

# Effects of *Leuconostoc mesenteroides* Starter Culture on Fermentation of Cabbage with Reduced Salt Concentrations

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**ABSTRACT:** Sauerkraut fermentations rely upon selection of naturally occurring lactic acid bacteria by addition of 2.0% to 2.25% granulated sodium chloride (NaCl) to shredded cabbage. Excess brine generated is a waste product with high levels of organic material (BOD) and nonbiodegradable NaCl. The objective was to determine whether addition of *Leuconostoc mesenteroides* starter culture to reduced-salt cabbage fermentations would yield sauerkraut with reproducible and acceptable chemical composition and sensory qualities. Shredded cabbage was salted with 0.5%, 1.0%, or 2.0% NaCl (wt/wt) at 2 starter culture levels, none or *L. mesenteroides* strain LA 81, ATCC 8293 ( $10^6$  CFU/g). Fermentation products were quantified by high-performance liquid chromatography, and pH was measured during the initial stages of fermentation and after 10 mo storage at 18 °C. A trained descriptive sensory panel used category scales to rate the flavor and texture of selected sauerkrauts. A modified Kramer shear test was used to measure firmness. Cabbage fermented with *L. mesenteroides* consistently resulted in sauerkraut with firm texture and reduced off-flavors across all salt levels ( $P < 0.05$ ). Conversely, sauerkraut quality was highly variable, with softening and off-flavors occurring as salt concentrations were decreased in natural fermentations ( $P < 0.05$ ). Fermentations were rapid, with a more uniform decline in pH when starter culture was added. *L. mesenteroides* addition to cabbage fermentations ensured that texture and flavor quality were retained, while allowing 50% NaCl reduction. Application of this technology to commercial sauerkraut production could improve the uniformity of fermentations and substantially reduce generation of nonbiodegradable chloride waste.

**Keywords:** acetic acid, mannitol, sauerkraut, sensory analysis, sodium chloride, texture

## Introduction

Pederson and Albury (1969) defined the optimum conditions for fermentation of cabbage into sauerkraut to be uniform salting of the shredded cabbage with 2.0% to 2.25% salt, tightly packing the salted cabbage into the fermentation vessel, covering the vessel to exclude air from the cabbage, and fermenting at a temperature of 18 °C. Under these conditions, the sauerkraut fermentation is consistently initiated by heterofermentative lactic acid bacteria (LAB), primarily *Leuconostoc mesenteroides*. As the pH decreases, *L. mesenteroides* begins to decline in number and the more acid-tolerant homofermentative LAB, predominantly *Lactobacillus plantarum*, increase in cell numbers and complete the fermentation. It was previously noted by Pederson and Albury (1954) that other LAB may grow to a limited extent during normal sauerkraut fermentation, including *Lact. brevis* and *Pediococcus cerevisiae*. In recent years, other researchers have isolated a wide variety of LAB from commercial sauerkraut fermentations (Harris 1991; Johanningsmeier and others 2004). Use of molecular methods has resulted in the identification of additional species in commercial sauerkraut fermentations. Barrangou-Pouey and others (2002) used 16S rRNA sequences to identify *L. fallax*, a heterofermentative species that they speculated could contribute substantially to the latter part of the heterofermentative phase of sauerkraut fermentation. Plengvidhya (2003) used RAPD PCR to identify *L. citreum* and *L. argentinum* along with *Lact.*

*paraplantarum* and *Lact. coryniformis* plus an unidentified *Weissella* species isolated from 4 commercial sauerkraut tanks sampled in two seasons.

Pederson and Albury (1969) concluded that inoculation of cabbage with a bacterial culture would provide no substantial benefit because the naturally occurring LAB could be relied upon to dominate the fermentation in the proper sequence to produce good-quality sauerkraut. Commercially, sauerkraut fermentations continue to be carried out following these guidelines. However, a problem with current commercial practice is that over 25% of the weight of cabbage is extracted as liquid brine when cabbage is salted (Hang and others 1972). The brine is very high in nondegradable chloride ions and BOD (Hang and others 1972), and most of it must be discarded after fermentation and storage. The ability to reduce the salt required for fermentation would have the advantage of reducing the concentration of sodium chloride in the waste stream. Salting with a lower salt concentration may also reduce the volume of brine formed in the fermentation, with a corresponding increase in yield of sauerkraut. In laboratory-scale fermentations, reduction of salt from 2.0% to 1.0% resulted in a 19% reduction in liquid loss from the cabbage (unpublished results).

Recent research has shown potential benefits of using starter cultures in low-salt sauerkraut fermentations. Tolonen and others (2002) compared cabbage inoculated with a mixed culture of *L. mesenteroides* and *P. dextrinicus* with cabbage fermented without a starter culture using a mixture of NaCl, KCl, MgSO<sub>4</sub>, lysine HCl, and SiO<sub>2</sub> (57:28:12:2:1) added to cabbage at only 0.9% (wt/wt). There was a more rapid decline in pH and a more rapid completion of fermentation with the added culture. Wiander and Ryhänan (2005) found several LAB mixed starter cultures resulted in rapid lowering of pH

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in cabbage that was salted with 0.5% (wt/wt) of a mixture consisting of 57% NaCl, 28% KCl, 12% MgSO<sub>4</sub>, 2% lysine.HCl, and 1% SiO<sub>2</sub>. The mixed culture containing *L. mesenteroides* and *Lact. plantarum* gave sauerkraut and sauerkraut juice having the most desirable sensory characteristics. The objectives of this investigation were to determine the effects of reduced salt on the chemical and sensory properties of sauerkraut and to determine whether addition of *L. mesenteroides* starter culture benefits the fermentation.

## Materials and Methods

### Fermentations

Laboratory fermentations with Megaton (3 different lots) and Hi-nova cultivars of kraut cabbage were conducted in 1 gal glass jars. Cabbage was prepared by removing the outer leaves and core. Cabbage was cut with the 1/16 inch slicing disk using a Hobart food processor (Hobart, Model FP150, Troy, Ohio, U.S.A.). The shredded cabbage was salted and inoculated according to a 3 × 2 factorial design with 3 levels of NaCl (0.5%, 1.0%, and 2.0%) and 2 levels of inoculation (none or 10<sup>6</sup> CFU/g *L. mesenteroides* strain LA 81 [ATCC 8293, type strain]). Jars were sealed with lids containing septa to allow sampling of the brine and manual release of pressure from the jars during early fermentation. Three jars for each treatment were incubated at 18 °C. Brine samples were taken aseptically through a septum in the lid of each jar after 0.5, 1, 2, 3, 6, 10, and 17 d of fermentation. Chemical changes were monitored by measurement of pH and fermentation end products. After 10 mo of fermentation, brine samples were taken for chemical analysis, and sauerkraut samples were subjected to instrumental texture analysis. Sauerkraut samples prepared from 1 lot of cabbage were additionally subjected to descriptive sensory analysis and colorimetric analysis.

### Starter culture preparation

*L. mesenteroides* strain LA 81 (MDC<sup>+</sup>, ATCC 8293, type strain) was obtained from the USDA-ARS Food Science Research Unit Culture Collection (Raleigh, N.C., U.S.A.) for use as a starter culture. Cabbage juice (2% NaCl) and cabbage juice agar (2% NaCl) were prepared and tested for ability to support the growth of *L. mesenteroides* strain LA 81. Cabbage juice has been found to contain bacterial growth inhibitors when made from either unheated or autoclaved cabbage (Kyung and Fleming 1994, 1997), so special precautions were taken. Cabbage juice was prepared from locally purchased cabbage of unknown cultivar. Outer leaves and cores were removed, and the remaining cabbage was quartered and heated in the microwave to an internal temperature of 95 °C to inactivate inhibitor-forming enzymes. Heated cabbage pieces were processed with a Braun Juicer (Braun, Kronberg, Germany). The resulting juice/slurry was centrifuged to remove particulates. NaCl (2%) was added and the resulting product was sterile filtered (Corning 0.22- $\mu$ m cellulose acetate bottle top filter, Corning, N.Y., U.S.A.). Cabbage juice agar was prepared by aseptically mixing equal parts autoclaved double-strength agar water with sterile filtered cabbage juice. A fresh starter culture was prepared as follows for each batch of sauerkraut. *L. mesenteroides* LA 81 was streaked from frozen stock onto cabbage juice agar plates and incubated at ambient temperature for 48 h. Several isolated colonies from the streak plate were inoculated into 10 mL sterile filtered cabbage juice (2% NaCl) and incubated 18 h at ambient temperature to prepare *L. mesenteroides* LA 81 overnight culture (10<sup>8</sup> to 10<sup>9</sup> cells/mL). LA 81 overnight culture was diluted 1:100 into 100 mL sterile filtered cabbage juice and incubated 18 h at ambient temperature to prepare enough culture for inoculating the sauerkrauts.

### Microbiological analysis

Cabbage samples (after slicing) were taken randomly at 3 intervals during packing and placed in sterile bags. Shredded cabbage (200 g) was aseptically blended in a Waring blender jar with 200 g sterile cold saline for 2 min on high speed. The resulting slurry was stomached on high for 1 min in a sterile stomacher bag with side filter (Seward Stomacher 400, Tekmar, Cincinnati, Ohio, U.S.A.). The filtrate was serially diluted and spiral plated onto PCA (total aerobes), VRBG (Enterobacteriaceae), YM (yeasts and molds), and MRS (LAB) agar plates with the Autoplate 4000 (Spiral Biotech, Exotech Inc., Gaithersburg, Md., U.S.A.). PCA and VRBG plates were incubated aerobically at 30 °C for 24 h. YM plates were incubated aerobically at 30 °C for 3 to 4 d. MRS plates were incubated anaerobically in gas pack jars at 30 °C for 48 h. Colonies were counted with the QCount system (Spiral Biotech, Exotech Inc.).

### Chemical analysis

Brine samples from each fermentation jar were collected in 15-mL vacutainer tubes at the time of sensory testing and stored at -83 °C. Samples were analyzed for pH, sugars, and acids. Glucose, fructose, mannitol, ethanol, and glycerol were measured by HPLC using water as eluent on an HPX-87C column at 75 °C (Bio-Rad Laboratories Inc., Hercules, Calif., U.S.A.) and a Waters 410 differential refractometer (Millipore, Millford, Mass., U.S.A.). Lactic acid, acetic acid, malic acid, succinic acid, butyric acid, and propionic acid were measured by HPLC using 0.03 N sulfuric acid as eluent on an HPX-87H organic acid column at 75 °C with UV detection at 210 nm (McFeeters and Barish 2003). A pH meter (Fisher Accumet® pH meter, model 825MP, Pittsburgh, Pa., U.S.A.) was calibrated with pH 4.00 and pH 7.00 buffers and used for brine pH determinations. Calcium determinations were performed on raw cabbage samples (Gindler and King 1972).

### Texture analysis

Instrumental firmness of sauerkraut produced from 4 lots of cabbage was measured 10 mo after the start of fermentation. A modified Kramer shear test was used to measure the firmness of the sauerkraut shreds using the TA-XT2 Texture Analyser with the 5-blade and slotted box attachments and the 50-kg load cell (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.). Sauerkraut was drained for 2 min to remove excess brine. Shreds of sauerkraut (25 g) were placed uniformly across the bottom of the slotted box attachment. The 5-blade attachment was lowered to just above the sauerkraut bed. The test speed was set to 1.3 mm/s for the test distance of 25 mm. Peak force (N) was recorded and firmness was reported as N/g.

### Sensory analysis

Ten volunteers from the Dept. of Food Science at North Carolina State Univ. (NCSU) in Raleigh, N.C., were trained to evaluate sauerkraut using category scaling. A scale of 0 = *not detectable* to 15 = *very strong* was used for flavor attributes of sauerkraut (kraut sulfur, raw cabbage, sweetness, saltiness, sourness, bitterness, astringency, and other). Firmness was scored using a scale from 0 = *very soft* to 15 = *very firm*. Crunchiness was scored using a scale from 0 = *not crunchy* to 15 = *very crunchy*. Panelists completed 9 h training prior to evaluating samples. Training included review of the basic tastes, selection of an appropriate reference standard, descriptor development and calibration, and practice. The basic tastes (sour, salty, sweet, and bitter) were trained using Spectrum method standards (Meilgaard and others 1991). Additional scales for product description were defined using verbal cues and sauerkraut samples. Several commercial sauerkraut samples were evaluated by the panel

during training for the purpose of selecting one that exhibited flavor attributes suitable for use as a reference (Table 1) throughout the study. Several jars from the same production lot were obtained.

Experimental sauerkraut treatments were evaluated in a fully balanced, randomized complete block design with 3 fermentation jars per treatment. Each sample was coded with its own random 3-digit number. Six samples were presented to each panelist in a random order at each evaluation session. Samples were served in 2-oz plastic portion cups at ambient temperature. The commercial reference sample was provided at each sensory analysis session for panelists' calibration along with water and unsalted soda crackers for palate cleansing between samples.

### Colorimetric analysis

Color was measured on samples evaluated by the sensory panel with a Hunterlab colorimeter (Model D25 with DP9000, Hunter Associates Laboratory, Reston, Va., U.S.A.). Sauerkraut shreds were packed tightly into 60 × 15 mm polystyrene petri dishes (Becton Dickenson Labware, Franklin Lakes, N.J., U.S.A.), which were then tapped lightly on the benchtop to remove air bubbles. *L* (lightness), *a* (red–green), and *b* (blue–yellow) color solid values were recorded.

### Statistical analysis

Analysis of variance (ANOVA) was used to determine statistically significant differences among treatments using SAS statistical soft-

ware, version 9.1.3 (SAS Inst. Inc., Cary, N.C., U.S.A.). Cabbage “lot” was treated as a random variable. Homogeneity of variance among treatments was tested using Levene's test (type = abs). Box-plots were constructed in Sigma-Plot graphing software. The boxes represent the 25th percentile (lower margin of box), median (solid center line), and 75th percentile (upper margin of box). The whiskers extend to the 10th and 90th percentiles and points outside of that (outliers) are represented by black circles. The width of the box indicates the degree of variability in the data. If the median does not appear near the center of the box, it indicates that the data are not normally distributed. The mean (arithmetic average) was added to the plots as a dashed line.

## Results and Discussion

The initial microbial load of the shredded cabbage varied among the 4 lots of cabbage (Table 2), but was in the range typical of the natural microflora of fresh cabbage (Fleming and McFeeters 1988). The addition of *L. mesenteroides* for inoculated treatments was approximately 2 logs higher than the natural microflora, which has been shown to be an effective inoculum level for vegetable fermentations (Gardner and others 2001). Furthermore, Plengvidhya and others (2004) found that the *L. mesenteroides* type strain used in our studies was more persistent in cabbage fermentations than 2 other *L. mesenteroides* strains when inoculated at this level. Mannitol production, indicative of metabolism of fructose by heterofermentative LAB, was more rapid and uniform in the first 6 d of fermentation at all salt concentrations with addition of *L. mesenteroides* starter culture (Figure 1). These data very closely resembled the production of mannitol when this same strain of *L. mesenteroides* was grown as a pure culture in sterile filtered cabbage juice with 2% NaCl (data not shown). In contrast, uninoculated sauerkrauts were slower and highly variable in their rate of mannitol production (Figure 1). Together these data indicate that the starter culture chosen was able to rapidly and reproducibly initiate the fermentation.

### Fermentation chemistry

The pH values of all sauerkraut treatments were not significantly different ( $P = 0.75$ ) after 10 mo of fermentation at 18 °C regardless of the initial salt concentration or starter culture addition (Table 3). However, during the first 6 d of fermentation, the decrease in pH was highly variable among jars without starter culture, and pH decreased somewhat more rapidly with lower salt concentrations. In contrast, the decline in pH was rapid and more uniform at all 3 salt concentrations in fermentations started by the addition of *L. mesenteroides* (Figure 2). The production of both lactic and acetic acids followed the same trend as pH with inoculated sauerkrauts, quickly and uniformly producing the appropriate ratio of fermentation acids regardless of salt level (data not shown). The rapid and uniform decline in pH in the fermentations carried out with *L. mesenteroides* starter culture is consistent with the rapid decline in pH observed

**Table 1 – Sensory attributes of the commercial reference sample**

Attribute	Definition	Intensity
Kraut sulfur	The strong sulfur note that is characteristic of properly fermented sauerkraut. Example: Aroma of commercial reference sample	12
Raw cabbage	Green, vegetative aroma and flavor of raw cabbage	1
Sweetness	Sweet taste. Example: sucrose in water	0
Saltiness	Salty taste. Example: sodium chloride in water	6
Sourness	Sour taste. Example: citric acid in water	9
Bitterness	Bitter taste. Example: caffeine in water	1
Astringency	Drying, shrinking sensation of oral tissues. Example: alum in water	0
Off-flavor	Open scale with space allotted for a write-in descriptor to be used when an unanticipated (and abnormal) flavor is observed in the experimental samples. Examples of commercial krauts with various off-flavors were given and discussed during training	0
Firmness	The amount of force or effort required for masticating the sample	8
Crunchiness	Sound and feeling associated with chewing raw vegetables	7

**Table 2 – Microbiological and chemical properties of raw cabbage**

Cultivar	Megaton lot 1	Megaton lot 2	Megaton lot 3	Hinova lot 4
Total aerobes (log CFU/g)	5.0 ± 0.2	4.6 ± 0.3	4.8 ± 0.3	5.1 ± 0.4
Lactic acid bacteria (log CFU/g)	3.1 ± 0.5	3.0 ± 0.2	3.6 ± 0.1	3.1 ± 0.2
Enterobacteriaceae (log CFU/g)	4.6 ± 0.4	4.3 ± 0.2	4.3 ± 0.3	4.2 ± 0.5
Yeasts and molds (log CFU/g)	4.2 ± 0.2	<2.9	2.6 ± 0.4 est	2.0 ± 0.2 est
Moisture (% by weight)	93.0 ± 0.2	93.0 ± 0.6	93.4 ± 0.3	92.6 ± 0.3
Calcium (mM)	8.8 ± 1.6	10.0 ± 1.0	7.4 ± 1.8	9.1 ± 0.7
Citric acid (mM)	6.5 ± 0.4	7.2 ± 2.0	5.6 ± 0.3	5.7 ± 0.4
Malic acid (mM)	3.1 ± 0.1	4.8 ± 0.7	6.7 ± 0.8	5.5 ± 0.8
Sucrose (mM)	6.4 ± 1.1	5.6 ± 1.7	6.2 ± 1.7	9.3 ± 2.2
Glucose (mM)	127.9 ± 8.4	115.5 ± 19.2	122.8 ± 5.7	121.5 ± 3.1
Fructose (mM)	77.3 ± 1.7	75.2 ± 12.6	94.2 ± 3.2	102.7 ± 5.5

when cabbage was fermented with 0.9% of a salt mixture and inoculated with several species of LAB, including *L. mesenteroides* (Tolonen and others 2002, 2004; Wiander and Ryhänen 2005). However, in those studies the fermentations were terminated after 2 wk or less to extract juice from the fermented cabbage, so there were no evaluations made of the sauerkraut quality related to different starter cultures.

Ten months after the start of fermentation, both the mean concentrations and the variability of lactic acid among 12 fermentations, including 3 fermentations from each of 4 lots of cabbage at each salt concentration, were similar with or without starter culture. This is illustrated in the box plot in Figure 3. Lactic acid is produced during both the initial heterofermentative stage and the subsequent homofermentative stage of sauerkraut fermentation, and there seemed

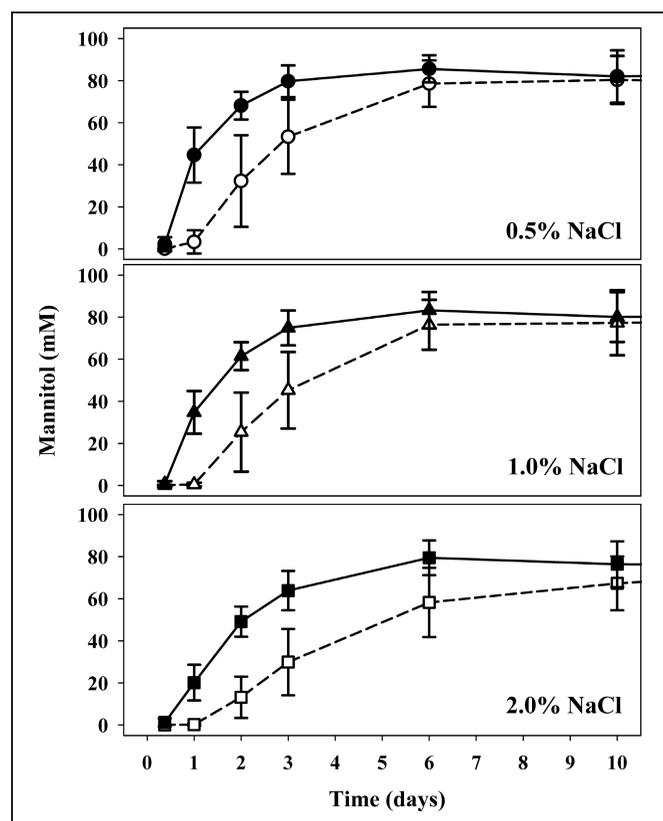
to be no effect of salt or starter culture ( $P = 0.40$ ) on this important fermentation product. The final concentrations of mannitol (Figure 4) and acetic acid (Figure 5), which are typically produced by heterofermentative bacteria, were more variable in 0.5% and 1.0% NaCl natural fermentations as illustrated by the long whiskers of the box-plots for those treatments. Comparison with the time course chemistry data showed that these compounds were originally produced in expected quantities, indicating that the outliers observed were due to undesirable secondary fermentations that caused a decrease in mannitol and an increase in acetic acid. The variability in concentration of these fermentation products decreased as the salt concentration was increased in natural fermentations. When *L. mesenteroides* starter culture was added to the shredded cabbage, the variability and mean concentrations of these compounds were similar regardless of the salt concentration. Although acid production and the corresponding decrease in pH are typical variables for monitoring the success of vegetable fermentations, the end product chemistry of the sauerkraut samples was not necessarily indicative of their sensory quality.

**Texture**

In natural fermentations, average instrumental firmness (N/g) decreased and the variability among fermentations increased (Levene's test  $P = 0.0051$ ) as the concentration of salt added to cabbage was decreased from 2.0% to 0.5%. Addition of *L. mesenteroides* starter culture resulted in sauerkraut with overall equal firmness ( $P < 0.05$ ) and less variability among replicate fermentations regardless of the salt concentration (Figure 6). Sauerkraut made with 1% NaCl and inoculated with *L. mesenteroides* had similar firmness as the control sauerkraut fermented with 2% salt by the indigenous LAB ( $P = 0.82$ ).

The concentration of calcium naturally occurring in cucumbers has been shown to relate to softening rates during acidified, brined storage (McFeeters and Fleming 1989). Therefore, calcium concentration was measured in the different lots of raw cabbage to determine if the natural variation might relate to sauerkraut texture (Table 2). Although there was an observed trend that lots of cabbage that exhibited softening during low-salt natural fermentations (lots 1 and 3) had a lower mean concentration of calcium, the differences in calcium were not statistically significant ( $P = 0.21$ ).

Firmness evaluated by sensory analysis followed the same pattern as instrumental firmness (N/g) measured by the shear press. In natural cabbage fermentations, reducing the salt resulted in significant softening of the sauerkraut ( $P < 0.001$ ). Without the addition of *L. mesenteroides* starter culture, the firmness of the sauerkraut decreased with decreasing salt concentration (Figure 7). Fermentation with less salt may allow the production or extended activity of softening enzymes leading to soft, less crunchy sauerkraut. However, even when structural integrity was maintained by adding a starter culture,



**Figure 1 – Mannitol production during cabbage fermentation as affected by NaCl and *Leuconostoc mesenteroides* starter culture. Natural fermentations are represented by open symbols. Fermentations with added *L. mesenteroides* starter culture ( $10^6$  CFU/g) are represented by filled symbols.**

**Table 3 – Chemical composition of sauerkrauts after 10 mo' storage at 18 °C as affected by salt concentration and starter culture addition compared to a range of commercial samples**

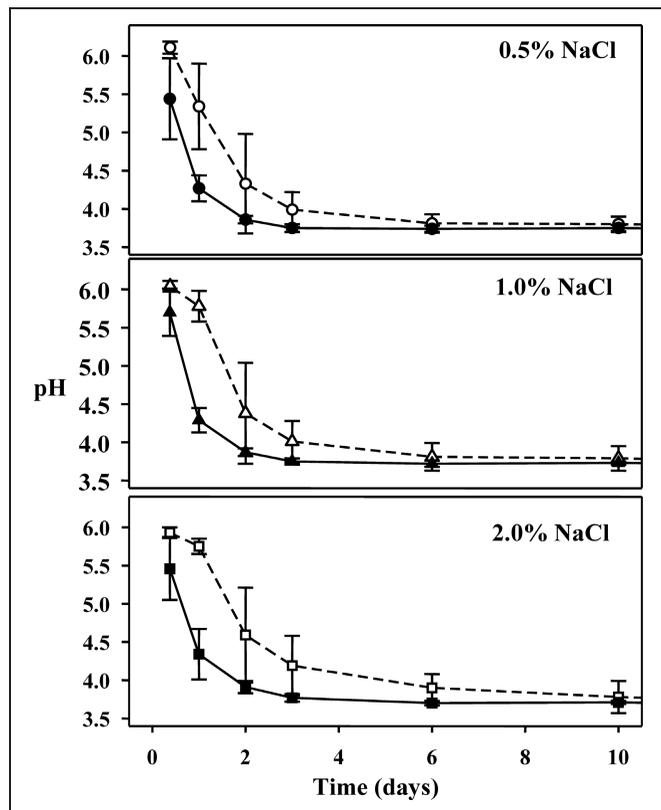
NaCl (% wt/wt)	Natural fermentations			<i>Leuconostoc mesenteroides</i> starter culture			Commercial <sup>a</sup>
	0.5	1.0	2.0	0.5	1.0	2.0	
pH	3.49	3.44	3.44	3.47	3.46	3.42	3.20–3.77
Lactic acid (mM)	144.1	149.3	135.3	141.0	141.5	131.5	118.1–164.6
Acetic acid (mM)	69.0	59.8	48.4	57.0	60.1	53.0	65.6–120.3
Mannitol (mM)	86.7	88.5	82.9	99.7	102.1	94.1	18.5–88.3
Ethanol (mM)	91.6	107.6	114.4	75.0	59.0	30.4	20.2–80.2
Residual glucose (mM)	17.5	11.1	16.1	28.4	37.5	53.9	1.2–27.7
Residual fructose (mM)	0.13	0.65	0.80	1.97	1.60	8.70	0–10.4

<sup>a</sup>The range found in 10 commercial sauerkraut samples including both pasteurized and refrigerated products packaged in cans, glass jars, or plastic bags.

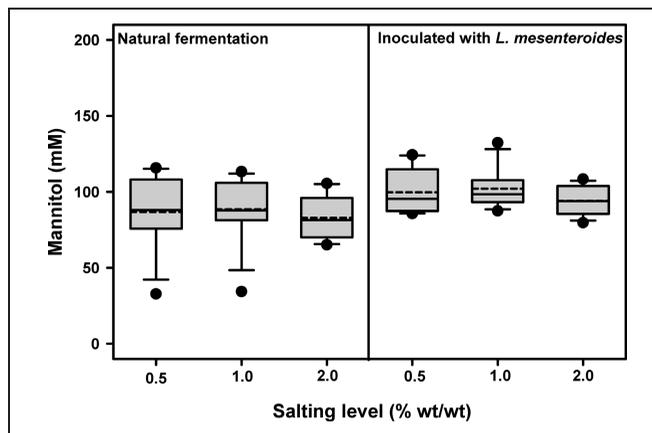
NaCl concentration seemed to play a role in the perceived crunchy texture of the sauerkraut. There was an increase in crunchiness as salt concentration increased in both inoculated and noninoculated fermentations (Figure 7,  $P < 0.001$ ). The firmness and crunchiness of sauerkraut produced with 1% NaCl and *L. mesenteroides* starter culture were equivalent to that of sauerkraut fermented naturally with 2% NaCl ( $P = 1.00$ ), indicating that textural defects caused by reducing the salt for fermentation can be overcome by addition of an appropriate starter culture.

**Color**

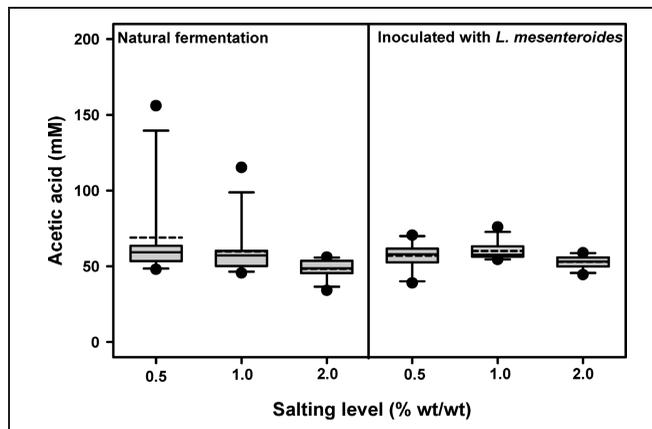
Color values were mostly in the range of commercial sauerkraut (Table 4). One notable exception was that *L* values for 0.5% and 1.0% salt treatments were higher than 2% NaCl treatments ( $P < 0.05$ ) and above the range of *L* values of the commercial samples tested. Higher *L* values indicate an overall lighter color, which is a desirable quality attribute for sauerkraut.



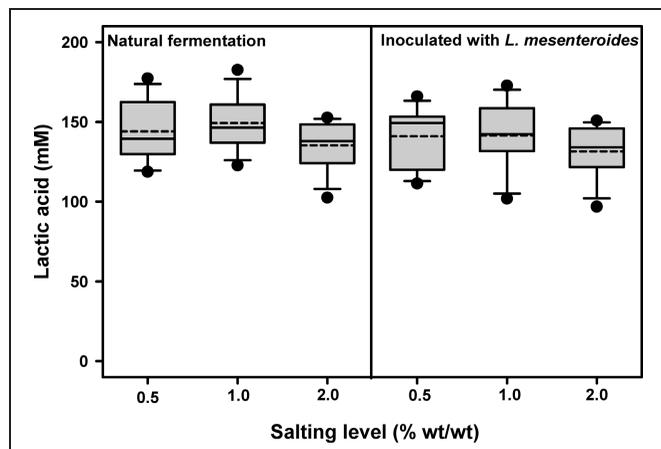
**Figure 2**—Changes in pH during cabbage fermentation as affected by NaCl and *Leuconostoc mesenteroides* starter culture. Natural fermentations are represented by open symbols. Fermentations with added *L. mesenteroides* starter culture ( $10^6$  CFU/g) are represented by filled symbols.



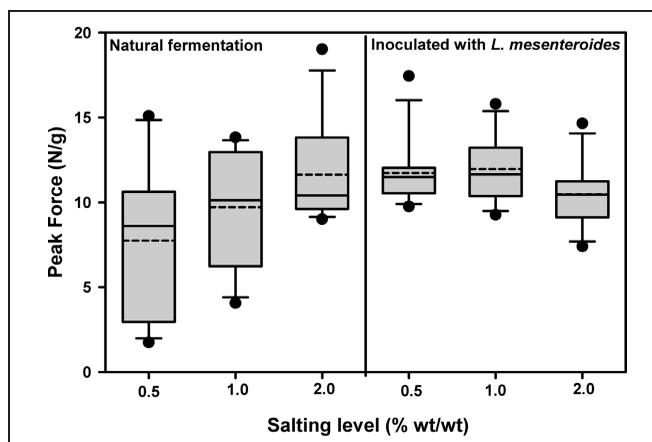
**Figure 4**—Variability in final mannitol concentration in sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition



**Figure 5**—Variability in final acetic acid concentration in sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition



**Figure 3**—Variability in final lactic acid concentration in sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition



**Figure 6**—Variability in firmness of sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition

**Flavor**

Kraut sulfur, which is the typical sulfurous odor and flavor associated with properly fermented sauerkraut, was slightly lower when only 0.5% salt was used. The highest kraut sulfur score was observed with sauerkraut fermented with 1.0% NaCl and *L. mesenteroides* starter culture (Figure 8). Off-flavor was significantly reduced by the addition of *L. mesenteroides* starter culture across all salt levels ( $P < 0.05$ ). In natural fermentations, the incidence of off-flavor increased and its intensity was more variable (Levene's test  $P = 0.006$ ) in sauerkraut produced with less salt (Figure 8). As might be expected, the intensity of salty taste increased with increasing salt concentration. However, it was notable that the saltiness score for sauerkraut with 1.0% NaCl was only about 1 unit less than the 2% NaCl samples on a 15-point scale (data not shown).

In summary, sauerkraut produced by fermenting cabbage with 2% NaCl at 18 °C had firm, crunchy texture, a normal kraut sulfur flavor, and only slight off-flavor. These results confirm the conclusion of Pederson and Albury (1969) that addition of a starter culture is not

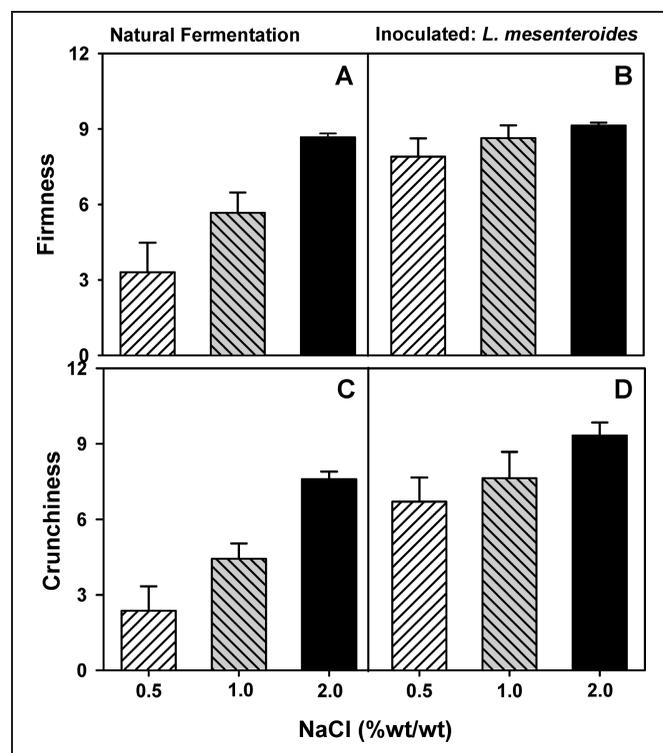
necessary for proper fermentation given the correct environmental conditions. Nevertheless, the ability to reduce the salt requirement for cabbage fermentation depends upon addition of an appropriate starter culture. We have shown that fermenting with 50% less salt results in increased variability among many quality factors, including unpredictable softening and generation of off-flavors. Addition of *L. mesenteroides* starter culture provided the appropriate fermentation regardless of salt level, ensuring the production of high quality sauerkraut.

**Conclusions**

Chemical analysis of sauerkraut brine samples during the period of rapid fermentation, instrumental texture measurements, and sensory evaluation of sauerkraut after 10 mo fermentation and storage all support the conclusion that the inoculation of salted cabbage with a persistent *L. mesenteroides* starter culture strain results in more uniform sauerkraut fermentations compared to non-inoculated fermentations. Fermentation of cabbage with the addition of only 1% NaCl and inoculation with the *L. mesenteroides* type strain consistently resulted in sauerkraut with firm, crunchy texture, no significant off-flavor, and a normal level of kraut sulfur flavor. Scale-up for commercial sauerkraut fermentation would have the potential for producing reduced-salt sauerkraut with consistent quality and reduced levels of sodium chloride in waste streams.

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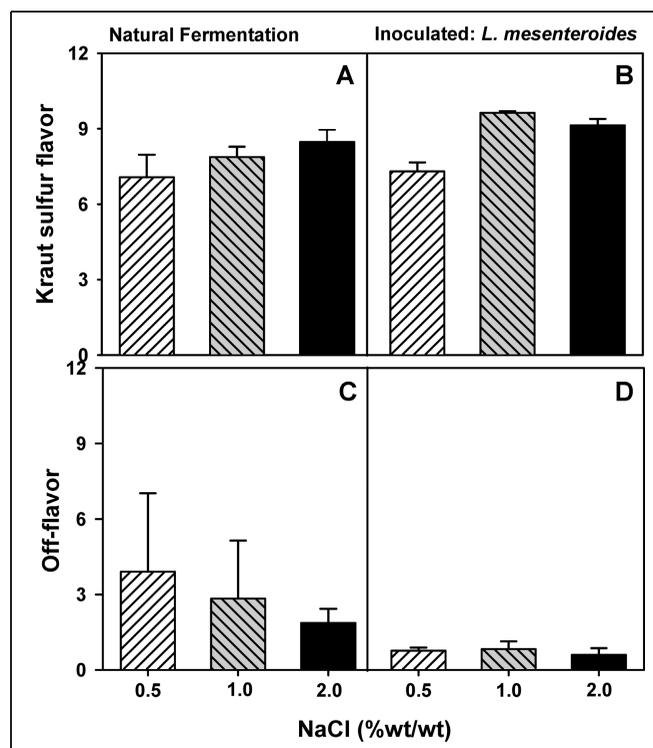


**Figure 7 – Sensory texture attributes of sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition**

**Table 4 – Hunterlab color measurements of sauerkrauts after 10 mo storage at 18 °C as affected by salt concentration and starter culture addition compared to a range of commercial samples**

Inoculum	NaCl, %	L	a	b
Natural	0.5	66.7 ± 1.3	-1.44 ± 0.29	20.7 ± 0.3
Natural	1.0	67.2 ± 0.9	-1.72 ± 0.21	21.1 ± 0.2
Natural	2.0	63.0 ± 1.0	0.58 ± 0.53	19.1 ± 1.2
<i>L. mesenteroides</i>	0.5	67.1 ± 0.5	-1.15 ± 0.50	20.5 ± 1.2
<i>L. mesenteroides</i>	1.0	67.9 ± 0.7	-1.08 ± 0.42	20.2 ± 0.3
<i>L. mesenteroides</i>	2.0	61.6 ± 1.6	1.12 ± 0.49	16.7 ± 1.9
Commercial samples <sup>a</sup>		50.6–64.8	-1.44–3.27	17.6–23.4

<sup>a</sup>The range found in 10 commercial sauerkraut samples including both pasteurized and refrigerated products packaged in cans, glass jars, or plastic bags.



**Figure 8 – Kraut sulfur flavor and off-flavor of sauerkrauts after 10 mo at 18 °C as affected by NaCl concentration and *L. mesenteroides* starter culture addition**

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