HERMETIC HAY WAFER STORAGE

by

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INTRODUCTION

Ever since time began, man has been trying to improve his place in the world. One of the ways he has been doing this is by domestication of animals. When he did this, he assumed the responsibility of providing food for the animals. In winter when there was no place for the cattle to graze, this meant spending much time and back-breaking labor to store the food in summer and then to feed the food in the winter. Much time and thought toward reducing this labor have been devoted by research engineers, economists, extension personnel, and particularly the people directly concerned - the farmers.

This means of supplying water and grain for cows has improved greatly over the years until little labor or attention to these details is required. However, the supplying of roughage (particularly alfalfa hay) to livestock, even in this modern time of automatic feed plants, push button silage feeding systems and linear computer programming for ration design, still involves much manual labor for the average farmer. Also, hay usually suffers much loss of quality from the time the stand is ready to be cut, [at 10 per cent bloom stage according to Meyer (23)] until it enters the digestive tract of the domesticated animal. The removal of the hay from storage and the distribution of it to the livestock seems about the only cattle feeding operation defying complete mechanization and automation.

Since hay is one of the most important feeds for livestock [average annual production in the United States is about 100

million tons according to Barger (2)_7, there is definitely a place for much research and development devoted towards the reduction of labor.

Many people have thought that if hay could be put into small self-contained packages which would have handling properties similar to cereal grains or pelleted alfalfa, but yet retain the roughage property, existing machines such as grain elevators, truck beds with hydraulic dumps, grain augers, granaries, and tractors with front-end loaders could be used to handle and store the hay without the use of manual labor.

One of the developments along this line of thinking to reduce the problems of handling alfalfa hay has been the introduction of various types of machines which will put the hay in a package which many people call a wafer.

The term "hay wafer" for purposes of this thesis means a conglomeration of hay retaining its identity in which a piece of hay could be as long as the smallest dimension of the mass. This conglomeration is packed into a package with or without the use of an artificial binding agent. This term "wafer" is different from a pellet in which the roughage loses its identity by going through a grinding process before being made into pellets. Pellets are a very easily handled material but have drawbacks to their use, including the high priced grinding operation, the large powerful equipment required, and the fact that the alfalfa in this form does not act as a roughage when it is eaten.

REVIEW OF LITERATURE

Hay Quality Determination

According to Gilbert (18) there is general disagreement by people directly concerned as to what should be used as an indicator of hay quality. Meyer (23) says that the ultimate test of hay quality is animal response (growth, fattening, or milk production); however, a simple chemical analysis can give some indication of the nutritive value. Nordfelt (24) says chemical analysis for some feed constituent of otherwise acceptable hay which would serve as an indicator of value is the most reliable method of determination for general public use.

Storage Losses

Since alfalfa hay is known to lose carotene content quite rapidly (22), there is a possibility that wafering might slow down this loss. However, Fulton (16) said, "There is no better quality retention in pellets by nature of the hay being in pellet form." However, by storing the pellets in an inert gas atmosphere, preservation of pellet quality is enhanced over other forms of hay in that inert gas will pass more readily through a mass of pelleted material and displace oxygen.

Under a properly designed and maintained environment, carotene levels can be maintained indefinitely at 98 to 99 per cent of input values according to Fulton (16). This gives rise to the thought that hermetic storage could lead to a higher carotene retention than would open storage. However, he also noted that because air

could circulate freely, there was experienced a problem of moisture movement through the mass and condensing on the walls of the bins to spoil the pellets next to the walls.

Much time, effort, and money have been spent on the problems of producing hay wafers in some sort of hay process whereby less room will be required to store and haul a ton of hay. Although a good many tons of wafers have been produced in Nebraska, Kansas, Texas, New Mexico, California, Oregon and Washington [one company's machine produced over 6,000 tons in 1962, according to Lamp (20)] by various commercial machines, there are many problems involved and they need to be resolved before the practice of wafering will be used by very many farmers. Although a great many of these problems are involved directly with the production of these wafers, the problems do not end there.

After three years of experience with hay wafers in Kansas and other states, the problem of hay stored in wafer form deteriorating in storage has come to be noted as an important problem to be investigated. Because of the high moisture content associated with the finished product, frequently up to or greater than 20 per cent wet basis reported by Lamp (20), and Dobie's (12) idea of the optimum range of hay moisture content being 15 to 25 per cent, there has been experienced in Kansas [Reece (26)] and elsewhere, the formation of a heavy white mold over the surface of the piles of hay. Sometimes a mold will be found next to the floor of the storage structure, particularly if this floor is concrete. The surface mold later seems to disappear. So even when a practical wafer machine is put on the market, storage and handling methods must

also be available before the farmer can put the machine to work.

This molding problem is associated with hay wafers and not with properly cured baled or loose hay for two reasons. One, in order to produce a good wafer with present operational wafer machines, it is usually necessary to add water to the hay and thus increase the moisture content above that in the windrow. Two, wafers are much more dense than baled hay so that it is much harder for air circulation through a pile of wafered hay to occur and dry the hay naturally, as happens with slightly tough baled hay for example.

The problems of the weather interfering with hay-making procedure has lead also into an investigation of methods of making hay in less total time.

If high-moisture hay could be wafered, hay losses because of adverse weather would be reduced. According to Buckingham (7), Burt Horace of Pennsylvania State University says:

> We must get the hay out of the field before weather damages it. For example, during June, weather data in Pennsylvania over a 50 year period shows us that we can expect about 12 - 16 days of rain. Now this includes showers, general thunderstorms, sprinkles, and what not. This is not hay-making weather, and this is when our heaviest yields of grasses and legumes should be harvested.

However, the moisture in wafers produced from hay that in the windrow is dry enough to bale and keep safely has caused problems including the surface molding already mentioned. So, until the storage problem is solved, the hay is going to have to cure in the windrow, subject to the elements of the weather; thus, if

progress is to be made in wafering, the problems of storing wafers including those associated with hermetic storage must be solved.

Vayssiere (27 p. 115) defines hermetic storage in this manner: "It is the storing of an agricultural product within a container in such a way that the product is protected from any change of gases or liquids with the outside environment." He also comments that hermetic storage of wheat grain "forestalls mold and overheating when the product contains a relatively high degree of moisture, without preventing the development of acidity carried by anaerobic fermentation when the humidity is excessive."

Anderson and Alcock (1 p. 350) said of hermetic grain storage: "It prevents mold development and heating in products carrying excess moisture through without stopping the development of acidity resulting from anaerobic fermentation."

PURPOSE

As part of a larger field of study by the Agricultural Engineering Department at Kansas State University, the object of this investigation was to determine what happens to the feeding quality of high moisture alfalfa hay in the form of wafers during hermetic storage. It is supposed that under hermetic storage conditions molding could be reduced to a very low level. Perhaps the wafers would then have storage characteristics similar to haylage. Standard procedure to make haylage is to chop the alfalfa very fine to decrease the amount of air in storage and increase density. However, density obtained in wafering could possibly be higher than that normally obtained in conventional haylage operations.

Since structures in which air-tight conditions are obtained are very expensive, if these wafers could be made more dense than haylage, the storage cost per ton of dry matter would be greatly reduced.

The specific objectives were as follows:

1. Investigate losses in nutrients during hermetic storage;
2. Investigate changes in hay occurring during wafering process;
3. Compare hay quality of wafers in hermetic storage with wafers dried with natural air;
4. Determine relationship between moisture content and protein or carotene loss occurring in hermetic storage.

METHODS AND EQUIPMENT

Outline of Investigations

The general overall procedure of the investigation will be briefly discussed in the following paragraphs. The alfalfa was prepared for wafering by a combination hay conditioner-swather followed by a period of field curing. Alfalfa grown in three different fields was used. Hay quality and moisture content samples were taken before and after the wafering process to determine the changes in hay quality occurring during the wafering process. Wafers were collected and stored in 60 hermetic storage containers and a steel bin with provision for natural air drying. Hay quality and moisture content samples were taken for each storage container. A complete foodstuffs analysis of each sample was used as an indicator of hay quality. Oven procedures were used to determine moisture contents.

Thermocouples were installed in half of the hermetic containers and in the steel bin so a record of the temperatures attained during storage could be made. Wire seals were installed on the lids of the containers so that any tampering with the lids resulting in destruction of the hermetic qualities of the containers could be detected.

These hermetically sealed containers were opened in the fall after four and one-half months of storage and samples to determine moisture migration and hay quality were taken. Also naked eye observations of the stored wafers were recorded. The wafer mass stored in the steel bin was core sampled for comparison purposes. Using the complete foodstuffs analysis reports on the hay quality samples, statistical tests were made to determine hay quality changes occurring during wafering and during storage, and to determine hay quality differences between air-dried wafers and hermetically stored wafers.

Equipment

The machine used to produce the wafers for this project was the Massey-Ferguson Hay-Packer, model number 48, serial number 11850-0031. The machine consisted of a flail type pickup, an auger feed for two rollers which forced the hay into and through the hydraulically controlled dies and a discharge elevator. Water was added to the hay by a selected number of the eight nozzles located in the auger feed chamber. The amount of water is regulated by the number of nozzles turned on and the water pressure of the nozzles. Supposedly, the density of the wafer can be controlled by the moisture

content of the hay and the hydraulic pressure on the dies to produce more or less resistance to the passage of the hay through the dies. The hydraulic pressure was maintained at 450 pounds per square inch (gage) for filling the first fourteen storage containers and at 400 pounds per square inch (gage) for filling the remainder of the storage containers. Because of the limitations of the machine and hay conditions, no other die pressure levels were feasible. No detectable difference was noted between the wafers produced at the two die pressure levels.

Sixty surplus naval ammunition cans were obtained to be the hermetically sealed storage containers. These cylindrical aluminum cans had straight sides and lids which were constructed such that the seal in the lid could be put under enough pressure to make the can airtight merely by twisting the cap into place and then forcing the handles down into the sealed position. During trials in the laboratory to check the seals, the two cans tested maintained twelve inches of mercury pressure for several days at 75 degrees Fahrenheit. Thirty of the cans had approximate inside dimensions of 10-3/4 inches in diameter by 39 inches long, and had capacities of 2.10 cubic feet. The remaining 30 cans had approximate inside dimensions of 14-1/4 inches in diameter by 42 inches long, and held approximately 4.02 cubic feet.

A Toledo 30-pound capacity balance scale which could be read to .01 pound was used to weigh moisture samples both in the field and in the laboratory after the samples had been in the oven. A Fairbanks 1,000-pound capacity scale was used to weigh the storage containers.

To record temperatures inside the containers, copper-constantan thermocouples in conjunction with a Minneapolis - Honeywell Brown recording potentiometer, serial number 5218, controlled by an intermatic time switch and stepping switch were used. A large electric oven belonging to the Dairy Department and housed at Kansas State University's dairy barn was used to oven-dry moisture samples. This oven could hold 25 samples at one time which expedited the routine of drying the samples. The large oven also allowed all of the samples to be dried before the high moisture samples could mold. A smaller electric oven belonging to the Agricultural Engineering Department was used for a small portion of the samples.

The device used to pack the hay into the cans was a two-inch diameter steel shaft with a round plate on one end that was four inches in diameter. The total weight of this device was 31 pounds.

Procedure

Plate I, page 12, shows the overall field operation which was used to produce the wafers and put them into the aluminum cans. Before this operation could be accomplished, the alfalfa was cut and put into windrows by a 14-foot self-propelled windrower and hay conditioner. It was then allowed to dry to the 13-1/2 to 32 per cent moisture (wet weight basis) range as indicated by samples taken directly ahead of the wafering operation. The man in the right foreground of Plate I is accomplishing this particular operation.

The two samples for each storage container which he is collecting are labeled A_n and B_n. The n is the number of containers

EXPLANATION OF PLATE I

An overall view of the field hay wafering operation.

PLATE I

previously filled plus one. Hay was removed from four or five places in the windrow 20 to 25 feet apart for each A_n sample. The A_n samples were used for determining as closely as possible the moisture content of the windrow. The B_n samples were taken on the same basis except that several B_n samples were omitted as only 21 B_n samples were made. These were taken so that a statistical analysis could be made to determine whether there was a significant change in hay quality as the hay passed through the machine.

The hay packer (wafer machine) in operation is shown in Plate I, being followed by the trailing, self-unloading trailer which catches the freshly made wafers as they are delivered by the elevator.

At the beginning of a production run, the machine was started and run until all of the wafers which had been in the machine overnight were pushed out of their respective dies and loaded onto the wagon. After 400 to 500 pounds of wafers had been produced, a helper would catch a bucket full of wafers as they fell from the machines' elevator. This is shown in Plate II, page 15. A second helper would take the full bucket and sample the wafers before emptying the bucket into the particular storage container that was being filled. Three identical samples were taken by retaining specimens from each bucket. These samples were labeled C_n, D_n, and E_n. Since it took more than one bucket to fill a model bin, samples were combined so that there was only one each of the C_n, D_n, and E_n samples for each storage container.

The D_n samples were sent to the university's biochemistry laboratory for a complete foodstuffs analysis. The C_n samples

EXPLANATION OF PLATE II

A view into the wagon trailing the wafering machine. This shows the storage container filling operation along with the packing tool held by the person on the right, the sacks used for containing the samples, and the wafer machine's discharge elevator at the point where the wafers for storage were taken.

PLATE II

were used to determine the average moisture content of the hay mass in the various containers. The E_n samples were for later observation of the quality of wafers which had gone into each aluminum can.

After each bucket had been sampled, it was emptied into the can which was being filled, as shown in Plate II. The order of filling the cans was such that the large cans were alternated with the small cans. The two men in the left foreground of the picture are placing a thermocouple wire in position so that the thermocouple junction will be in the center of the diameter and about mid-point longitudinally in the can. The man in the left foreground is also holding the packing device described earlier. In order to more closely simulate the density which might be found in taller, larger, farm sized storages in which the wafers own weight would tend to pack the wafers in storage, this 31 pound tool was used in a pile driving motion.

The machine produced wafers faster than the can filling operation could utilize them, and the wafers which were not put into the cans were collected on the floor of the wagon. These wafers were then put into storage in a 1,000 bushel steel bin. In this manner the hay packer could be kept busy even when the can filling operation was temporarily halted between containers and the wafers thus stored in the 1,000 bushel bin would be comparable to that stored in the aluminum cans. For comparison, the quality of hay entering the steel bin was considered to be the same as that entering hermetic storage. A direct comparison of final quality between the two storage methods was planned at the end of the storage period.

A separate data sheet was maintained on the wafers in each storage container. The sacks in the right foreground of Plate II were the sacks in which the moisture content and complete foodstuffs analysis samples were contained until the respective tests could be performed.

Every attempt was made to obtain a wet weight on the moisture samples as soon after sampling as possible. The balance scales were hauled to the field for more immediate use. The chemistry laboratory samples were delivered to the quick freeze locker in Willard Hall twice during the afternoons so that an accurate analysis representative of the hay entering storage could be made by the university Biochemistry Department.

The samples for the oven dry moisture determinations were put into brown grocery sacks and the tops of these sacks rolled closed as the samples were taken. These sacks were weighed as soon as possible after the samples were taken. These samples were put into the Dairy Department's drying oven with the tops of the sacks opened for better air circulation. The temperature inside the oven was maintained at 55 ± 4^{o} Centigrade for 48 hours and samples were again weighed. The difference between field weight and post oven weight was considered to be the weight of water in the sample at the time it was collected in the field. Using this assumption, the moisture content of the wafer was calculated on a per cent of the wet weight of the sample (wet weight basis) and also as a per cent of the dry weight of the sample (dry weight basis). It is common practice to give moisture content of hay on the wet weight basis. It is also common practice for the complete

foodstuffs analysis report to be given on the wet weight basis for convenience of the person receiving or using the report. Moisture contents reported by the Biochemistry Department could not be satisfactorily statistically correlated (computed r = .512) with the moisture contents determined from the C_n samples. It is probable that the D_n samples which went to the quick freeze locker in Willard Hall dried somewhat before the analysis was made. Some of the samples had longer opportunities to dry than others and this would explain the reason for poor correlation. The moisture contents of the C_n samples as determined by the oven dry procedure were assumed to be correct.

In order to have the samples on a comparable basis, the complete foodstuffs analysis reports were converted to the dry weight basis. For simplification purposes, the moisture contents in the data tables are given on a wet weight basis.

The wafers which were produced and put into the cans varied in structure and content. Four examples of the wafers produced and stored during this study are shown in Plate III on page 21. Wafer pile number one is an example of what are called good wafers in this thesis. The wafers have maintained good shape with the approximate physical dimensions of 2-1/4 inches thick by 2-1/2 inches wide by 1 - 5 inches long. Notice the absence of large amounts of fines. These wafers were not made of such high moisture content that they became rock hard upon drying under natural air drying conditions. Probably the hay moisture content upon formation of these wafers was 20 - 25 per cent wet weight basis.

Wafer pile number two is a sample of hay which was processed by the wafer machine but which did not stick together in conglomera-

tions of the size wafers which the machine was supposed to produce. Note that there are some pieces of wafers almost 2-1/4 inches by 2-1/2 inches by 1/2 to 1 inch, but also there is a large amount of fines present. It was observed that this situation seemed to occur when an insufficient amount of water was added by the machine and the hay was dry and immature enough to be finely chopped by the wafer machine. These wafers disintegrated badly when handled.

Wafer pile number three is a sample which more nearly approximates an average of the wafers stored in the 60 cans. It contains a number of conglomerations the size of wafers and at the same time, there are quite a few fines present. Note that there is a small amount of wheat straw present as there were small areas in fields two and three where there was some volunteer wheat present.

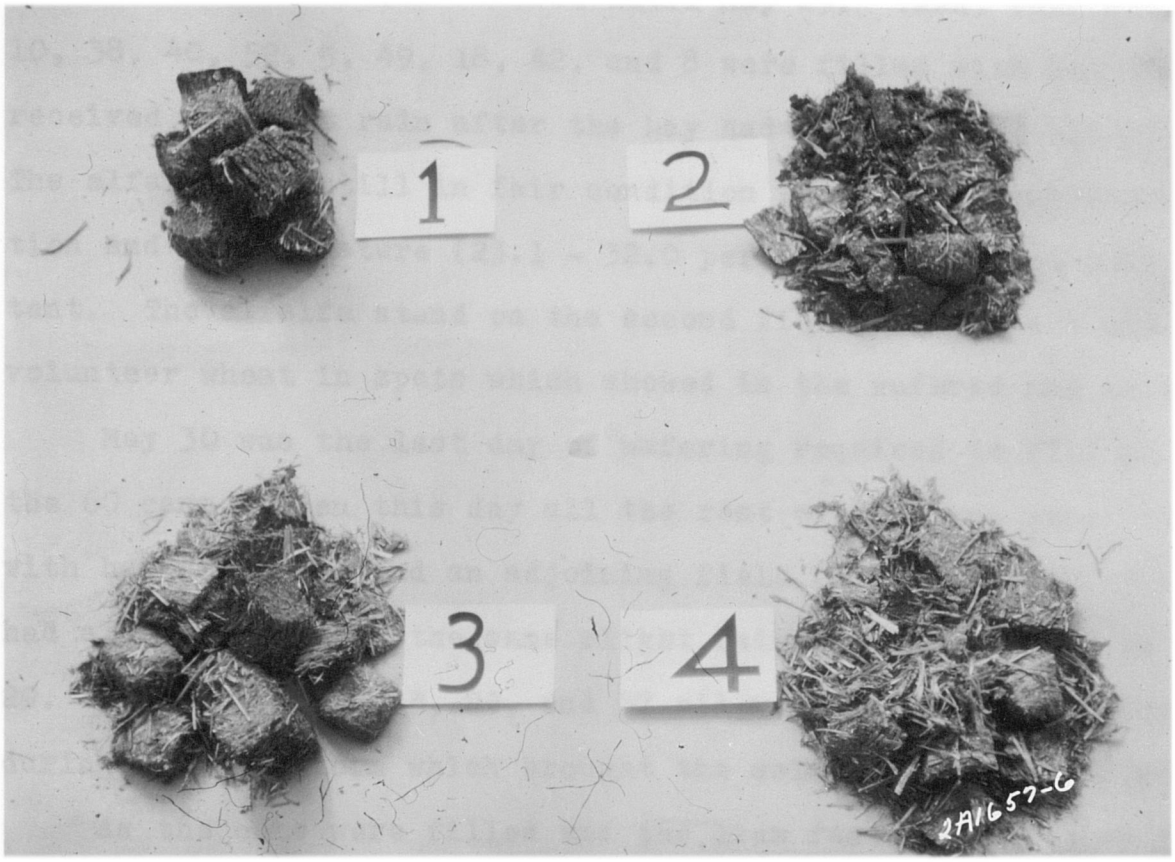
Wafer pile number four is an example of very poor wafers which were produced. A large portion of this sample is made up of fines. The conglomerations which are present do not closely resemble the shape wafers which the machine produces. Many of the individual pieces of wafer in this sample are actually pieces of straw. This is one example of a material that does not seem to bind into wafers under normal field procedures. Not all the poor wafers contained straw. Actually, only one or two storage containers were filled with such poor wafers.

Hay used in this study was first cutting alfalfa grown approximately a mile northwest of the present Kansas State University campus. Cans 15, 57, 12, 47, 26, and 31 were filled during the afternoon of May 22 with good quality hay grown in field one which had received no rain between cutting and wafering.

EXPLANATION OF PLATE III

Four examples of the various physical characteristics of wafers stored in the hermetically sealed containers.

PLATE III



Cans 35, 34, 7, 45, 20, 53, and 24 were filled on the morning of May 23, and again this was good alfalfa hay from field one with no rain. That was all of the hay from one field and because of rains, no more hay was wafered until May 29. Then, cans 25, 58, 10, 38, 40, 52, 5, 49, 18, 42, and 8 were filled with hay that had received a slight rain after the hay had been cut and windrowed. The alfalfa was still in fair condition except for some discoloration and high moisture (23.1 - 32.0 per cent wet weight basis) content. The alfalfa stand on the second field had quite a bit of volunteer wheat in spots which showed in the wafered hay as straw.

May 30 was the last day of wafering required to fill all of the 60 cans and on this day all the rest of the cans were filled with hay from this and an adjoining field (field three). This hay had also experienced the same slight rain as that wafered on May 29. Cans 14, 41, 9, 4, 29, and 37 all were filled with wafers made during a light storm which brought the moisture content up slightly.

As the cans were filled and the lids fastened on, they were put off the wagon to lie in the field so that a coat of permatex could be carefully applied and the lid reinstalled with no leaves or stems being pressed into the seal to cause a leak. A tractor and wagon were then employed to haul the filled containers to the Agricultural Engineering bin site for wafer storage located immediately west of the Kansas State University Animal Husbandry feed mill. The cans were stored in an upright position by the south side of the south 1,000 bushel bin as shown by arrow "a" in Plate IV, page 24. The steel bin arrow "b" located directly next to these cans is the bin in which the wafers used as controls were

EXPLANATION OF PLATE IV

View of hay wafer storage area located immediately west of the Animal Husbandry feed mill. Arrow "a" points to aluminum storage cans. Arrow "b" shows 1,000 bushel steel bin in which wafers were dried with natural air. Arrow "c" points to the instrument house.

PLATE IV

stored. The low structure marked with arrow "c" in Plate IV was the instrument house in which the recording equipment was located. Temperatures in some of the storage containers of the air surrounding the cans and inside the large steel bin were recorded.

Plate V, page 27 is a view from a different vantage point but showing the same location of aluminum storage cans and large steel bins. All 60 aluminum cans were set on the ground as closely together as possible in a checkerboard pattern of large and small cans so that if there were differences between storage in large and small cans, they could be determined without error influenced by can position. The cans with thermocouples approximate a random distribution throughout the storage arrangement.

In the extreme left of Plate V a hose can be seen which runs from one of the cans on the corner of the storage area upwards and out of the picture. This hose is connecting the can to a mercury manometer whose base support can be seen directly below the hose. Two cans located near this manometer were modified so that the hose could be connected to the manometer to determine the amount of pressure inside the cans relative to the existing atmospheric pressure.

As soon as the cans were in place, the thermocouples in the cans were connected to the brown recorder. Arrow "a", plate V, points to the bolt and neoprene washers which were used in conjunction with permatex number two to provide an air-tight passage through the side of the cans for the thermocouple wire (arrow "b").

The temperatures in these cans, highest when the first reading after connecting to the recorder was made, gradually approached a mean ambient temperature.

EXPLANATION OF PLATE V

A view of the sixty hermetically sealed storage containers in position for the storage period. Arrow "a" points to the point where the thermocouple wires enter the container. Arrow "b" shows the thermocouple wire.

PLATE V

RESULTS

Table 1, page 28 is a record of some of the pressures in the cans. Can number 23 had a leak that was discovered when the can was opened in October. This explains the reason for zero pressures. Since only one manometer was available for use, each can had to be connected or disconnected once for each pressure reading taken. The varying pressure readings taken for can number one would indicate that possibly during this necessary operation a slight leak would sometimes develop. These pressure readings merely indicate that a pressure gradient exists which would retard outside air and oxygen from entering the can in the event of a very small leak. Also it indicates that pressure built up must be taken into consideration in designing a hermetic storage unit. These should not be considered as maximum pressures that will develop.

Table 1. Pressures developed in hermetically sealed cans.

Time	Date	Can number 1 pressure (inches of mercury)	Can number 23 pressure (inches of mercury)
3:00 P.M.	6/03/63	1.9	-0.1
11:00 A.M.	6/04/63	2.3	0.0
4:00 P.M.	6/05/63	3.8	0.0
11:00 A.M.	6/06/63	3.7	0.0
1:00 P.M.	6/07/63	5.0	0.0
7:00 P.M.	6/08/63	4.8	0.0
8:30 A.M.	6/10/63	2.8	0.0
4:00 P.M.	6/10/63	4.0	0.0
9:30 A.M.	6/11/63	2.8	0.0
8:30 A.M.	6/17/63	2.2	0.0
8:30 A.M.	6/28/63	3.9	0.0
11:00 A.M.	7/08/63	4.2	0.0
4:00 P.M.	7/25/63	5.2	0.0

Plate VI, page 31 shows the hermetically stored wafers as they appeared on October 3, 4, 5, and 9 when the 60 storage containers were opened after 125 - 141 days storage. The can in Plate VI was one of the 30 large cans which had the lid locking flange on the outside of the can. The man's hand in the top of the picture gives size perspective to the wafers in view.

The tops of these wafers present a smooth surface indicating that the top of the can pressed them down somewhat. The picture also indicates that there was no settling during storage because this surface is located where the lid surface had been located with the lid secured to the can. The wafers in this particular can appear to be good wafers as there is a very small amount of fines in view. The wafers have browned somewhat since the can was sealed in May, but there was no mold in evidence. Similar observations were made on half of the storage containers as they were opened. Most of the rest of the containers did not have wafers with as good structural properties, but the color and lack of mold evidence still described the contents of these cans.

Before opening each can, the total weight of the can was determined and recorded. The wire seal for the detection of any tempering which would have broken the hermetic seal was checked for breakage, of which there was none.

The following samples were taken as the cans were opened in October: Z_{1n}, Z_{2n}, Z_{3n}, H_n, and J_n. The Z_{1n}, Z_{2n}, and Z_{3n} samples were representative of the wafers stored at 3/4 can height, 1/2 can height and 1/4 can height respectively in the nth opened storage container. These were used to determine the distribution of moisture from top to bottom in the cans.

EXPLANATION OF PLATE VI

A view of the wafers as they appeared when the containers were opened in the fall.

PLATE VI

Assuming that the moisture contents were randomly mixed within each can at the time of filling, and that final moisture contents are from a normal population, statistics showed that when the hermetically sealed containers were opened in the fall, there was a difference in moisture content between the three vertical positions as determined by use of the Z_{1_n}, Z_{2_n}, and Z_{3_n} samples. This moisture content data is given in Table 12 of the Appendix. Using a 95 per cent confidence level, the interval estimate of the increase in moisture content from the bottom sampled location to the top sampled location was $0.72 \leq u \leq 3.20$ per cent wet weight basis. Provided that this was not a rare one in twenty samples, this would indicate that there was vertical moisture migration within the storage containers. This moisture migration could be due to unequal heating and cooling of the mass; however, the daily temperature variation of the whole mass would be much less if a larger mass were involved as would normally be the case in farm storage structures.

The H_n samples were sent to the biochemistry laboratories for analysis so the sampling technique for these H_n samples attempted to make them representative on the wafers in the nth can. The J_n samples were equivalent to the H_n samples except that the J_n samples were used to determine the average moisture content of the mass inside the can.

The alfalfa as it was removed from most of the aluminum cylinders appeared to be somewhat brown and had a very pungent odor. But this odor would dissipate once the wafers were exposed to the atmosphere. There seemed to be little difference in appearance

(with the exception of color) of some of the wafers when comparing the before storage and after storage views of the wafers. A very few of the stored masses appeared to contain many more mold colonies and to have deteriorated to a much worse condition than other stored masses. Many alfalfa masses appeared to have no visible mold.

Cans which indicated a tight seal upon opening by the hiss of escaping gas when the clamping levers were released showed no measurable sign of mold. There was a pungent odor of sweet silage immediately after the hissing sound was heard indicating that the pressure inside the cans was higher than atmospheric pressure and the gas was being propelled out of the can. For this reason, it was assumed that there had not been much leakage of air into the can to support respiration.

Cans 13, 26, and 32 contained wafers located near the tops of the containers which showed very slight evidence of molding. There was very little hissing sound noted as these cans were opened. More mold was found on wafers stored in cans 46, 50, and 51. No pressure difference was noted. The sealing surfaces on each of these cans had at least one badly damaged portion where the permatex did not seal. Can number 42 had some alfalfa stems traversing through the sealing surfaces which left a leak large enough for rain water to enter so that the can gained 11 pounds of weight during the summer. The contents of can number 42 were completely spoiled.

The wafers retained their identity much better than was expected as evidenced in Plate VI, page 31. Since the wafers were put into storage when they were still quite warm and some had a

high moisture content, it was thought that the wafers would lose their shape during the packing operation as the wafers were put into storage.

Samples were also taken of the hay wafers stored in the 1,000 bushel bin by coring the mass inside the bin from top to bottom in two locations. The core samples were sent to the Biochemistry laboratory along with the H_n samples. The hay wafers stored in the steel bin had been dried with natural air to remove the excess moisture above the point at which rapid molding would occur; however, some heating within the mass had occurred before the fans were operating before the hay became dry enough to prevent heating and molding.

The total hay stored in the 60 cans was 5,851 pounds with a mean moisture content of 24.88 per cent wet weight basis yielding a dry matter weight of 4,937 pounds. The density of the wafers stored during the summer ranged from 25 pounds per cubic foot to 39 pounds per cubic foot with a mean bulk density of 31.7 pounds per cubic foot. Table 8 of the Appendix lists the bulk densities obtained in each can. The large cans had an average bulk density of 32.6 pounds per cubic foot against the small can average of 30.7 pounds per cubic foot. Assuming normal distribution of the bulk density population within each can size and comparing the small size can against the large size can which was filled either immediately prior to or immediately following the small can, the 95 per cent confidence interval on the mean difference of bulk densities is $.07 \leq u \leq 2.72$ pounds. Thus, since the smaller diameter cans were probably more difficult to pack because of increased wall area

per pound of mass, the bulk density was somewhat less in the smaller cans.

To compare the wafers immediately after they were produced with the hay in the windrow immediately before the hay was processed, a confidence interval on the mean difference between the per cent (dry weight basis) of nutrient X in the windrow and the per cent (dry weight basis) of nutrient X in the wafer was computed. Nutrient X was one of the following for each confidence interval: protein, ether extract, crude fiber, ash, nitrogen free extract, carbohydrates, and carotene. The data for this is listed in Table 9 of the Appendix. The resulting confidence intervals are listed in Table 2.

Table 2. Confidence intervals on the changes in quality as the hay passes through the wafering machine. (21 samples)

Nutrient	Estimate of sample standard error	Alpha level	Confidence interval on change (% D.B.*)
Protein	.46103	.05	$-1.922 \leq u \leq +0.008$
		.10	$-1.754 \leq u \leq -0.160$
Ether extract	.02516	.05	$+0.014 \leq u \leq +0.119$
		.10	$+0.023 \leq u \leq +0.110$
Crude fiber	.59450	.05	$-1.782 \leq u \leq +0.717$
		.10	$-1.566 \leq u \leq +0.490$
Ash	.40784	.05	$+0.691 \leq u \leq +2.669$
		.10	$+0.965 \leq u \leq +2.375$
Nitrogen free extract	.63838	.05	$-1.444 \leq u \leq +1.229$
		.10	$-1.211 \leq u \leq +0.996$
Carbohydrates	.76872	.05	$-2.238 \leq u \leq +0.989$
		.10	$-1.958 \leq u \leq +0.699$
Carotene	.20127	.05	$-1.290 \leq u \leq -0.478$
		.10	$-1.217 \leq u \leq -0.521$

* - indicates loss as hay passes through machine. Carotene change is given as mg./100 gm. Confidence interval must not contain zero to be significant.

In Table 2 a positive percentage change indicates an increase in terms of per cent dry weight basis of the constituent under consideration as it underwent the wafering process. The confidence intervals of u which do not contain zero in the interval are considered to be significant at the alpha level given for that particular interval. The alpha level indicates percentage divided by 100 of the time that the result could be expected to give an erroneous answer concerning acceptance or rejection of the null hypothesis. For example, the confidence interval for carotene in Table 2 is $-1.290 \leq u \leq -0.478$ for an alpha level of .05. This means that unless a one in twenty chance happening occurred, the mean difference of the carotene contents of alfalfa wafers and the carotene contents of the alfalfa in the windrow was less than zero. Or, putting it another way with the same reservations on the statement, there was a loss of carotene during the wafering operation.

This is reasonable as the hay passing through the machine is subjected to high pressures and heat. The wafers as they left the elevator of the machine were hot enough to discourage a person from holding them in his hand. Perhaps the heat and pressure act as catalysts in decomposing the carotene. The fact that the mean differences for protein, ether extract, ash and carotene were all significantly different from zero is more difficult to explain. Perhaps the sampling technique was not as good as it should have been. It is possible that the necessary speed of collection and the dryness of the leaves of the hay caused the windrow samples to be collected without the ratio of stems to leaves being representative of the hay in the windrow. Since much of the food content of

the alfalfa hay is contained in the leaves, this would lead to false information as to the quality of hay in the windrow. This fault would not be nearly as apt to occur in the wafer samples because once the machine picks up the leaves (apparently it did a good job of this) they were forced to become part of the wafers.

Because of this suspicion of technique, the significant difference observed between the two sets of samples cannot label the process of wafering as causing a significant change in hay quality. It does, however, suggest the possibility of hay quality loss effected by the wafering process.

Because of lack of funds, a complete foodstuffs analysis was made on only the contents of five of the 60 hermetically sealed cans when they were opened in October. The resulting analysis compared with the equivalent spring analysis is shown in Table 10 of the Appendix. Confidence intervals were computed on the mean difference between spring and fall food nutrient content on a per cent dry weight basis. The confidence intervals are given in Table 3.

Table 3. Confidence intervals on hay quality changes during hermetic storage. (5 samples)

Nutrient	Estimate of sample standard error	Alpha level	Confidence interval on change (% D. B.*)
Protein	.1586	.05	$-0.356 \leq u \leq +0.524$
		.10	$-0.254 \leq u \leq +0.422$
Ether extract	.0964	.05	$+0.229 \leq u \leq +0.763$
		.10	$+0.291 \leq u \leq +0.701$
Crude fiber	.9604	.05	$-3.904 \leq u \leq +1.428$
		.10	$-3.285 \leq u \leq +0.809$
Ash	.2021	.05	$-0.357 \leq u \leq +0.765$
		.10	$-0.227 \leq u \leq +0.635$

Table 3 (cont.)

Nutrient	Estimate of sample standard error	Alpha level	Confidence interval on change (% D.B.*)
Nitrogen free extract	.5316	.05	$-1.032 \leq u \leq +1.920$
		.10	$-0.689 \leq u \leq +1.577$
Carbohydrates	.4373	.05	$-2.008 \leq u \leq +0.420$
		.10	$-1.726 \leq u \leq +0.138$
Carotene	.6473	.05	$+1.543 \leq u \leq +5.137$
		.10	$+1.960 \leq u \leq +4.720$

* + indicates loss during storage. Confidence interval must not contain zero to be significant. Carotene change is given in mg./100 gm.

Note that there was no significant difference at either the .05 or .10 alpha level for protein, crude fiber, ash, nitrogen free extract or carbohydrate content. While carotene content loss was quite significant at both the .10 and the .05 alpha levels, the loss would appear to be in line with or below losses occurring in baled hay stored for the same length of time. If Vitamin A need not be supplied by the alfalfa, at least in large amounts, then this loss might not be considered significant to the end user of the alfalfa. It does, however, exist. Ether extract loss is significant at both the .05 and .10 alpha levels; however, the magnitude of the loss is not great percentagewise and for this reason should probably not be a detriment to hermetic storage.

Although complete foodstuffs analyses were run only on five fall samples, a protein and carotene determination were run on fall samples for each of the 60 cans. The spring and comparable fall analyses can be seen in the Appendix in Table 7. The protein and

carotene confidence intervals for the respective changes in the 60 storage containers given in Table 7 are shown below.

Table 4. Changes in hay quality during hermetic storage (60 samples)

Nutrient	Estimate of sample standard error	Alpha level	Confidence interval on change (% D.B.*)
Protein	.1134	.05	$-0.383 \leq u \leq +0.071$
		.10	$-0.346 \leq u \leq +0.033$
Carotene	.2687	.05	$+1.328 \leq u \leq +2.413$
		.10	$+1.417 \leq u \leq +2.315$

* + indicates loss during storage. Confidence interval must not contain zero to be significant. Carotene change is given in mg./100 gm.

Here again for both alpha levels (.05 and .10) there is no significant changes in protein content during the four and one-half month storage period. Carotene content loss is significant but here again the magnitude of this loss when compared with losses occurring in storage of alfalfa in other forms such as good alfalfa bales or the wafers stored in the steel bin as reported in Table 6, page 41, is not great enough to be considered excessive.

The possibility was considered that the amount of mass stored in a single container might affect the processes acting on the hay and be reflected in hay quality. The reasoning behind the idea that mass might affect hay quality changes was that temperatures above ambient air temperatures occurring soon after the wafers were stored might act as a catalyst for the various chemical reactions that would decrease or retain hay quality. The smaller container would allow faster heat transfer per pound mass and the heat of production of the wafer, respiration, and molding would not raise

the temperature as high and the higher temperature would not exist as long in the smaller container.

In looking for significant differences in hay quality changes between large and small containers (the large containers stored approximately twice the mass of the smaller containers) the spring to fall difference of small and large cans were compared as shown in Table 13 of the Appendix.

The results of "student's t test" [Snedecor (27)] are given below in Table 5.

Table 5. Group comparison of hay quality change differences between large cans and small cans.

Nutrient	Computed "t" value	Tabled "t" value
Protein change	t = 1.460	$t_{.05,\ d.f.\ =\ 58} = 2.001$
Carotene change	t = 0.1672	$t_{.10,\ d.f.\ =\ 58} = 1.672$

The computed "t" value must be greater than the tabled "t" value in order for the change to be significant. The $t_{.05,\ d.f.\ =\ 58}$ and $t_{.10,\ d.f.\ =\ 58}$ designate that the "t" values are for alpha levels of .05 and .10 with 58 degrees of freedom.

Since the computed "t" values are not significant at either the .05 or .10 level, the null hypothesis that there is no difference in protein and carotene changes between large and small cans is accepted, versus the alternative hypothesis that there is a difference.

A comparison was also made between the hay stored and natural air dried in the 1,000 bushel steel grain bin and the hay stored in the hermetically sealed aluminum cans. The hay which entered storage in the steel bin was assumed to be of the same quality as

that entering hermetic storage since those wafers entering hermetic storage were in effect samples of the hay produced for storage in the 1,000 bushel bin.

Thus to compare changes in hay quality between the two types of storage, a direct comparison was made on the basis of the fall complete foodstuffs analysis. The five cans used as comparisons with the five samples taken from the bin were selected at random before the fall sampling began so that these five cans were the ones upon which the complete foodstuffs analysis were run. The data as listed in Table 11 of the Appendix was to determine the confidence intervals listed in Table 6.

Table 6. Confidence intervals on difference of hay quality between hay wafers stored in hermetic storage and hay wafers dried and stored in a 1,000 bushel steel bin.

Nutrient	Estimate of sample standard error	Alpha level	Confidence interval on differences (% D.B.*)
Protein	.4626	.05	$-4.237 \leq u \leq -1.674$
		.10	$-3.939 \leq u \leq -1.969$
Ether extract	.1136	.05	$-0.801 \leq u \leq -0.171$
		.10	$-0.728 \leq u \leq -0.244$
Crude fiber	1.6357	.05	$-0.572 \leq u \leq +8.608$
		.10	$+0.493 \leq u \leq +7.543$
Ash	.3899	.05	$+0.692 \leq u \leq +2.856$
		.10	$+0.943 \leq u \leq +2.605$
Nitrogen free extract	1.0291	.05	$-5.241 \leq u \leq +0.503$
		.10	$-4.548 \leq u \leq -0.160$
Carbohydrates	.8817	.05	$-0.794 \leq u \leq +4.102$
		.10	$-0.226 \leq u \leq +3.534$
Carotene	.6176	.05	$-6.085 \leq u \leq -2.656$
		.10	$-5.687 \leq u \leq -3.053$

* + indicates a higher percentage of the nutrient retained in wafers dried and stored in the steel bin. Confidence interval must not contain zero to be significant. Carotene change is given in mg./100 gm.

The negative signs on the confidence intervals indicate a lower content in the hay stored in the steel bin. The carbohydrates were the only constituent involved which did not have a significant difference between the two groups.

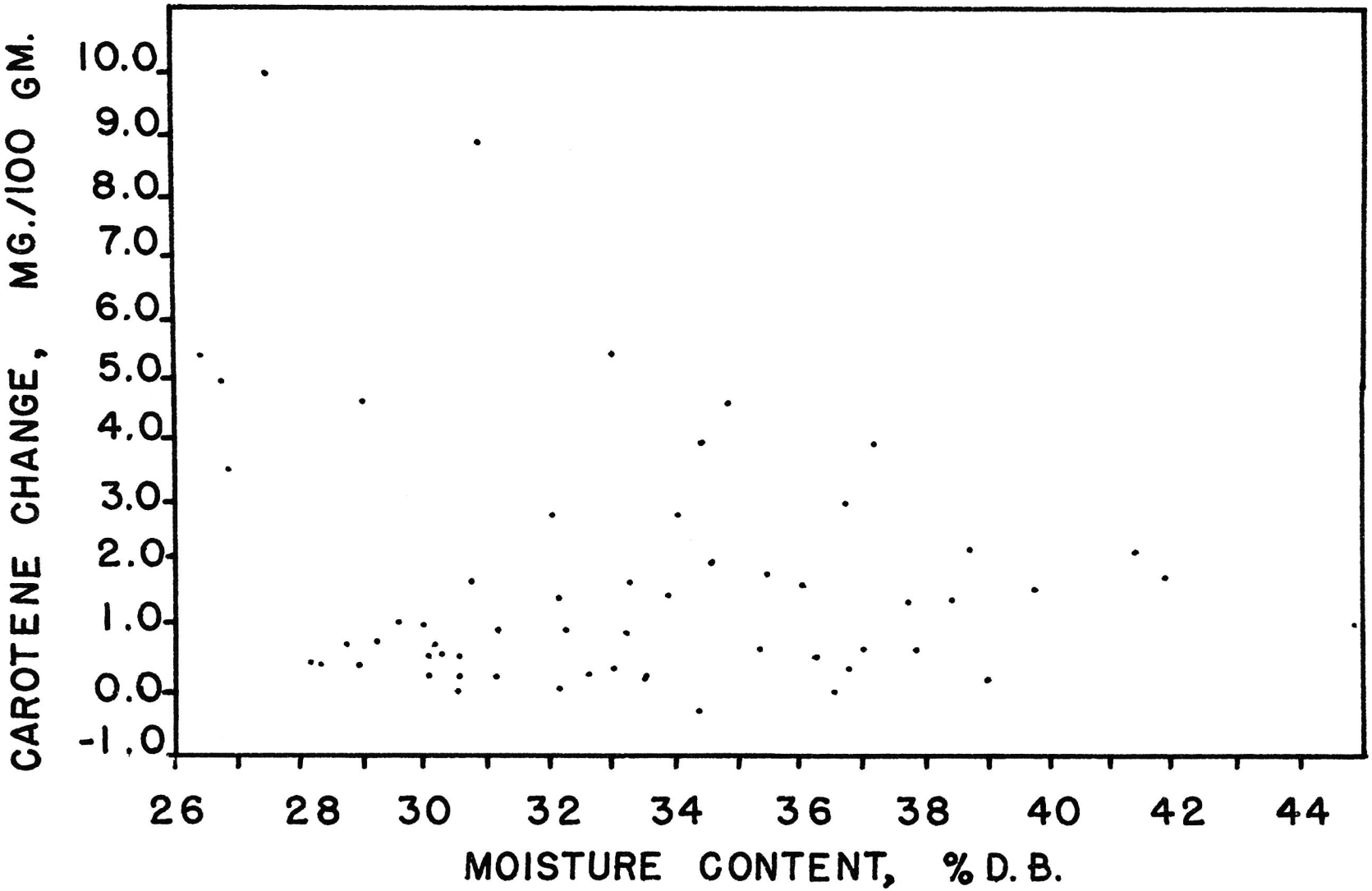
The nitrogen free extract and the crude fiber had no significant difference at the .05 alpha level. The protein, ether extract, ash, and carotene all had significant changes at both the .05 and .10 alpha levels. While the above information would indicate that the hay quality did not suffer as much loss under hermetic storage as under the natural air drying, it must be understood that the wafers stored in the 1,000 bushel steel bin were allowed to heat somewhat during a period of one to three days before the fan was turned on. The heating continued even after the fans were turned off at the end of the drying period indicating that drying was not continued long enough to prevent all heating. The loss in hay quality under natural air drying conditions would perhaps not be as great if larger fans had been employed sooner and for perhaps a longer period of time than those used this past summer.

Since it was hoped at the beginning of this work to show whether or not a relationship between moisture content of hay wafers stored under hermetic conditions and deterioration of hay quality existed, a plot of moisture content versus changes in carotene and a plot of moisture content versus changes in protein content were made as shown in Plates VII and VIII, pages 44 and 46. Each dot on the graph represents the data gathered from one can. The scatter of dots seems to indicate no correlation between either carotene changes or protein changes and moisture content.

EXPLANATION OF PLATE VII

Effect of varying moisture content on carotene change during storage.

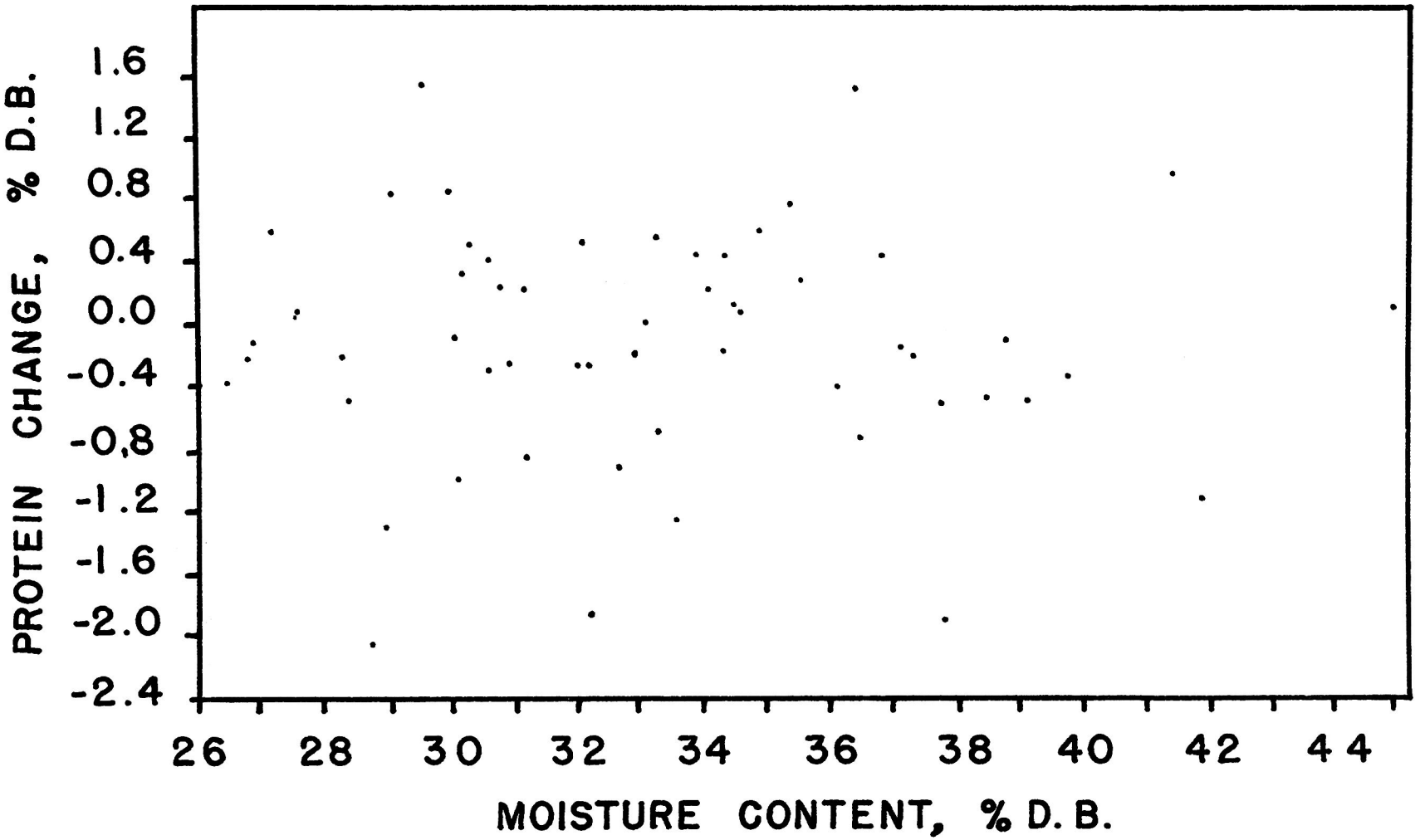
PLATE VII


CAROTENE CHANGE, MG./100 GM.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
26
28
30
32
34
36
38
40
42
44
MOISTURE CONTENT, % D.B.

EXPLANATION OF PLATE VIII

Effect of varying moisture content on protein change during storage.

PLATE VIII


PROTEIN CHANGE, % D.B.
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-2.0
-2.4
26
28
30
32
34
36
38
40
42
44
MOISTURE CONTENT, % D.B.

Because of the manner in which wafers are formed in the particular wafer machine used, it appeared that moisture content might affect the density of the wafers even though the hydraulic pressure on the dies remained constant. So the plot shown on Plate IX, page 49 was constructed with each dot representing the conditions in a particular can. The density shown here is bulk density of the wafers as stored in the aluminum container. There appears to be a slight negative linear correlation ($r = -.202$).

Because one of the objects of wafering hay is to store more hay in the same storage volume (increase density), graphs were constructed to view the effect, if any, which density had on change in hay quality during storage. Plate X on page 51 shows a scatter of dots with no apparent order or correlation. Thus apparently over the range of densities tested, there was no direct influence of density on protein change. Plate XI, page 53 shows very little correlation between density and carotene change.

Since the wafers would be no good unless the consumer finds them palatable and will eat them in large enough quantities to maintain or increase production, some dairy cows here were hand fed samples of the stored wafers to determine if they would eat them. These cows had a fancy for the wafers and begged for more like a horse wanting sugar cubes.

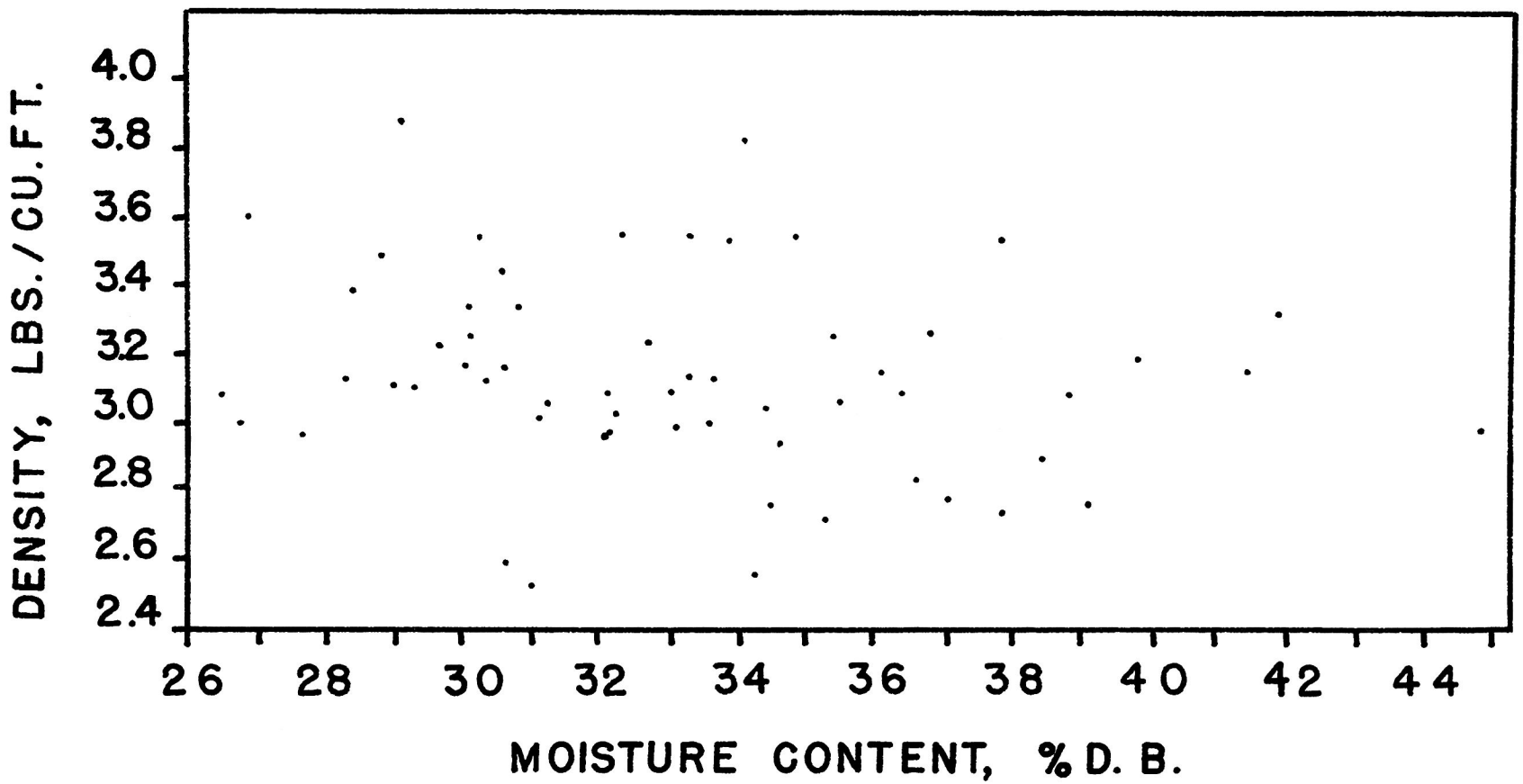
CONCLUSIONS

1. There was enough evidence in this research to give strong basis for the belief that hay wafers could be hermetically stored with perhaps less loss than damp wafers slowly dried and stored inside a storage structure.

EXPLANATION OF PLATE IX

Effect of changing moisture content on density of wafer produced.

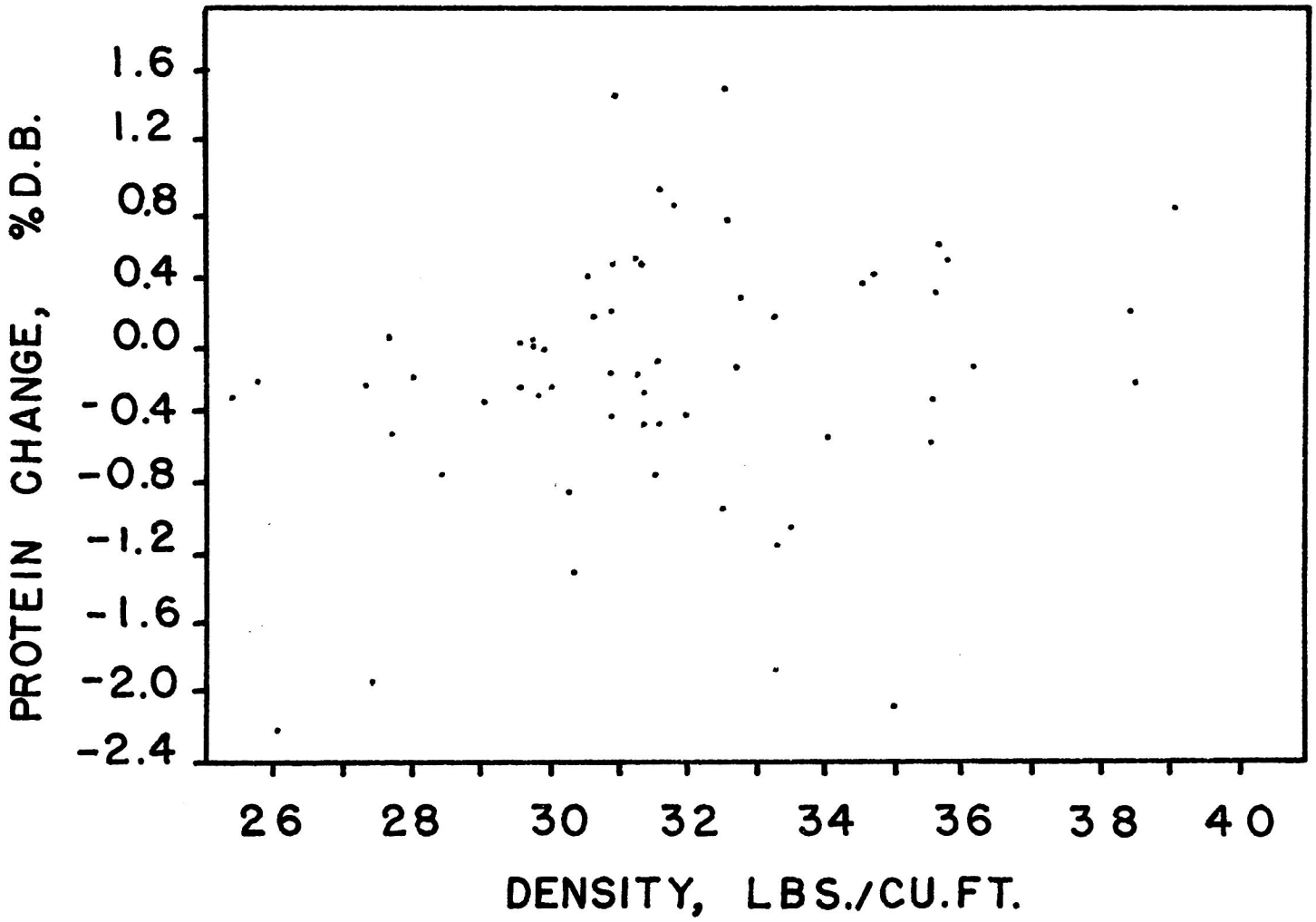
PLATE IX


DENSITY, LBS./CU.FT.
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
26
28
30
32
34
36
38
40
42
44
MOISTURE CONTENT, % D. B.

EXPLANATION OF PLATE X

Effects of varying density on protein change during storage.

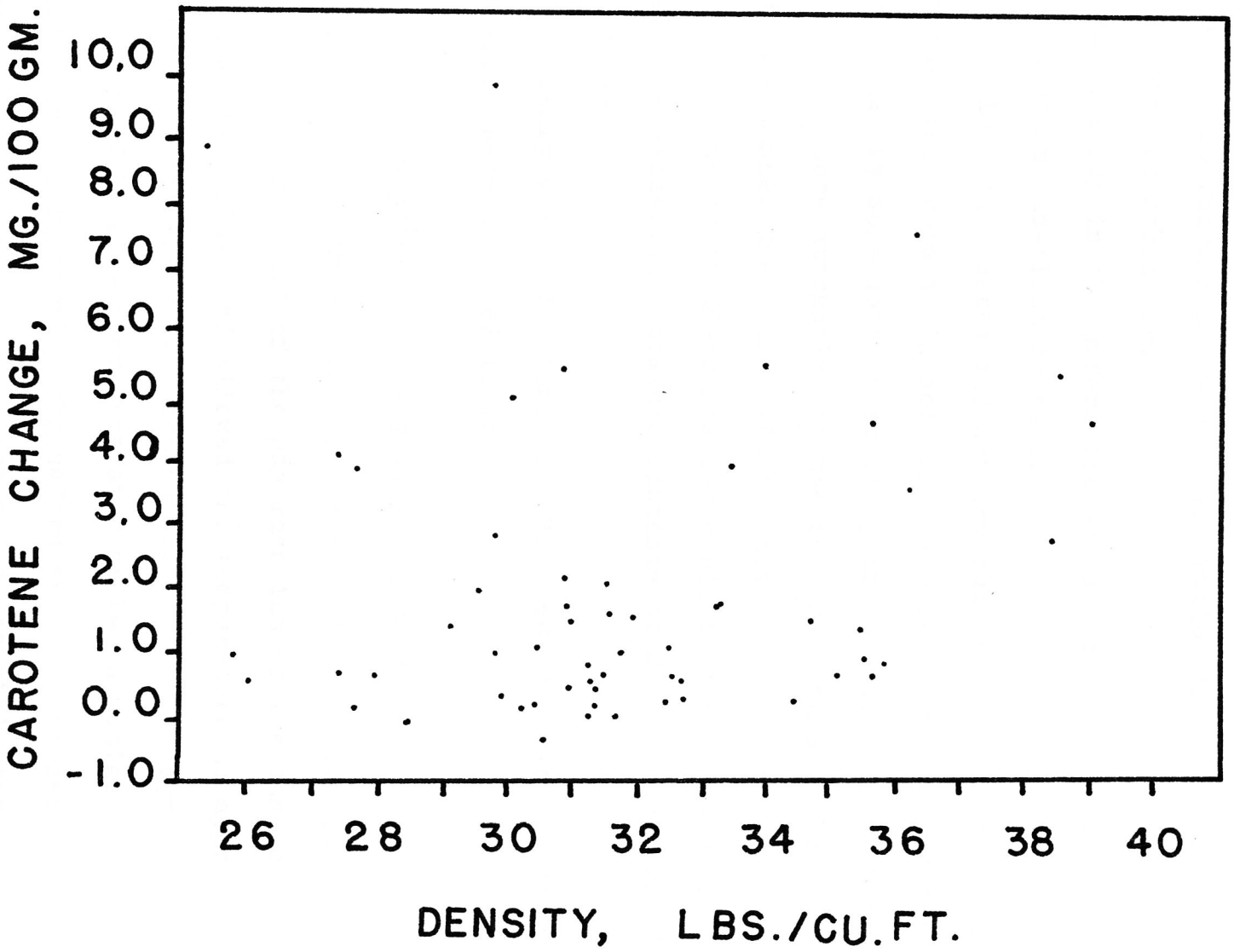
PLATE X


PROTEIN CHANGE, %D.B.
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
-1.6
-2.0
-2.4
26
28
30
32
34
36
38
40
DENSITY, LBS./CU.FT.

EXPLANATION OF PLATE XI

Effect of varying density on carotene change during storage.

PLATE XI


CAROTENE CHANGE, MG./100 GM.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
26
28
30
32
34
36
38
40
DENSITY, LBS./CU.FT.

2. There is some gas pressure produced in the hermetically sealed storage containers which helps to prevent O_2 entry into the storage and which must be a consideration in designing a hermetic storage structure.

3. The hay in the wafers seemed to undergo a slight browning reaction in gas-tight storage.

4. Since the wafers did not dry out under those storage conditions, they were still soft and plyable (perhaps even tenderized somewhat by some sort of ensiling process). In this manner they could be more attractive to the consuming animal than those stored in a manner where the wafers become dry and hard.

5. A density of 30 pounds per cubic foot or greater would be easily obtainable at moisture contents of 22 - 27 per cent dry weight basis.

6. Dairy cows had a fancy for the few hermetically stored wafers which were hand fed to them.

SUGGESTIONS FOR FURTHER RESEARCH

1. Since the small size of the hermetically sealed cans used in this work allowed all of the hay mass inside the can to transfer its heat quite rapidly and allowed the temperature to approximate equilibrium conditions with surroundings, it is suggested that in the future full size prototype storage be investigated. Here the heat produced in forming the wafers and heat caused by respiration would remain with the mass longer and possibly the temperature of the mass would reach higher levels than those experienced with this work. Storage trials could be conducted in the laboratory

where temperature and other environmental factors could be controlled so that even with the small size storage containers necessary for large numbers of trials, the effects of high temperatures or slow heat transfer characteristics could be investigated.

2. Feeding trials need to be made on hermetically stored hay wafers since, at the present, these trials seem to be the only way agreed upon by authorities to be a sound index of hay quality.

3. Investigations into the effects of density on hermetic storage would be desirable.

4. For storage structure design requirements, a knowledge of the gas pressures involved with such storage needs investigation.

5. Experiments in the future on storage qualities of alfalfa wafers could possibly be conducted with wafers produced in the laboratory. (Objective: more uniform wafers for basic research data.)

6. Comparisons need to be made among wafers stored outdoors, in corn crib type structures, inside barns, and in hermetically sealed storages.

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REFERENCES

1. Anderson, J. A. and A. W. Alcock.
   Storage of cereal grains and their products. St. Paul: American Association of Agricultural Chemists, 1954.

2. Barger, E. L.
   The field baler. Unpublished paper presented at the Sixth International Grassland Congress: Pennsylvania State College, August, 1952.

3. Barnett, A. J.
   Silage fermentation. New York: Academic Press Inc., 1954.

4. Bellinger, P. L. and H. F. McColly.
   Energy requirements for forming hay pellets. Agr. Engg. 42 (4): 180-181, 1961.

5. Browning, C. B., J. W. Lusk, and J. T. Miles.
   Baled, wafered, and pelleted hay compared in feeding experiments. Mississippi Farm Research 23 (7), 1960.

6. Bruhn, H. D.
   Engineering problems in pelletized feeds. Agr. Engg. 38 (7): 522-525, 1957.

7. Buckingham, Frank.
   Is wafering the answer? Implement and Tractor 76 (6): 24-26, 34, 1961.

8. Butler, J. L. and H. F. McColly.
   Factors affecting the pelleting of hay. Agr. Engg. 40 (8): 442-446, 1959.

9. Curley, R. G. and J. B. Dobie.
   Systems for handling wafered hay. Paper number 62-602 presented at the 1962 winter meeting of American Society of Agricultural Engineers at Chicago.

10. Dobie, J. B.
    Hay wafering: an analysis of current machinery for production, handling, and feeding. California Agriculture 16 (4): 8-9, April, 1962.

11. Dobie, J. B.
    Materials handling systems for hay wafers. Agr. Engg. 42 (12): 692, 695, 697, 1961.

12. Dobie, J. B.
    Production of hay wafers. Agr. Engg. 41 (6): 366-369, 1960.

13. Eheart, J. G., N. W. Linkour, R. B. Davis, V. H. Baker, and P. M. Reaves. Chemical composition of hay in barn drying. Agr..Engg. 32 (4): 218-220, 1951.

14. Fryer, H. C.
Statistical methods I notes. Unpublished class notes, Kansas State University, 1962.

15. Fryer, H. C.
Statistical methods II notes. Unpublished class notes, Kansas State University, 1962.

16. Fulton, Robert.
Quality control in forage harvesting and processing. Paper for Sixth Technical Alfalfa Conference, Albany, California. U.S.D.A. A.R.S. -74-15, July 16, 1959.

17. Greenhill, W. L., J. F. Couchman, and De Freitas.
Storage of hay: effect of temperature and moisture on loss of dry matter and changes in composition. Sci. Food and Agr. 12 (4), 1961.

18. Gilbert, Howard and Martin Waananen.
Hay quality: a literature review. Wash. Agr. Expt. Sta. Cir. 391, July, 1961.

19. Hull, Dale O.
Systems in handling forage crops. Paper presented at the 40th annual meeting of the Pacific Coast Section of the American Society of Agricultural Engineers at Anaheim, California, April, 1962.

20. Lamp. B. J. and M. H. Peterson.
Experiences with a commercial hay wafering machine. Paper number 62-603 presented at the 1962 winter meeting of the American Society of Agricultural Engineers at Chicago.

21. Lundell, V. J. and D. O. Hull.
Field production of hay wafers. Agr. Engg. 42 (8): 412-415, 423, 1961.

22. Meyer, J. H. and G. P. Lofgreen.
Evaluation of alfalfa hay by chemical analysis. Jour. Animal Sci. 18 (4): 1233-1241, 1959.

23. Meyer, J. H. and L. G. Jones.
Controlling alfalfa quality. Calif. Agr. Exp. Sta. Bul. 784, March, 1962.

24. Nordfeldt, S., O. Svanberg, and O. Claesson.
Studies regarding the analysis of crude fibre. Acta Agr. Suecana. 3: 135-177, 1949.

25. Pedersen, T. T. and W. F. Buchele.
Drying rate of alfalfa hay. Agr. Engg. 41 (2): 87-89, 107-108, 1960.

26. Reece, F. N., Robert Mensch, and H. E. Judy.
Hay wafering on kansas farms. Kan. Agr. Expt. Sta. Report of Progress number 66, February, 1963.

27. Snedecor, George W.
Statistical methods. Ames, Iowa. Iowa State Univ. Press. 1956, Fifth ed.

28. Vayssiere, P.
Hermetic storage, the process of the future for the conservation of foodstuffs. Preservation of Grain in Storage, F. A. O. Agr. Studies No. 2: 115-122, February, 1948.

29. Waite, Dr. R.
The relation between moisture content and molding in cured hay. Annals of applied Biology, 36 (4): 496-503, December, 1949.

APPENDIX

Hay Quality Data

TABLE 7
BEFORE AND AFTER STORAGE HAY QUALITY COMPARISON

SAMPLE	NUMBER	PROTEIN PER CENT D. B.	CAROTENE MG/199GM	NUMBER	PROTEIN PER CENT D. B.	CAOTENE MG/100GM
SPRING	01	17.21	3.21	12	19.18	10.40
FALL	01	16.96	1.23	12	19.40	5.31
CHANGE	01	+0.25	+1.98	12	-0.22	+5.09
SPRING	02	16.38	1.74	13	14.20	0.85
FALL	02	16.06	0.92	13	14.93	0.82
CHANGE	02	+0.32	+0.82	13	-0.73	+0.03
SPRING	03	17.81	1.20	14	18.82	1.68
FALL	03	16.33	0.61	14	18.91	1.03
CHANGE	03	+1.48	+0.59	14	-0.09	+0.65
SPRING	04	19.02	1.99	15	18.93	12.75
FALL	04	18.48	1.03	15	18.87	2.82
CHANGE	04	+0.54	+0.96	15	+0.06	+9.93
SPRING	05	17.99	3.07	16	14.22	1.50
FALL	05	17.55	1.47	16	14.37	0.77
CHANGE	05	+0.44	+1.60	16	-0.15	+0.73
SPRING	06	19.44	8.27	17	15.75	1.27
FALL	06	19.57	4.62	17	15.74	0.83
CHANGE	06	-0.13	+3.65	17	+0.01	+0.44
SPRING	07	19.98	9.17	18	17.62	2.88
FALL	07	19.14	4.46	18	18.15	1.36
CHANGE	07	+0.84	+4.71	18	-0.53	+1.52
SPRING	08	17.27	2.55	19	17.62	2.06
FALL	08	17.20	1.44	19	19.66	1.24
CHANGE	08	+0.07	+1.11	19	-2.04	+0.82
SPRING	09	18.84	3.03	20	20.19	8.31
FALL	09	18.61	1.14	20	19.99	5.43
CHANGE	09	+0.23	+1.89	20	+0.20	+2.88
SPRING	10	16.48	3.01	21	14.87	1.71
FALL	10	16.85	1.36	21	14.32	0.77
CHANGE	10	-0.37	+1.65	21	+0.55	+0.94
SPRING	11	16.31	1.11	22	17.14	1.32
FALL	11	17.16	0.82	22	18.19	0.92
CHANGE	11	-0.85	+0.29	22	-0.15	+0.40

TABLE 7 (CONT.)

SAMPLE	NUMBER	PROTEIN PER CENT	CAROTENE MG/100GM	NUMBER	PROTEIN PER CENT	CAROTENE MG/100GM
SPRING	23	15.28	1.06	35	18.57	6.09
FALL	23	15.83	0.77	35	18.84	3.19
CHANGE	23	-0.45	+0.29	35	-0.27	+2.90
SPRING	24	20.42	9.20	36	18.48	1.98
FALL	24	20.62	3.75	36	18.27	0.87
CHANGE	24	-0.20	+5.45	36	+0.21	+1.11
SPRING	25	19.28	3.30	37	19.06	2.67
FALL	25	16.35	0.97	37	18.53	1.09
CHANGE	25	+2.93	+2.33	37	+0.53	+1.58
SPRING	26	18.86	8.28	38	16.59	2.93
FALL	26	18.77	4.31	38	16.53	0.82
CHANGE	26	+0.09	+3.97	38	+0.06	+2.11
SPRING	27	16.37	1.00	39	15.63	1.01
FALL	27	18.23	0.92	39	15.68	0.88
CHANGE	27	-1.86	+0.08	39	-0.03	+0.13
SPRING	28	15.50	1.80	40	16.38	3.04
FALL	28	16.88	1.23	40	16.86	1.52
CHANGE	28	-1.38	+0.57	40	-0.48	+1.52
SPRING	29	19.44	1.80	41	19.52	2.06
FALL	29	17.92	0.61	41	20.25	1.24
CHANGE	29	+1.52	+1.19	41	-0.73	+0.82
SPRING	30	16.15	1.76	42	17.15	3.04
FALL	30	15.40	1.03	42	18.29	1.13
CHANGE	30	+0.75	+0.73	42	-1.14	+1.91
SPRING	31	19.22	7.51	43	14.89	1.20
FALL	31	19.42	3.37	43	16.18	0.92
CHANGE	31	-0.20	+4.14	43	-1.29	+0.28
SPRING	32	15.79	1.15	44	12.03	1.45
FALL	32	15.46	0.75	44	12.21	0.44
CHANGE	32	+0.33	+0.40	44	-0.18	+1.01
SPRING	33	15.94	1.44	45	19.74	7.74
FALL	33	17.17	1.04	45	20.02	6.71
CHANGE	33	-1.23	+0.40	45	-0.28	+1.03
SPRING	34	19.48	9.37	46	15.61	1.16
FALL	34	19.99	3.79	46	16.54	0.81
CHANGE	34	-0.51	+5.58	46	-0.93	0.35

TABLE 7 (CONCL.)

SAMPLE	NUMBER	PROTEIN PER CENT	CAROTENE MG/100GM	NUMBER	PROTEIN PER CENT	CAROTENE MG/100GM
SPRING	47	19.44	10.75	54	18.11	2.09
FALL		19.82	5.25	54	17.28	0.98
CHANGE	47	-0.38	+5.50	54	+0.83	1.11
SPRING	48	13.25	1.56	55	16.28	1.37
FALL		15.46	0.92	55	16.78	0.72
CHANGE	48	-2.21	+0.64	55	+0.50	0.65
SPRING	49	17.26	2.73	56	15.97	1.70
FALL		17.68	1.03	56	17.88	0.93
CHANGE	49	-0.42	+1.70	56	-1.91	0.77
SPRING	50	17.90	0.58	57	19.00	12.47
FALL		17.45	0.83	57	19.29	3.57
CHANGE	50	+0.45	-0.25	57	-0.29	8.90
SPRING	51	18.07	0.99	58	14.97	3.49
FALL		17.68	0.62	58	15.09	1.24
CHANGE	51	+0.39	+0.37	58	-0.12	2.25
SPRING	52	17.76	3.35	59	17.16	1.27
FALL		16.82	1.13	59	17.63	0.99
CHANGE	52	+0.94	+2.22	59	-0.47	0.28
SPRING	53	20.46	8.37	60	16.48	1.38
FALL		19.85	3.69	60	16.74	0.82
CHANGE	53	+0.61	+4.68	60	-0.26	0.56

TABLE 8
BULK DENSITY AND AVERAGE MOISTURE CONTENT OF WAFERS IN EACH CAN

CAN NUMBER	BULK DENSITY LBS./ CU. FT.	MOISTURE CONTENT PER CENT D. B.	CAN NUMBER	BULK DENSITY LBS./ CU. FT.	MOISTURE CONTENT PER CENT D. B.
1	30.9	26.2	31	27.4	27.2
2	35.6	23.3	32	32.8	27.0
3	31.0	26.7	33	32.6	----
4	35.8	25.0	34	34.0	24.3
5	34.7	25.3	35	29.8	22.1
6	36.2	21.2	36	30.6	23.8
7	39.0	22.6	37	31.0	24.3
8	29.8	31.0	38	29.6	25.7
9	33.0	23.6	39	31.7	24.3
10	32.0	28.4	40	29.1	27.8
11	30.3	23.8	41	31.5	25.0
12	30.1	22.9	42	33.3	29.5
13	28.5	26.8	43	30.4	25.1
14	32.7	23.1	44	25.8	25.6
15	29.8	21.6	45	35.6	24.4
16	28.0	27.1	46	32.5	24.6
17	30.0	24.9	47	30.9	21.0
18	35.5	27.4	48	26.0	23.4
19	35.1	22.4	49	31.6	26.5
20	38.4	25.4	50	30.6	25.6
21	31.3	22.7	51	34.5	23.4
22	33.5	23.1	52	31.6	29.3
23	31.4	25.1	53	35.6	25.9
24	38.5	24.8	54	31.8	23.0
25	31.2	----	55	31.3	23.2
26	27.7	25.6	56	27.4	27.5
27	33.3	24.4	57	25.4	23.6
28	31.3	22.5	58	30.9	28.0
29	32.5	22.8	59	27.7	28.1
30	32.6	26.2	60	31.4	22.1

TABLE 9

WAFER VS WINDROW COMPARISON OF COMPLETE FOODSTUFFS ANALYSIS REPORTS

CAN NUMBER	PROTEIN PER CENT D. B.	ETHER EXTRACT PER CENT D. B.	CRUDE FIBER PER CENT D. B.	ASH PER CENT D. B.	NITROGEN FREE EXTRACT PER CENT D. B.	CARBO-HYDDRATES PER CENT D. B.	CAROTENE MG/100GM
L15	15.64	2.23	27.13	09.64	45.98	73.10	3.23
W15	19.28	2.45	27.63	14.23	36.41	64.04	3.30
CHANGE	-4.24	-.22	-0.50	-4.59	+9.57	+9.06	-.07
L17	14.20	2.10	27.46	08.46	47.77	75.24	2.37
W17	16.48	2.23	25.06	11.68	44.55	69.61	3.01
CHANGE	-2.28	-.13	+2.40	-3.22	+3.22	+5.63	-.64
L19	16.75	2.04	25.31	10.62	45.27	70.58	3.35
W19	16.92	2.12	24.32	13.92	42.73	67.05	2.32
CHANGE	-0.17	-.08	+0.99	-3.30	+2.54	+3.53	1.03
L20	16.84	2.15	26.41	11.25	43.35	69.76	3.98
W20	16.38	2.14	25.92	13.64	41.92	67.84	3.04
CHANGE	+0.46	+.01	+0.49	-2.39	+1.43	+1.92	+.94
L23	18.99	2.04	26.22	10.86	41.89	68.11	2.79
W23	17.99	2.22	24.60	11.47	43.72	68.32	3.07
CHANGE	+1.00	-.18	+1.62	-0.61	-1.83	-0.21	-.28
L25	18.89	2.00	26.94	10.73	41.44	68.38	2.60
W25	17.62	2.05	24.73	12.84	42.76	67.49	2.88
CHANGE	+1.27	-.05	+2.21	-2.11	-1.32	+0.89	-.28
L27	19.48	1.97	22.98	12.30	43.27	66.25	3.97
W27	17.27	2.13	26.19	10.71	43.70	69.89	2.55
CHANGE	+2.21	-.16	-3.21	+1.59	-0.43	-3.64	1.42
L30	18.00	1.97	24.11	13.46	42.43	66.57	3.71
W30	14.22	1.93	23.56	14.71	45.58	69.14	1.50
CHANGE	+3.78	+.04	+0.55	-1.25	-3.13	-2.57	2.21
L32	14.61	2.06	25.86	12.19	45.28	71.13	2.06
W32	15.50	2.29	27.96	09.94	47.40	75.36	1.80
CHANGE	-0.89	-.23	-2.10	+2.25	-2.12	-4.23	+.26
L34	17.26	2.02	26.65	11.49	42.58	69.23	2.28
W34	14.87	1.88	23.43	14.49	45.33	68.76	1.71
CHANGE	+2.39	1.14	+3.22	-3.00	-2.75	+0.47	+.57
L37	18.90	1.85	24.95	11.00	43.29	68.25	2.47
W37	15.28	2.01	28.15	12.27	42.29	70.44	1.06
CHANGE	+3.62	-.16	-3.20	-1.27	+1.00	-2.19	1.41
L39	16.36	2.11	28.75	09.36	43.42	72.17	2.46
W39	16.38	1.93	24.39	12.19	45.09	69.49	1.74
CHANGE	-0.02	+.18	+4.36	-2.83	-1.67	+2.68	+.72
L41	17.07	2.00	25.09	10.94	44.91	69.99	2.36
W41	15.94	1.96	27.53	12.55	42.02	69.55	1.44
CHANGE	+1.13	+.04	-2.44	-1.61	+2.89	+0.44	+.92
L43	18.76	1.97	25.10	09.77	44.40	69.50	1.61
W43	14.20	2.03	24.62	11.39	47.76	72.38	0.85
CHANGE	+4.56	-.06	+0.48	-1.62	-3.36	-2.88	+.76
L45	19.21	1.81	22.88	10.66	45.43	68.31	1.50
W45	17.14	1.96	23.83	12.94	44.13	67.96	1.32
CHANGE	+2.07	-.15	-0.95	-2.28	+1.30	+0.35	+.18
L49	16.54	1.84	30.34	09.86	41.42	71.76	2.84
W49	18.07	1.90	22.46	15.17	42.39	64.86	0.99
CHANGE	-1.53	-.06	+7.88	-5.31	-0.97	+6.90	1.85
L53	18.16	1.90	24.65	11.93	43.35	68.00	2.18
W53	15.75	1.93	25.73	13.29	43.29	69.03	1.27
CHANGE	+2.41	-.03	-1.08	-1.36	+0.06	-1.03	+.81
L55	19.71	2.05	23.80	10.12	44.32	68.12	3.46
W55	17.62	2.11	25.06	10.50	44.71	69.78	2.06
CHANGE	+2.09	-.06	-1.26	-0.38	-0.39	-1.66	1.40
L57	21.01	1.95	22.75	11.62	42.67	65.42	4.54
W57	18.82	2.05	24.77	11.00	43.37	68.13	1.68
CHANGE	+2.19	-.10	-2.02	+0.62	-0.70	-2.73	2.86
L59	18.79	1.94	27.14	09.32	42.81	69.95	3.00
W59	18.84	2.15	24.29	11.92	42.79	67.09	3.03
CHANGE	-0.05	-.21	+2.85	-2.60	+0.02	+2.86	-.03
L61	19.53	2.08	23.57	11.31	43.51	67.08	4.01
W61	19.44	2.01	22.57	11.11	44.88	67.45	1.80
CHANGE	+0.09	+.07	+1.00	+0.20	-1.37	-0.37	2.21

L DENOTES LOOSE HAY SAMPLE OBTAINED FROM THE WINDROW
W DENOTES WAFERED HAY SAMPLE OBTAINED FROM THE MACHINE

TABLE 10

SPRING AND FALL COMPARISON OF COMPLETE FOODSTUFFS ANALYSIS REPORTS

CAN NUMBER	PROTEIN PER CENT D. B.	ETHER EXTRACT PER CENT D. B.	CRUDE FIBER PER CENT D. B.	ASH PER CENT D. B.	NITROGEN FREE EXTRACT PER CENT D. B.	CARBO-HYDRATES PER CENT	CAROTENE MG/100GM
S20	20.19	2.80	19.77	10.03	47.21	66.97	8.31
F20	19.99	2.25	21.52	09.65	46.59	68.16	5.43
CHANGE	+0.20	+.55	-1.75	+0.38	+0.62	-1.19	2.88
S26	18.86	2.54	25.67	09.40	43.53	69.20	8.28
F26	18.77	1.96	27.20	09.30	42.77	69.97	4.31
CHANGE	+0.09	+.58	-1.53	+0.10	+0.76	-0.77	3.97
S31	19.22	2.51	26.37	09.54	42.36	68.73	7.51
F31	19.42	1.95	27.30	09.50	41.83	69.13	3.37
CHANGE	-0.20	+.56	-0.93	+0.04	+0.53	-0.40	4.14
S45	19.74	2.50	22.88	09.51	45.37	68.25	7.74
F45	20.02	2.38	20.88	09.87	46.85	67.73	6.71
CHANGE	-0.28	+.12	+2.00	-0.36	-1.48	+0.52	1.03
S53	20.46	2.80	18.91	10.19	47.59	66.56	8.37
F53	19.85	2.13	22.89	09.33	45.80	68.69	3.69
CHANGE	+0.59	+.67	-3.98	+0.86	+1.79	-2.13	4.68

S DENOTES SPRING SAMPLE
F DENOTES FALL SAMPLE

TABLE II

STEEL BIN AND HERMETIC STORAGE COMPARISON DATA

CAN NUMBER	PROTEIN PER CENT D. B.	ETHER EXTRACT PER CENT D. B.	CRUDE FIBER PER CENT D. B.	ASH PER CENT D. B.	NITROGEN FREE EXTRACT PER CENT D. B.	CARBO HYDRATES D. B.	CAROTENE MG/100GM
H11	16.73	1.48	29.94	10.43	41.42	71.36	0.28
H12	17.36	1.57	27.76	11.62	41.68	69.44	0.22
H13	17.26	1.71	27.56	11.97	41.50	69.06	0.24
H14	16.60	1.73	27.01	12.10	42.56	69.57	0.48
H15	15.33	1.75	27.61	10.40	44.91	72.52	0.44
F53	19.85	2.13	22.89	09.33	45.80	68.69	3.69
F45	20.02	2.38	20.88	09.87	46.85	67.73	6.71
F31	19.42	1.95	27.30	09.50	41.83	69.13	3.37
F26	18.77	1.96	27.20	09.30	42.77	69.97	4.31
F20	19.99	2.25	21.52	09.65	46.59	68.16	5.43

H DENOTES HAY WAFER SAMPLE TAKEN FROM STEEL BIN
F DENOTES HAY WAFER SAMPLE TAKEN FROM SEALED ALUMINUM CAN

TABLE 12

VERTICAL MOISTURE DISTRIBUTION IN STORAGE CONTAINERS

CAN NO.	MOISTURE CONTENT AT TWO LOCATIONS Z (1) N	Z (0) N	DIFFERENCE	NO.	MOISTURE CONTENT AT TWO LOCATIONS Z (1) N	Z (0) N	DIFFERENCE
1	23.43	31.68	-8.25	28	27.55	27.57	-0.02
2	27.90	26.18	+1.72	31	24.68	17.01	+7.67
3	37.69	23.81	13.88	34	26.73	19.22	+7.51
4	30.48	27.93	+2.55	35	25.60	23.20	+2.40
5	23.66	23.21	+0.45	36	27.40	20.53	+6.90
6	23.00	24.04	-1.04	37	25.53	25.46	+0.07
8	30.43	26.73	+3.70	38	21.78	20.57	+1.21
10	24.70	30.89	-6.19	40	27.73	24.76	+2.97
12	17.12	16.38	+0.74	41	27.36	23.05	+4.31
14	28.17	24.50	+3.67	44	25.62	23.81	+1.81
15	23.65	16.05	+7.60	45	27.45	22.89	+4.56
16	33.80	25.07	+8.70	47	19.93	18.25	+1.68
19	25.36	29.51	-4.15	51	29.92	25.20	+4.72
20	28.85	24.16	+4.69	52	28.87	25.20	+3.67
21	22.90	23.89	-0. 9	53	24.69	28.29	-3.60
22	29.36	33.14	-3.78	54	24.85	26.90	-2.05
23	30.89	25.27	+5.62	55	20.06	23.39	-3.33
24	29.77	26.05	+3.72	56	34.60	27.23	+7.37
26	27.60	21.19	+6.41	57	14.34	16.71	-2.37

TABLE 13

HAY QUALITY CHANGES DURING STORAGE

LARGE CAN NUMBER	PROTEIN CHANGE PER CENT D. B.	CAROTENE CHANGE MG0100GM	SMALL CAN NUMBER	PROTEIN CHANGE PER CENT D. B.	CAROTENE CHANGE MG0100GM
1	+0.25	+1.98	31	-0.20	+4.14
2	+0.32	+0.82	32	+0.33	+0.40
3	+1.48	+0.59	33	-1.23	+0.40
4	+0.54	+0.96	34	-0.51	+5.58
5	+0.44	+1.60	35	-0.27	+2.90
6	-0.13	+3.65	36	+0.21	+1.11
7	+0.84	+4.71	37	+0.53	+1.58
8	+0.07	+1.11	38	+0.06	+2.11
9	+0.23	+1.89	39	-0.03	+0.13
10	-0.37	+1.65	40	-0.48	+1.52
11	-0.85	+0.29	41	-0.73	+0.82
12	-0.22	+5.09	42	-1.14	+1.91
13	-0.73	+0.03	43	-1.29	+0.28
14	-0.09	+0.65	44	-0.18	+1.01
15	+0.06	+9.93	45	-0.28	+1.03
16	-0.15	+0.73	46	-0.93	+0.35
17	+0.01	+0.44	47	-0.38	+5.50
18	-0.53	+1.52	48	-2.21	+0.64
19	-2.04	+0.82	49	-0.42	+1.70
20	+0.20	+2.88	50	+0.45	-0.25
21	+0.55	+0.94	51	+0.39	+0.37
22	-0.15	+0.40	52	+0.94	+2.22
23	-0.45	+0.29	53	+0.61	+4.68
24	-0.20	+5.45	54	+0.83	+1.11
25	+2.93	+2.33	55	+0.50	+0.65
26	+0.09	+3.97	56	-1.91	+0.77
27	-1.86	+0.08	57	-0.29	+8.90
28	-1.38	+0.57	58	-0.12	+2.25
29	+1.52	+1.19	59	-0.47	+0.28
30	+0.75	+0.73	60	-0.26	+0.56

HERMETIC HAY WAFER STORAGE

by

HAL EVERETT JUDY

B. S., Kansas State University
of Agriculture and Applied Science, 1961

AN ABSTRACT OF A MASTER'S THESIS

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The objectives of this investigation were as follows:

1. Investigate losses in nutrients during hermetic storage of hay wafers;
2. Investigate changes in hay occurring during the wafering process;
3. Compare hay quality of wafers in hermetic storage with wafers dried with natural air and stored in a steel bin;
4. Determine relationship between moisture content and protein or carotene loss occurring in hermetic storage.

Sixty surplus naval ammunition cans with storage volumes of 2.1 and 4.0 cubic feet were used to store samples of hay wafers under hermetic conditions. The hay was allowed to dry to the 13.5 to 32.0 per cent moisture (wet weight basis) range in the windrow before wafering was begun. Samples of the hay in the windrow were taken immediately ahead of the wafer machine so that windrow hay quality and moisture content could be determined. Samples of wafers representing the hay in each storage container were obtained as the cans were filled so that the quality and moisture content of the hay entering storage could be known for comparison with the hay in the windrow and also with the wafered hay after the storage period. The wafers which were stored in the cans were actually samples of the production run of the wafering machine and those wafers which were not stored in the sealed containers were stored and air dried in a 1,000 bushel steel bin for comparison purposes.

During the course of the investigation 5,851 pounds of alfalfa hay were stored at an average moisture content of 24.88 per cent on a wet weight basis. Bulk density obtained during hermetic storage varied from 25 to 39 pounds per cubic foot.

The hermetically sealed containers were opened in the fall after four and one-half months of storage and a sample for hay quality was taken from each can. Using complete foodstuffs analysis reports on the individual samples, statistical tests were made on various comparisons. Since all of the comparisons made during the investigation except the hermetic storage versus steel bin with natural air drying utilized paired comparisons, 90 and 95 per cent confidence intervals were determined using "students t test" for all paired comparisons.

Because of suspected sampling error, the results of the effects of wafering on hay quality determinations that showed significant changes at both the 90 and 95 per cent confidence intervals can only be said to point out that there is a definite possibility that there exists a hay quality loss incurred in the wafering process. Comparison of the before and after foodstuffs analysis of the hay stored hermetically shows no significant change in protein content at either the 90 or 95 per cent confidence levels; however, there was a significant loss of carotene content for both confidence levels. This carotene loss does not look great when the hay stored in the steel bin is compared with the hermetically stored wafers. Using a 95 per cent confidence interval, the carotene content of the alfalfa stored in hermetic conditions is significantly higher than the carotene content of the hay stored in the steel bin. Protein, ether extract, and ash all had significant differences at the 95 per cent confidence level.

No definite relationship between moisture content and protein loss or carotene loss during hermetic storage could be determined.

Neither could a relationship between bulk density and protein loss or carotene loss be determined.

The investigation leads to the conclusion that there is a good possibility that high quality hay wafers with moisture contents of 26 - 42 per cent wet weight basis can be stored hermetically without serious nutrient losses.