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*Dairy Technologist.*
SAUERKRAUT
CARL S. PEDERSON

ABSTRACT

The preparation of sauerkraut from cabbage is described both from the standpoint of the process of making kraut and from that of the fermentation. The fermentation is normally carried on by certain bacteria that change the sugar of the cabbage to lactic and acetic acids, alcohol, mannitol, and carbon dioxide. The effect of the use of starters prepared from various bacterial cultures is discussed, showing that most of the possible types of starters are detrimental to a good fermentation. The temperature of fermentation, the proper covering of the kraut, and the correct salt content are of major importance in a proper fermentation.

A discussion is given of the various types of spoilage in sauerkraut, showing the effect of direct contact with air, lack of kraut juice, lack of or too much salt, improper temperature, and the many other factors that may cause an inferior product.

INTRODUCTION

Sauerkraut, according to the definition formulated in a regulation under the Federal Food and Drugs Act, is "The clean, sound product, of characteristic flavors, obtained by full fermentation, chiefly lactic, of properly prepared and shredded cabbage in the presence of not less than 2 per cent, nor more than 3 per cent of salt. It contains, upon completion of the fermentation, not less than 1½ per cent of acid expressed as lactic acid. Sauerkraut which has been rebrined in the process of canning contains not less than 1 per cent of acid."

Literally, "sauerkraut" is acid or sour cabbage. It has a very ancient origin, but in the beginning it was a very different product from that now on the market. It was first made from fresh cabbage leaves dressed with wine or vinegar. Later, the heads were broken or quartered and packed in vinegar or wine, and still later salt was added to inhibit the fermentation. It was probably during the 16th century when it was first actually shredded and allowed to ferment
spontaneously, in the presence of a small quantity of salt. It is unknown who first prepared kraut in this way, but it is generally attributed to the Germans, altho some German writers ascribe a Slavic origin and still others are equally certain that it was obtained from the Chinese.

Sauerkraut has always been considered a wholesome and healthful food. Captain Cook, the English navigator of the 18th century, was signally honored for the manner in which he protected the health of his crew on his long voyages of exploration and he ascribed their good condition and freedom from scurvy to the liberal use of this conserve. More recent research has shown that cabbage and sauerkraut are unusually rich in the antiscorbutic vitamin.

HOW SAUERKRAUT IS MADE

It is apparent that the old German-made sauerkraut is not altogether the same as the present American-made product. There are a great many methods of preparing kraut, most of them adaptations of the old German methods. Some of them call for the addition of various spices or fruits. Sliced apples are quite generally added to the raw kraut. Many of the methods call for an insufficient amount of salt and this results in a rapid fermentation but a kraut of soft texture and in many cases a kraut which has undergone some spoilage and therefore has a decided odor. Such kraut will not can well as it is too soft and will not stand the double cooking. Present regulations call for an addition of 2 to 3 per cent of salt only. Ordinarily 2½ per cent is used.

COMMERCIAL PRODUCTION OF SAUERKRAUT

New York State has about 30 kraut factories. Twenty-five of these are within a radius of 50 miles from Geneva. This region is one of the largest kraut producing sections in the world. In 1929, about 140,000 tons of kraut were made in the United States, of which 39,100 tons were made in the central New York area. One plant alone has 77 vats, each having a capacity of 80 tons of kraut. These can be filled from one to four times a season. There are several other factories almost as large as this one.

In these factories, the cabbage and kraut are handled to a great extent by machinery. When the cabbage comes from the field it is placed in aerated buildings and allowed to remain for a day or two to wilt. This results in a more uniform temperature and a cabbage
that can be cut with the least amount of breaking of the shreds. The cabbage then passes by conveyors to the coring machine. This machine cuts the core by means of a spiral drill, but allows the finely cut core to remain in the cabbage. The cored cabbage then passes by conveyors to the trimming table where the outer leaves and any bad spots are removed, and then it is passed directly to the cutting machines where large power-driven knives slice the cabbage. It is conveyed to or dropped into carts or carriers and by these placed into the vats. The kraut is spread evenly with salt and packed under sanitary conditions. Very little actual packing is necessary, but more attention is paid to uniform distribution of the salt and cabbage. Some kraut makers practice salting in the vat, while others salt in the carts. Either method is good if care is taken to distribute the salt evenly.

When the vats are filled the kraut is covered and as many weights are placed on the covers as are necessary to press the cabbage enough to cause the juice to rise to the surface. Round covers are used which fit within the tank and allow little exposure of the kraut to the air. In some plants the kraut is first covered with a white muslin cloth. Various types of weights are used, but cement blocks with handles are the most common. The temperature in the plant is often raised, and the fermentation of the kraut is ordinarily completed in from 3 weeks to a month. That is, the kraut has attained an acidity 1.5 per cent or more of acid and when canned will contain at least 1 per cent acid. In the more carefully operated factories, kraut is tested by laboratory methods to determine when the fermentation is completed, thus insuring a uniform product. The rate of fermentation varies greatly in different tanks, therefore, it is improbable that a uniform product will be obtained just because the tanks are opened in the order in which they were packed. The uniformity of the product is still further assured by testing the salt content of the kraut.

When the kraut is removed it has very little odor, is of a white to light straw color, has a firm texture, and a clean acid kraut flavor. Most factories in New York preserve the greater part of their product in tin cans, but some kraut is shipped to the larger cities and sold as barrelled kraut. This latter is not a desirable way of selling kraut since unless extreme care is taken, air is introduced in repacking and undesirable changes may take place. The kraut may also be spoiled by being left open to the air too long in warm grocery stores or meat markets.
Kraut is ready for canning when an acidity of 1.5 per cent lactic acid is attained. It is then removed by tubs or conveyors to the canning room, heated to about 110°F, and packed in cans. These pass thru machinery by conveyors to be rebrined and closed. The kraut is cooked in the can at 212°F for about 20 minutes and immediately cooled in water. The cooking process varies somewhat with different packers and with the size of the can as well as with the type of cooker.

PREPARATION OF SAUERKRAUT IN THE HOME

Altho most of the sauerkraut now used is made in factories, there is a considerable amount packed in the home. In many cases enough is prepared to supply neighbors, or to sell in small amounts to local merchants. A few persons have unusual success with kraut and succeed year after year in preparing a wholesome, bright-colored, palatable product. Others may be successful some years, but at other times meet with failure, altho apparently they have used the same methods as formerly. But there are so many factors that influence the fermentation that, altho success may follow a certain faulty method for a time, failure eventually results.

Kraut is prepared in the home from large, firm, well-ripened heads of cabbage. These are ordinarily allowed to stand at room temperature for a day to wilt, the wilting causing the leaves to become less brittle and thus not so likely to break in cutting. The outer leaves are trimmed down to the white leaves. Some wash the cabbage at this stage. This is a very good practice as shown by recent experimental work. With ordinary home equipment, the heads must be cut in halves or quarters with a large knife and the core removed or cut fine. The kraut is cut with an ordinary kraut cutting board with blades set to cut shreds about the thickness of a dime. The setting of the blades varies, some preferring to cut the cabbage very fine, while others use a coarse cut. The cabbage is packed in clean, paraffined barrels or jars with a light sprinkling of salt. Salt is used in the proportion of 1 pound to 40 to 45 pounds of cut cabbage. If the salt is allowed to remain on the shredded cabbage a short time before packing, less breaking of the shreds is obtained.


Packing is quite often the cause of much unnecessary bruising and tearing of shreds which results in a softening of the kraut. A large wooden tamper should be used and with it the kraut should be firmly pressed or pushed down to force out the air rather than pounded until juice is produced. Ordinarily, pounding is not necessary to draw out the juice for if the salt is added as noted above, it will draw out more than enough juice by the time the container is filled. When the container is filled, the juice should come to the surface. The kraut should be covered with a clean white muslin cloth and then with a round paraffined cover of such size that it just fits within the container. A weight is placed upon the cover of such size that the juice comes to the bottom of the cover, but not over it. This will keep the cloth moist, but juice will not cover the cloth. The weight necessary for this purpose varies somewhat, especially during the first few days of fermentation and with changes in temperature, and therefore should be watched carefully. For smaller containers a weight consisting of a jar to which water can be added or taken from serves very well. The placing of weights on the kraut is very important in producing good quality sauerkraut as will be shown later. Commercial packers are very particular about this point.

Fermentation starts within a day after packing and is usually, but not always, evidenced by the formation of gas bubbles on the surface. The time required for the kraut to ferment completely depends upon the temperature. At a temperature of 70° to 75°F fermentation is complete and the kraut ready for use in two weeks to a month. Fermentation is more rapid at higher temperatures, but more spoilage is likely to occur. The better quality kraut is produced at the lower temperatures. At temperatures below 70°F it usually takes a month or more for complete curing.

If it is used quite frequently, and if the intention is to consume it entirely in the fall and winter, kraut may be left in the container in a cold room; otherwise it should be canned. Canning is simple and insures a good supply of kraut throughout the year. In canning kraut, the cold pack method results in a superior product. The kraut is warmed to between 110 to 130°F in its own juice, packed into sterilized jars, covered, and cooked in a boiling water bath for 15 to 20 minutes. The jar is sealed when removed and placed in a cold place so that it may cool as rapidly as possible. If allowed to remain hot for a long period the kraut softens and darkens in color. When canned and cooled properly, the resulting kraut is very much like the raw product in texture and flavor.
The use of flavors, such as apples, pears, spices, dill pickles, etc., prevails in Europe to some extent but is not common in America. Spice or dill produce somewhat of a pickle flavor, but they are unsightly in the finished kraut. Furthermore, they may lead to other difficulties, particularly to the darkening of the kraut when in contact with iron or iron rust. This may occur in packing and in canning as well as at the time of cooking for consumption. Apples and pears are occasionally sliced and added. The flavor imparted is somewhat distinctive.

WHAT HAPPENS IN SAUERKRAUT FERMENTATION

Altho many people have made kraut for years, very few realize what happens to the cabbage during the so-called curing fermentation or during the typical change from the sweet and slightly bitter cabbage to the sauerkraut.

Cabbage consists of approximately 91 to 93 per cent water, 3 to 4 per cent sugar, 1¼ per cent protein, and small amounts of mineral substances, fat, and fiber. When salt is added to the shredded cabbage, water is withdrawn from the cabbage to form the cabbage juice or brine. This necessarily contains some of the soluble sugar which is subject to attack by any bacteria or yeasts that happen to be upon the cabbage when packed, provided conditions are right for growth of these organisms.

BACTERIA INVOLVED IN FERMENTATION

There are a great number of types of bacteria and yeast normally present on cabbage, but from the standpoint of their effect upon the cabbage or kraut they may be grouped into the spoilage group of bacteria, the yeasts, and the fermentation bacteria.

The first type are typical soil organisms and require air for growth. They do not attack the sugars to any extent, but rather act upon the protein and produce undesirable changes. Since they fail to grow in the absence of air and in the presence of acid, they are quickly killed off in a normal sauerkraut fermentation. The yeasts are not inhibited by acids, but they also require air for growth. They may produce considerable change in the lactic acid, as well as in the sugars, if allowed to grow, but they very seldom develop early in the fermentation process.

The ordinary group of kraut fermenters may be further classified into the lactic acid, gas-producing cocci; the lactic acid, non-gas-
<table>
<thead>
<tr>
<th>Group</th>
<th>Specific name</th>
<th>Percentage from glucose</th>
<th>Percentage from fructose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lactic acid</td>
<td>Acetic acid</td>
</tr>
<tr>
<td>Gas-producing coci</td>
<td><em>Leuconostoc mesenteroides</em></td>
<td>40-45</td>
<td>5-10</td>
</tr>
<tr>
<td>Gas-producing rods</td>
<td><em>Lactobacillus pentoaceticus</em></td>
<td>40-45</td>
<td>5-10</td>
</tr>
<tr>
<td>Non-gas-producing rods</td>
<td><em>Lactobacillus cucumeris</em> and <em>L. plantarum</em></td>
<td>88-93</td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>88-93</td>
<td>2-4</td>
</tr>
</tbody>
</table>
producing rods; and the lactic acid, gas-producing rods (Table 1). All of these act upon the sugars of the cabbage but produce very little change in the proteins or other constituents. They are favored by absence of air, so they find conditions ideal for growth when kraut cabbage is packed correctly. They vary in their resistance to salt and to acid.

**ACTION OF THE BACTERIA**

In an ordinarily good kraut fermentation, these three types are the only ones which develop. The first type (the gas-producing, lactic acid producing cocci called *Leuconostoc mesenteroides*) find conditions most suitable for growth at a temperature of $70^\circ$F or lower and in the presence of $2\frac{1}{2}$ per cent of salt. They act upon the sugar (glucose and fructose, Table 1) drawn out by the salt, changing part of it to lactic acid (the acid of sour milk), acetic acid (the acid of vinegar), alcohol, mannitol, and carbon dioxide (Table 1). The acids, in combination with the alcohol, form esters and produce the flavor of kraut. When approximately 0.7 to 1.0 per cent of acid is produced these organisms are killed off. Analyses of krauts have been made (Table 2, first four analyses) at this stage. In these cases approximately 0.9 per cent acid has been produced and the amount of acetic acid was approximately 0.4 the amount of lactic acid (Table 2, column 5). There was very little sugar present but a fairly large quantity of mannitol, altho this determination always gives results that are low. Mannitol is a sugar-like substance produced by the bacteria from the fructose. It can be fermented, as will be shown later.

In the meantime, the two other types of organisms which are inhibited slightly by the salt content and by the low temperature of fermentation have increased in numbers sufficiently to carry on the fermentation until 1.5 to 2.0 per cent of acid is produced and the fermentation is complete. The second of these types include two species, *Lactobacillus plantarum* and *Lactobacillus cucumeris* (Table 1). These produce lactic acid only from the sugar and from the mannitol produced by the first group of organisms. They are not quite as resistant to acid as the last type and therefore are slowly but finally killed off, leaving the completion of the fermentation to the last type (*Lactobacillus pentoaceticus*). These organisms may carry the fermentation to as high as 2.4 per cent acid. They produce the same products from sugar as do *Leuconostoc mesenteroides*.

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### Table 2.—Analysis of Partially and Completely Fermented Sauerkrauts.

<table>
<thead>
<tr>
<th>Kraut No.</th>
<th>Total Acid, Per Cent</th>
<th>Lactic Acid, Per Cent</th>
<th>Acetic Acid, Per Cent</th>
<th>Acetic Acid Lactic Acid Ratio</th>
<th>Alcohol, Per Cent</th>
<th>Mannitol, Per Cent</th>
<th>Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partially Fermented Kraut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>0.65</td>
<td>0.535</td>
<td>0.210</td>
<td>0.39</td>
<td>0.44</td>
<td>0.58</td>
<td>Trace</td>
</tr>
<tr>
<td>109</td>
<td>0.98</td>
<td>0.615</td>
<td>0.237</td>
<td>0.38</td>
<td>0.32</td>
<td>0.54</td>
<td>Trace</td>
</tr>
<tr>
<td>111</td>
<td>0.94</td>
<td>0.515</td>
<td>0.283</td>
<td>0.55</td>
<td>0.36</td>
<td>0.42</td>
<td>Trace</td>
</tr>
<tr>
<td>113</td>
<td>0.88</td>
<td>0.530</td>
<td>0.234</td>
<td>0.44</td>
<td>0.32</td>
<td>0.39</td>
<td>Trace</td>
</tr>
<tr>
<td>Completely Fermented Kraut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>1.17</td>
<td>1.288</td>
<td>0.288</td>
<td>0.21</td>
<td>0.62</td>
<td>Trace</td>
<td>None</td>
</tr>
<tr>
<td>111</td>
<td>1.78</td>
<td>1.304</td>
<td>0.318</td>
<td>0.24</td>
<td>0.47</td>
<td>Trace</td>
<td>None</td>
</tr>
<tr>
<td>113</td>
<td>1.67</td>
<td>1.183</td>
<td>0.324</td>
<td>0.27</td>
<td>0.65</td>
<td>Trace</td>
<td>None</td>
</tr>
</tbody>
</table>

The completely fermented kraut (Table 2, last three analyses) contains only traces of sugar or mannitol. The acetic acid content and alcohol content have increased only slightly, but the lactic acid content has increased considerably. These conditions show a slight activity only on the part of the gas-producing rods, while the main part of the fermentation of both the sugar and the mannitol has been carried out by the non-gas-producing rods. These organisms (Table 1) produce lactic acid only.

The total result of the sequence of growth of these three types is a typical sauerkraut that is pleasing to everyone. Any disturbance of this sequence will result in changes in the kraut which ordinarily are detrimental, but in a few cases may produce distinctive flavors which a few individuals may prefer. Altho apparently none of these types produces any appreciable change in the protein or in the cellulose structure of the cabbage, it is apparent that the organisms of the *Leuconostoc* types produce the least change.

### The Effect of Addition of Starters or Cultures of Bacteria

From time to time it has been recommended that starters similar to those used in the preparation of cheese be used in making sauerkraut to produce a more favorable fermentation. One laboratory in Germany prepares such starters and they are used to some extent in Europe. Altho their use has been suggested in this country, they have not been employed upon a practical scale.

Various types of starters may be prepared, such as starters of the sour milk organisms (*Streptococcus lactis*), starters made by using pure cultures of any of the three types of organisms mentioned above, mixtures of these pure cultures, or juice from fermenting kraut secured at various stages in the fermentation process.
The use of any of these starters has one beneficial effect which is common to all, namely, the starter itself is always acid and therefore it acidifies the kraut slightly, thereby inhibiting the growth of the undesirable soil group of organisms. If this were their only effect it might be concluded that starters produce a desirable effect on kraut.

Starters prepared from sour milk or the sour milk organism (*Streptococcus lactis*) acidify the kraut slightly and thus inhibit the growth of undesirable types. The resulting kraut is ordinarily good to excellent, but the flavor is not changed from an ordinary normally fermented kraut. The organisms introduced by such starters, if they grow at all, grow for such a short period of time that an increase in numbers can not be noted. They do not disturb the natural sequence of bacterial growth that is necessary to a good fermentation. Any appreciable effect produced by these starters should be evident in the final chemical analysis of the kraut. A number of such krauts have been made and analyzed but show practically no difference from normal kraut. A typical analysis is given in Table 3 in which kraut No. 35 compared with kraut No. 71 shows the same proportion of fermentation by-products.

Starters composed of other types of micro-organisms that do not grow in kraut have the same effect as do starters prepared from the sour milk organism.

The use of the coccus forms (*Leuconostoc mesenteroides*) found in the early fermentation of kraut has been tried. Altho the flavor of the resulting kraut was good to excellent there apparently was a disturbance of the sequence of growth since the kraut was not fermented as completely as normal kraut.

The addition of organisms of the gas-producing rod type (*Lactobacillus pentoaceticus*) results in an abnormal kraut (Table 3, kraut No. 51). Note the proportionately higher acetic acid content and lower lactic acid content. Some people like the flavor produced which may be described as sharper or more acid. The kraut fermentation is not normal and often is not completed.

The addition of cultures of lactic acid producing rods is detrimental to a good fermentation (Table 3, krauts Nos. 27, 55, and 56). The resulting kraut, which fails to ferment completely, is decidedly bitter and abnormal and apparently more subject to spoilage by yeasts. Proportionately, the amount of lactic acid is greater, as may be noted by the acetic acid, lactic acid ratio. In the analyses
Table 3.—Typical Analyses Showing the Effect of the Use of Starters Upon the Completely Fermented Kraut.*

<table>
<thead>
<tr>
<th>STARTER USED</th>
<th>KRAUT NO.</th>
<th>TOTAL ACID, PER CENT</th>
<th>ACETIC ACID, PER CENT</th>
<th>LACTIC ACID, PER CENT</th>
<th>ACETIC ACID RATIO</th>
<th>ALCOHOL, PER CENT</th>
<th>QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>71</td>
<td>1.74</td>
<td>0.307</td>
<td>1.279</td>
<td>0.24</td>
<td>0.19</td>
<td>Good +</td>
</tr>
<tr>
<td><em>Streptococcus lactis</em></td>
<td>35</td>
<td>1.57</td>
<td>0.290</td>
<td>1.131</td>
<td>0.26</td>
<td>0.23</td>
<td>Excellent</td>
</tr>
<tr>
<td><em>Lactobacillus pentoaceticus</em></td>
<td>51</td>
<td>1.53</td>
<td>0.327</td>
<td>1.033</td>
<td>0.32</td>
<td>0.34</td>
<td>Fair</td>
</tr>
<tr>
<td><em>Lactobacillus brassicae</em></td>
<td>27</td>
<td>1.40</td>
<td>0.182</td>
<td>1.127</td>
<td>0.16</td>
<td>—</td>
<td>Poor</td>
</tr>
<tr>
<td><em>Lactobacillus cucumeris</em></td>
<td>55</td>
<td>1.60</td>
<td>0.118</td>
<td>1.425</td>
<td>0.08</td>
<td>0.28</td>
<td>Poor</td>
</tr>
<tr>
<td><em>Lactobacillus plantarum</em></td>
<td>56</td>
<td>1.44</td>
<td>0.176</td>
<td>1.176</td>
<td>0.15</td>
<td>0.26</td>
<td>Unfit</td>
</tr>
<tr>
<td><em>S. lactis, L. mesenteroides, and L. pentoaceticus</em></td>
<td>80</td>
<td>1.52</td>
<td>0.264</td>
<td>1.124</td>
<td>0.24</td>
<td>0.36</td>
<td>Excellent</td>
</tr>
<tr>
<td><em>S. lactis, L. pentoaceticus, and L. cucumeris</em></td>
<td>49</td>
<td>1.31</td>
<td>0.110</td>
<td>1.140</td>
<td>0.10</td>
<td>0.31</td>
<td>Unfit</td>
</tr>
<tr>
<td>Old kraut juice</td>
<td>152</td>
<td>1.61</td>
<td>0.186</td>
<td>1.330</td>
<td>0.14</td>
<td>0.33</td>
<td>Poor</td>
</tr>
<tr>
<td>Kraut juice 18 days old</td>
<td>161</td>
<td>1.56</td>
<td>0.265</td>
<td>1.162</td>
<td>0.22</td>
<td>—</td>
<td>Poor</td>
</tr>
<tr>
<td>Kraut juice 2 days old</td>
<td>160</td>
<td>1.74</td>
<td>0.324</td>
<td>1.254</td>
<td>0.26</td>
<td>0.67</td>
<td>Good +</td>
</tr>
</tbody>
</table>

*Typical analyses taken from Tech. Buls. Nos. 168 and 169 of this Station.
given, the alcohol content is low but sometimes it is quite high due to growth of yeasts.

Two other types of starters or inoculation may be used with more or less success. The first of these is a mixture of the various organisms natural to a kräut fermentation. Such mixtures have been tried with varied results. The tendency has been toward a good kraut, but no improvement has ever been noted over a naturally fermented product. Analysis of the kraut using a starter of such mixture is given in Table 3 (kraut No. 80). This was one of the most successful, while some of them were failures (kraut No. 49).

The other type of inoculation or starter is a juice from fermented sauerkraut. A number of tests have been made using kraut juice obtained from sauerkraut during various stages of the fermentation. Such tests have all shown that the addition of kraut juice to shredded cabbage for kraut is detrimental if the juice is obtained from kraut more than 4 days after packing (Table 3, kraut Nos. 152 and 161). When juice has been obtained previous to this the results have been variable but in general good (Table 3, kraut No. 160). As yet, results have been too variable and no definite advantage has been noted, so the use of this type of starter is not recommended.

THE RÔLE OF SALT IN FERMENTATION

Salt has had a varied career in its use in the preparation of kraut. It has been used in such high quantities that the kraut had to be soaked before use. On the other hand, kraut has been made containing no salt. Strictly speaking, such products are not sauerkraut. The Germans apparently have always used a lower salt content than that used in this country. This is in accord with their apparent desire to produce a softer kraut than is ordinarily desired by the commercial manufacturer of kraut here.

As kraut is made at present, salt is added primarily to draw out the juice from the cabbage. The more salt added, the greater will be this effect and, as a result, the firmer will be the resulting cabbage or kraut.

On the other hand, the more salt added within certain limits, the more the growth of bacteria will be retarded. It is essential, therefore, that a happy medium be found for the maximum growth of the organisms and the best condition of turgor of the cabbage shreds. Commercial kraut manufacturers apparently favor kraut made with about 2½ per cent of salt. This salt concentration, altho it does not
Table 4.—The Effect of the Salt Concentration Upon the Fermentation of Glucose by Bacteria from Sauerkraut.

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Strains Tested</th>
<th>1 per cent</th>
<th>2 per cent</th>
<th>2½ per cent</th>
<th>3 per cent</th>
<th>5 per cent</th>
<th>7 per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 day</td>
<td>4 days</td>
<td>10 days</td>
<td>1 day</td>
<td>4 days</td>
<td>10 days</td>
</tr>
<tr>
<td>Leuconostoc mesenteroides</td>
<td>7</td>
<td>1.1*</td>
<td>1.5</td>
<td>1.5</td>
<td>0.8</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Lactobacillus cucumeris</td>
<td>7</td>
<td>0.5</td>
<td>2.1</td>
<td>2.5</td>
<td>0.1</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Lactobacillus plantarum</td>
<td>8</td>
<td>0.3</td>
<td>1.9</td>
<td>2.4</td>
<td>0.1</td>
<td>1.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Lactobacillus pentoaceticus</td>
<td>6</td>
<td>0.1</td>
<td>0.3</td>
<td>1.0</td>
<td>0.0</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Streptococcus lactis</td>
<td>1</td>
<td>1.1</td>
<td>1.5</td>
<td>1.5</td>
<td>0.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Gram-negative bacteria</td>
<td>12</td>
<td>11†</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

*Figures represent average number cc of N/10 acid produced in 10 cc of culture medium.
†Number of strains showing growth.
inhibit the growth of the fermenting organisms to a great extent, nevertheless, does have an effect (Table 4). From the table it is evident that this inhibiting effect is greatest in the case of *Lactobacillus pentaceticus*, as no growth was obtained in glucose with salt concentrations of 3 per cent or more even after 10 days; and next in the case of *Lactobacillus cucumeris* and *L. plantarum* in which definite inhibition of growth was obtained in 2½ to 3 per cent salt. These results explain to some extent the failure of these types to develop as rapidly as the *Leuconostoc* types when kraut is packed under normal conditions, that is 2½ per cent of salt. On the other hand, the Gram-negative bacteria (the rotting or spoilage types) are not retarded in their activity until from 5 to 7 per cent of salt is added. From this it is evident that the salt does not retard the growth of undesirable organisms as much as does the acid. The relation of salt to various types of spoilage is of importance and will be discussed later.

The question is often asked as to what kind of salt should be used in the preparation of kraut. Sauerkraut is a food product and therefore only pure salt should be used. There are any number of grades of purity in salt from chemically pure salt to the cheapest of the cattle salts.

The majority of the grades of salt sold for use in kraut making are comparatively free from contaminating salts and lime which have a tendency to neutralize the acid formed. The neutralization of the acid by lime in the salt is not as important a factor in kraut making as it is in pickle packing where larger quantities of salt are used and less acid is produced. Nevertheless, the quantity of lime in the salt should be considered.

Some salts are extremely fine and white, others are very coarse. They may be identical chemically on a dry basis and a pound of one salt will be the same as a pound of any other salt. On the other hand, salt in many cases is measured by some sort of pail or bucket rather than by weighing. This may result in a great difference in percentage of salt, as shown in Table 5. In this case equal volumes of four high grades of salt were weighed, giving differences in weight from 7.5 to 9.2 pounds. If salt were measured in making kraut on the basis of 2.5 per cent of the first salt and a change was made to the fourth type, 3.1 per cent of salt would be obtained. The latter, as will be pointed out later, is too high to permit a normal fermentation. It is essential, therefore, that a weight basis be used; and if a pail is used, the capacity by weight should be frequently determined.
Table 5.—The Relation of the Volume to the Weight of Salt Used in Sauerkraut.

<table>
<thead>
<tr>
<th>Grade of salt</th>
<th>Weight of unit volume, pounds</th>
<th>Percentage obtained if measured by volume</th>
<th>Calcium</th>
<th>Moisture, per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse high grade...</td>
<td>7.5040</td>
<td>2.50</td>
<td>Trace</td>
<td>0.16</td>
</tr>
<tr>
<td>Fine high grade.....</td>
<td>8.3186</td>
<td>2.77</td>
<td>Trace</td>
<td>0.05</td>
</tr>
<tr>
<td>Flake grain..........</td>
<td>8.1356</td>
<td>2.71</td>
<td>—</td>
<td>0.07</td>
</tr>
<tr>
<td>Coarse grade........</td>
<td>9.2803</td>
<td>3.09</td>
<td>++</td>
<td>1.14</td>
</tr>
</tbody>
</table>

EFFECT OF TEMPERATURE UPON FERMENTATION

Temperature is one of the most important of the many factors which have to do with normal kraut fermentation. In kraut making sections, the normal fall temperature is fairly low and therefore cabbage is brought in from the fields at temperatures ranging from 25° to 65°F. This cabbage is warmed somewhat by the natural heat of the building in the process of preparation and cutting for kraut, but in commercial practice it very seldom enters the vat at temperatures much above 70°F. This natural temperature is desirable since it affords a better opportunity for the Leuconostoc or flavor-producing types of bacteria to outgrow the straight acid producers. They have become acclimated to lower temperatures and therefore have a lower temperature range of growth than the lactobacilli. Higher temperatures favor the growth of the other types, and altho it is desirable that they complete the fermentation, early growth of these types is undesirable. Heat is developed in their growth processes, and if the temperature at time of packing is not too low, the lactobacilli will develop quite rapidly and complete the fermentation.

It has been recommended in the past that kraut be fermented at as high as 86°F. This has been based upon the known fact that the optimum temperature for growth of many lactobacilli is near this temperature. It is practically impossible to attain such temperatures by natural means and it is really undesirable to do so. To obtain such a temperature the kraut must be heated before going into the tank or the building must be heated. If the room or building is heated a temperature much higher than 86°F is necessary and the outside kraut is very likely to spoil at these high temperatures.

The results found in the work done at this Station, as well as in the laboratories of Fred and Peterson, have shown that a lower temper-

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ature (60° to 70°F) is more desirable from the standpoint of quality. On the other hand, when kraut is packed at too low a temperature (30° to 60°F), fermentation is retarded too much. In such cases the *Leuconostoc* grow, producing about 1 per cent of acid, but fermentation ceases at this stage. A large number of krauts have been tested four to five months after packing that were not fermented completely and the outside temperature of spring and summer was necessary to warm them enough to complete fermentation.

The temperature of 65° to 70°F is easily attained and is probably the most desirable from the standpoint of quality and speed of fermentation.

**HOW AND WHY SAUERKRAUT SPOILS**

Sauerkraut, like any other food preparation, is subject to spoilage, but the type of spoilage is entirely different from that of most food products. Spoiled sauerkraut is objectionable no matter what may have been the cause of the spoilage and should not be consumed. The more common types of spoilage may be classified as dark kraut, pink kraut, soft kraut, slimy kraut, rotted kraut, and poor-flavored kraut.

**DARK KRAUT**

Dark kraut is a very common form of spoilage and one whose cause is difficult to determine. Darkening should not occur when sauerkraut is packed under normal conditions, but occasionally, because of some fault which may not be noted at the time, it does occur. It may be caused by failure to weight the kraut properly so that the juice does not come to the surface. Under such conditions, certain aerobic types of bacteria and yeasts are allowed to grow near the surface, causing a faulty fermentation and subsequent dark kraut on and near the surface. In some cases apparently darkening is due only to contact with the air. In other instances the kraut may become too dry either due to leaks or to overdraining in those factories in which the excess kraut juice is drained off, thus allowing air to enter. This may also affect the kraut in another way in that the salt does not become evenly distributed and dark spots are noted thru the product. These darkened spots are always found to be oversalted. Such kraut is sometimes referred to by kraut packers as “burned.” The excess salt inhibits or stops the growth of fermenting bacteria but may allow the growth of spoilage types. The condition has often
been noted. In some cases as high as 9 per cent of salt has been found in these darkened spots, while in other spots in the same vat as low as 0.6 per cent of salt has been noted. If there is sufficient juice on the kraut, it tends to dissolve this excess and distribute it evenly through the mass.

Occasionally, kraut is packed and fermented at an excessively high temperature. Under such conditions, the normal bacteria of kraut fail to develop properly and an abnormal flora takes its place with a decidedly off or darkened color. Dark kraut may also be due to rapid rotting at the surface and diffusion of the rotted product throughout the kraut. This is very common in kraut kept at high temperatures and where fruit flies may gain access to the surface.

Occasionally, kraut may be taken out of the tanks and repacked in barrels to be shipped. This leads to further difficulties, since in the repacking it may be difficult to distribute the kraut juice evenly between the various barrels. Some barrels may be packed with a low amount of liquid and, because of this, air may be present which may allow rotting bacteria or yeast to grow. The barrels may be carelessly packed or may leak, resulting in the same growth. Lastly, the barrels themselves may cause certain difficulties. Barrels are very often used interchangeably for kraut and pickles. Pickles are usually spiced and spices contain tannin. This material soaks into the barrels and coming in contact with iron or iron rust a chemical reaction takes place, resulting in a dark-colored material which may at times become impregnated throughout a barrel of kraut. The only remedy for this is a thorough cleaning and reparation of the barrels. Wood itself contains tannin which may cause darkening in the same way. This type of spoilage has been noted on several occasions. It is one whose cause is very hard to determine, since only small traces of iron and tannin cause a considerable change in color, but it usually can be noted by the dark color and the absence of any change in the chemical fermentation products from those normally found. The kraut shows very little change in texture, flavor, and odor except for a slight mustiness. In one case of such spoilage a spicy flavor was noted and in another a slight dill flavor was noted. In both cases chemical analyses gave normal results.

**Pink Kraut**

Pink kraut is due to the growth of certain types of yeast. The so-called pink kraut may vary from a very light pink to an intense red.
Yeasts do not develop unless air is present, so it might be said that the presence of air is the primary cause of pink kraut. Yeast will practically always develop on free juice upon the surface of kraut, forming a white scum. Occasionally, especially when the salt content is a little high, pink varieties of yeast develop and produce the color. This may diffuse down the sides of the tank resulting in pink kraut several feet deep. A condition may be found occasionally in which cabbage and salt are not distributed evenly in packing, especially between the spot where the shredded cabbage is dumped into the vat and the inner wall. Air and salt pockets may result, especially near the surface, and pink kraut may develop in such places. Chemical analyses of such krauts very often show an increased alcoholic content and some destruction of acid.

Finally, pink yeasts apparently do not develop well in a properly and completely fermented kraut. It has been found that pink yeast very often develops in experimental kraut in which the normal fermentation has been disturbed by the addition of pure cultures of certain micro-organisms. In some of these cases, the pink color had passed completely thru the kraut. Analyses have shown an increased alcoholic content and a low acetic acid content. In all cases of pink or red kraut the presence of a great number of yeast cells may be noted by microscopic examination. On no occasion has pink kraut been noted thruout normally fermented kraut unless re-packed into smaller containers.

SOFT KRAUT

Soft kraut may be associated with air, faulty salting, raised temperatures, or faulty fermentation. When kraut is fermented normally certain bacteria or yeast may develop near the surface which cause a slight digestion of the kraut but not a typical darkening or rotting. Such softening is relatively rare, since usually under such conditions a typical darkening or rotting is obtained.

A second form of softening of kraut is due to the growth of organisms common to kraut but growing in the wrong sequence. That is, the coccus forms which should ferment to the normal 0.7 to 1.0 per cent acid before the rod forms begin to ferment and predominate the fermentation may, for some reason or other, fail to develop properly before the rods predominate. The rod forms apparently have greater ability to break down the structure of the cabbage than do the cocci and therefore a softer kraut results. The early develop-
ment of the rod forms of bacteria may be due to a high temper-
ature or to a lowered salt content, both of which favor their pre-
dominance over the coccus forms. One kraut has been prepared by
use of a starter which to all appearances was perfectly normal but
was so badly broken down in texture that it was impossible to use it.

Softening of kraut has been noted which primarily had the same
cause as noted above but was brought about in a different way.
Occasionally, kraut vats or barrels are packed a second or third time
during a season without a thororo cleaning and steaming of the sides of
the vat. The organisms which complete the fermentation of kraut
are on the walls of the vats in large numbers. These organisms ap-
parently have, as noted, a greater digesting effect upon the cabbage
but require a higher temperature for growth. Therefore, in re-
filling vats without thororo cleaning and steaming when the temper-
ature is fairly high, these organisms begin development immediately
and produce a softened condition around the sides of the kraut vat.
Somewhat the same result is obtained when kraut is inoculated with
old kraut juice. Kraut softened in this way may or may not have
fermentation end-products similar to normal kraut, but the actual
predominance of one type of organism over the other may be recog-
nized by microscopic examination during the fermentation.

Low salt content has two effects. It allows the rod forms of
bacteria to develop more rapidly, as stated above, and its absence
results in an improper turgor of the cabbage cells and a resulting
soft or rubbery condition. Numerous cases of soft kraut have been
noted in which the salt content has been low. In one case in which
a large quantity of kraut had spoiled, analysis showed the presence
of only 0.3 to 0.6 per cent salt. The kraut itself had a bright color
and good odor and flavor but was very badly broken down. The
addition of 2½ per cent salt corrected this difficulty in kraut made
subsequently. On the other hand, this kraut was made in a warm
season and possibly if packed during a colder period a firmer kraut
might have resulted. Other cases of soft kraut have been noted in
which the salt content was low (0.6 to 1.0 per cent). They have
been edible, but the texture was very poor from the canners view-
point.

SLIMY KRAUT

Slimy or ropy kraut, altho not common, may at times prove to be
very annoying. While edible, this type of kraut is usually rejected by
the consumer. Sliminess is ordinarily caused by certain strains of
*Lactobacillus cucumeris* or *L. plantarum*, the non-gas-producing rods. They grow very rapidly, especially when the temperature is raised, and become enveloped within a slimy material which causes the organisms to adhere to each other. At times the slime may string out a foot or more in length. The kraut may sometimes become normal after further curing. It is also possible at times to dissolve the sliminess in cooking or canning. This form of sliminess should not be confused with soft kraut. The texture of slimy kraut is seldom broken down as in the case of soft kraut.

**ROTTED KRAUT**

A condition that causes considerable distaste for kraut and kraut factories is the presence, odor, and flavor of rotted kraut or cabbage. It is caused by any of a great number of bacteria, yeasts, and mold, and in some cases by fruit flies. The odor of rotted cabbage is very often noted from the roadside near cabbage fields in late fall. Cabbage in the field is certain to rot and the odor can only be overcome by plowing under the refuse. The rotting also occurs in cabbage refuse around factories, and it is especially distasteful when found on the surface of sauerkraut containers. In some cases the kraut may be black and soft or almost completely broken down. In such cases the very disagreeable flavor and odor may diffuse for some distance into the kraut, and thus what otherwise may have been an excellent kraut may be poor or unfit for use.

The rotting on the surface of kraut may be overcome to a considerable extent. A heavy muslin cloth should be spread over the surface of the kraut when packed, taking care to push it down the sides of the vat. The cover is placed over this and weighted so that the juice does not flow over the cloth. This cloth keeps fruit flies from the kraut as well as keeping the surface of the kraut moist, thus inhibiting the growth of undesirable bacteria. Naturally, cabbage refuse should always be removed and utmost cleanliness practiced.

**OFF FLAVORS IN KRAUT**

There is considerable variation in flavors of kraut which may be caused by certain disturbances in the sequence of bacterial growth. This may result in kraut of an unobjectionable flavor, but flavor which cannot be considered as good or excellent. For instance, it has been noted that the gas-producing lactobacilli or rod-shaped bacteria, if allowed to develop too early in the fermentation, produce a rather
sharp or biting kraut. The non-gas-producing types, on the other hand, do not change the flavor enough, so that a kraut is produced with the somewhat bitter flavor of cabbage accentuated by the destruction of the sugar of the kraut. The resulting product is not appetizing and is sometimes said to be raw or unfermented. In some cases normal fermentation is so rapid that the kraut, even tho completely fermented, does not have a typical kraut flavor and does not acquire it until a week or so after it is completely fermented.

Sauerkraut which has undergone a natural fermentation with the normal salt content and at a proper temperature, and which has not been affected in any way by some one of the forms of spoilage is a very appetizing food product and one which will gain in favor. Regardless of whether kraut is made in homes or in factories, it should be made under the most careful conditions since it has more chance to undergo spoilage than other food products. More attention should be given by kraut makers and consumers to details of quality rather than to the less important matter of fineness of cut, length of shreds, etc., altho these factors affect the appearance of the product.

CONCLUSIONS

Altho some sauerkraut is successfully prepared in the home, most of the kraut now used is made in large plants.

Sauerkraut curing is a fermentation in which three types of organisms are involved. They ferment the sugar of the cabbage which has been withdrawn by the action of salt. The final end-products from sugar in the kraut fermentation are lactic and acetic acids, alcohol, and carbon dioxide.

The use of starters has not yet been placed upon a successful basis. The proper distribution of salt and cabbage, the use of approximately 2½ per cent salt, the covering of the cabbage after packing, and a fermentation at a temperature that is not too high are the most important factors in the production of high-grade kraut.

Sauerkraut may spoil in various ways producing dark, pink, soft, slimy, rotted, or off-flavored kraut. These conditions are brought about by various faulty procedures used in the handling or packing of the product.

Since the spoiling of sauerkraut is due in nearly all cases to harmful types of bacteria or yeast, it is apparent at once that utmost cleanliness should be followed in all plants to insure a wholesome product.