine concentrations that will allow lactic acid bacteria (LAB) to grow and out compete other microorganisms. Anaerobic conditions are defined as environments with low or no oxygen. In aerobic conditions or rather, oxygen-rich environments, there are other microorganisms present on vegetables that contribute to spoilage and rotting. However, in fermentation, the environmental conditions are sub-optimal for pathogens and other organisms that compete with LAB. Thus, these organisms cannot survive, and their growth is inhibited by the growth of LAB.

The first condition that creates an environment for fermentation is the anaerobic environment and salt concentration. The salt concentration acts as a means to pull water from the cells of bacteria which can cause dehydration and the death of certain bacteria. However, pathogens can be salt tolerant and can survive in high salt concentrations. Additionally, although one may think that the lack of oxygen may kill pathogens, this would be an incorrect assumption. For example, salmonella, e. coli, and listeria monocytogenes are facultative anaerobes which means they prefer oxygen rich environments but can survive under anaerobic conditions. This is shown in Table A-1. Therefore, anaerobic conditions do not guarantee the death of these types of pathogens. However, the anaerobic conditions are favorable conditions for LAB where they grow quickly and outcompete other organisms by converting sugar to acid which inhibits the growth of other organisms. Not only does the salt pull the water out of the cells of bacteria, it also pulls water out of the vegetables as well as water-soluble nutrients such as sugars and starches and makes them available for fermentation.

The second condition that creates an environment for fermentation is the acidic environment. As the lactic acid bacteria (LAB) converts the available sugars into lactic acid, this will increase the acidity and decrease the pH. The production of acid lowers the pH and limits the growth of harmful pathogens. Table A-1 is from Fish and Fishery Products Hazards and Controls Guidance on the minimum pH growth conditions needed for growth of certain pathogens (1). As we see in the diagram below, once the pH drops below 3.7, this creates conditions where growth of other harmful pathogens is no longer possible.

Table A-1 Limiting Conditions for Pathogen Growth							
Pathogen	Min. A_w (Using Salt)	Min. pH	Max. pH	Max % Water Phase Salt	Min. Temp	Max. Temp	Oxygen Requirement
BACILLUS CEREUS	0.92	4.3	9.3	10	39.2°F 4°C	131°F[1] 55°C	facultative anaerobe[4]
CAMPYOBACTER JEJUNI	0.987	4.9	9.5	1.7	86°F 30°C	113°F 45°C	micro-aerophile[2]
CLOSTRIDIUM BOTULINUM, TYPE A, AND PROTEOLYTIC TYPES B AND F	0.935	4.6	9	10	50°F 10°C	118.4°F 48°C	anaerobe[3]
CLOSTRIDIUM BOTULINUM, TYPE E, AND NON-PROTEOLYTIC TYPES B AND F	0.97	5	9	5	37.9°F 3.3°C	113°F 45°C	anaerobe[3]
CLOSTRIDIUM PERFRINGENS	0.93	5	9	7	50°F 10°C	125.6°F 52°C	anaerobe[3]
PATHOGENIC STRAINS OF ESCHERICHIA COLI	0.95	4	10	6.5	43.7°F 6.5°C	120.9°F 49.4°C	facultative anaerobe[4]
LISTERIA MONOCYTOGENES	0.92	4.4	9.4	10	31.3°F -0.4°C	113°F 45°C	facultative anaerobe[4]
SALMONELLA SPP.	0.94	3.7	9.5	8	41.4°F 5.2°C	115.2°F 46.2°C	facultative anaerobe[4]
SHIGELLA SPP.	0.96	4.8	9.3	5.2	43°F 6.1°C	116.8°F 47.1°C	facultative anaerobe[4]
STAPHYLOCOCCUS AUREUS GROWTH	0.83	4	10	20	44.6°F 7°C	122°F 50°C	facultative anaerobe[4]
STAPHLOCOCCUS AUREUS TOXIN FORMATION	0.85	4	9.8	10	50°F 10°C	118°F 48°C	facultative anaerobe[4]
VIBRIO CHOLERAE	0.97	5	10	6	50°F 10°C	109.4°F 43°C	facultative anaerobe[4]
VIBRIO PARAHAEMOLYTICUS	0.94	4.8	11	10	41°F 5°C	113.5°F 45.3°C	facultative anaerobe[4]
VIBRIO VULNIFICUS	0.96	5	10	5	46.4°F 8°C	109.4°F 43°C	facultative anaerobe[4]
YERSINIA ENTEROCOLITCA	0.945	4.2	10	7	29.7°F -1.3°C	107.6°F 42°C	facultative anaerobe[4]

1 Has significantly delayed growth (>24 hours) at 131°F (55°C).
2 Requires limited levels of oxygen.
3 Requires the absence of oxygen.
4 Grows either with or without oxygen.

Table A-1 Limiting Conditions for Pathogen Growth

Under anaerobic conditions, optimum salt concentration, and the rapid fermentation by LAB and yeasts, other microorganism growth is inhibited by LAB competition, and the other microorganisms die off within a few days of the onset of fermentation (2). We will discuss this more in the pathogen lethality section of this article.

Vegetable Microflora

The number of organisms on fresh fruits, grains, and vegetables can range greatly from as low as 10^2 to 10^9 aerobic colony forming units (CFU) per gram (2). Additionally, the amount of LAB on vegetables may vary. For example, on pickling cucumbers, there can typically be between 10^4 to 10^6 cfu/mL of aerobic microorganisms with less than 10^1 cfu/g for LAB (2). Another example where microorganism counts can vary is cabbage and lettuce. The counts of viable LAB on cabbage, Chinese cabbage, and lettuce samples from a study showed counts of 10^3 to 10^4 and 10^6 to 10^7 for aerobic bacteria (3). Thus, the starting number of LAB and other organisms can have an impact on the fermentation process. This is important to keep in mind because not all vegetables have the same count, concentration, or types of LAB. Thus, the fermentation time, salt concentration, and temperature ranges can and will vary by vegetable.

Additionally, there may also be the presence of pathogenic bacteria such as salmonella, shigella, listeria monocytogenes, escherichia coli, and other harmful viruses. These harmful pathogens and viruses may come from exposure to manure, insects, animals, poor personal hygienic practices, post harvest contamination, and storage conditions. It is important to understand that the likelihood of harmful pathogens or viruses could be present on vegetables. Table A-2 represents the microorganisms that can be present on fresh vegetables (4).

Organisms	Log CFU/g	Abundance (%)
Aerobic Bacteria *Pseudomonas* *Flavobacterium* *Micrococcus* *Bacillus*	4-6	1-6
Lactic acid bacteria *Lactobacillus* *Pediococcus* *Streptococcus* *Teragenococcus* *Leuconostoc*	0.7-4	1-7
Enterobacteriaceae *Enterococcus* *Enterobacter* *Klebsiella* *Escherichia*	3-3.5	20-60
Yeasts and Mold *Fusarium* *Ascochyta* *Aspergillus* *Penicillium* *Rhodotorula*	0.3-4.6	Not Determined

Table A-2 Enumerative data adapted from Nout and Rombouts, 1992 and abundance data from Leff and Fierer, 2013.

Thus, it is important to use good hygienic practices and safely handle the food, use appropriate and clean fermenting containers, monitor time, monitor pH, and monitor the product for unusual mold growth.

Vegetable Selection

It is important to select vegetables that are free from damage, disease, or visible rotting and spoilage. Selecting vegetables that are damaged, diseased, rotting, or spoiling will have an impact on the fermentation process. Therefore, selecting vegetables that are in good condition and absent from defects is important.

It is also important that you select the vegetables that are called for in an evidence-based recipe. Not all vegetables will ferment the same depending on their size. Larger size vegetables may not ferment as well as smaller size vegetables. Additionally, it cannot not be assumed that an evidence-based fermentation recipe for pickles can be applied to cabbage/sauerkraut because of the difference in LAB counts, type of product, optimal salt concentration, and more.

Washing Procedures

After selecting the vegetable of choice, it is important to wash the vegetables. It is important to note that washing vegetables has a minimal effect in decreasing bacterial cell numbers. In a study, it was shown that washing with water or chemical sanitizers resulted in only a 1 to 2 $\log_{10}$ decrease in bacterial cell numbers (2). The reason that washing has a modest effect on removing bacteria from produce can be attributed to whether the bacteria may be protected and inaccessible from washing due to wounded regions and pores. There may also be other factors such as temperature and pressure which can contribute to the effectiveness of washing and removing bacteria from produce. Regardless, this is

an important step to not only wash and rinse away soil and undesirable filth but also wash and partially remove microorganisms.

Starting Concentration of Lactic Acid Bacteria on Cabbage, Sauerkraut, and other Vegetables

As we mentioned earlier, the starting number of LAB may vary depending on the type of vegetable or produce that is used. Not only this, but there are different LAB families in vegetable fermentation which can include such organisms as *Leuconostoc, Lacobacillus*, and *Pediococcus spp* (4, 5). LAB organisms are responsible for converting sugar to byproducts such lactic acid, acetic acid, carbon dioxide, and ethanol (5, 6). The lactic acid and acetic acid byproducts serve to reduce the pH and inhibit the growth of other bacteria while the production of carbon dioxide contributes to preserving the anaerobic environment. As noted above, the starting LAB cell counts can vary from as much as 10^1 to 10^6 depending on the type of vegetable (3).

Lactic Acid Bacteria Fermenters and Fermentation Chemistry

The sequential growth of LAB can be broken out into specific stages: initiation, primary, and secondary fermentation (5). The initiation stage is where the salt-tolerant LAB that is present in the vegetable will quickly grow. If there is a fermentation culture added which is not naturally occurring on the vegetable, it would be added in this first sequential initiation stage.

The next stage would be the primary stage where most of the fermentation occurs. This is the stage where there is rapid growth of LAB and the production of byproducts such as acid and carbon dioxide. The combination of acid production and carbon dioxide contributes to an environment that favors LAB which also inhibits the growth of other bacteria. Toward the end of the primary stage and at the beginning of the secondary stage, the primary fermenting bacteria die as more acid is produced (5).

The final stage is secondary fermentation. In this stage, the fermenters that are acid-tolerant will finish the fermentation process and add more acid and byproducts such as carbon dioxide and flavor components. Acid-tolerant LAB that are responsible for the secondary fermentation include *Lacobacillus* brevis and *Lactobacillus plantarum*. The fermentation will stop when enough acid accumulates and kills the LAB or through a kill-step that inactivates the fermenters. The graph in diagram 1 gives us a helpful visual of the growth of different LAB throughout the fermentation cycle of sauerkraut. We'll make several points as we work our way through this diagram.

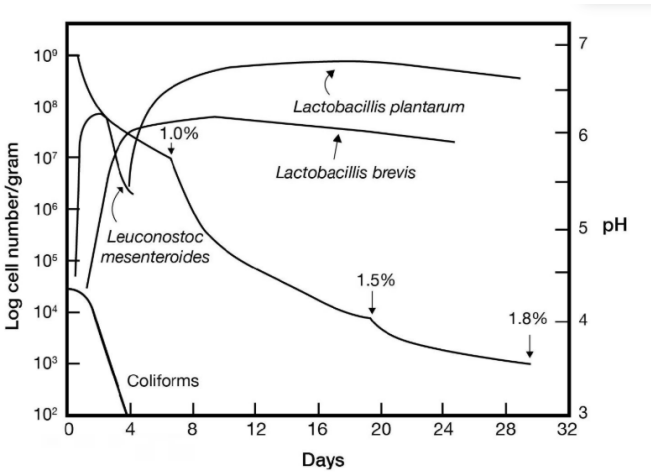

Diagram 1 – Sequential growth of fermenting microorganisms in sauerkraut. (Taken from Joell Eifert).

First, we can see in the initiation stage, there is rapid growth of *Leuconostoc mesenteroides* (yellow arrows) and a steep decline in the cell count of coliforms (green dotted line). Additionally, we see a decline in the pH which drops from 7 to 6.5 in a couple days (blue circle).

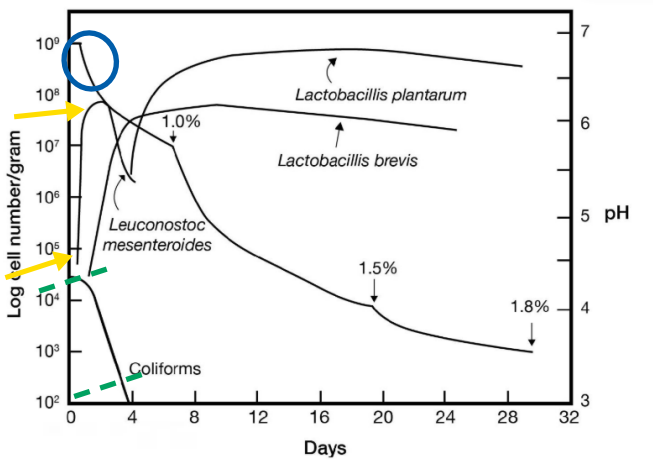

Diagram 1A – Bacterial kinetics and acid production in the initiation stage

The second point we see is that there is a decline in *Leuconostoc mesenteroides* (yellow arrows) as there is an increase in acid production and drop in pH. As *Leuconostoc mesenteroides* dies off, we see another LAB, *Lactobacillis brevis*, begin growing rapidly which spans across the initiation stage and primary stage (green dotted line). We also see *Lactobacillis brevis*

produces acid and continues to drop the pH over the course of two to three weeks (blue circles). Although this graph doesn't show the other byproducts that are created, the LAB also contributes flavor and aroma compounds to the vegetable product. Other byproducts include peroxides, amines, thiols, bacteriocins, and other enzymes (2). As mentioned earlier, it's not the anaerobic environment, the salt concentration, or solely the pH that leads to the death of other microorganisms. Rather, it's a combination of the byproducts that are produced by the LAB and other fermenting microorganisms, conditions which favor LAB, pH, and other fermenting microorganisms growing rapidly which leads to the death of other vegetative pathogens (2). Eventually, *Lactobacillis brevis* reaches a stationary phase (red box) where nutrients are consumed, and growth slows and then enters into the death phase and dies off (purple box).

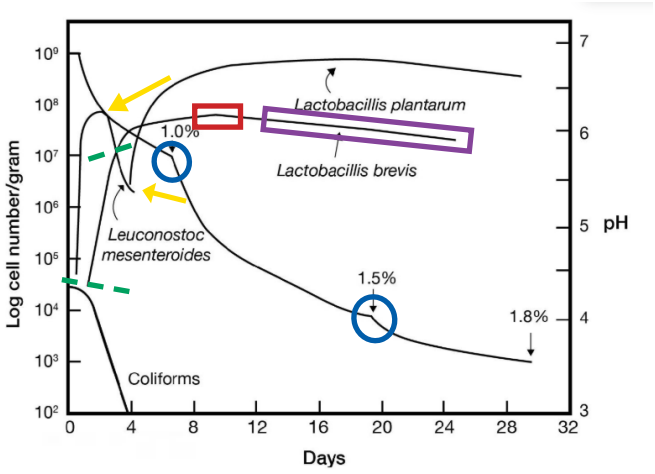

Diagram 1B - Bacterial kinetics and acid production in the primary stage

The third point we see is that there is another LAB, *Lactobacillis plantarum* (navy box), that continues to produce acid in the secondary stage. *Lactobacillis plantarum* is more resistant to acid which allows it to survive and continue to produce acid in the later stage. Eventually, as more acid is created and the pH drops, *Lactobacillis plantarum* enters the stationary phase where there is no more growth and then eventually the death phase where it will die off.

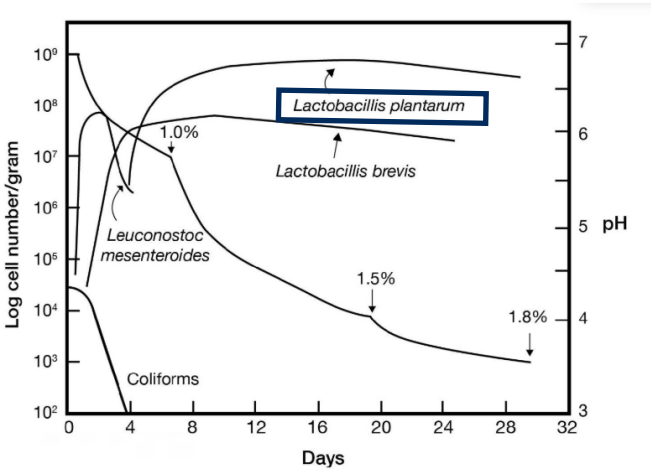

Diagram 1C - Bacterial kinetics and acid production in the primary stage

As we can see, microbiological interactions in fermentation can be complex and serve to help us understand how LAB grow, produce acid, produce carbon dioxide, produce flavor and aroma compounds, out compete and inhibit other organisms, and eventually die off. Thus, when we consider these graphs as well as what we've learned thus far, we understand that fermentation can be impacted by the following factors:

- Types of LAB present
- Amount of LAB present
- LAB starter cultures which can be added and alter the fermentation process depending on where it's added
- Temperature of the brine and vegetable
- Salt/brine concentration
- Quality of vegetable (defects and damages)

To highlight the wide variety of LAB that is present on vegetables and fruit, I've included a chart which highlights the different types of LAB and microorganisms present on a variety of different produce (7). The associated studies show the wide range of LAB that is present. These studies document and detail the differing cell counts of LAB and other microorganisms that are present throughout the fermentation process. These studies also document differing temperatures and unique conditions that contribute to the unique fermentation of each individual product.

Fermented Food Product	Country	Fruit and/or Vegetable	Other Ingredients	Microorganisms	Reference
Burong ustala	Philippines	Mustard leaf	Rock Salt	*L. brevis* *Pediococcus cerevisiae*	8
Ca muoi	Vietnam	Eggplant	N/A	*L. fermentum* *L. pentosus* *L. brevis*	9, 10
Dakguadong	Thailand	Mustard leaf	Salt	*L. plantarum*	11
Dhamuoi	Vietnam	Cabbage, Various Vegetables	N/A	*Leuconostoc mesenteroides* *L. plantarum*	12
Gundruk	Nepal, India	Cabbage, Radish, Mustard, Cauliflower	N/A	*Pediococcus and Lactobacillus spp.*	12, 13, 14
Inziangsang	India	Mustard Leaf	N/A	*L. plantarum* *L. brevis,* *Pediococcus acidilactici*	13, 15
Jiang-gua	Taiwan	Cucumber	Salt	*Weissella cibaria* *W. hellenica* *L. Plantarum* *Leuconostoc lactis* *Enterococcus casseliflavus*	16
Khalpi	Nepal	Cucumber	N/A	*L. plantarum* *Pe. Pentosaceus*	13, 14
Kimchi	Korea	Cabbage, Radish, Various Vegetables	Garlic, Red Pepper, Green Onion, Ginger, and Salt	*Leuconostoc mesenteroides* *L. brevis* *L. plantarum* *L. sakei*	17
Nozawana-Zuke	Japan	Turnip	N/A	*L. curvatus*	18
Olive	Spain, Italy	Olive	Salt	*L. plantarum* *L. brevis* *L. pentosus* *P. cerevisiae* *L. mesenteroides*	19, 20
Pak-Gard-Dong	Thailand	Mustard Leaf	Salt and Sugar Solution	*L. brevis* *P. cerevisiae* *L. plantarum*	21
Paocai	China	Cabbage, Celery, Cucumber, and Radish	Ginger, Salt, Sugar, Hot Red Pepper	*L. pentosus,* *L. plantarum* *Leuconostoc mesenteroides* *L. brevis* *L. lactis* *L. fermentum*	15, 22
Pobuzihi	Taiwan	Cummingcordia	Salt	*Lacobacillus pobuzihii,* *L. plantarum* *W. cibaria* *W. paramesenteroides* *P. pentosaceus*	23, 24

Fermented Food Product	Country	Fruit and/or Vegetable	Other Ingredients	Microorganisms	Reference
Sauerkraut	Intl	Cabbage	Salt	*L. mesenteroides* *L. plantarum* *L. brevis* *L. rhamnosus* *L. plantarum*	25, 26, 27
Sayur Asin	Indonesia	Mustard, Cabbage	Salt, Liquid from Boiled Rice	*L. mesenteroides* *L. confuses* *L. plantarum* *P. pentosaceus*	28

Table 2 - Sources of Lactic Acid Bacteria on Vegetable and Fruit

Pathogen Lethality and pH Monitoring

As mentioned earlier, acid production and LAB growth and competition are important factors which inhibit and eliminate pathogens. There have been studies which have looked at the relationship between pH drop and a 5-log reduction of *Escherichia coli* O157:H7 in commercial fermented vegetables (30, 31). The study found that as acid accumulated and the pH of the brine dropped, the 5-log reduction time correspondingly dropped. For example, a sterilized commercial brine having little or no lactic acid at the start of fermentation took 3 weeks to achieve a 5-log reduction while a similarly prepared commercial brine with a pH of 3.1 and 150mM lactic acid took 3 days to achieve a 5-log reduction. Thus, this study demonstrated that there is pathogen death as the LAB grows and the pH drops. If there is successful fermentation, this should lead to a 5-log reduction in pathogens.

Additionally, general guidelines suggest that effective fermentation typically reaches a pH of ≤4.6 within a week after start of fermentation (36). It is also recommended that the pH be considered a critical control point (CCP) with the critical limit being a pH ≤4.6. The pH can be measured from the brine of the fermentation and it's recommended to take two or three distinct measurements at each time point (36). Additionally, it's recommended to take pH readings at designated time intervals such as every 12 hours under ambient temperature or every 24 hours under refrigerated temperatures until a pH ≤4.6 is achieved (36). *C. botulinum* can grow in anaerobic conditions in high water activity products with a pH >4.6. Thus, the fermentation process needs to ensure that the pH is ≤4.6. A pH >4.6 would render the product unsafe as *C. botulinum* would be able to grow and produce toxin.

It should be noted that if there is mold growth, this could impact pathogen reduction as some mold can consume acid and decrease the total amount of acid in the brine and increase the pH.

Starting Cultures

There are three different methods in which a microbiological culture can be used in fermentation. These methods include spontaneous/natural, back-slopping, and culture inoculation. In home food preservation, it is likely that most home processors will use a natural or spontaneous method while mid or large-scale commercial producers may use culture inoculation to control the fermentation process.

Spontaneous or Natural

This method allows the natural and present LAB and fermenting microorganisms to grow. This method does not use a starter culture and does not pasteurize, or heat treat the vegetable prior to fermentation. Because there may be differing levels and differing types of LAB present, this method has the least amount of control. However, since the LAB and fermenting microorganisms are allowed to go through the whole fermentation cycle, it produces the most flavor and aroma byproducts (5).

Back-slopping

This method uses live bacteria from a fermented product to start other batches. This method disrupts the natural or spontaneous fermentation because it does not allow for the natural or spontaneous growth of LAB and fermenting microorganisms. This would impact the initiation stage. Thus, the flavor and aroma byproducts that are normally produced in the initiation stage are bypassed. There are other changes to texture and overall product quality that may be impacted by using back-slopping. Therefore, it's important to note that this method could yield a different product quality for the same type of fruit or vegetable.

Culture Inoculation

This method uses specific bacterial culture with known counts to initiate fermentation. This method is used more

in commercial production to deliver consistent product quality. Additionally, vegetables would be heat treated prior to use to ensure that the same microbiological cell count is used to start each fermentation. If a home-processor would desire to use a culture, they should follow an evidence-based recipe. As we've learned earlier, not all LAB are created equal and adding a LAB at a certain stage in the fermentation process does not mean they will grow and ferment because it depends on the LAB that's already present, the salt concentration, pH, temperature, and other factors.

Purpose and Function of Salt

Salt is a very important ingredient in the fermentation process. Below are the functions of salt in fermentation (5):

- Contributes to osmosis which pulls water and carbohydrates from the vegetables. This process of osmosis makes carbohydrates available to the LAB and other fermenting microorganisms
- Creates favorable conditions for LAB and other fermenting microorganisms.
- Salt will decrease the activity of pectinase. Pectinase is an enzyme that breaks down pectin. Because pectinase activity decreases, there is less breakdown of pectin, and thus, a crisper vegetable. In fact, there have been studies which show that the salt concentration has an inverse relationship with the relative softening of cucumbers (29). This simply means that higher salt concentrations will lead to less softening. Likewise, lower salt concentrations will lead to higher softening. Although higher salt concentrations help with maintaining the firmness of vegetables, a salt concentration that is too high can impact the fermentation by inhibiting LAB and other fermenters from growing.
- Salt also provides flavor to the product.

Salt Concentration

Salt concentration is very important in the fermentation process. For commercial cucumber fermentations, the typical salt concentration is 5-6% while the salt concentration for cabbage is 2-3% (2). Lower salt concentrations will support the growth of LAB and other fermenting microorganisms in the initiation stage of the fermentation process in natural fermentation. As mentioned earlier, the lower salt concentration also can lead to softer produce since higher salt concentrations decrease pectinase activity. Thus, salt concentration plays an important role in supporting fermentation and produce firmness and can vary by product.

When calculating the salt concentration, the below formula can be used:

- 1000g water x 0.02 = 20g salt for 2% brine

Also, remember that the produce which is being fermented must be completely submerged in the brine as you consider the amount of water and salt needed depending on how much product is being fermented.

Salting Methods

Salting methods can include the following:

- **Direct or dry-salting:** In this method, salt is added directly to vegetables. The salt will then pull out the water from the vegetable through osmosis. This method is utilized for products that are high in water.
- **Brining:** This method employs the use of mixing salt and water to form a brine. This method is more widely used because it provides better coverage of the vegetable and it is easier to use known salt concentrations for the brine. Using known salt concentrations and covering the entire vegetable helps provide consistency in the fermentation process.

Effect of Temperature on Fermenting Vegetables

The temperature of fermentation is important as it dictates the growth rate which impacts the rate of acid production (31). Recommended fermentation temperatures can range from 50-75°F (31). In one study it was observed that temperatures in excess of 86°F can negatively impact product quality in texture and off odors (32). In another study, it showed that temperatures in excess of 80°F yielded selective growth of spoilage bacteria and enhanced enzymatic activity which contributed to vegetable softening, off-flavor development, and discoloration (31, 33). It is best to used evidence-based recipe temperatures when fermenting vegetables while knowing that optimal recommended temperature ranges around 65-72°F.

Additionally, having temperatures that are too low can impact fermentation and potentially the safety of the product. Temperatures that are lower than optimal may slow the growth of LAB and fermenting organisms and decrease the amount of acid production. Thus, if the vegetable is held at lower temperatures in anaerobic conditions, there is the possibility that *clostridium spp*

could grow if there is not enough LAB growth and acid production. As we saw in Table A-1 *C. botulinum* can grow in temperatures as low as 37.9°F. Starting the fermentation off at too low of a temperature needs to be considered as well as this could introduce food safety risk to the product and process.

Size of Vegetable and Produce on Fermentation

The size of vegetables can also have an impact on fermentation. In a study that looked at the fermentation rate between thin versus rough cut carrot and cabbage, it was found that the thinly cut vegetables displayed more rapid fermentation compared to roughly-cut vegetables, had higher titratable acidity, and that acids were produced more rapidly (37). The reason for the higher titratable acidity and more rapid fermentation was attributed to more surface area. Thus, the size and available surface area of the produce can have an effect on the rate of fermentation.

Shelf Life of Fermented Vegetables

The shelf life of the fermented vegetable can vary by product. As we've mentioned earlier, if the fermentation process is followed, there will be a 5-log reduction. However, there are other factors that may determine the shelf life of the product. Vegetable firmness, color, taste, and aroma are other factors to consider for the shelf life of the product. It has been suggested that desirable texture and nutritional properties of fermented vegetables may be maintained during storage in the fermentation brine for extended periods of time (a year or more) without refrigeration (2). However, other guidance suggests that the shelf life could be several weeks to several months (34). The salt brine concentration and temperature of the specific vegetable will play important roles in maintaining vegetable firmness and enzyme activity. Assuming that there is no post-contamination or mold growth, the shelf life may be determined by reviewing the vegetable firmness, off odors, and off flavors. These would likely be the key characteristics in understanding the shelf life in the absence of shelf-life challenge studies. Additionally, storing fermented vegetables at refrigerated temperatures could potentially slow down pectinase and other enzyme activity which could lead to product quality deterioration. Lastly, keeping the fermented produce in an anaerobic environment would also help support longer shelf life.

Container Selection

The type of container used for fermentation can vary. The National Center for Home Food Preservation (NCHFP) recommends food-grade plastic, glass, and stone crock can all be used for fermentation (35). The NCHFP also recommends that a 1-gallon container is needed for each 5 pounds of fresh vegetables. If a plastic liner is used, the liner should be food-grade plastic. Garbage bags or trash liners are not considered food grade.

Additionally, the NCHFP notes that the fermented vegetable must be kept 1 to 2 inches under brine while fermenting. Once all the vegetables and brine have been added to the fermentation vessel, a weight must be added inside the fermentation vessel to cover the vegetable. The purpose of the weight is to keep the product submerged under the water so an anaerobic environment is maintained. The weights should also be food grade.

Regulatory

SD HB 1322 allows processors to sell non-heated-processed fermented foods under the cottage food laws as long as they adhere to the laws by taking the state-certified online training and ensuring the food is consistently maintained and sold at a temperature that is at or below 41°F. This means that if the processor completes the online cottage food law course, they would be allowed to sell non-heated-processed fermented foods under the cottage food law. There is currently no restriction on the types of fermented fruits or vegetables which could be sold. Thus, it is up to the processor to adhere to this law as well as ensure that they are making and selling fermented food that is safe and adheres to SD law.

Evidence-Based Recipes and Non-Evidence Based Recipes

When making fermented vegetables, an evidence-based recipe should be followed. There are evidence-based fermenting recipes for sauerkraut, pickles, and kimchi that are available with the NCHFP and other Extension sites. However, there are many fruits and vegetables that do not have evidence-based recipes. Thus, there is a gap where processors may desire to make fermented fruits or vegetables but do not have evidence-based recipes to utilize.

So, what should the processor do in the absence of

evidence-based recipes? Consider the factors that contribute to the fermentation of vegetables:

- Presence of LAB and other fermenting microorganisms
- Types of LAB present and other fermenting microorganisms
- Amount of LAB present and other fermenting microorganisms
- Temperature of the brine and vegetable
- Salt/brine concentration
- Anaerobic environment
- Size and surface area of vegetable/produce
- Quality of produce (defects and damages)

If a processor wants to try fermenting a non-evidence-based vegetable or fruit recipe, they should proceed with caution and understand the basics of fermentation. With that said, if a processor chooses to use a non-evidence-based recipe, it is highly recommended that they purchase and use a pH meter for every fermentation to ensure that there is a good fermentation cycle and the pH is ≤4.6. A fermentation that yields a pH >4.6 would be unsafe and could cause serious illness or injury or death. Likewise, a fermentation that took a long time to reach a pH that was ≤4.6 could be dangerous because *C. botulinum* can grow in temperatures as low as 37.9°F so if the fermentation takes too long to achieve a pH ≤4.6, there could be the potential of C. botulinum growth which could render the product unsafe. There are many factors which can influence the successful fermentation of produce so consistently controlling the factors that impact fermentation are crucial as well as measuring the pH throughout the process. SDSU Extension does not perform challenge studies or shelf-life studies due to the many variables of fermentation.

Closing

Many people are interested in fermented fruits and vegetables for the unique nutritional benefits as well as for their delicious flavors. The science of fermentation of vegetables and other produce is complex and is influenced by a variety of factors. Whether you're making fermented produce to enjoy at home or you have the intention of selling at your local farmers market, it is important to understand the science and safety behind making fermented produce so that you make, sell, or eat fermented produce that is safe and/or regulatory compliant.

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