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SILAGE AND SILAGE FERMENTATION

By A. R. Lamb

There would be much less spoilage and waste of silage if the more than 22,000 farmers in Iowa who put up this valuable feed understood just what happens in the fermentation process, instead of following directions in "cook book" style. There would also be more use of other crops than corn for silage, especially in cases of emergency, if the merits of some of them for this purpose were known. Conditions are not always normal and favorable for the best results in making silage, and a knowledge of the principles upon which the proper preservation of silage depends is of considerable value when conditions are unusual. A great deal of uncertainty about silage fermentation still exists. This is evidenced by the number of samples of moldy silage sent in to the Iowa Agricultural Experiment Station and by the incorrect ideas regarding the fermentation that are still current.

Investigations and experiments carried on at the Iowa Agricultural Experiment Station during the past six years, as well as at certain other stations, have cleared up a number of doubtful points concerning silage fermentation and disposed of a great deal of the "guess-work" in the discussion of silage problems. Some of the results of that work, as to what silage fermentation really is, the causes of the fermentation, and the adaptability of soft corn ears, alfalfa, rape, and other crops to the making of silage, are presented in this bulletin.

THE FERMENTATION OF SILAGE*

Certain other well-known fermentative processes are somewhat similar to silage fermentation. When hay is stored too green it is likely to heat, even to the combustion point. This heat is only the outward evidence of other changes which are taking place in the hay. Grain stored in bins undergoes certain chemical changes, which sometimes develop a noticeable amount of heat. These and similar changes, which are undergone by all living plant material when stored in large masses, are in some respects like silage fermentation. The fermentation of sauer kraut is also similar in that the preservation of the kraut depends upon the formation of organic acids by bacterial action. The formation of vinegar from cider involves the production of acetic acid, which is one of the acids found in silage. This change takes

*Since corn (maize) is the principal silage crop in this country, all references to silage will be understood as being to corn silage unless otherwise stated.
place necessarily in the presence of air. On the contrary, the changes which are normal to the formation of good silage take place almost entirely in the absence of air.

In silage making, the chopped corn forage is tightly packed into an air-tight silo, with plenty of moisture present, and fermentation begins at once. The first evidences of change are a slight rise in temperature and the evolution of carbonic acid gas.* The temperature of the silage rarely exceeds 85° to 90° Fahrenheit, except near the surface, where fermentative processes are greater, owing to the presence of air. Erroneous ideas regarding the importance of the heating in silage fermentation were derived from observations made only on the surface of the silage. The oxygen in the silage is used up early in the process of fermentation or driven out by the carbonic acid gas. From this point the presence of air or oxygen is fatal to the proper preservation of the silage, because air permits the development of molds, which are themselves sometimes poisonous, and which quickly destroy the acids and thus allow the silage to spoil. The importance of air-tight walls and proper packing down of the silage to keep out the air is, therefore, at once apparent.

THE FORMATION OF ACIDS

The next changes noticed during the silage-making process are a change in color, and the development of a more or less pleasant aromatic odor and a sour taste. The color and odor are characteristic of silage and are of considerable value in judging its quality; but the most important change is the formation of acids, which cause the sour taste. The acids formed are chiefly lactic acid, which is the acid found in sour milk, and acetic acid, the acid of vinegar. The total amount of acid formed averages between 1 per cent and 2 per cent of the weight of the silage. This change is important because it indicates that the fermentation is healthful, like the ripening of cream or the formation of vinegar, instead of being a state of unhealthful decay, like the putrefaction or spoiling of meat. In the presence of this acid fermentation it is impossible for the bacteria which cause decay to live and work, unless the presence of air should allow the growth of molds, which in turn destroy the acids, and thus allow the putrefactive bacteria to thrive. This last process is what occurs in the top layer of the silage in the silo, which is spoiled because of the presence of air. The formation of acid is, therefore, one of the most important of the changes which take place in the fermentation of silage.

*This gas is generally known to be poisonous, but accidents still occur occasionally when the gas, which is heavier than air, collects in a partially filled silo. If a lighted lantern lowered into the silo is extinguished, it is almost certain death to enter before the gas has been driven out by starting the silo-filler or by opening a door near the surface of the silage.
THE FORMATION OF ALCOHOLS

Other changes occur in the process which are not appreciable to the senses, and which can generally be detected only by chemical analysis. One of these is the formation of a small amount of alcohols, chiefly ordinary or grain alcohol. The total amount of alcohols generally varies between 0.1 per cent and 0.4 per cent of the weight of the silage, or as much as 0.5 per cent of the juice. The source of the alcohols, as well as of the acids, is the sugar originally present in the plant. Experiments conducted by the writer show that the amount of sugar which disappears is almost exactly equivalent to the amount of alcohol and acid formed. About one-half of the sugar present is ordinary cane sugar. This is first broken up into simpler sugars, such as glucose, and then the simple sugars are changed into alcohol and acid.

Other recent experiments show that the amount of simple sugars in the silage is at first increased by the breaking up of some of the starch; but the total amount of sugar present, after fermentation is over, is much less than in the green plant material. Sometimes practically all the sugar is used up. The amount of sugar in the green plant, and, therefore, the amount of acid in the silage, depend upon the maturity of the plant when harvested. The amount of sugar in the plant decreases as the plant approaches maturity.

Another characteristic change is the breaking down or digestion of protein matter, or the flesh-building constituent of foods. This merely anticipates some of the digestive processes in the alimentary tract of the animal which eats the silage, and therefore does no harm, since little or no nutritive value is lost.

THE CHANGES COME RAPIDLY

These various changes take place with the greatest rapidity during the first five days, and are practically complete at the end of 10 or 12 days. The writer measured the amount of carbonic acid gas produced in several instances, and found that the rate at which this gas was produced was always greatest during the first 24 hours after the corn was put into the silo. The development of heat at the surface of the silage and some of the changes in the sugar are generally most rapid in the first day or two, while the formation of acid is often more rapid somewhat later, or during the second, third, and fourth days. After the fermentative changes which have just been described are finished, or after the first two weeks, there is practically no further change in the silage. Silage has been kept for years in a tight silo without losing either its palatability or its value.

The losses which occur during the fermentation process are appreciable, but can be greatly reduced by taking proper precautions, especially by making the silo absolutely tight, including
the bottom, and by covering the top with well-packed straw, stover, or other materials. These losses are more than made up for by the increased efficiency of the feed.

**THE CAUSE OF SILAGE FERMENTATION**

Ever since silage was first made, there has been doubt about the causes of these important preservative changes in the fermentation of silage. At first, bacteria were thought to be responsible, as in the case of vinegar. Later, other investigators claimed that the cells of the plant itself carried chemical substances called enzymes,* which were the only agents actually concerned. Other writers have taken one side or the other on the subject.

The greater part of the past two years has been spent by the writer in an effort to settle this much discussed question. The results obtained show definitely that neither bacteria alone nor plant enzymes alone are responsible for the fermentation of silage.†

It has been found that a plant enzyme digests the starch and gives a preliminary increase in some cases to the sugar content. Another enzyme breaks down cane sugar into simple sugars. The acid-forming bacteria are the agents which form most of the acid from the sugar. This statement is supported by the fact that bacteriologists have found large numbers of acid-forming bacteria in silage. Part of the alcohol is formed by the plant enzymes and more alcohol is formed later by yeasts,‡ which are microscopic one-celled plants like bacteria. Some of the protein is digested by plant enzymes and some by bacteria. Both plant enzymes and bacteria seem to have a share in the production of the heat which raises the temperature of the silage. The evolution of carbonic acid gas, which is formed in such large quantities at the beginning of the fermentation, seems to be due largely to the plant enzymes, although the bacteria and yeasts doubtless furnish part of it.

Direct evidence has been found of an enzyme called invertase which hydrolyses or breaks down cane sugar, and of an enzyme called zymase, which forms alcohol from sugar. Other investigators have found enzymes in the corn plant which act on sugar and on proteins. Enzymes of similar nature have been found in practically all plants, as they are the agents which promote plant growth. Additional evidence has been obtained by fermenting silage and even corn juice in the presence of antiseptics, showing that plant enzymes are active in silage fermentation, but that they are not the only active agents in the process.

*Enzymes are substances produced by living cells of plants and animals, which carry on the life processes of the plant or animal. For example, enzymes in the stomach and intestines of animals digest its food, and enzymes in the corn plant cause it to grow.

†A detailed account of these experiments is to be published later.

‡Yeasts are the cause of ordinary alcoholic fermentation in beer and wine.
SOFT CORN EAR SILAGE

In the fall of 1915, the unusually large amount of "soft corn" that was harvested, owing to the unfavorable season and early frosts, presented a rather difficult problem in Iowa. Much of the corn grain was so immature and contained so much moisture that it could not be safely cribbed, but would mold and be a total loss unless preserved in some way. The proportion of the average total crop that could be preserved in the ordinary way in the available silo space was small. Therefore the question arose as to the possibility of preserving the ears alone in the silo, without the stover.

The writer, in cooperation with John M. Evvard, assistant chief of the animal husbandry section of the Iowa Agricultural Experiment Station, ensiled soft corn ears successfully in small laboratory silos. Silage made in these small silos is identical in quality and composition with properly made silage in a farm silo. The ears, which were in late roasting stage, were husked, run thru a silage cutter which cut them into half-inch and one-inch pieces, and tightly packed into large cylindrical glass jars. A small amount of water was added. The silage resulting was of excellent appearance and odor, clean, free from mold, and palatable. There was quite enough sugar in the grain and cobs to furnish enough acid to preserve the material, altho the acidity developed was not as great as in ordinary corn silage. One jar of this silage has now been kept in perfect condition for more than a year.

It is indicated by these experiments that in the event of another unfavorable season or early frost, a great deal of valuable corn grain could be saved by ensiling the ears alone. In this way the softer corn may be preserved in a clean and palatable condition, and the most nearly mature corn may be allowed to dry out in the field until dry enough to crib. However, the very softest corn had better be fed at once, since the weight of the silage will crush corn that is too soft. It is considered a good plan to ensile the husks with the ears since the husks tend to tie the mass together. In contrast to ordinary corn silage, it must be remembered that this silage is a concentrate and not a roughage. For this reason soft corn ear silage can be used to considerable advantage in feeding swine, while ordinary corn silage contains too much roughage for them.

PRECAUTIONS WITH SOFT CORN

If it is desired to make this kind of silage, the following precautions must be observed:

1. Chop quite finely. No pieces should be over an inch across, and the smaller the better, within reasonable limits.
2. Pack tightly by trampling well, especially near the walls.

3. Add water. This is best done by adding slowly during the filling, being careful not to add an excess so that the water collects at the bottom of the silo. It is well to have a small opening at the base of the silo, which will indicate when there is an excess of added water. In general, late roasting corn will require about a ton of water to every 6 or 7 tons of silage corn. Less mature corn may not require any water.

4. Cover the filled silo with some cheap material such as stover or straw, in order to avoid the loss by spoiling of a layer of good concentrated feed.

5. It is best not to have too large a proportion of nearly mature ears, because the hard cobs prevent packing, and also because the mature corn may not contain enough sugar to furnish the necessary acid to preserve it in the silo.

6. Snapped corn, or ears plus husks, may be used in this manner to better advantage than husked corn.

7. Of course moldy corn should not be put into the silo, but corn in good condition, ensiled carefully in a tight silo is perfectly safe from mold.

Silage made from the immature whole plant is generally of poor consistency, too sour, too high in moisture, and otherwise unsatisfactory. Its feeding value is much less than that of mature corn, because the amount of nutrients stored in the corn plant increases continually up to the ensiling time. The loss during the fermentation is also greater, on account of the larger amount of sugar in the plant at this stage and the consequent greater production of acid and carbonic acid gas.

It is better, therefore, to leave corn in the field as long as possible, even until after frost, rather than to ensile it too soon. Corn which has been absolutely frozen will make good silage, as freezing will not destroy the enzymes, and there will be plenty of opportunity for the entrance of acid-forming bacteria during the silo filling. Of course the corn must not be left in the field so long after being killed by frost that it begins to mold, or the leaves become so dry that they are brittle.

The following experiment furnished evidence of the fact that frozen corn makes good silage. Several stalks of corn were cut and placed in an artificial ice machine, so that they were solidly frozen for 12 days. They were then thawed out, chopped, and ensiled as usual. The consequent evolution of carbonic acid gas, and the formation of acid and alcohol were about the same in amount as in the normal corn silage. The appearance and odor were normal and good. Of course, after corn is frozen, the plant cells are killed and after thawing, will spoil. Therefore the corn should be ensiled as soon as possible thereafter.
RAPE SILAGE

Also with the cooperation of Mr. Evvard, the writer has succeeded in making good silage from rape and from mixtures of rape with other materials. Rape and alfalfa are among the very best pasture crops for swine, on account of their luxuriant growth, high protein content, and efficiency as growth producers. If rape proves to be as efficient in the form of silage as when green, its value to swine growers will be greatly increased.

Rape is rather more difficult to ensile than corn, because it contains more water and a higher percentage of sugar, as well as certain substances containing sulphur, which are likely to form disagreeable products if the fermentation progresses too far. The higher sugar content also tends toward the development of more acid than in corn silage. The silage made from the entire rape plant and from rape leaves was, however, pleasant in taste and odor, but very sour. If the same precautions are observed as in making corn silage, such as packing well into an air-tight silo of the proper shape, there should be no great difficulty in preserving rape.

The mixtures which were made with rape and other plant materials were much better, however, especially in the case of added legumes, such as alfalfa and red clover. The rape supplies to the mixture the necessary sugars, which are deficient in amount in the legumes. This mixed rape-legume silage may be made in almost any proportion, from 20 parts to 80 parts per hundred of rape, and the resulting silage, if properly made, will be pleasant and aromatic in taste and odor, and not too sour. The alfalfa-rape mixture will furnish a silage high in flesh-building and growth-producing constituents, and perhaps better for swine feeding than the other mixtures. The following plant materials, however, made successful silage when mixed with rape: corn grain, whole corn plant, potatoes, blue grass, and timothy.

Feeding experiments with rape silage have not yet been conducted, but are contemplated. However, a number of samples of pure rape and mixed silages were offered to pigs to ascertain whether they would be palatable. The pigs ate the silage quite readily, after a few preliminary sniffs, and appeared to enjoy it, in contrast to their then regular ration of corn and tankage. The second day it was offered to them, the same animals ate the silage with relish. It is, however, well to remember that the feeding of rape silage is still in the preliminary experimental stage, and while there is no apparent reason for its failure, it should be attempted only with caution.

The sugar content of rape makes it an excellent complement of alfalfa as far as having the proper composition for good silage.
is concerned. Neither plant will make as good silage alone as the mixture of the two. As it is often of advantage to ensile alfalfa, especially when weather conditions are not right for making hay, the combination of the alfalfa with 20 to 50 parts per hundred of rape will make excellent silage, and preserve the alfalfa crop in an excellent condition, besides avoiding the great loss in feeding value which occurs in making hay during unfavorable weather. This kind of silage would probably be of value in feeding cattle, although too high a percentage of rape in the mixture would be likely to taint the milk if fed to dairy cows.

**OTHER SILAGE CROPS**

Many other crops have been advocated and used for silage, such as pea vines, beet pulp, beet tops, sorghum, oats, rye, vetch, and many others. In Iowa it will rarely be found necessary to ensile these unusual materials except when the material would otherwise be lost, as in the case of waste from canneries. Certain mixtures are not without their value, however, such as the addition of clover, soybeans, rape or cowpeas to corn, as protein supplements. In these cases it is best to plant the material between the corn rows, to be cut and ensiled at the same time as the corn. It is well to remember that as far as its content of protein and sugar is concerned, the corn plant furnishes the most nearly ideal single plant material for silage. Plants similar to the legumes contain too much protein material in proportion to the sugar content; and rape has a rather high sugar content. Thus it is easily seen why a mixture of rape and a legume makes such excellent silage.

**GENERAL PRECAUTIONS**

The following facts regarding corn silage are briefly reviewed on account of their value at silo-filling time.

The corn forage should be ensiled when the grains are well dented, which is generally when the lower leaves and husks are beginning to dry up, and the corn is nearly ready to be cut for shocking. The sizes of pieces into which the corn should be cut is not of very great importance, but an average of one-half to one inch long is very generally accepted as correct. The corn will usually not need added water if cut at the proper time in a normal season. In general it is better, however, to allow the corn to become as mature as possible and add water, rather than to ensile it when too green. If it is dried out or has been severely frozen, so that it does not feel moist in the silo, water should be added, preferably at the blower. Then when the silo is filled the top of the silage should be thoroughly soaked with water. The addition of water and thorough tramping during the filling
help to prevent spoiling. During the filling the sides should be kept slightly higher than the level of the center, and the silage should be tramped especially well near the walls, in order that air spaces may not be left when the silage settles, thus allowing the growth of mold. If the silo is air-tight and the filling is conducted with care, there should be little if any moldy silage, except at the top. The loss at the top may be lessened by covering with stover or waste material, soaking down, and sowing to oats—or better still by starting to feed the silage at once. In the latter case, the silo may be refilled after the silage has settled, without having to throw out any spoiled silage.

The refilling after settling may be done with fodder which has dried out in the shock. Of course this must be well soaked with water. The entire silo may be refilled with dry fodder, after the first lot of silage is fed, provided it is well packed and about an equal weight of water added. The water should be added slowly, to give it an opportunity to soak into the cut forage before running off. The silage resulting is not as palatable or as aromatic as normal corn silage, but it is much more succulent and is eaten more readily by cattle than is the dry fodder. Thus the usefulness of the silo may be extended over a much greater part of the year.

Moldy silage is best not fed to any farm live stock. Mature cattle sometimes seem to be able to eat moldy silage without harm, but horses are peculiarly susceptible to it.