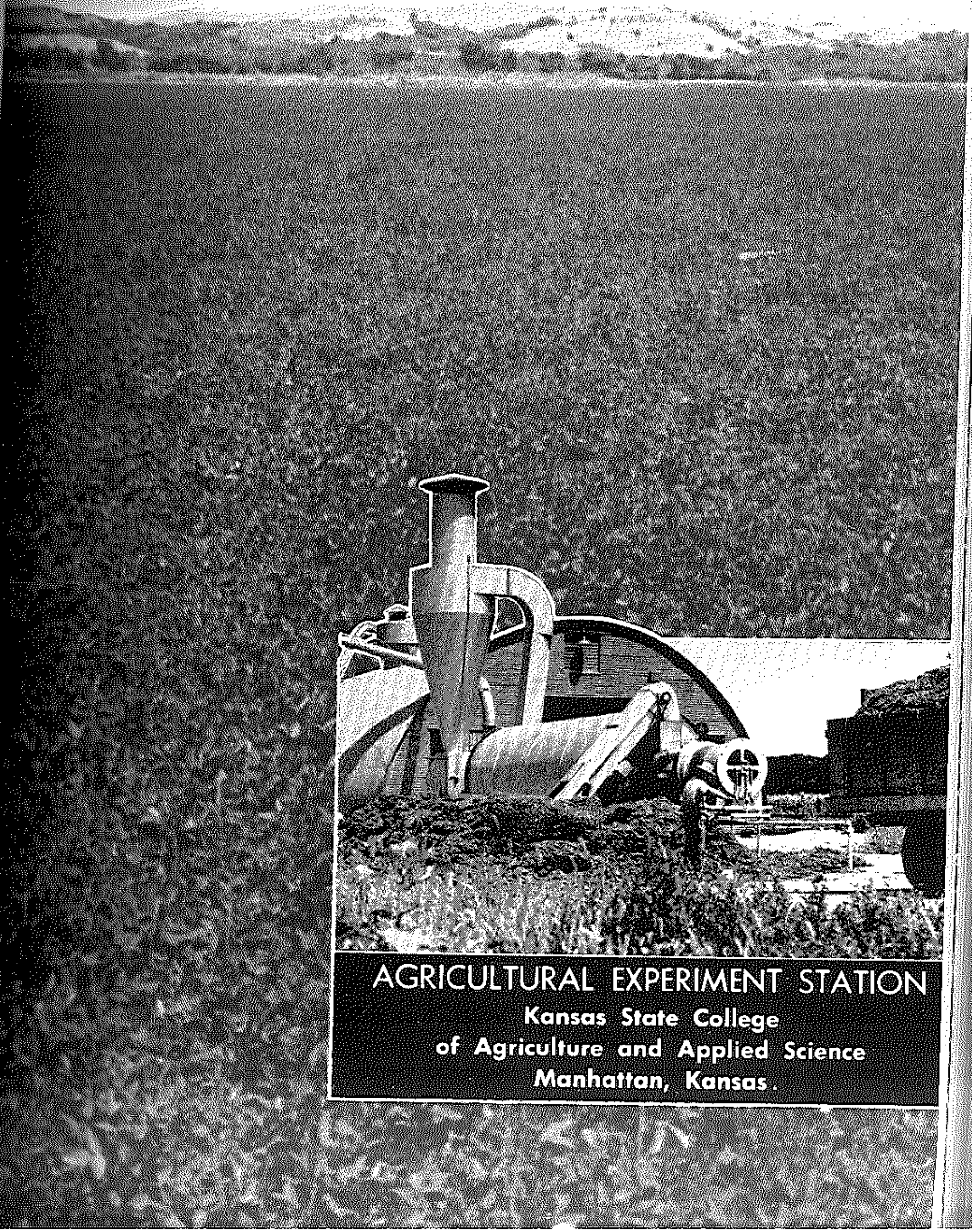
This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Bulletin 356
February, 1953

LIBRARY
630
K133
#356

Dehydrated Alfalfa



AGRICULTURAL EXPERIMENT STATION
**Kansas State College
of Agriculture and Applied Science
Manhattan, Kansas.**

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

KANSAS AGRICULTURAL EXPERIMENT STATION

MANHATTAN, KANSAS

STATE BOARD OF REGENTS

WALTER S. FEES, *Chairman*, Iola

MRS. ELIZABETH HAUGHEY .... Concordia
ARTHUR W. HERSHBERGER .... Wichita
WILLIS N. KELLY .... Hutchinson
LESTER MCCOY .... Garden City
DREW MCLAUGHLIN .... Paola
GROVER POOLE .... Manhattan
L. B. SPAKE .... Kansas City
OSCAR S. STAUFFER .... Topeka

HUBERT BRIGHTON, *Secretary*

ED BURGE, *Business Manager*, Concordia

ADMINISTRATION

JAMES A. MCCAIN .... *President of the College*
ARTHUR D. WEBER .... *Director of the Station*
HAROLD E. MYERS .... *Associate Director*
C. PEAIRS WILSON .... *Assistant Director*
ARNOLD R. JONES .... *Comptroller*

STAFF MEMBERS IN CHARGE

GEORGE MONTGOMERY .... Agricultural Economics
F. C. FENTON .... Agricultural Engineering
R. V. OLSON .... Agronomy
R. F. COX .... Animal Husbandry
V. D. FOLTZ .... Bacteriology
S. M. PADY .... Botany
R. E. SILKER .... Chemistry
H. T. WARD .... Chemical Engineering
F. W. ATKESON .... Dairy Husbandry
R. C. SMITH .... Entomology
GLADYS E. VAIL .... Home Economics
W. F. PICKETT .... Horticulture
J. A. SHELLENBERGER .... Milling Industries
A. B. CARDWELL .... Physics
L. F. PAYNE .... Poultry Husbandry
E. E. LEASURE .... Veterinary Medicine
D. J. AMEEL .... Zoology
H. C. FRYER .... Statistician
S. M. CREEK .... Editor

SUPERINTENDENTS OF BRANCH STATIONS

E. H. COLES .... Colby
W. W. DUITSMAN .... Fort Hays (P. O., Hays)
A. B. ERHART .... Garden City
T. B. STINSON .... Tribune
F. E. DAVIDSON .... Mound Valley

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

TABLE OF CONTENTS

DEHYDRATED ALFALFA[1]

W. G. Schrenk, H. L. Mitchell, Ralph E. Silker, C. O. Grandfield, W. H. Honstead, and R. G. Taecker[2]

INTRODUCTION

Since Kansas occupies a favorable position with respect to potential production of dehydrated alfalfa the Kansas Industrial Development Commission felt a research program devoted to the problems of this industry would be of value to the state. As a result such a program was initiated, and although this bulletin is an attempt to survey alfalfa and alfalfa dehydration in general, there are numerous references to the research which was sponsored by the Kansas Industrial Development Commission.

Other agencies are also engaged in similar research. Among these organizations are the Agricultural Experiment Stations in other states, the United States Department of Agriculture, especially at the Western Regional Research Laboratory, Albany, California, and the various commercial firms which use the product.

Recently the American Dehydrators Association also has seen the need of research in this field and they, through their research council, are financing and sponsoring projects of direct interest to them.

HISTORICAL

Alfalfa as a valuable feed material has been known for centuries. Earliest records of alfalfa production date back to about 500 B.C. It was grown at that time in what is now the northern part of Iran. The Greeks and Romans also were familiar with alfalfa and its value as a feed. Cato (B.C. 234-149) wrote of its use in "De Agricultura" as a means of improving the soil. In about 60 A.D. Columella wrote of its usefulness for feed, its value to the soil, its perennial nature, and methods of cultivation. Hendry (48) has written a history of alfalfa, and recently Griffiths (38) has given a review of its history, bringing to attention its importation to the United States. The name "Alfalfa" probably originated in the Arabian language and literally means either "best fodder" or "horse fodder." The name "lucerne," which is used commonly in Europe for alfalfa, probably originated from the fact that in its early history in

[1] Contribution No. 475, Department of Chemistry; No. 468, Department of Agronomy; and No. 2, Department of Chemical Engineering.

[2] Professor, Department of Chemistry; associate professor, Department of Chemistry; professor and head, Department of Chemistry; agronomist, Division of Forage Crops, B.P. and S.A.E. Agr. Res. Adm. U.S.D.A.; associate professor, Department of Chemical Engineering; and associate professor, Department of Chemical Engineering, respectively.

7.5M—2-53

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Europe it was cultivated and grew well in the Lake Lucerne area in Switzerland.

Alfalfa probably was introduced in Greece during the Macedonian and Persian invasions. From Greece alfalfa spread to Italy and Africa. The Arabians also carried the plant to Spain and from there it traveled to Mexico, Peru, and Chile. It is likely that its arrival on the west coast of the United States was brought about by the gold seekers enroute to California by way of Cape Horn and South America.

George Washington and Thomas Jefferson both grew alfalfa in the colonial period (4), according to reports.

From the standpoint of alfalfa production in the United States two important importations were the introduction of a Chilean variety in California in 1850 during the Gold Rush and the introduction into Minnesota in 1857 of alfalfa brought from Baden, Germany, by Wendell Grimm. Alfalfa grew so well in the California valleys that it became known as "California Clover."

Alfalfa supplies one-third of the hay crop of the United States and is the leading forage crop in Kansas. Most of the alfalfa is grown in the Midwest and Far West. Six midwest states including Kansas each have over a million acres. In Kansas the acreage has increased steadily since 1938 to its present figure of 1,026,000 acres (Fig. 1). The increase in the

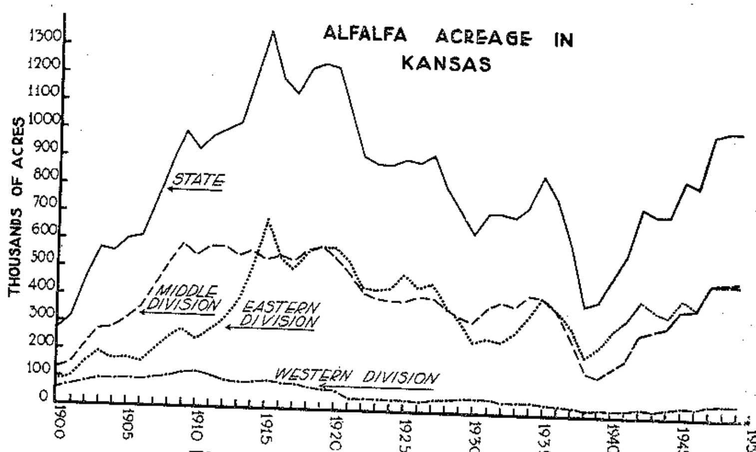


Fig. 1.—Alfalfa acreage in Kansas.

use of alfalfa for commercial purposes has contributed to this growth, since dehydrated alfalfa and alfalfa meal are important ingredients of many mixed feeds.

Alfalfa first came into Kansas from the west in the late 1860's and early '70's. It was first mentioned in the Report of the Kansas State Board of Agriculture in 1877, and in 1882 the Kansas Agricultural Experiment Station recommended the seeding of alfalfa. Alfalfa was not readily accepted by farmers; some claimed stock wouldn't eat it, and not until about 1900 did the alfalfa acreage make much increase. At that time there were about 300,000 acres. Up to 1900 alfalfa was more or less in an experimental stage and no one could tell the farmers how to obtain stands or how to make good hay. Seed was scarce and little home-grown seed was available. During this early period alfalfa itself was becoming acclimated to Kansas conditions. After several generations of production the survival of the best plants began to assert itself in Kansas alfalfa and this strain became known as Kansas Common. Kansas Common established itself as a variety, and in the past had as wide an area of adaptation as any single variety grown in the United States. It established a reputation for Kansas-grown alfalfa seed throughout the eastern part of the United States. Buffalo alfalfa, a new variety developed by the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, and the Kansas Agricultural Experiment Station, which has all the qualifications of Kansas Common plus resistance to bacterial wilt **Corynebacterium insidiosum,** will eventually replace Kansas Common in its adapted area.

During the period between 1900 and 1915, alfalfa acreage in Kansas increased by one million acres. This rapid growth necessitated the use of unadapted seed to supply the demand, especially during the last two years of the period. Because of this there was an immediate reaction and the acreage decreased rapidly for the next two years. During the next 20 years the acreage fluctuated but on the whole decreased by almost a million acres. This decline was due to diseases such as bacterial wilt and to economic factors brought about by demands for more grain. During the next 10-year period, up to 1950, there was a gradual increase in the alfalfa acreage to the present figure of over one million acres. This increase in acreage was due to improved varieties, improved methods of handling, and the increase in the commercial demand for alfalfa meal.

Alfalfa with a production of over 38½ million tons annually (1948) is harvested primarily as sun-cured hay. Within recent years, however, the artificial drying of alfalfa has developed into an important commercial method of processing. A more uniform product of higher nutritional quality results.

In 1903, Otto Weiss of Wichita, Kansas, first put ground alfalfa in commercially mixed feeds. This marked the beginning of the alfalfa milling industry. Shortly thereafter, M. E. Peters of Omaha, Nebraska, mixed ground alfalfa and molasses in a feed. These feeds met popular favor and resulted in an in-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

creased use of alfalfa in mixed feeds. The industry, however, received demands for a uniform product, with color being important. As a result, artificial drying was attempted in order to meet this new demand. In 1931 the first dehydrator west of the Mississippi and probably the second of commercial value in the United States was constructed. By 1937 the United States Department of Agriculture recognized the growth of the dehydration industry and published a circular describing equipment used in the industry (32). Since that time the alfalfa dehydration industry grew rapidly with an accelerated growth in the early and middle 1940's. Kansas now has 86 units producing some 180,000 tons of meal annually valued at over $10,000,000. Thus this industry, developed in the Middle West in the last 20 years, has added greatly to the demand for the product and provided employment for 1200 to 1500 people in the state.

Production of dehydrated alfalfa in the United States now exceeds 717,000 tons per year (102). Figure 2, which is similar to that presented by Chrisman (21) in his excellent review of

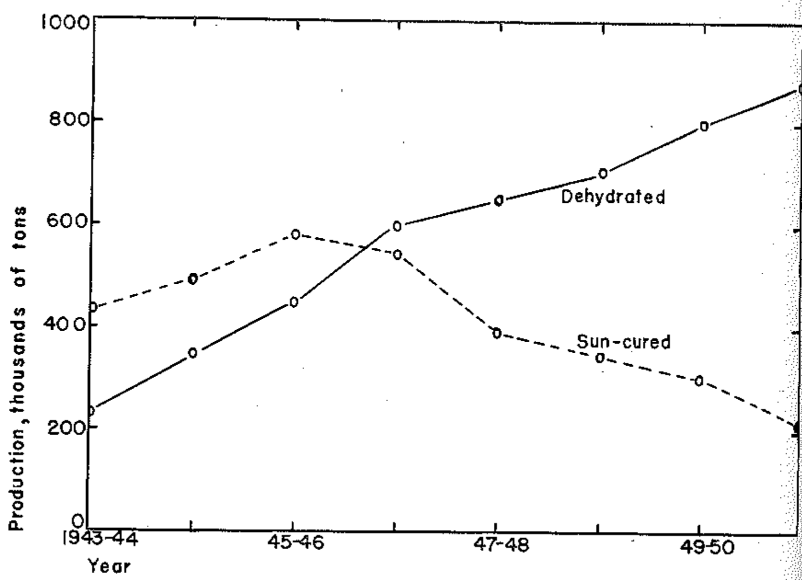


Fig. 2.—Production of alfalfa meal in the United States.

dehydrated alfalfa production, illustrates the growth of the dehydration industry since 1943. Most of the meal is used in chicken rations, but more and more of it is finding its way into cattle feed, hog rations, sheep feed, and turkey mash. The formula feed industry is now using large quantities and it is

beginning to stabilize as a new and valuable industry, providing another outlet for an important farm crop.

The problems associated with the growth of such a new industry are many. Such factors as equipment, efficient operations, high quality products, uniform products, packaging, sales promotions, etc., are much more numerous and subject to fluctuation and change than in an established industry.

ALFALFA FOR DEHYDRATION

Alfalfa Breeding

Alfalfa breeding in the past has been limited largely to the increase in production of the plant itself as hay or to seed yields. This has been accomplished by obtaining resistance, through breeding techniques, to some of the diseases of alfalfa and through the selection of plants that have the inherent ability to produce more hay or seed than others. Through alfalfa breeding several new varieties have been developed. The two most important of these are Buffalo and Ranger, both of which have a high degree of bacterial wilt resistance. Buffalo alfalfa, as previously mentioned, was developed at the Kansas Agricultural Experiment Station by selection and close breeding of plants selected from an old line of Kansas Common, known to have been grown in Kansas since 1907. Selected plants showing resistance to wilt were grown under isolation and allowed to intercross, and were then reselected, resulting in what we now know as Buffalo. Tests have shown Buffalo alfalfa to yield as much hay as Kansas Common as long as the stands are comparable, but over a period of years it surpassed Kansas Common because of the loss of stands in the Common, due to wilt (Table 1).

TABLE 1.—Comparative Stands of Alfalfa, After Four Years on Wilt-Infested Soil, Manhattan, Kansas.

Variety	Percentage Stand original	final
Buffalo	95	95
Kansas Common	100	25
Grimm	98	12
Oklahoma Common	98	20
Dakota Common	98	6

Experimental results from other states have shown Buffalo to produce as much hay as other varieties commonly grown in the test and to maintain stands longer.

Table 2 presents data from a test conducted at Davis, Cali-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

fornia, which clearly indicates the ability of Buffalo to maintain its stands longer and to make good yields at the same time.

TABLE 2.—Comparative Stands of Buffalo Alfalfa After Seven Years California Agricultural Experiment Station, Davis, California.

Variety	Percentage Stand original	Percentage Stand final	Average Yields First 3 years, in tons per acre
Buffalo	92	87	7.3
Kansas Common	90	32	6.7
California Common	95	42	7.8

Buffalo alfalfa is purple flowered, erect in its habits of growth, and rather quick to recover growth in the spring and after cutting.

Buffalo alfalfa is more resistant to the leaf and stem diseases common to this area than Kansas Common or Ranger, and for this reason produces a higher quality feed during periods of weather favorable to the growth and development of the diseases. Some dehydrator operators have mentioned the high carotene content of the Buffalo alfalfa they have processed. Most of the nutrients in alfalfa are in the leaves; therefore any variety containing a high percentage of leaves will be higher in the nutritive elements than the varieties that may drop their leaves before being harvested.

The range of adaptation of Buffalo alfalfa is limited on the north to the northern boundary of Kansas by its degree of cold resistance, and in the south it is limited in the areas where wilt is not a factor by its ability to compete with the local strains of common alfalfas in hay-yielding ability. Generally speaking, Buffalo alfalfa can be grown successfully across the United States between the 31st and 43rd parallels. The area where Buffalo is best adapted will be bounded on the north by the 40° parallel extending west to the Utah State line and then diagonally up to the Puget Sound area. The southern boundary of its area of adaptation will extend south to the 31° parallel, then west to Texas and slightly north and west to the west coast, eliminating the tropical areas of Arizona and California and the eastern coastal area. In all the area west of the Kansas line Buffalo will be in competition with high-yielding, non-wilt-resistant, local strains in the south, and Ranger, a wilt-resistant variety, in the north. Buffalo will be used as far north as the 43° parallel in the north central and east, extending west to the Wyoming line. In this area Buffalo may be used for pasture mixtures and in short rotations where rapid recovery is desired in the spring and after cutting, and when a heavier late fall growth may be obtained, than can be obtained from Ranger or other northern varieties.

Ranger Alfalfa is a synthetic alfalfa as described by Tysdal (101) produced through the co-operative efforts of the Nebraska Agricultural Experiment Station and the Division of Forage Crops and Diseases, United States Department of Agriculture. Ranger was synthesized from five selections. In morphological characteristics it exhibits considerable variability in both habit of growth and flower color. It is distinctly variegated in flower color. Ranger has more cold resistance than Buffalo, therefore its range of adaptation is further north. In Kansas, Ranger has proved to be one of the high-yielding varieties, yielding slightly below Buffalo. It is highly wilt-resistant but more susceptible to the leaf and stem diseases than is Buffalo.

Most of the alfalfa breeding in the past has been to increase yields of hay, seed, and resistance to alfalfa diseases. Incidentally, some of this work has resulted in the increase of the quality of the product. Enough research has been done to show that it is possible to increase the quality of alfalfa by increasing the amount of some of the feed elements in fresh alfalfa.

Some work has been done at this station on carotene (provitamin A), and has indicated that carotene content in alfalfa is controlled by heritable factors. It is reasonable to believe that there are inherent differences in alfalfa plants in the amount of other elements as well as other biologically active ingredients. Ham and Tysdal (44) obtained strains and hybrids which they considered to differ inherently in carotene content, since the variations shown by the progeny were consistent when factors detrimental to carotene content were held under control. Hackerott (41) found differences in total carotenoid content between strain and clones of alfalfa and obtained a significant correlation between carotene content of polycross progeny and of their maternal parents. He concluded that carotene content in alfalfa is inherited. Brackney (15) obtained similar evidence and concluded that the inheritance of carotene content in alfalfa rests on complex interaction between environment and heritable factors within the plant.

CUTTING ALFALFA

As previously stated, alfalfa is a multiple crop. The best management procedure for one of the products for which alfalfa is grown may not be the best for another. Grandfield (34) stated that many alfalfa stands have been ruined because of improper cutting treatments, and described time of cutting treatments to maintain stands, to increase hay yields, and to increase seed yields, all of which are different in some detail. A fourth item, to increase quality, may be added.

To Maintain Stands with Alfalfa. The important factor in maintaining the stand is to keep a plant healthy and vigorous.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

This can be done by allowing the plant time between cuttings to accumulate plant food in the roots. This will make for more vigorous growth and higher cold resistance. The critical period is the fall season, and it is necessary to plan the late cuttings in order to allow the fall top growth to supply the roots with plant food for winter protection (Fig. 3).

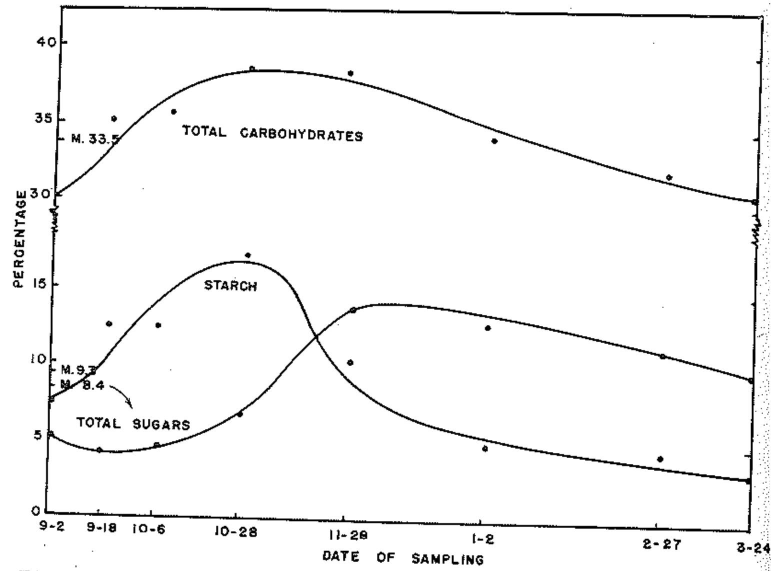


Fig. 3.—Trend of plant food reserves in alfalfa roots, plotted as deviations from the mean.

In this area the best management practice for hay production is to make the first and second cuttings in the early stages of growth, then regulate the third and fourth to allow sufficient top growth to develop on the plants after the last cutting to build up food reserve in the roots for winter protection.

To Increase Hay Yields. If tonnage is all that is desired, the hay should be allowed to reach the mature stage before cutting. The quality of the product will be lowered and the timing of the fall growth disregarded, thereby shortening the life of the stand.

Table 3 illustrates what happens to hay yields and hay quality when alfalfa is cut at different stages of growth. The change in quality is primarily due to the loss of leaves as the plant matures, even though the tons per acre increase up to the full bloom stage.

To Increase Seed Yield. To produce a seed crop the recommended practice is to allow the crop previous to the seed crop to go to the full bloom stage. This may not be the best management practice to maintain stands or to produce high quality hay. If a seed crop is desired it is necessary that the grower decide early in the season and cut the alfalfa accordingly.

To Increase Quality. Table 3 illustrates when to cut to obtain a high quality hay. This holds true with other nutritive elements in alfalfa as well as with proteins. Hauge (46) reported that young alfalfa was higher in vitamin A potency than was alfalfa in the bloom stage. Meenen (61) has shown that the carotene content of a leaf is continually being built up until the bloom period of the plant. He found more carotene in leaves of older plants than he did in young material and considered that the loss of total carotenoid content of the plant as it matured was probably due to the loss of leaves. Any factor which causes a chlorosis of the plant leaf will reduce its carotene content. Some of the factors that cause alfalfa plants to drop their leaves prematurely in Kansas are leaf and stem diseases, such as leaf spot, **Pseudopeziza medicaginis,** leaf blotch **Pseudopeziza medicaginis Ionesii,** alfalfa rust, **Uromyces striatus** Schroet, black stem, **Ascochyta imperfecti** Pech; leafhoppers **Deltocephalus,** low soil fertility, drought, etc.

TABLE 3.—Effect of Stage of Maturity of Alfalfa on Yield of Hay, Percent of Leaves and Protein, and Total Protein Produced Per Acre (Average for 8 years).

Stage of Maturity	Yield of moisture-free hay per acre	Leaves in hay	Protein in hay	Total protein per acre
	Tons	Percent	Percent	Pounds
Bud stage	2.427	53.4	19.78	960
One-tenth bloom	2.931	51.1	18.92	1,109
Full bloom	3.037	48.4	17.63	1,071
Seed stage	2.647	41.6	16.04	849

The practice of all commercial processors of alfalfa is to cut alfalfa in the early stages of growth. This assures them of a high quality product, because of the high percentage of leaves. The recommended practice for cutting alfalfa for quality is to cut in the bud stage. However, if this practice is continued throughout the season the plants will be weakened and more subject to diseases and winter killing, thereby reducing the stand. The dehydrator must be assured of a steady flow of alfalfa to the plant over the entire season for efficient operation, making it necessary to start on some fields earlier in the season than recommended as the best cutting practice.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

This may be compensated for partially by allowing these fields to go to later stages of growth later in the season.

The conclusion that may be drawn from the recommended cutting practice is that the producer must decide the purpose for which he is growing alfalfa and use the recommended cutting practice that will give him the greatest returns in longevity of stand, tons of hay, bushels of seed, or quality of product.

Soil Treatment

To grow alfalfa successfully the soil must be well supplied with the necessary plant food elements, lime, phosphorus, and potassium. Lime and phosphorus are lacking in much of the eastern half of Kansas, and potassium only in the extreme southeastern part.

TABLE 4.—Effect of Fertilizer on Alfalfa Hay Yields on Southeast Kansas Experiment Fields.

	Average yield, air-dry hay, tons per acre			
	Thayer 4-year average	Moran 17-year average	Columbus 16-year average	Weighed average 37 crop yrs.
No treatment	1.27	.90	.58	.80
Lime	1.13	1.56	1.95	1.68
Manure	1.57	1.65	......	1.63*
Lime and superphosphate	2.29	2.44	2.31	2.37
Lime, manure, and superphosphate	2.98	2.78	2.87	2.84
Lime, potash, and superphosphate	2.00	2.37	2.41	2.35

* 21 crop years.

The data in Table 4 are from experiments conducted in Southeast Kansas Experiment Fields. The response to lime and phosphate was good. Any treatment that will increase the hay yield will also increase the yield of the nutritive elements if alfalfa is cut at the proper time.

METHODS OF PRODUCTION OF DEHYDRATED ALFALFA

Dehydrated alfalfa varies considerably in quality, although it is almost always of much higher quality than sun-cured alfalfa.

Attempts are being made to standardize dehydrated alfalfa. The American Dehydrators' Association (5) has devised a set of trade rules which include a definition of dehydrated alfalfa. These include, essentially, that the product be dried rapidly by artificial means at a temperature above 212° F. and that no sun-cured alfalfa be mixed in the product.

Equipment is quite expensive and must include, in addition to the dehydrator proper, field equipment, trucks, trailers, feeders, hammer mills, sacking equipment, and a repair shop. Storage space is desirable and locations near railroad sidings are preferred. Most units in Kansas operate on natural gas and use electricity for motor-driven equipment; therefore these sources of power must be available.

Field Equipment

Field equipment may vary considerably, from mowers and rakes to self-propelled cutters, choppers, and trailer combinations that can make field operation a one-man job.

Equipment such as that shown in Figures 4 and 5 is owned by the dehydrators and moves from one field to another. Thus the entire operation from cutting the fresh alfalfa to selling the dehydrated product is under the control of the plant owner. The operators attempt to stay as close to the dehydrating unit as possible in order to reduce transportation costs. They seldom go more than 10 miles for alfalfa, and prefer to stay closer. One dehydrating unit requires about 1000 acres of alfalfa in order to operate efficiently during a normal season.

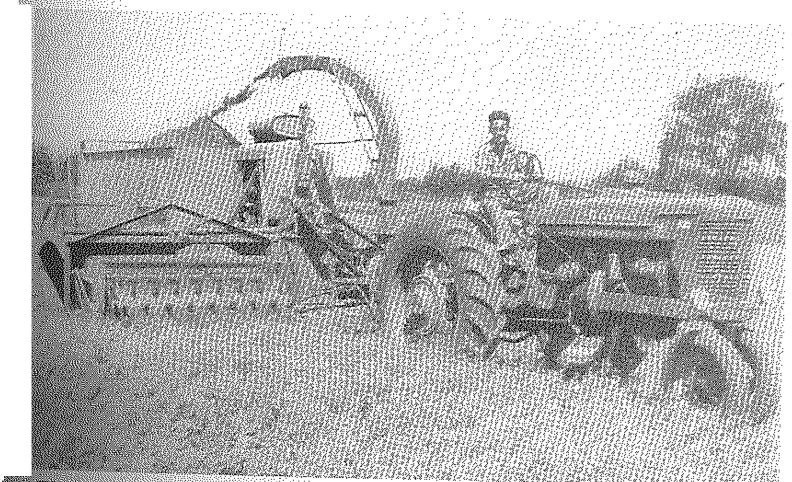


Fig. 4.—Tractor powered field harvesting equipment. Photo courtesy of W. J. Small Co., Division of Archer-Daniels-Midland Co.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

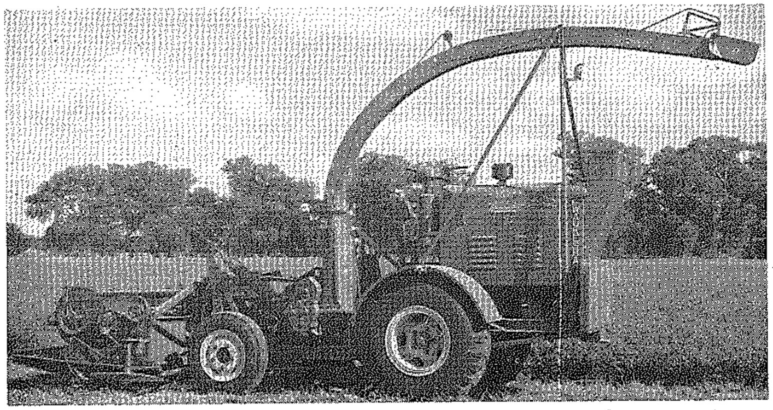


Fig. 5.—Self-propelled field harvesting equipment. Photo courtesy of Bert and Wetta, Maize, Kansas.

Dehydrators

There are several different types of dehydrators in use. A few low temperature units are in use, but most units are high temperature units of rotating drum type construction. The rotary drum driers are usually 10 to 12 feet in diameter and approximately 30 feet long. Two general types of rotary drum driers are in use. Gas is the usual fuel in Kansas, but oil can be used and coal has been used in one or two instances.

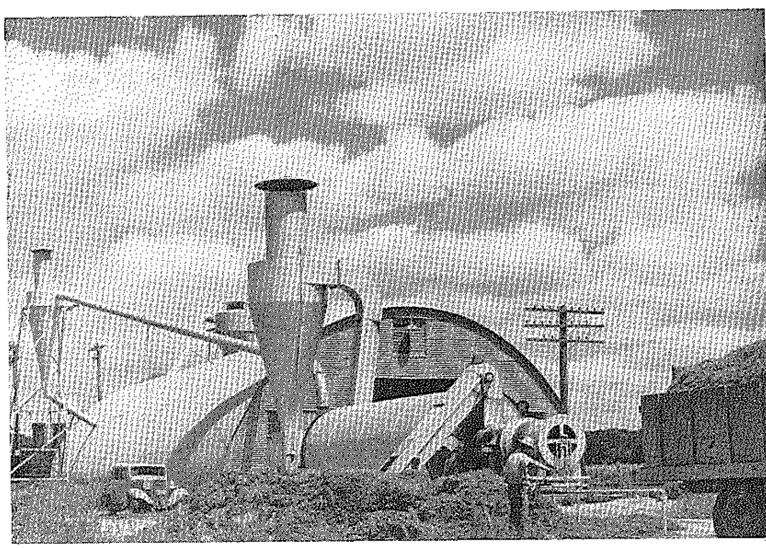


Fig. 6.—Howard-type dehydrating unit. Eureka Lake Alfalfa Co., Inc., Manhattan, Kansas.

Single Drum. The Howard type of drier uses a single rotating drum with baffles arranged along the inner surface. The baffles serve to keep the alfalfa falling through the stream of hot air and combustion gases passing through the drum. The freshly chopped alfalfa enters one end of the drum and is dried to a moisture content of 4 to 8 percent in a single pass through the unit. Figure 6 shows a unit of this type.

The temperature in the drum varies from about 1500° F. at the inlet end of the drum to about 250° F. at the exit end. In spite of the high initial temperature very little alfalfa is burned during drying if a proper balance is maintained between the temperature and the feeding rate. The alfalfa passes through the drum and is dried in 5 to 8 minutes. The gas is burned in the front third of the drum in this type of unit. More recently, however, a short firing tube has been used on the front of the drum. It is claimed that more efficient firing is thus obtained and that closer control of the temperature in the drum can be maintained.

Multiple Drum. The Heil dehydrator is similar in outside appearance to the Howard. Its inner construction, however, consists of three concentric drums with different drying con-

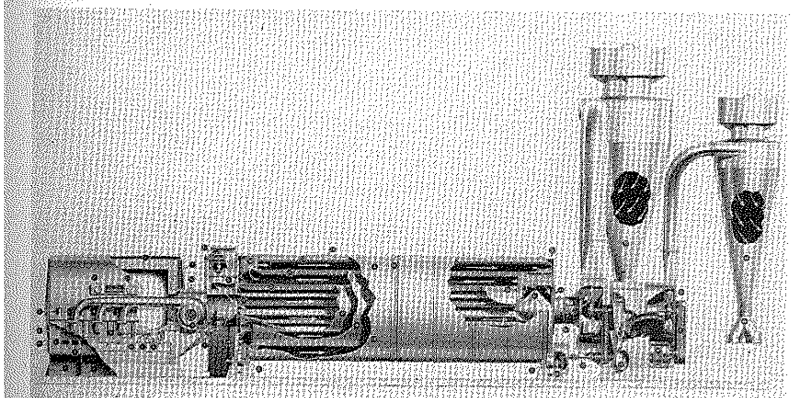


Fig. 7.—Cut-away view of Heil-type dehydrator. Photo courtesy of Arnold Dryer Co., Milwaukee, Wis.

ditions in the three compartments. The fresh material enters the drum which is at the highest temperature. The alfalfa then passes in successive stages into the second and third drums, which are maintained at lower temperatures. Figure 7 represents the construction of the multiple drum dehydrator and Figure 8 shows a regular installation of this type. An auxiliary furnace or firing tube is used with this type of dehydrator.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

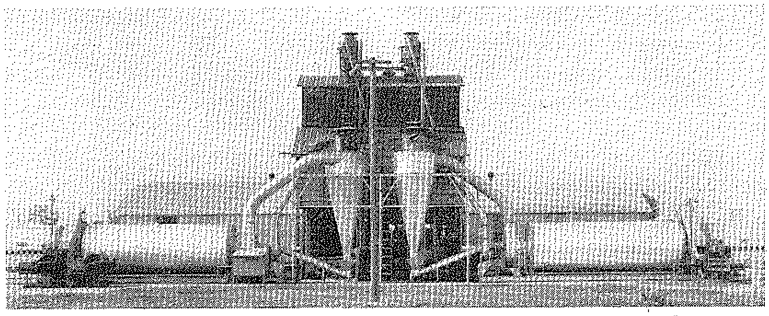


Fig. 8.—Double unit installation of Heil-type dehydrators. Photo courtesy of the Arnold Dryer Co., Milwaukee, Wis.

Automatic Feeding Equipment

One of the critical points in producing a good quality, uniform product is the maintenance of proper balance between feed rate and temperature. Until recently this operation was performed manually, with the workers adjusting the feed rate according to the temperature in the dehydration drum.

Within recent years several automatic feed devices have been manufactured and most operators now use some type of automatic feeder. Some of these units are regulated automatically according to drum temperature. Others run at a fairly constant rate, which may be varied slightly by a manual control, in which case the operator has the responsibility for maintaining proper feed rate. In any case, the use of automatic feeders has eliminated the need for manual labor in the feeding operation, and a more uniform meal is produced. Figures 9 and 10 illustrate typical automatic feeding equipment.

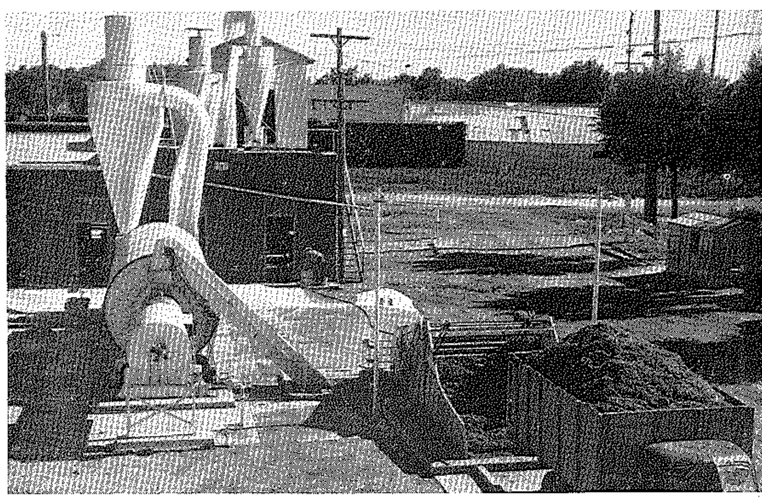


Fig. 9.—Automatic feeder at the National Alfalfa Dehydrating and Milling Company, Lamar, Colorado.

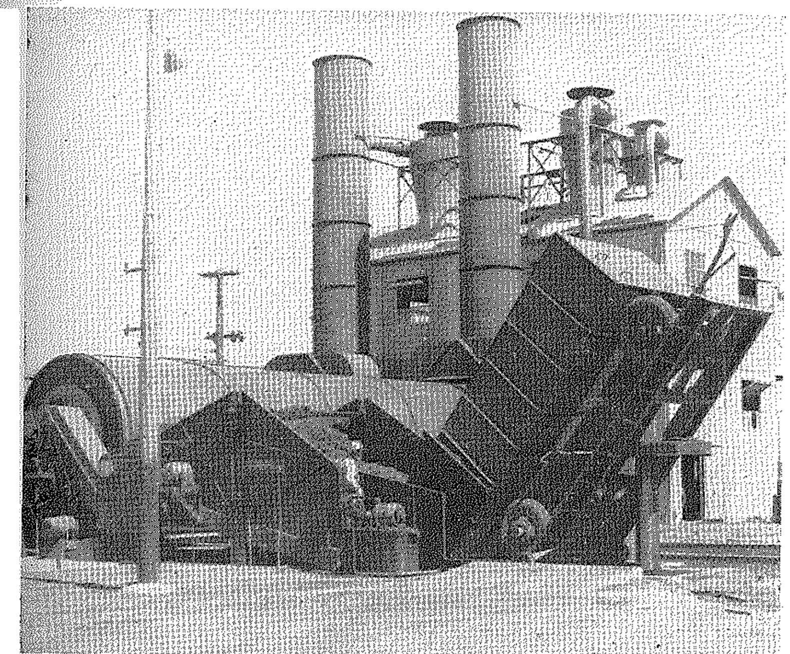


Fig. 10.—Automatic feeder at Cozad, Nebraska. Courtesy, The W. J. Small Co., Neodesha, Kansas, Division Archer-Daniels-Midland Co.

Maintenance of Feeding Value

In order to produce a good quality dehydrated alfalfa it is necessary to have a good quality raw material. However, good alfalfa can be damaged by poor handling and dehydration. Most operators attempt to dry the alfalfa as soon after cutting as possible, since destruction of nutrients in the alfalfa, particularly carotene, begins as soon as the alfalfa is cut. Silker and King (92) in a study on carotene losses showed that the loss of carotene from fresh chopped alfalfa was most rapid immediately after chopping, but amounted to less than 3 percent per hour over a period of several hours. The average length of time between cutting the alfalfa and feeding it into the dehydrator will be less than one hour under good management. A breakdown in equipment may account for a longer time lag, on rare occasions.

The carotene content of the dehydrated alfalfa is also af-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

TABLE 5.—Summary of Chemical Phase 1945 Survey Commercial Dehydrators.[1]

Dehydration Plant No.	1	1a	2	2a	3	3a	4	4a	5	5a	6	6a
Date	7/6	8/21	7/17	8/14	7/31	8/16	7/19	8/27	7/10	8/7	8/2	9/4
Carotene mg/100 g. Sample fresh alfalfa	4.8	6.2	4.5	5.7	6.1	6.7	7.0	7.8	6.7	7.4	5.7	7.0
Percent moisture	73.7	71.2	76.7	75.8	74.1	72.8	76.4	72.0	74.6	72.5	69.2	73.4
Carotene mg/100 g. fresh (dry wt. basis)	18.3	21.5	19.3	23.6	23.6	24.6	29.7	28.0	26.4	26.9	18.5	26.3
Vitamin A thousand I.U./lb.	137.3	161.5	145	177	177	184.5	222.4	210	198	202	138.7	197.3
Percent moisture[2] dehydrated meal	4.6	4.8	6.5	6.4	3.3	3.7	3.4	4.5	5.0	4.6	3.0	4.3
Carotene mg/100 g. meal (dry wt. basis)	13.9	19.2	17.9	26.8	20.4	19.3	25.5	26.4	22.4	23.1	15.8	23.7
Vitamin A thousand I.U./lb.	119.2	143.5	134.2	201	153	144.7	191.2	198	168	173.2	118.5	117.7
Percent loss of carotene in dehydration	13.1	10.7	7.3	412.0	13.6	21.5	21.3	5.7	15.2	14.1	14.6	9.9

[1]Six dehydrators located in the Kansas river valley each visited twice during the season.
[2]Present day operations yield meal with higher moisture content (6-8).

fected by the operation of the dehydrating unit. Silker and King (92) have shown that the losses in the dehydrator vary considerably, but may be held to a relatively low value of 5 to 10 percent.

In a further study losses of carotene during dehydration in a series of units located in the Kansas river valley were investigated. These data were taken along with engineering data which measured the efficiency of operation of the units. Carotene losses ranged from 5.7 to 21.5 percent. The data are presented in Table 5 and substantiate those obtained in the other study mentioned.

Efficiency of Dehydration

The engineering data obtained included (a) pounds of green alfalfa per hour; (b) pounds of dry meal per hour; (c) pounds of dry air passing through the drum per minute, and (d) fuel consumption per hour. From these data the rate of evaporation of moisture and the amount of water removed per unit of fuel consumed could be calculated. The carotene content of the dehydrated meal as compared with the fresh material was also obtained. Table 6 presents the engineering data on these units.

The capacity of each unit is best measured by the rate of water removal. As shown in the table, the capacity ranged from 7,675 pounds per hour to 4,860 pounds per hour.

The efficiency of each unit is best measured by the ratio of the rate of gas consumption to the rate of evaporation of water. Since the latent heat of water is 970 B.T.U. per pound and the heating value of natural gas is approximately 1000 B.T.U. per standard cubic foot, 100 percent efficiency is very close to a consumption of one cubic foot of gas per pound of water evaporated. This ratio actually varied from 1.155 to 1.98, indicating approximate efficiencies from 50 to 85 percent. This neglects several small heat quantities such as the sensible heat in the water and air leaving the dehydrator, and the sensible heat in the dry alfalfa, but it is still a good relative index of the thermal efficiency of the process.

Special Equipment

There are some pieces of equipment used in processing and handling dehydrated alfalfa which, although not of universal application, are of considerable interest. Included are such items as blending equipment, pelleting machines, automatic weighing equipment, automatic sacking equipment, loading devices, coolers for cooling alfalfa meal before sacking, spray equipment for adding oil to dehydrated alfalfa, shredders for

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

TABLE 6.—Summary of Engineering Phase 1945 Survey Commercial Dehydrators.*

Dehydration Plant No.	1	1a	2	2a	3	3a	4	4a	5	5a	6	6a
Date	7/6	8/21	7/17	8/14	7/31	8/16	7/19	8/27	7/10	8/7	8/2	9/4
Lbs. of wet hay per hour	10,000	9,300	7,400	7,750	7,230	8,000	8,050	7,230	8,350	7,740	6,780	6,940
Lbs. of dry meal per hour	2,325	2,340	1,600	1,775	1,765	1,940	1,600	1,980	1,950	2,040	1,920	1,720
Lbs. of water evaporated per hour	7,675	6,960	5,800	5,975	5,465	6,060	6,450	5,250	6,400	5,700	4,860	5,220
Lbs. of dry air per min. through drum	442	309	424	292	430	347	449	454	523	491	344	322
Lbs. of dry air per lb. of water removed	3.46	2.66	4.39	2.92	4.84	3.44	4.18	5.19	4.90	5.16	4.25	3.70
Gas consumption std. cu ft. per hour	8,850	8,740	7,600	8,580	8,750	8,913	9,380	8,050	10,400	9,300	9,640	7,980
Std. cu. ft. gas per lb. of water removed	1.155	1.255	1.313	1.44	1.235	1.43	1.453	1.53	1.63	1.63	1.98	1.53

*Six dehydrators located in the Kansas river valley, each visited twice during the season.

disintegrating stems before dehydration, and numerous other items.

Blending equipment is frequently used to combine various grades of alfalfa meal to meet certain specifications. This type of equipment is quite common, especially where the operator is producing sufficient meal to warrant such operations; high quality and lower grade meal can then be mixed in the correct proportion to meet the requirements of the buyer. Many types of blenders are in use. Typical of this kind of equipment is that shown in Figure 11.

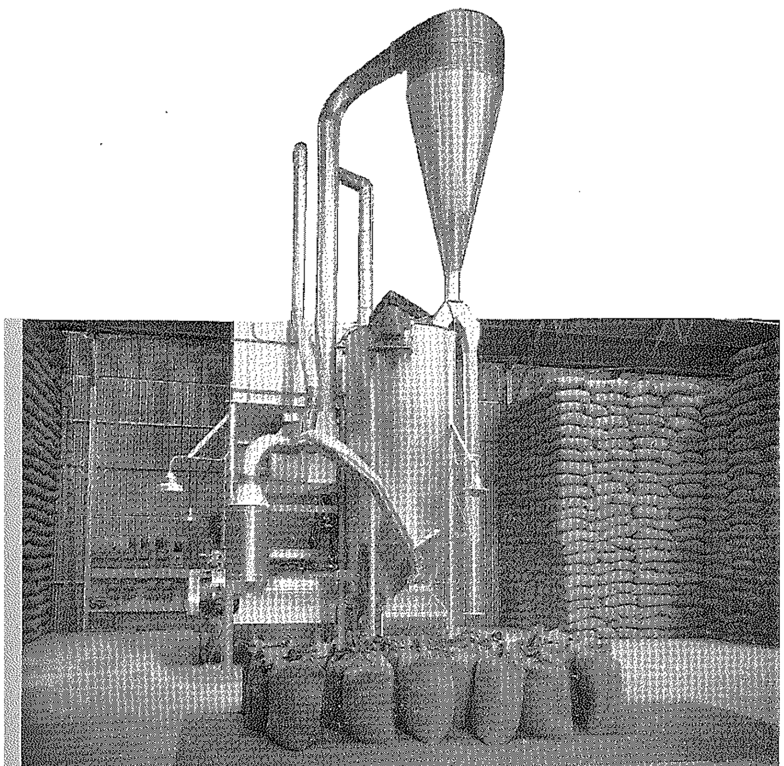


Fig. 11.—Alfalfa meal blending equipment. Photo courtesy of Bert and Wetta, Maize, Kansas.

Some operators are using equipment to cool alfalfa meal before sacking. The meal will average 20 to 30 degrees F. higher than atmospheric temperature as it leaves the hammer mill. The increased loss of carotene caused by the higher temperature can be reduced by cooling. Several different types of cool-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

ing units are available commercially, and in some cases plant operators have designed their own coolers. One installation of a cooling device is shown in Figure 12.

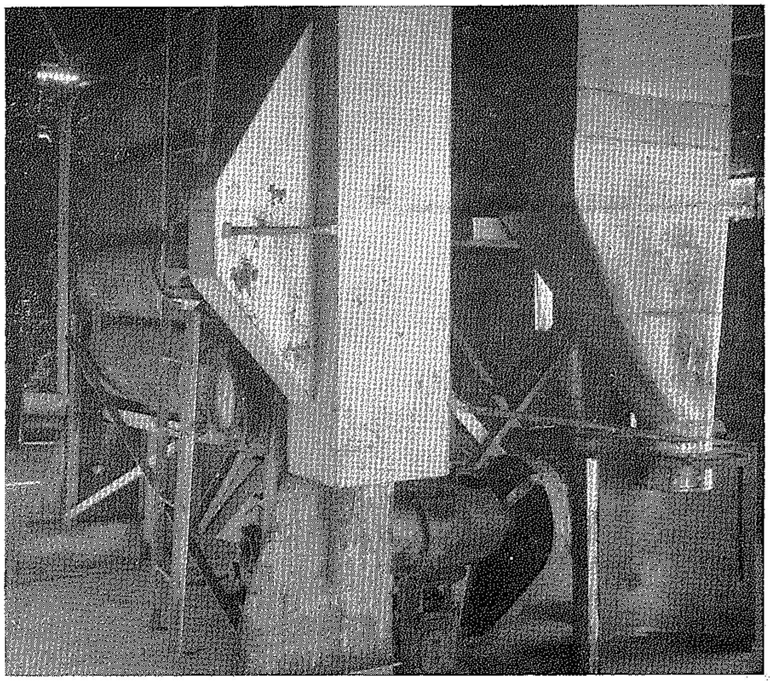


Fig. 12.—Alfalfa meal cooling equipment. Photo courtesy of the A. B. Caple Co., Toledo, Ohio.

Another device commercially available is a shredder which crushes and tears up the stemmy portion of the alfalfa immediately before it enters the dehydrating unit. This device is said to make dehydration of the alfalfa more uniform and require less heat because of the relative ease of drying the crushed stems as compared to whole stems. It is claimed that better quality meal results from such operations. The outside construction of such a crusher is shown in Figure 13.

Sacking operations have been simplified in many cases by using automatic weighing and sacking equipment. Paper bags are also finding use in the industry. Typical of sacking equipment is that shown in Figure 14, while a stack of paper-bagged alfalfa loaded in a freight car is shown in Figure 15.

Still other variations of equipment are in use. Pelleting machines make it possible to handle dehydrated alfalfa with bulk loading equipment when buyers are interested in this

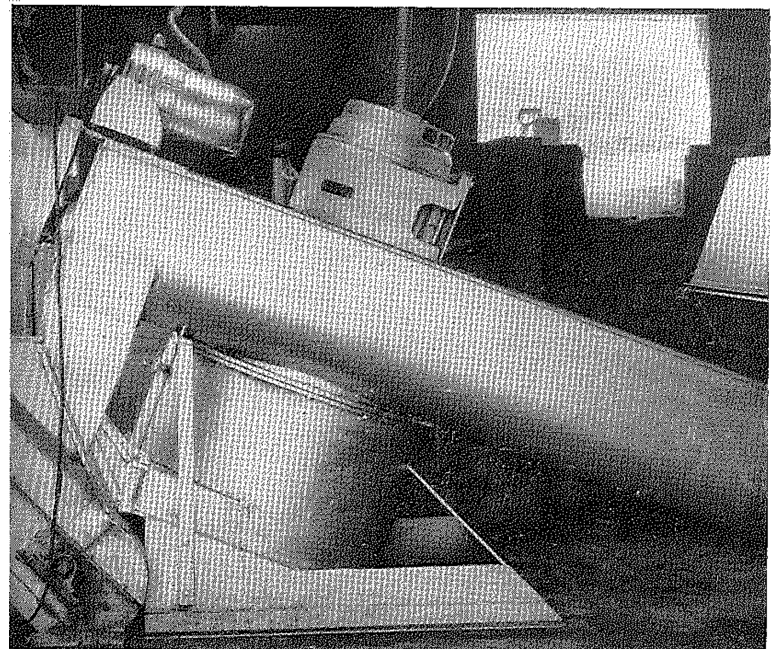


Fig. 13.—Equipment for shredding and crushing alfalfa stems before dehydration. Photo courtesy of U. S. Alfalfa Products Co., Verdon, Nebraska.

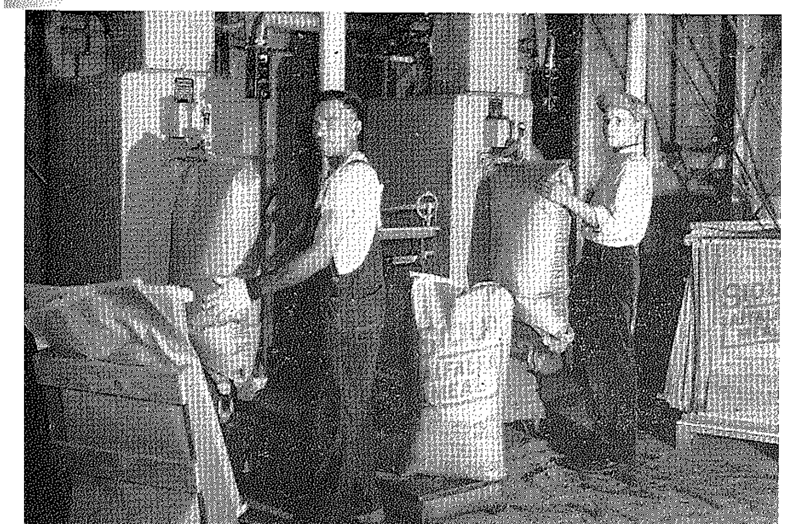


Fig. 14.—Alfalfa sacking equipment. Photo courtesy of Sioux Alfalfa Meal Co., Vermillion, South Dakota.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

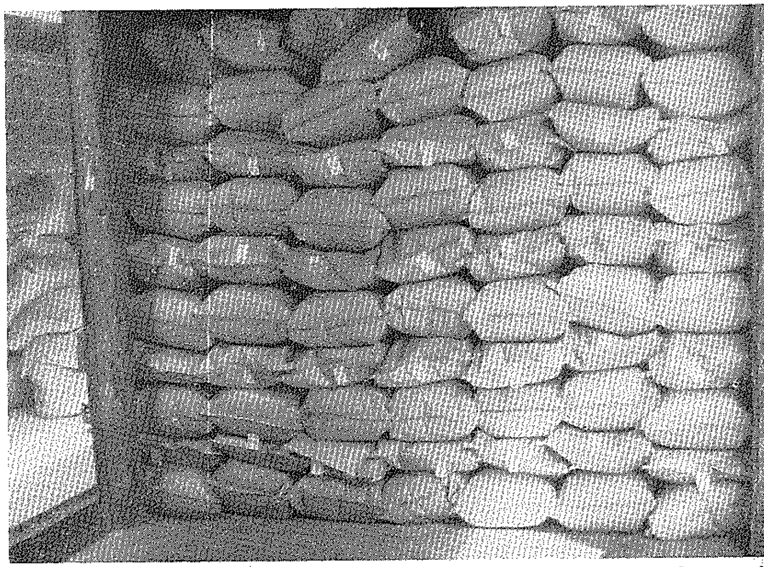


Fig. 15.—Alfalfa sacked in paper bags and stacked in freight car for shipment. Photo courtesy of the W. J. Small Co., Division of Archer-Daniels-Midland Co.

type of product. These devices also serve to reduce labor costs by reducing labor requirements, but probably increase overall cost due to machine operations. A few instances of equipment for bulk loading alfalfa meal are also known and can be used to reduce costs if the buyer is willing to purchase carload lots of alfalfa meal loaded in this manner. The cost of bags alone amounts to approximately $8.00 per ton at present quotations.

Cost of Production

Costs of producing dehydrated alfalfa vary considerably among various locations in the United States as well as within local areas. The industry is subject to wide variations in production costs due to different methods of management and different equipment. Many operators are prone to experiment with their units. This also tends to produce variations in production costs. The industry as a whole is a new industry which is changing rapidly, which again tends to make for unequal production costs.

In spite of difficulties in making accurate estimates, it is likely that the data presented by Dombrowski and Palmer (25) are as good as any available. They reported a cost-of-production figure of $37.00 per ton in 1948 as being a fairly accurate estimate. This value did not include storage, sales costs, traveling expenses, bank credit, dues, and taxes, which they estimate at $4 to $5 per ton.

Their estimates of cost of production are as follows:

Alfalfa	$10.00
Gasoline	2.00
Gas	2.00
Electricity	2.00
Bags	5.00
Labor	8.00
Repairs	2.00
Depreciation	6.00
Cost per ton	$37.00

Griffiths (37) estimated the cost of production at a somewhat lower figure. He gave as production costs a value somewhere between $15 and $23 per ton, excluding the cost of alfalfa. If alfalfa were purchased at $10 a ton the cost would be from $25 to $33 a ton, somewhat below the estimate of Dombrowski and Palmer.

Honstead and Silker (50) reported a cost estimate, made in 1946, of $49.00 per ton. Their data were based on a production rate of one ton of meal per hour, operating 20 hours per day 25 days a month and 5 months per year.

The total cost was placed at $49 per ton, broken down as follows:

Raw material	$15.00
Power, 130 KWH	2.00
Fuel (gas)	2.00
Bags, storage, shipping	10.00
Labor (10 men)	10.00
Amortization, interest, taxes	5.00
Maintenance, insurance, misc.	5.00
	$49.00

It can be seen that considerable variation in cost estimates has been made. It must be remembered, however, that there have been fluctuations in the price paid for the alfalfa, labor costs, equipment costs, etc., which have resulted in considerable variation in production costs. The amount of "down time" for repairs, inclement weather, etc., are factors which also greatly affect the actual cost.

As an example, Honstead and Silker's (50) estimate of the labor costs is based on 10 men per dehydrator. Present opera-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

tional practices such as the use of automatic feeders, self-propelled harvesters, etc., have eliminated some of the labor. As a result Dombrowski and Palmer have lower labor costs in their more recent estimate. They also use a cost of raw material of $10.00 a ton rather than the $15.00 used by Honstead and Silker. These two factors account for most of the difference in the two estimates.

An estimate of cost also was made for the United States Department of Agriculture in 1950 by Schoenleber and reported in Feedstuffs (83) as totaling $37 per ton. Costs on certain items included labor $8.28, gas $2.20, electricity $1.62, and machine repairs $2.57. These figures agree closely with those of Dombrowski and Palmer.

Investments in plant and equipment also vary widely. For a one-unit plant the investment may vary from $40,000 to $190,000, with an average of $95,000 (82, 83). Cash reserves of $10,000 to $15,000 per unit are required at the beginning of the season.

Schoenlẽber also estimated the typical crew to number seven men, including one mill operator and feeder, two sackers, one field operator, two haulers, and one repair man.

Market prices on dehydrated alfalfa also have varied widely over the past several years. Prices in Kansas City have fluctuated in one year (1948) from $81.25 in January to $41.50 in August. When prices were fixed in 1944-45 the figure was $60.30. In 1949 the price dropped to $39.55. Recent market quotations (1951) have been $73.60 per ton (in Kansas City). Thus it can be seen that the plant managers are dealing with a widely fluctuating market which makes operation at a more or less stable margin almost impossible.

ENGINEERING RESEARCH

Retention of Carotene

One of the most important problems the alfalfa dehydration industry has is that of preserving the original carotene content of the green alfalfa, both during dehydration and during subsequent storage of the alfalfa meal.

Since the destruction of carotene might result from an oxidation process, and since aldehydes, which can act as oxidizing agents, are produced by poor combustion of the fuel, the type of furnace and quality of the fuel-air mixture were investigated as factors in carotene retention. This approach seemed to offer real possibilities, since the work of Greene, **et al.** (35) had shown that the quality of dehydrated egg powder was reduced materially as the result of the adsorption of aldehydes and peroxides formed by incomplete combustion of the fuel.

Experiments conducted in a small, pilot size, Howard-type dehydrator loaned to the Department of Chemical Engineering by the Cerophyl Laboratories, Inc., failed to produce any significant changes in carotene retention as a result of changes in quality of combustion. This fact was verified by carotene retention tests on alfalfa meal from Heil dehydrators with furnaces, in which combustion should be complete, and on meal from dehydrators, such as the Howard, in which the gas was burned in the drying space; thus every opportunity was provided for the production and adsorption of aldehydes, peroxides, and other oxidizing materials. Again, no significant difference was found.

A second approach to the carotene retention problem involved the inactivation of the enzyme systems. The destruction of carotene could well be the result of enzymic activity. An attempt was made to remove this possibility by steaming or blanching the alfalfa prior to dehydration. As shown by Silker, Schrenk, and King (89), this procedure worked very well (Fig. 16) when the dehydration was conducted at relatively

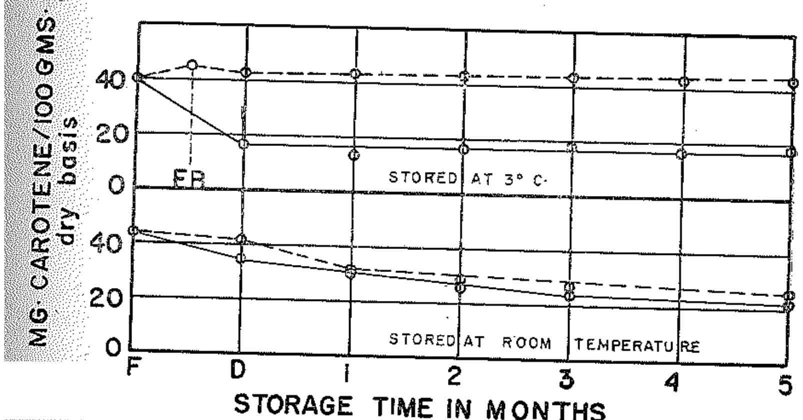


Fig. 16.—Effect of blanching on the carotene retention of alfalfa after low temperature dehydration. Dotted line, blanched; solid line, unblanched. FB, fresh blanched; F, fresh alfalfa; D, dehydrated.

low temperatures over several hours. When high temperature dehydration in the small Howard dehydrator was used, however, blanching had no significant effect on carotene retention, during either dehydration or subsequent storage. It has been proven since that the enzyme systems are inactivated by the temperatures to which the alfalfa is subjected during the usual dehydration process.

A third attempt to improve the carotene retention during storage subsequent to dehydration involved the addition of

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

antioxidants. This was accomplished by dipping the alfalfa in a dilute aqueous solution of an antioxidant. A 0.2 percent alkaline pyrogallol solution was used. The results are shown in Figure 17. It will be noted that this treatment increased the

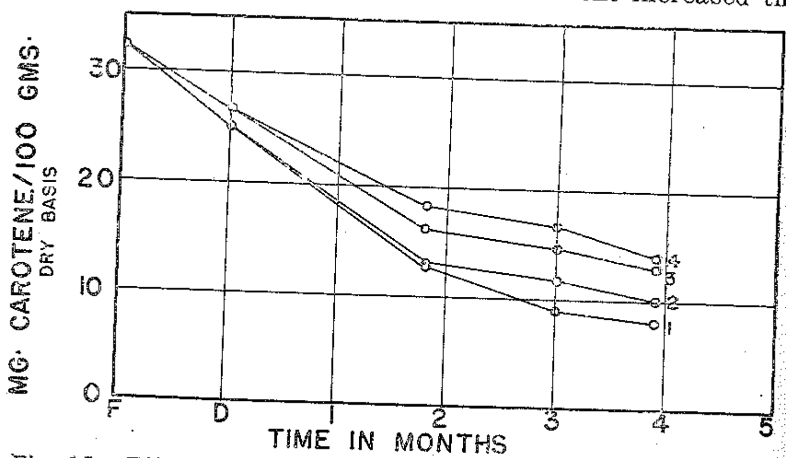


Fig. 17.—Effect of dipping fresh alfalfa in 0.25 percent pyrogallol solution before dehydration in rotary kiln dehydrator.

(1) Undipped meal, stored in glass jars exposed to light.
(2) Undipped meal stored in glass jars wrapped with black paper to prevent penetration of light rays.
(3) Meal from alfalfa dipped in pyrogallol solutions and stored in glass jars exposed to light.
(4) Meal from alfalfa dipped in pyrogallol solutions and stored in the dark (as in 2).

carotene retained by over 50 percent during 4 months of storage. The expense of such an operation made further development impractical.

Fractionation of Dehydrated Alfalfa

The possibility of separating the fibrous, stemmy parts of dehydrated alfalfa from the finer leaf fraction, which is richer in both protein and carotene, was investigated. This seemed desirable because the smaller bulk of the richer components could be stored under refrigeration, or in an inert atmosphere, at less cost than the total meal. The high quality meal so produced then could be blended with other meal to bring the total carotene content up to desirable levels.

The unground, dehydrated alfalfa came from the pilot dehydrator in ½-inch lengths. These were fed to a small Raymond air separator which separated the meal into two fractions on the basis of density and particle size. By varying the operation of the air separator, the proportions of the meal found in

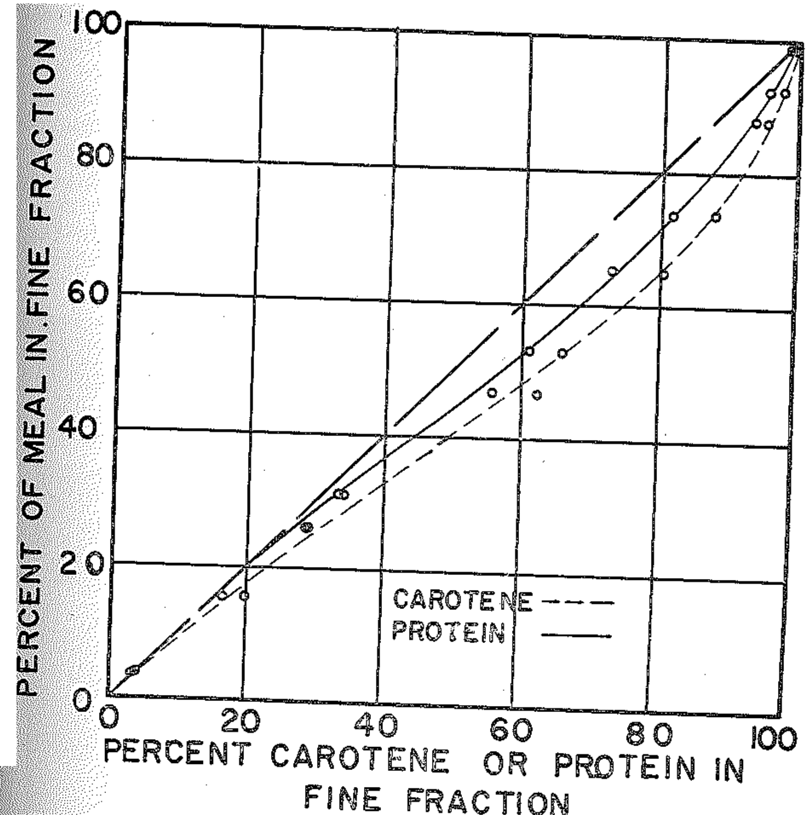


Fig. 18.—Fractionation of unground, dehydrated alfalfa by air separation.

each fraction could be controlled. The results of this fractionation are shown in Figure 18 in which the percent by weight in the fine fraction is plotted against the percent of the total protein, or total carotene, found in the fine fraction. Thus a material can be produced containing 80 percent of the carotene in a fraction containing 65 percent of the weight. This means that high quality meal containing 200,000 I. U. per pound could be separated into two fractions, the larger of which would have a carotene content of 246,000 I. U. per pound and contain 65 percent of the meal. The smaller fraction would have a carotene content of 114,000 I. U. per pound and contain 35 percent of the meal. This latter fraction is still good meal and meets the market specifications for a guaranteed carotene content of 100,000 units. This could be placed on the market immediately, and only the high carotene meal stored for later

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

sale. Since the cost of storage is an important item, the meal placed in storage should have as high a carotene content as possible.

The wide variation in the quality of alfalfa meal produced by commercial dehydrators indicated the need for some fundamental studies on the factors affecting the rate of drying of alfalfa. To this end, a small rotary drum dehydrator adapted for measuring temperatures throughout its length and for controlling as many variables as possible was constructed in the Department of Chemical Engineering. This dehydrator is shown in Figure 19.

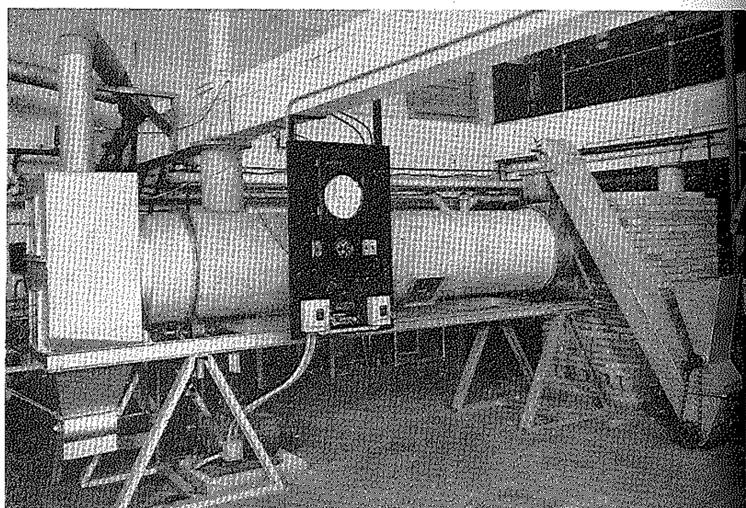


Fig. 19.—Experimental pilot plant alfalfa dehydrator at Kansas State College, Manhattan.

Drum Rotation Rate

One of the most important variables in this type of dehydrator is the rate of rotation of the drum. A study of this variable therefore was conducted in the pilot plant dehydrator by Koegle (56). While the rate of feed to the dehydrator, the air flow through the dehydrator, and the outlet temperatures were held constant, the rate of revolution of the drum was varied between 12 and 39 revolutions per minute.

It was expected that, as the rate of revolution increased, the alfalfa would progress through the dehydrator more rapidly. This, in effect, shortens the time of drying and should result in higher moisture content for the product. At the same time the gas temperature at the inlet to the drum and at points through the drum should be higher as the rate of rotation increases. This comes about because the actual amount of water evaporated decreases but slightly for a considerable change in the final moisture content. In order to remove this water in less time, then, the driving force for the drying process must be increased, which would be manifested by the increased temperature gradient mentioned above.

This was actually found to be true between rotation rates of 12 and 30 revolutions per minute. Between 30 and 39 revolutions per minute, however, the moisture content of the product decreased and the temperature gradient through the drum also decreased. It was observed at the same time that there was a tendency for the alfalfa to pile up in the front end of the drum.

These facts were interpreted to mean that between 30 and 39 revolutions per minute, the centrifugal force developed held the alfalfa along the circumference of the drum. The rate of revolution at which this should occur can be calculated from theoretical considerations for a smooth drum with no flights. This calculation gives 38.2 revolutions per minute for the small 2-foot diameter drum used. The flights in the drum, which were inclined at an angle of 15° to the radii, would tend to reduce the r.p.m. required to produce this effect.

The commercial installations have drums 8 feet in diameter. The rate of revolution required to hold the alfalfa along the periphery in this case was calculated to be 19.2 r.p.m., while the rate corresponding to the limiting value of 30 r.p.m. found with the pilot plant drum would be about 15 r.p.m.

It is obvious that the desirable operating range will lie below the point where centrifugal force becomes important. In this region, the time spent in the drier will be proportional to the inverse of the rate of revolution, if the air velocity is held constant. Of the total time spent in the dehydrator, however, part is spent in riding around the circumference of the drum to the high point of the drum, and part is spent in falling from here through the air stream to the low point of the drum. The latter time is more effective than the former, because of the much better contact between the alfalfa and the hot gases.

Because of this fact, it seemed desirable to investigate a dehydrator in which the contact between the alfalfa and the gases was at the highest possible efficiency. This requirement was satisfied by the so-called pneumatic type drier.

Pneumatic Type Alfalfa Drier

Pneumatic drying, also known as pneumatic conveyor drying, floating bed drying, or Flash Drying*, is the removal of moisture from a dispersed material as the material is being transported in a duct under the impulse of hot gases. Usually

*A registered trademark of Combustion Engineering Company, Inc., New York.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

the duct in which drying occurs is vertical; hence, by proper design and operation, a considerable degree of classification can occur according to density, shape, and size of the dispersed particle. Since a decrease in moisture content is often accompanied by a corresponding decrease in density without a corresponding change in the physical dimensions of the dispersed particle, the drying column may be so shaped that the dispersed particle will be automatically retained in the drying column until dry and then expelled.

Although artificial drying itself has been practiced for centuries, the commercial application of the principle of pneumatic drying dates back only to about 1930. Several commercial makes of driers are available for general purchase. Successful drying of chopped grasses, alfalfa, sugar beet tops, etc., has been claimed for units of foreign manufacture, among which are the Pherson (Sweden), Bamag (Great Britain), Van den Broek (Holland), and Buttner (Germany). The use of the Raymond Flash Drier manufactured by Combustion Engineering Company in the United States has been confined mainly to drying materials such as pulverized coal, chemical salts, sewage sludge, and the like. Material which has a tendency to cake must be disintegrated before introduction into the drying column.

De Lorenzi (23) lists four fundamental factors which govern the rate of moisture removal from a dispersed particle within a pneumatic drier. They are:

1. Moisture distribution
2. Temperature differential
3. Agitation
4. Particle size

A material in which the moisture is close to the surface may be dried rapidly to low moisture levels without heat damage. This rapid rate is possible because the major portion of water is evaporated under a condition such that the rate of moisture movement from the internal portion of the solid to the surface is sufficiently high to supply water to the surface as rapidly as it is evaporated. During this period of drying, known as the "constant-rate period" of drying, the rate of evaporation from the particle is independent of the structure of the particle, and the particle as a whole remains at the wet-bulb temperature of the hot gas stream if adiabatic drying conditions* prevail. At some value of moisture content of the solid, known as the "critical moisture content," the rate of moisture migration to the surface begins to diminish and the temperature of the surface of the particle being dried begins to rise.

*Adiabatic drying conditions heat energy for drying available only from a decrease in the sensible heat content of the hot gas stream.

The period following this point is the "falling-rate period" of drying, during which the rate of moisture removal diminishes at an accelerated pace, while the surface temperature of the particle and the particle as a whole approaches the dry-bulb temperature of the hot gas stream. Unless precautionary measures are taken to reduce the hot gas temperature or to remove the material being dried from the hot gas stream, scorching or "burning" can occur. The critical moisture content, the rate of drying during the falling-rate period, and the temperature at which heat damage occurs are influenced primarily by the internal structure of the particle and by the temperature and humidity of the hot gas stream.

In order that a high rate of drying be maintained, a broad temperature differential between the dry-bulb temperature of the gas stream and the surface of the particle from which moisture is being evaporated must be maintained. During the constant-rate period, the temperature difference is established largely by the dry-bulb temperature and wet-bulb temperature of the drying gas. The temperature difference during the falling-rate period is of secondary importance, however, as the drying rate is controlled almost entirely by the rate of moisture migration or "diffusion" to the surface. In other words, temperature and humidity of the gas stream tend to fix the rate of drying during the constant-rate period, while the character of the material being dried tends to fix the rate of drying during the falling-rate period. Time, not temperature, is the most important controlled variable during the falling-rate period of drying.

A degree of agitation or turbulence is also frequently desirable, although not always essential to the successful functioning of a pneumatic drier. The rate of drying during the constant-rate period is related directly to the fundamental equation for steady-state heat transfer by conduction which states that the rate of heat transfer to a surface is proportional to the temperature difference, the extent of the particle surface, and the "film coefficient of heat transfer." The film coefficient of heat transfer represents the rate at which heat is transferred through a hypothetical stagnant film composed of a mixture of water vapor and dry, hot gas surrounding the particle. Agitation of the particle in the hot gas stream or turbulence in the hot gas stream has a marked effect in increasing the rate of heat transfer for a given temperature differential by reducing the resistance to heat transfer. As the critical moisture content and the possibility of heat damage during the falling-rate period are functions of the rates of heat transfer, a protective stagnant film separating the particle surface from the major part of the hot gas stream may often be advantageous. Ideally, a particle should be subjected to extreme

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

turbulence during the early part of the constant-rate period, followed by a quiescent region extending from the latter portion of the constant-rate period to some point of withdrawal of the dried material within the falling-rate period.

Particle size, particle shape, and particle density are closely related in any consideration of pneumatic drying theory. The size and shape are an index of the surface-to-volume ratio. A high exposed surface-to-volume ratio for a material being dried is desirable in that the geometry favors minimum distances for migration of internal moisture to the surface; and, therefore, low values of critical moisture content and favorable falling-rate periods of drying occur. The particle shape and particle density together determine the relative movement between the particle and the hot gas stream. This movement, in turn, directly influences the value of the film coefficient of heat transfer and the height of drying column required for a given drying service. Material having the shape of a flake is ideally suited to drying to low-moisture values in a pneumatic-type drier because of short distances for moisture migration.

Experimental Drier

With meager design information an experimental pneumatic drier was set up in the chemical engineering department of Kansas State College for the purpose of learning of its possible use as a pre-drier to boost the capacity of commercial drum-type driers used for alfalfa drying. This first unit, erected during the summer of 1949, was never successful because of insufficient drying capacity and extravagant use of heat.

Profiting from the experience of the first attempt, the engineers constructed a new column with the purpose of (a) increasing the time of contact of the particle with the hot gases, (b) providing greater opportunity for flotation and classification of the dispersed particles, and (c) providing a column from which data might be obtained for the more rational design of future pneumatic drying columns.

The experimental drier finally used consisted of a gas-fired furnace, blower, drying column, and cyclone separator. The arrangement of these units and other details are shown schematically in Figure 20. As noted, the drying column was a cylindrical metal duct 24 feet in length and 16 inches in diameter, with a tapered transition section at the lower end. Observation windows and thermocouple connections for measuring gas temperatures were suitably placed along the wall of the insulated column. A stem separator was included in the transition section to remove large stems from the field-chopped alfalfa before appreciable drying occurred.

Details of furnace, blower, feeder, and cyclone construction are omitted here, since they were auxiliary equipment to the

drying column under study. The blower could be installed to take suction on the cyclone separator, thereby avoiding operation at excessive temperatures.

During each test, samples of alfalfa were collected every 10 minutes from the feed to the column, from the stem separa-

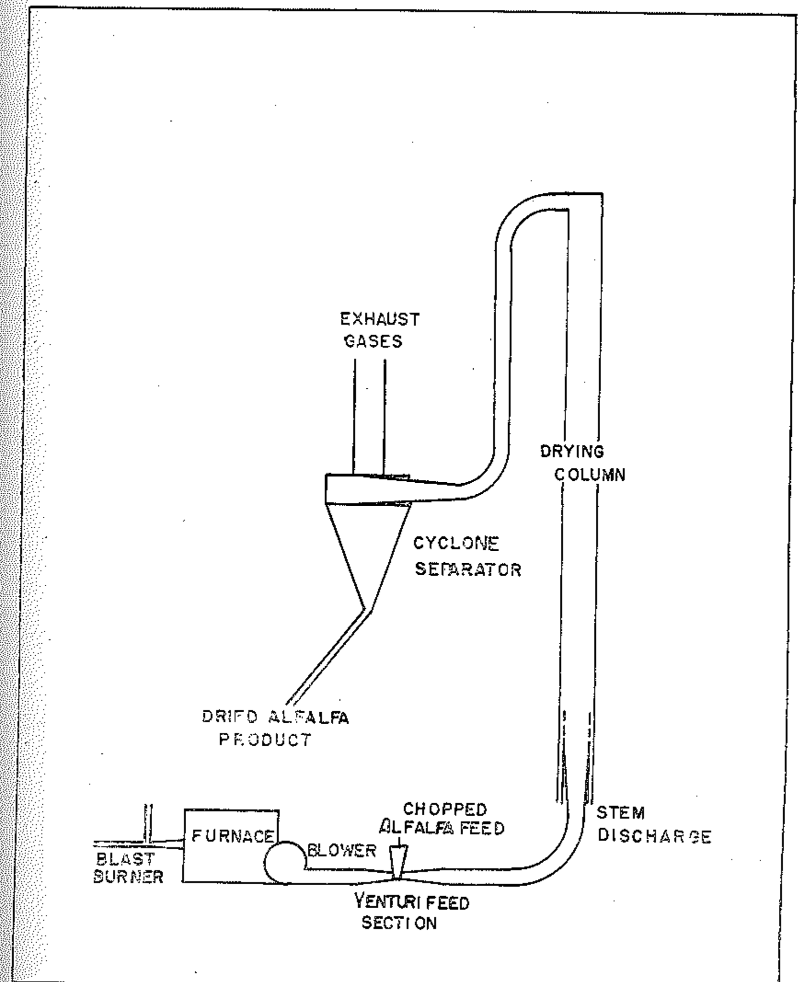


Fig. 20.—Diagram of experimental, vertical drying unit at Kansas State College, Manhattan.

tor, from the top of the pneumatic drying column, and from the dried product withdrawn from the cyclone separator. In addition, temperatures of the hot gases entering and leaving

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

the test section were recorded, together with necessary data for determining the alfalfa feed rate, the rate of stem withdrawal from the separator, the hot conveying gas rate, and the humidity of the conveying gas. These data were analyzed to provide an insight into the drying operation.

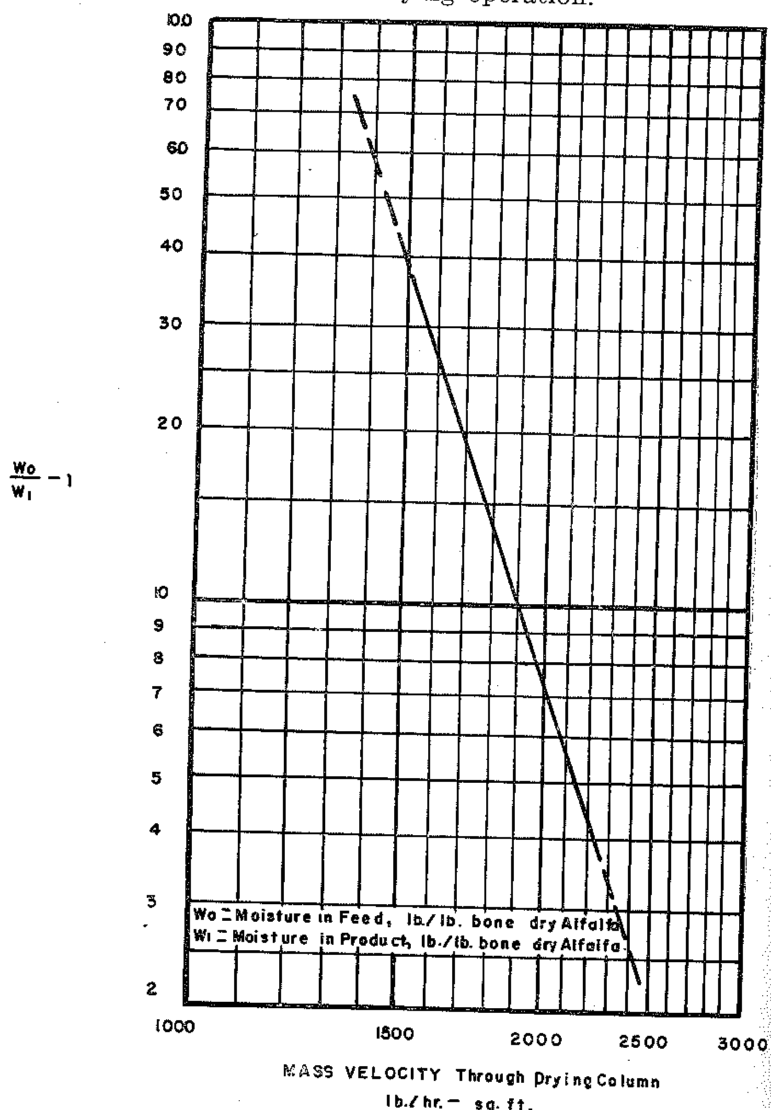


Fig. 21.—Relationship between drying gas rate and initial and final alfalfa moisture content.

Experimental Results

Study of the data obtained for a total of 63 separate drying runs using alfalfa of widely different initial moisture content indicated the drying rate was influenced primarily by the velocity and temperature of the hot conveying gas, and the moisture content and rate of the alfalfa feed. For inlet hot gas temperatures of over 720° F., the reduction in moisture content of the alfalfa during drying in the experimental column was found to be a function of the mass velocity (lb./hr.–sq. ft.) of hot gas flow through the cross-section of the drying column. By using the mass velocity of the gas instead of the velocity of the gas (which is sensitive to temperature because of the temperature effect on the density), a group $(\frac{Wo}{W_1} - 1)$ was correlated (Fig. 21), where Wo is the moisture content of the feed and W_1 is the moisture content of the product, both expressed as lb./lb. of alfalfa (moisture-free). The temperature effect of the hot gas stream was reduced by this method of correlation because of the interrelationship of temperature, density, and velocity of the gas stream at any cross-section of the column, and because of the temperature, density, and velocity gradient through the column.

Although alfalfa was fed to the experimental drying column at a rate of only 200 lb./hr., much higher feed rates are possible with a suitable feeding system. For an assumed value of 70 percent (wet basis) for the alfalfa feed, and 6 percent (wet basis) for the dry leaf leaving the drying section, $\frac{Wo}{W_1}$-1 equals 11.7 corresponding to a hot gas rate of 1950 lb./hr.-sq. ft. If the initial gas temperature to the drying section were 1600° F and the drying gas were exhausted at 250° F, the available heat energy would be about 680,000 BTU/hr.-sq. ft. of drying column cross-section. This heat energy would correspond to a moisture removal from the alfalfa of 680 lb./hr.-sq. ft. This moisture removal rate indicates a feed rate of 1000 pounds of wet alfalfa per hour per square foot, and a dry product rate of 300 lb./hr.-sq. ft. For a drier of this type, heat losses should not exceed 25 percent of the available heat energy for drying; therefore, the final column would have an approximate capacity of 750 lb./hr. of wet alfalfa for each square foot of column cross-section area.

Actual practice may require that this figure be reduced somewhat because the presence of a more dense suspension of alfalfa tends to produce higher linear gas velocities. Since the linear velocity must be carefully controlled to properly "float" the alfalfa, a greater alfalfa feed rate tends to reduce the al-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

lowable mass velocity together with the heat energy carrying capacity of the gas.

The height of the drying column in the floating bed type pneumatic drier is not critical, provided that it exceeds a certain minimum for practical operation. Theoretically, an alfalfa leaf should remain in a drying section, regardless of length, until sufficient moisture has been lost to allow it to be expelled. Actually, however, a minimum height of column is set by the distance required to reduce the velocity of the wet alfalfa being injected upward into the column to the settling velocity in the hot gas stream. A height of 24 feet was found to be satisfactory, although higher columns are recommended for industrial installations. Short columns are undesirable in that the alfalfa is virtually thrown from the inlet to the point of egress, allowing very little time for drying. This is especially true when the feed is composed of alfalfa containing many coarsely chopped stems.

The pneumatic-type drier shows promise in the field of artificial alfalfa drying. A drier of this type may be designed from energy balance considerations and experimental data presented. Further work is required to determine the proper degree of field chopping and control features to yield a dried product of consistently uniform quality.

Storage of Dehydrated Alfalfa

Dehydrated alfalfa frequently is stored before being sold and used in mixed feeds, since production in Kansas is limited to about a six-month period, while peak use occurs during the winter. Frequently it is advantageous to store high quality meal produced early in the season and use it for blending operations later. Market prices are also a factor in storage operations.

Dehydrated alfalfa has been commonly packaged in burlap bags each containing 100 pounds of meal. Recently many operators have shifted to paper bags. These are usually 50-pound bags. Silker, Schrenk, and King (91) previously had shown that such packaging had no deleterious effect on the meal. The paper bags help eliminate some of the dust associated with packaging and also with storage, thus being of value in the warehouse. The burlap bags have salvage value, while paper ones have none.

Some alfalfa meal is pelleted after passing through the hammer mill. The most common size is 3/16 inch in diameter. Some pellets are produced as large as ½ inch in diameter. The dust problem is not as troublesome with pellets, but an additional operation is required. Pelleted meal can be handled with grain weighing and loading equipment, and bulk shipment is possible.

Pelleting requires careful control of moisture if the pellets are to be satisfactory. The pressure of pelleting also produces considerable heating. The extra heat of pelleting is usually dissipated in a storage hopper before the pellets are weighed and loaded into freight cars or trucks or placed in storage.

Some pellets are produced without the use of hammer mill by pelleting the dry chops. These pellets usually are consumed in the dairy industry and apparently are quite satisfactory for the intended use.

Pelleting alfalfa meal has certain advantages. The dust problem is diminished, less volume is required, and bulk loading and handling are quite satisfactory.

Some manufacturers have experimented with a small amount of binding material in the pellets. One such additive, bentonite, a type of clay, has been used in quantities of less than 2 percent. This binding material, contrary to some reports, had no effect on the stability of carotene in the alfalfa.

Alfalfa usually is dried to a moisture level of 6-8 percent on a dry weight basis. This level is lower than the normal equilibrium value for moisture in the meal and the average vapor pressure of the moisture in the atmosphere. As a result, dehydrated alfalfa meal usually will pick up moisture from the atmosphere. The gain in weight, due to moisture, may be as much as 2-4 pounds per 100 pounds of alfalfa during even a relatively short period of storage. Schrenk and King (85) measured the vapor pressure of water adsorbed on dehydrated alfalfa and have indicated that excessive drying is an additional cost of operation.

Drying must be continued, however, until all stemmy material is sufficiently dry to pass through the hammer mill efficiently. It appears likely that with present types of dehydrating units the maximum moisture level that will permit effective operation of the hammer mill would be most desirable. This level may vary with different grades of alfalfa, but an average figure appears to be in the neighborhood of 8-10 percent. An additional advantage to be gained is in the extra protection afforded the carotene content of the alfalfa, since Silker, Schrenk, and King (91) pointed out that increasing the moisture content of alfalfa resulted in slowing down the destruction of carotene in the meal during storage.

The dust hazard in storage is also eliminated in part by the use of a small amount of oil added to the meal. This procedure is said to have no effect on carotene or other nutrients in alfalfa but does tend to eliminate dust. Schoenleber (83) has estimated the cost of adding oil to the meal at $1.50 per ton. This oil has no stabilizing effect on the carotene in alfalfa.

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Fire Hazards

Alfalfa storage is also hazardous from the standpoint of fire. Alfalfa, sacked as it comes from the hammer mill, will have a temperature 20° to 30° F. above the atmosphere. Since it is finely divided the meal insulates itself well. The net result is that the center of a sack of meal cools very slowly. If any foreign particles are in the meal, small rocks, metal, etc., they may start a slow fire in the interior of the bag which may be unnoticed for considerable time. Care, therefore, should be exerted to remove all such foreign substances from alfalfa meal before sacking. Electromagnets are frequently used to remove particles of magnetic substances.

The temperature differential of alfalfa in a bag also causes carotene losses to be uneven. The greatest loss of carotene takes place in the center of the bag where temperatures are highest. This requires that care be exercised in sampling stored alfalfa meal when blending operations are carried on, and the meal is sold with a carotene guarantee.

STABILIZATION OF CAROTENE

Freshly dehydrated alfalfa will have a much greater content of carotene (pro-vitamin A) than will alfalfa which has been sun-cured under good conditions. During sun-curing, carotene destruction is brought about by the catalytic effect of the enzyme lipoxidase (62), by sunlight in the presence of chlorophyll (72), and perhaps to some extent by uncatalyzed oxidation. By dehydration, enzymic and photochemical destruction are eliminated to a large extent. Hence, properly dehydrated alfalfa may contain 95 percent of the carotene present in the fresh alfalfa, while sun-cured alfalfa may contain only 20-50 percent of the original carotene (immediately after sun-curing) (19,24,57,58,81). However, both dehydrated and sun-cured alfalfa lose vitamin A potency during storage, due to slow oxidation. Thus, one of the most important problems confronting the dehydration industry in its efforts to produce meal of greatest nutritional value is the prevention of the carotene oxidation that occurs during storage of the dehydrated product.

Nature of Carotene Destruction

Considerable time has been devoted to determining the manner in which carotene is destroyed during storage. It was suggested that perhaps enzymes in the plant were not inactivated completely during dehydration, and that these enzymes contributed to carotene destruction during subsequent storage. Mitchell and King (63) found that lipoxidase was inactivated easily by the dehydration process, but that peroxidase was not. However, it was shown that neither peroxidase nor other oxidases present in the meal were responsible for carotene destruction, as blanching the alfalfa before dehydration did not alter the rate of destruction during storage of the meal. Such treatment would have inactivated any enzymes which could cause carotene destruction.

It has been suggested that such metal ions as iron, copper, manganese, and cobalt, which frequently function as catalysts, were responsible for carotene destruction during storage. However, Thompson (98) was unable to reduce carotene loss by spraying alfalfa meal with various metal deactivators, and he concluded that metal ions apparently do not catalyze carotene destruction in alfalfa meal. Thus, it must be concluded that the mechanism by which carotene is oxidized during storage still is not known.

Storage Temperature

Several methods have been proposed for preventing or slowing down the loss of carotene during storage. It was observed by Guilbert (40) that storage temperature was a major factor, and that the rate of loss was approximately doubled for every 10° C rise in temperature. Wilder and Bethke (105) reported that alfalfa meal stored for 6 months lost 10 percent of its carotene at –23° C, 50 percent at 16° C, and 60-72 percent at room temperature. Silker, Schrenk, and King (91) stored alfalfa meal both in a commercial warehouse and in a large cave near Atchison, Kansas. The cave is used by the United States Department of Agriculture as a natural storage cooler. A temperature of 37-40° F was maintained in the cave by means of a number of refrigeration units. They found that meal stored in moisture-proof bags in the warehouse lost about 70 percent of its carotene in 5 months, while meal in the natural cooler lost about 39 percent. A few of the larger dehydrating companies now are using refrigerated warehouses to take advantage of this temperature effect.

Inert Atmospheres

Since carotene destruction is an oxidative process, it should be possible to reduce carotene loss by replacing the oxygen which surrounds the particles with a non-oxidizing atmosphere. It was noted by Taylor and Russell (96) that storage of alfalfa meal in cans which had been evacuated or which had been flushed with nitrogen preserved more carotene than did normal storage. Hoffman, Lum, and Pitman (49) studied the effect of an inert atmosphere, and concluded that probably the oxygen content of the atmosphere surrounding the alfalfa meal will have to be reduced to less than 3 percent if storage in inert atmospheres is to be successful. A patent issued to

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Graham (33) for storage under non-oxidizing gas is being used by the Cerophyl Laboratories, Inc., Kansas City, Mo., for storage of dehydrated alfalfa and cereal grasses at their Midland, Kansas, plant. The process consists essentially of placing the meal in large steel bins and flushing out the air with gases produced by the incomplete combustion of natural gas. This method of storage, like refrigeration, requires more elaborate facilities than the small dehydrator can afford.

Moisture Content of Meal

Bielefeldt (11) and Silker, Schrenk, and King (91) reported that alfalfa meal containing a high moisture content lost less carotene during storage than did meal of low moisture content. Bielefeldt recommended that the alfalfa contain about 13 percent water and that it be stored at 75 percent humidity. Under these conditions his meals lost 30 to 60 percent of their carotene. Silker **et al.** (91) correlated better carotene retention in burlap and paper bags, as compared to moisture-proof bags, with an increase in moisture content during storage from about 5 percent up to 8-10 percent in the burlap and paper bags.

Halverson and Hart (42), and Mitchell, Schrenk, and King (65) investigated high moisture storage with air-tight containers. Meals containing 12 percent or more of water fermented, during which oxygen was consumed and carbon dioxide was produced. If the containers were air-tight, the meals then were being stored effectively in an inert atmosphere, and only about 10 percent of the carotene was destroyed. This process has been patented by Halverson and Hart (43). Unfortunately, it has been found (65) that after opening of such samples carotene destruction is very rapid. Thus, a sample containing 15.9 percent moisture and stored at 25° C in a tightly sealed bottle had lost about 10 percent of its carotene when opened at the end of 5 months. The sample was returned to storage, and one month later it had lost 42 percent of its carotene. Another disadvantage of such storage is a change in color from a normal green to an olive green. This change is due to the production of acid during fermentation, which causes the conversion of chlorophyll to pheophytin. These changes probably will discourage the use of high-moisture storage.

Bailey, Atkins, and Bickoff (8) reported that 8 percent moisture is optimum for storage in air-tight containers if no head space is left in the container. At this moisture level there was no change in color. However, rapid loss still occurred once the seal was broken. These workers suggest that such storage may be feasible if an inexpensive container which is impervious to oxygen should become available.

Pelleting

Much attention has been given to the possibility of improving carotene retention by pelleting the meal. There is general agreement, however, that pelleting does not have a beneficial effect (105). In fact, some carotene destruction results from the pelleting operation (66), due to the heat produced and to the retention of this heat for some time following the operation (Table 7). Hence, the pellets may contain less carotene than the meal after several months of storage.

TABLE 7.—Effect of Pelleting on the Carotene Content of Dehydrated Alfalfa (66).

	Carotene (International units per pound)			
	Months in Storage			
	0	1	3	5
Loose meal	209,300	112,500	59,700	40,000
Pelleted meal	182,100	95,200	55,200	36,300

Antioxidants

The present trend in stabilization studies is toward the use of antioxidants. Appreciable stability can be imparted to carotene concentrates by the addition of various antioxidants (10), but one of the problems connected with their use with meals is the difficulty of getting them through the proteins of the meal and into the fat phase where the carotene is located. Some penetration does occur, however. Kephart (53) has obtained a patent on the use of diphenyl-p-phenylenediamine, which is being sold under the trade name "Caromax." This patent claims that meal containing 163,000 International Units of vitamin A potency per pound immediately after dehydration contained 100,000 International Units after six months when sprayed with a solution of Caromax dissolved in a vegetable oil.

Thompson (98) tested 54 chemicals for their ability to inhibit carotene destruction. The chemicals were dissolved in Cellosolve (ethylene glycol monoethyl ether) and were sprayed on the meal so that the final concentration of the antioxidants was 0.125 percent of the meal. By this technique it was found that N,N'-di-sec-butyl-p-phenylenediamine, 6-ethoxy-2, 2,4-trimethyl-1,2-dihydroquinoline, and 2, 5-di-tert-butyl-hydroquinone were effective inhibitors of carotene oxidation. One problem involved in the use of such chemicals is their possible toxicity. *The use of Caromax has been approved by the U. S. Food and Drug Administration, indicating its lack of toxicity.*

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Toxicity studies on the chemicals tested by Thompson have not been published as yet.

Addition of Feed Ingredients

Mixing alfalfa meal with other feed ingredients often has a marked stabilizing effect on the carotene in the alfalfa. Brunius and Hellstrom (17) reported that soybean meal improved carotene retention when a mixture of 30 percent soybean meal and 70 percent alfalfa meal was compressed and stored. They found no improvement if the mixture was not compressed. The addition of oat meal had no influence under either condition of storage.

Mitchell and Silker (67) mixed alfalfa meal in a 1-1 ratio with various ingredients frequently found in mixed feeds, and stored the loose mixtures at 25° C. Contrary to the results obtained by Brunius and Hellstrom, the presence of cottonseed meal, soybean meal, and crude rice bran meal increased carotene stability appreciably in these loose mixtures (Table 8).

TABLE 8.—Carotene Stability in 1:1 Mixtures of Dehydrated Alfalfa Meal and Various Diluents (Stored at 25° C) (67).

Material Added	Percent Carotene Destroyed months in storage					
	1	2	3	4	6	8
None	18	33	52	64	76	80
Cottonseed meal	8	17	26	35	50	55
Westland milo grain	10	27	39	52	66	69
Distillers' fried solubles	14	29	41	49	63	68
Spent hops	48	59	73	79	88	90
Unspent hops	21	42	56	69	79	84
Glucose	17	29	48	63	78	82
Fresh brewer's yeast (10%)	4	19	36	50	67	74
Dried brewer's yeast	13	26	41	55	66	70
Dehydrated sorghum plants	16	28	48	58	73	76
Soybean meal	11	20	31	39	56	62
Linseed meal	20	40	60	74	85	89
None	21	55	65	71		
Converted rice bran	25	43	51	66		
Unconverted rice bran	10	30	40	52		

Pelleting did not enhance this effect. However, only expeller soybean and cottonseed meals were effective. This indicates that the stabilizer is associated with the small amount of fat left in the meal by the expeller. Some of the additives actually increased carotene destruction (hops, linseed meal), while others had little effect (glucose, dehydrated sorghum plants).

It is apparent from the above discussion that the problem of preventing carotene destruction during storage has not been solved satisfactorily. Although refrigeration and inert gas storage are helpful, they probably will not be used by the smaller companies because of the cost. The use of antioxidants appears to be most promising at the present time. None has been found yet that will preserve all of the carotene, but some of the chemicals being studied may reduce destruction sufficiently that meal can still meet a guarantee of 100,000 units per pound after six months of storage.

COMPOSITION OF ALFALFA

Major Constituents

The major constituents of dehydrated alfalfa meal are indicated in Table 9. Such an analysis is the type usually made by chemists in the feed industry. However, it does not indicate the true composition of alfalfa, since each of these fractions consists of a number of definite chemical substances. Frequently a knowledge of the individual components of these gross fractions is desirable, and much effort has been expended in isolating and identifying various substances in alfalfa.

TABLE 9.—The Major Constituents of Alfalfa Meal Dehydrated in Early Bloom Stage (84).

Component	Percent (dry basis)
Crude protein	16.4
Crude fiber	30.9
Nitrogen-free extract	42.8
Ether extract	2.2
Ash	7.7

One of the most important constituents of dehydrated alfalfa, at least from the viewpoint of the feed mixer, is protein. This is evident from the fact that alfalfa meal long has been sold on the basis of its protein content. A common grade of meal is guaranteed to contain 17 percent protein. The protein content of unblended meal depends upon the stage of maturity at which the alfalfa is dehydrated, and upon such things as weather conditions and insect injury. About 65-70 percent of the protein is digestible by cattle and sheep, and 60-65 percent by swine (84).

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

Amino Acid Content

The amino acid content of the proteins of alfalfa meal has been studied by Stokes **et al.** (94) and by Almquist (3) and Williams (106). The amounts of the essential amino acids in alfalfa meal are shown in Table 10, from which it will be seen that alfalfa meal will contribute to a ration appreciable amounts of all of the essential amino acids except methionine.

TABLE 10.—The Essential Amino Acid Content of Alfalfa Meal (94).

Amino Acid	Percent (dry basis)
Histidine	0.22
Arginine	0.56
Lysine	0.89
Leucine	1.19
Isoleucine	0.65
Valine	0.80
Methionine	0.03
Threonine	0.60
Tryptophane	0.26
Phenylalanine	0.74

Another very important constituent of dehydrated alfalfa is carotene. The amount of carotene present at the time of dehydration varies considerably with the season and the stage of maturity at which the crop is harvested. If harvested at early bloom, it normally will contain 150,000-250,000 International units of vitamin A potency per pound, with the first and last cuttings being the highest. The carotene content decreases rapidly if harvest is delayed until the crop is past early bloom. The importance of the carotene content to the feed mixer also is reflected in the fact that it is customary for the seller to guarantee a certain amount of carotene per pound.

Associated with carotene are other pigments such as chlorophyll and xanthophyll. These are not of sufficient importance as yet to require that a certain amount be present. However, the chlorophyll content is important, for the quality of meal often is judged by the color. Chlorophyll may be present in excess of 3000 ppm and xanthophylls over 400 ppm.

Lipids

The lipids of alfalfa leaf meal were studied by Jackson and Kummerow (51). They found the meal to contain 0.24 percent phospholipid, 1.13 percent crude wax, 2.19 percent triglycerides, and 0.55 percent unsaponifiable material. The triglycerides contained 16.9 percent linoleic acid, 32.2 percent linolenic acid, 31.0 percent oleic acid, and 19.9 percent saturated acids. Chibnall **et al.** (20) found the wax fraction to contain the alcohol n-triacontanol and a paraffin. Work now being done at Kansas State College indicates that the wax fraction also contains a high molecular weight ester.

A sterol, a-spinasterol, was isolated from the unsaponifiable fraction of alfalfa lipids by Fernholz and Moore (29). It constitutes about 0.05 percent of the meal (12). Petering **et al.** were able to convert the sterols of alfalfa partially to vitamin D by ultraviolet irradiation (73). They assumed that the vitamin D formed in this manner resulted from the activation of ergosterol, although ergosterol is not known to occur in alfalfa.

Vitamins

The vitamin content of alfalfa is of extremely great importance to the feed mixer. Most of the known vitamins are found in alfalfa, and based on reports of additional growth obtained when alfalfa is added to what has been considered to be a complete ration, there probably are present also one or more growth factors which have not been identified. Table 11 lists some of the vitamins which may be present in a high grade dehydrated alfalfa meal.

TABLE 11.—Vitamin Content of Dehydrated Alfalfa Meal.

Vitamin	Amount	Reference
Thiamine	8 mcm/gm	27
Riboflavin	16 mcm/gm	13, 45
Pantothenic acid	33.7 mcm/gm	13
Niacin	40.4 mcm/gm	13
Folic acid	11.3 mcm/gm	60
Tocopherols	174 mg/lb	97
Choline	475 mg/lb	97
Carotene	100,000 I.U. Vit.A/lb	97

Other Organic Constituents

The presence of a saponin which may have physiological effects on animals has been suggested by several investigators (75). Another substance having physiological activity was isolated from alfalfa by Ferguson **et al.** (28) by ether extrac-

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

tion of clarified alfalfa juice. Their material, a yellow crystalline substance, inhibited muscle activity and may have some connection with bloat of cattle. It appeared to be 3', 4', 5-trihydroxy-7-methoxyflavone.

Minerals

Alfalfa contains a considerable quantity of some of the minerals essential to nutrition. They are generally overlooked when mention is made of the nutritive value of alfalfa but they do play a part in the overall value of the product. Schrenk and Silker (86) analyzed a series of dehydrated alfalfa samples obtained from mills in Kansas, Nebraska, and Missouri. Included in the analyses were total ash, potassium, calcium, phosphorus, magnesium, sodium, iron, manganese, boron, and copper. Table 12 presents the results of the analyses. The average value is given as well as the range and the standard deviations for each element.

The alfalfa meal analyzed was ordinary mill run. The data, therefore, represent the meal as sacked and sold and do not represent the analysis of the plant tissue only, since some metallic contamination may have been picked up during the handling and processing of the alfalfa.

Two other elements have been determined on alfalfa in the midwest, but not on the series reported in Table 12. Zinc (47) in a series of samples obtained in Kansas averaged 35 ppm for 20 samples. Values ranged from a low of 25 ppm to a high value of 89 ppm.

TABLE 12.—Mineral Content of Dehydrated Alfalfa Meal* (86).

Constituent	Av. %	Range %		Std. Dev.	Std. Dev. %
Ash*	10.8	7.7 –	18.0	4.70	43.5
K	2.60	1.78 –	3.27	.384	14.7
Ca	1.59	1.11 –	3.00	.280	23.9
P	0.310	.20 –	.43	.066	21.3
Mg	0.310	.18 –	1.07	.278	89.7
Na	0.167	.118 –	.301	.0467	28.0
Fe	0.089	.025 –	.310	.0894	100.0
Mn	0.0059	.0024–	.0108	.0025	42.4
B	0.0047	.0032–	.0072	.0011	23.4
Cu	0.0037	.0012–	.0112	.0139	376

*All data reported on dry weight basis.

The cobalt content of a few samples of alfalfa was also determined. These samples came from eastern Kansas and averaged 0.2 ppm of cobalt. This figure should not be considered as an average value for alfalfa, however, since too few samples were represented.

Molybdenum also has been determined in still another series of 30 samples analyzed at the Kansas Agricultural Experiment Station. The molybdenum content averaged 2.6 ppm. The range for molybdenum was 1.3 ppm to 4.9 ppm. This is well in line with other reports on molybdenum.

There are other mineral constituents that have been identified in small quantities in alfalfa. Bear and Wallace (9) made a survey of alfalfa from 11 states and found nickel, strontium, lead, and palladium in the samples in addition to those previously reported.

Proper mineral nutrition is necessary to produce good alfalfa, since yield and composition may be affected by fertilizer treatment. Bear and Wallace (9) suggested that the following are the critical levels in the alfalfa plant: potassium 1.4 percent, phosphorus 0.27 percent, manganese 10 ppm, boron 20 ppm. They also indicate that for longest life of the stand the potassium content of alfalfa should lie between 1.5 and 2.5 percent.

The proper use of fertilizer may also cause changes in the composition of components other than the ash. Bear and Wallace reported (9) that an increase in sugars, dextrins, and fat-like materials occurred with increased potassium applications. Sheldon, Blue, and Albrecht (88) have shown that the amino acid content of alfalfa is regulated in part by manganese and boron, two of the essential trace elements.

Greenwood (36) of the Utah Agricultural Experiment Station reported that fertilization of alfalfa significantly increased the cobalt, copper, and manganese content of alfalfa in Utah. He also indicated that rabbits grew better on the hay produced from the fertilized alfalfa.

UTILIZATION OF DEHYDRATED ALFALFA

Chicken Rations

Dehydrated alfalfa has been used primarily in the preparation of mixed feeds for chickens. It usually has been used at levels of 5 to 10 percent of the ration. In addition to carotene, considerable quantities of other known vitamins also are supplied by the dehydrated alfalfa.

When attempts were made to raise the level of dehydrated alfalfa used in mixed feeds it was found that average gains in weight decreased slightly. For some time there existed doubt

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from www.ksre.ksu.edu.

as to the validity of these results. However, data now available indicate that such effects do exist.

Alderson (2), using alfalfa meal at levels of 7.4 to 49.2 percent in chick rations, found that as alfalfa was increased, feed consumption per pound of net gain increased and average gain per chick decreased. At the highest level of alfalfa a mortality rate of 60 percent occurred.

Some thought had been expressed that the fiber content of the dehydrated alfalfa was responsible for the decreased rate of growth encountered as the percentage of alfalfa in the ration increased. Cooney **et al.** (22) found, however, that chicks fed rations containing a fiber (Cellu Flour) did not substantiate this theory, but indicated that there might be a factor in alfalfa meal which inhibited growth when fed at levels above 10 percent of the total ration.

Draper (26) compared sun-cured and dehydrated alfalfa in chick rations and reported beneficial results up to about the 10 percent level. Above the 10 percent level the rate of gain decreased. He reported no observable difference between the two types of meal. Earlier Payne, Caldwell, and Hughes (71) had reported that dehydrated alfalfa meal occasionally produced a laxative condition in young chicks which was not produced by sun-cured alfalfa meal.

German and Couch (31) noted that the depressing factor was present in one meal and not in another. The depression of growth could not be overcome by the addition of copper (an element suspected of being too low) to the ration.

German and Couch (31), however, made the following statement: "It is not felt that the observation reported as a result of these studies should in any way alter the use of dehydrated alfalfa leaf meal as a source of carotene for growing chicks and poults, because the high potency leaf meals now available are not ordinarily used at levels higher than 5 percent in chick and poults' diets."

Lepkovsky **et al.** (59) also reported the presence of a growth-depressing factor in dehydrated alfalfa which could be eliminated by exhaustive extraction of the meal with hot water. The extracted meal had little growth-depressing activity, while the water extract produced marked inhibition of growth. The compound(s) responsible apparently were stable to autoclaving. Alfalfa ash was not responsible for the effect, so the growth inhibitor was probably organic in nature. Lepkovsky also reported that the B-complex did not counteract the effect.

Peterson (74) found the inhibitor to have hemolytic properties, which were destroyed by boiling with cholesterol. These properties led Peterson to postulate that the inhibitor was a saponin. He has shown recently (75) that adding a saponin to an alfalfa-free chick ration caused growth depression similar to that which results when alfalfa meal is added to the ration.

Kodras, Cooney, and Butts (55) carried out experimental work with sun-cured and dehydrated alfalfa in the rations when both were produced from the same field. They also tried various additive agents in an attempt to determine if any depressing action could be counteracted. They reported a definite depression of growth at a 20 percent level of alfalfa meal with essentially no difference between dehydrated or sun-cured meal. They also reported that fiber level apparently had no effect, since a bulky ration containing 40 percent mill run and alfalfa showed no depressing effect. A ration containing 20 percent alfalfa supplemented with 1 percent cholesterol counteracted the growth-depressing substance. Glycerol, butanol, octanol, and vitamin supplements were ineffective, thereby confirming the work of Peterson (74).

Turkey Rations

Dehydrated alfalfa is also being used in turkey rations. Musseh1 (69) has indicated that alfalfa is desirable in these rations, but suggests that coarse grinding may be preferred to the fine grinding used for chickens. He also indicates that up to 20 percent alfalfa may be desirable in finishing rations (16 to 28 weeks) and in breeding flock rations. Adler (1) has reported favorable results with 35 to 40 percent alfalfa leaf meal in turkeys over 8 weeks old. Above 50 percent some growth depression was evident.

Swine Production

Krider (57) has shown the value of alfalfa meal in swine production. He reported that alfalfa meal in the ration increased survival and proved to be the most adequate supplement fed when young pigs were kept in a drylot. Growth rates also increased by the addition of alfalfa meal to the ration. He further reported that 10 to 15 percent alfalfa meal should be the minimum amount to include in drylot rations for pregnant and lactating sows and gilts. His results indicated the presence of unknown factors in alfalfa meal which were beneficial to swine when fed in dry lots.

Lamb Production

Dehydrated alfalfa has been studied as a supplement in rations for fattening lambs. Warner **et al.** (104) reported favorable results in experiments conducted at the Scottsbluff, Nebraska experiment station. Burkitt (18) also reported favorable results in feeding experiments on lamb fattening conducted at the Montana Agricultural Experiment Station. He reported

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

that 10 percent dehydrated alfalfa pellets in grain mixtures increased the daily gain and that the feed required per 100 pounds of gain was decreased. With pellets at $70 per ton the lambs on dehydrated alfalfa returned $0.93 a head more than those getting no alfalfa.

Other Feed Uses

Other uses for alfalfa meal are known. Some dairies add alfalfa pellets to the rations. Dehydrated alfalfa is also used as a supplement in winter range feeding, and some is used in preparing certain food products for human consumption. Thus, the nutritional value of dehydrated alfalfa is being realized and its usefulness as a feed ingredient is being extended into all phases of poultry and animal production.

Industrial Utilization

Alfalfa is a source of many substances, a few of which have commercial value. Some processing of alfalfa as a source of carotene was under way several years ago (87). The advent of synthetic vitamin A with a consequent reduction in price made processing of alfalfa for carotene less favorable than previously. Prices are still high enough, however, to make the search for economical methods of carotene extraction continue, particularly if such extraction could be a part of a more complete separation of commercially valuable substances.

Xanthophyll is useful in feeds as a material to impart a yellow color to fat. Its separation and use as a naturally occurring coloring material has been carried out on a relatively small scale.

Chlorophyll has been used also in various forms, industrially, particularly as a pigment, in pharmaceuticals and as a deodorizer. A chlorophyll-containing toothpaste is now being marketed. It is possible that some of the waxes and sterols (12) reported in alfalfa may also have economic value. Still another possibility is the use of alfalfa as a raw material in the preparation of protein concentrates.

At present the amount of alfalfa used as an industrial raw material is limited. With proper research and development, however, it appears that future uses of alfalfa in this manner may become more and more favorable, since the research in this field seems to have just commenced.

ANALYTICAL PROBLEMS

Determination of Carotene

The producer and buyer of dehydrated alfalfa are usually most interested in two of the many ingredients of the dehydrated product, protein and carotene. Most alfalfa meal is being sold under guarantees for these two components. Methods for protein analysis are quite well established, and although errors can arise, the method is usually not at fault. The industry generally uses the procedure adopted by the Association of Official Agricultural Chemists.

In contrast to this situation with respect to protein, the methods for carotene analysis have been the subject of considerable study and almost continuous revision. As a result, these analyses have been subject to considerable variation between laboratories. Further research, however, will result eventually in an acceptable procedure. The following traces the development of methods of carotene analysis up to the present time.

Earliest methods of carotene analysis made use of the research of Borodin (14) who discovered that the carotene pigments could be separated into petroleum ether-soluble and alcohol-soluble fractions, with carotene being in the ether fraction. Willstatter and Stoll (107) used this idea in their method of analysis reported in 1913, and numerous modifications have followed. These early methods of analysis involved solvent extraction of the lipid fraction of the plant material with ethyl ether, saponification in alcoholic KOH, and extraction of the chlorophyllins thus formed. This was followed by extraction of a petroleum ether solution of the residue with 90 percent methyl alcohol in order to remove xanthophylls. The carotene in the ether fraction then was determined quantitatively by means of a colorimeter, although Sprague (93) used a dye standard as a comparison. Guilbert (39) modified the procedure somewhat but still used the alcohol wash as a means of removing the carotenols. He used Sprague's method of dye comparison for determining the concentration of carotene in the final solution. The Guilbert method was very widely used for several years.

Peterson, Hughes, and Freeman (76) modified the Guilbert technique by eliminating the diethyl ether extraction and substituting direct extraction of the alcoholic potassium hydroxide digestion mixture with petroleum ether. They suggested the use of Skellysolve instead of petroleum ether in the procedure. Their method was the basis of a procedure tentatively approved by the A.O.A.C., which was widely used.

One difficulty with all of these procedures was the uncertainty of complete removal of the non-carotene substances by the phasic separation with methanol. These pigments, if not removed, tend to give high readings for carotene. Also, if carotene is not removed completely from the methanol and transferred to the petroleum ether fraction, erroneous results will be obtained. These uncertainties of extraction and separation

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

suggested that another approach to the problem would be advisable.

Another method of separating closely related plant pigments involves the adsorption and elution of such pigments from a suitable adsorbing agent. This method of separation was first demonstrated by Tswett (100) in 1906, but only within about the last 12 years has it been used for analytical purposes. Since then developments in adsorption techniques have been rapid.

It is possible to effect very efficient separation of plant pigments by proper choice of adsorbents and eluting agents. In most cases chlorophyll is most strongly adsorbed and remains at the top of the adsorption column. The xanthophylls are next in order, with the carotenes being least strongly adsorbed. This technique of separation therefore requires adsorption of the plant extract, followed by elution of all the carotene but none of the other pigments. The carotene must not be destroyed as a result of the adsorption and elution procedures.

A number of adsorbents and solvents for elution of pigments have been proposed. Kernohan (54) suggested hydrated lime as an adsorbent, Kemmerer (52) used magnesium carbonate, Moore (68) made use of dicalcium phosphate, and Wall and Kelley (103) made use of magnesium oxide. Fraps and Kemmerer (30) reported the successful use of magnesium hydroxide, when properly prepared, as a good adsorbing agent. Strain (95) earlier had used magnesium oxide for a study of plant pigments but had not used it specifically for analytical purposes. It has been shown that not all adsorbents are similar in their capacity to retain the pigments or to effect good separations. Thus, not all are equally effective when used for analytical purposes. For example, hydrated lime does not permit effective separation of carotene and the xanthophylls, and errors in analysis result when this adsorbent is used.

The dicalcium phosphate was especially well adapted to the separation of carotene from non-carotene pigments and did not cause destruction of carotene. As a result it received wide usage. Properly prepared magnesium oxide was also found to be a very satisfactory adsorbent. Since magnesium oxide of quite uniform properties was commercially available, this material was suggested by Wall and Kelly (103) for use in the carotene procedure which they developed. At the present time this adsorbent is the most widely used, and is employed in the method tentatively approved by the A.O.A.C.

As a result of the apparently successful application of chromatographic methods to the separation of carotene from other plant pigments, many modifications of the original procedures developed. The A.O.A.C. began studying the use of adsorption techniques in 1941 (52), and in 1944 (6) first published a

chromatographic procedure for carotene, recommending the use of calcium hydroxide as the adsorbent. Nelson (70), however, pointed out several problems still associated with carotene determinations and suggested further study. His suggestion was followed and further collaborative study led to a recommendation of magnesium oxide as the adsorbing agent in a method published in 1947 (7).

Study continued, however, and Quackenbush (78) reported on a collaborative study involving instrument calibration, adsorbents, solvents, and check samples. This collaborative work has led to the adoption of still further modifications in the procedure (79), but the essential character of the method has not changed recently. Further modifications are still under investigation, and in 1951 Quackenbush (80) reported on a procedure suggested by Thompson and Bickoff (99), who used an overnight "soaking" technique of extraction of carotene first proposed by Silker, Schrenk, and King (90). The results indicated the soaking technique to be more effective than the A.O.A.C. procedure, with differences amounting to about 10 percent. Quackenbush (80) also suggested that the quantity of eluant used to elute the carotene be increased. Work of this type is continuing under the auspices of the A.O.A.C. in an effort to develop the method further.

At the same time that the A.O.A.C. was actively engaged in research on carotene methods other workers kept pace in their own laboratories. Silker, Schrenk, and King (90) reported on a method involving soaking the dehydrated alfalfa in a mixture of 30 percent acetone and 70 percent Skellysolve B overnight as a means of extraction. They used a magnesia column and a 4-percent acetone-Skellysolve B mixture for eluting the carotene.

Zscheile and Whitmore (108) reported on carotene in fresh and dehydrated alfalfa. They suggested blanching the fresh alfalfa and storing in a frozen condition until analyzed. Extraction was accomplished with 40 percent acetone in a Waring blendor. A magnesia column was used for adsorption, and 10 percent acetone was used for elution of carotene. For dehydrated samples they suggested extraction in a Coors procelain extraction thimble in an ASTM extraction apparatus. Extraction continued for three hours. The remainder of the method was the same as for fresh material.

Mitchell and King (64) suggested that fresh material be blanched and dehydrated, with the procedure then being the same as for dehydrated material. Silker, Schrenk, and King (89) had shown that carotene loss during drying was negligible if the sample was first blanched. Mitchell and King verified these results and further suggested that the drying temperature

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service has been archived. Current information is available from http://www.ksre.ksu.edu.

be held below 65° C. Their method followed the Silker, Schrenk, King procedure in other respects.

Thompson and Bickoff (99) also have suggested modifications in the carotene procedure recommended by the A.O.A.C. They recommended soaking the sample over night in 30 percent acetone and Skellysolve B, followed by dilution of the solution with Skellysolve B to reduce the acetone concentration. This is followed by chromatographing on a magnesia column. They claim a coefficient of replication on a series of 10 samples of 1.4 percent. This procedure also has the disadvantage of requiring overnight soaking of the sample.

Pumpelly, Mitchell, and Silker (77) also have studied the proposed A.O.A.C. procedure. They reported that not all of the carotene is extracted by the A.O.A.C. technique, and they had difficulty eluting all of the adsorbed carotene with the quantity of eluant recommended by the A.O.A.C. As a result of their study, it appears that further collaborative work would be desirable before final recommendations are made.

The points now under consideration are primarily details which must be considered individually when attempts are being made to develop an analytical procedure of high precision. Research is centered around chromatography as a means of separating carotene from the other plant pigments. The only adsorbent under active consideration at present is the activated magnesia previously mentioned. This adsorbent seems quite satisfactory, but since adsorbents are known to vary slightly from one batch to another, it probably would be advisable to check each new batch for uniformity before use.

Detection of Sun-cured Alfalfa in Dehydrated Alfalfa

A method for the detection of sun-cured alfalfa in dehydrated alfalfa has been developed recently by Brew (16). Since trade rules of the American Dehydrators' Association do not permit use of the term "dehydrated" for a mixed product, such an analytical procedure is desirable.

Essentially the method is based on the change in solubility of the protein fraction caused by the high temperature of dehydration. Brew states that if sun-cured alfalfa is present in excess of 10 percent, its presence is readily detectable. He mentions, however, that the reliability of the test is limited to dehydrated alfalfa produced by high temperature dehydration, since in a few cases where alfalfa was dehydrated on a belt type, low temperature unit the test was unsuccessful. Since most dehydrated alfalfa is produced at high temperature, however, the test should prove quite useful in most cases where adulteration is suspected.

ACKNOWLEDGMENT

Research at Kansas State College on dehydrated alfalfa as well as the preparation of this bulletin would not have been possible without the assistance of many people and the financial support of several organizations.

The encouragement and assistance of the late Dr. H. H. King, formerly head of the Department of Chemistry at Kansas State College, must be acknowledged. He, with others, took an active part in the formation of the Kansas Industrial Development Commission. The financial assistance of this group initiated the dehydration project at Kansas State College, and their continued support has been of great aid in the development of the alfalfa dehydration industry.

Other financial assistance and encouragement has come from the American Dehydrators' Association. The co-operation and encouragement of former Director R. I. Throckmorton of the Kansas Agricultural Experiment Station was invaluable. The help of individual members of the Kansas Agricultural Experiment Station and of members of the United States Department of Agriculture should also be acknowledged. The assistance of private alfalfa dehydrators has been excellent and they also have contributed greatly to the research.

LITERATURE CITED

(1) Adler, Byron. Alfalfa meal as a part of a turkey growing mash. Poultry Sci. 27:651. (Abstract of a paper). (1948).

(2) Alderson, R. F. Various levels of alfalfa meal in chick rations. Unpublished. Dept. of Poultry Husbandry, Oregon State College. (1947).

(3) Almquist, H. J. Proteins and amino acids in animal nutrition. F. E. Booth Co., Inc., San Francisco, Calif. 22 pp. (1945).

(4) American Breeders' Assoc. Alfalfa and its improvement by breeding. Report of committee for breeding forage crops. Report 5:94-115. (1909).

(5) American Dehydrators' Assoc. Trade rules, constitution, by-laws, and code of ethics. 23 pp. (1950).

(6) Assoc. Off. Agr. Chemists. Changes in official and tentative methods of analysis made at the 58th annual meeting. Jour. Assoc. Off. Agr. Chemists. 27:71-103. (1944).

(7) Assoc. Off. Agr. Chemists. Changes in official and tentative methods of analysis made at the 60th annual meeting. Jour. Assoc. Off. Agr. Chemists. 30:60-108. (1947).

(8) Bailey, G. F., Atkins, M. E., and Bickoff, E. M. Carotene retention in alfalfa meal. Effect of moisture content. Ind. Eng. Chem. 41:2033-2036. (1949).

(9) Bear, Firman E., and Wallace, Arthur. Alfalfa, its mineral requirements and chemical composition. New Jersey Agricultural Experiment Station. Bull. 748, 32 pp. (1950).

(10) Bickoff, E. M., Williams, K. T., and Sparks, M. Stabilization of carotene with nordihydroguaiaretic acid and other antioxidants. Oil and Soap. 22:128-131. (1945).

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

(11) Bielefeldt, J. Studies of carotene, with special reference to the keeping properties of alfalfa meal. Kemisk. 23:149-151. (1942). Chem. Abstracts. 38:4058. (1944).

(12) Blair, E. T., Mitchell, H. L., and Silker, Ralph E. The sterols of alfalfa and certain cereal grasses. Plant Physiology. 26: 337-342. (1951).

(13) Blaylock, L. G., Richardson, L. R., and Pearson, P. B. The riboflavin, pantothenic acid, niacin, and folic acid content of fresh, dehydrated, and field-cured alfalfa. Poultry Sci. 29:692-695. (1950).

(14) Borodin, L. Crystalline pigments associated with chlorophyll. Bull. Acad. Imp. Sci. St. Petersburg. 9:512. (1883). Abs. in Bot. Ztg. 41:577-579. (1883).

(15) Brackney, C. T. Variation of carotene content of alfalfa. Unpublished Thesis. Kansas State College, Manhattan, Kansas. 37 pp. (1949).

(16) Brew, William B. Detection of sun-cured alfalfa in dehydrated alfalfa meal. Jour. Assoc. Off. Agr. Chemists. 34:966-970. (1950).

(17) Brunius, E., and Hellstrom, V. The stability of carotene in dehydrated alfalfa meal. Svensk. Kem. Tid. 57:86-90. (1945). Chem. Abstracts. 40:2541. (1946).

(18) Burkitt, W. H. Dehydrated alfalfa in ruminant nutrition. Feedstuffs. p. 17a, Nov. 17. (1951).

(19) Camburn, O. M., Ellenberger, H. B., Jones, C. H., and Crooks, G. C. The conservation of alfalfa and timothy nutrients as silages and as hays. III. Vermont Agr. Exp. Sta. Bull. 509. 32 pp. (1944).

(20) Chibnall, A. C., Williams, E. F., Latner, A. L., and Piper, S. H. The isolation of n-triacontanol from lucerne wax. Biochem. Jour. 27:1885-1888. (1933).

(21) Chrisman, Joseph. How alfalfa is processed. Feedstuffs. p. 30a, Nov. 17. (1951).

(22) Cooney, W. T., Butts, J. S., and Bacon, L. E. Alfalfa meal in chick rations. Poultry Sci. 27:828-830. (1948).

(23) De-Lorenzi, Otto. Combustion Engineering, Combustion Engineering Superheater, Inc., New York. 1009 pp. (1947).

(24) Dexter, S. T., and Moore, L. A. Carotene (vitamin A) in alfalfa hay. Michigan Agr. Expt. Sta. Quart. Bull. 20. No. 2:75-76. (1937).

(25) Dombrowski, A. E., and Palmer, E. Z. The alfalfa dehydration industry in Nebraska. Business Res. Bull. Univ. of Neb. No. 53. 56 pp. (1949).

(26) Draper, E. I. A comparison of suncured and dehydrated alfalfa meal in the diet of the chick. Poultry Sci. 27:659. (Abstract of a paper). (1948).

(27) Escudero, P., and Landabure, P. Use of alfalfa in human diets. Rev. Assoc. Argentina Dietol. 1:143-147. (1943).

(28) Ferguson, W. S., Ashworth, de B., and Terry, R. A. Nature of a muscle-inhibiting compound in lucerne and its possible connection with bloat in cattle. Nature. 163:606. (1949).

(29) Fernholz, E., and Moore, M. L. The isolation of a-spinasterol from alfalfa. Jour. Am. Chem. Soc. 61:2467–2468. (1939).

(30) Fraps, G. S., and Kemmerer, A. R. Improved method for estimating carotene in feeds. Jour. Assoc. Off. Agr. Chemists. 22:190-195. (1939).

(31) German, H. L., and Couch, J. R. The effect of feeding varying levels of dehydrated alfalfa leaf meal on the growth of chicks and poults. Poultry Sci. 29:841-845. (1950).

(32) Gordon, E. D., and Hurst, W. M. Artificial drying of forage crops. United States Dept. of Agr., Circular No. 443. (1937). 28 p. revised by L. G. Schoenleber. (1950).

(33) Graham, Wm. R., Jr. Preserving organic materials such as forage crops or vitaminic vegetables in large quantities in storage. U. S. Patent No. 2, 353, 029. (1944).

(34) Grandfield, C. O. Alfalfa in Kansas. Bulletin, Kansas Agricultural Experiment Station. 65 pp. (1951).

(35) Greene, J. W., Conrad, R. M., Olsen, A. L., and Waggoner, C. E. Production of stable spray-dried egg powder. Chem. Engg. Progress. 44:591-602. (1948).

(36) Greenwood, D. A. Effect of fertilization on nutritive values of alfalfa. News and Abstracts from West Coast Conference Reviews on Alfalfa Research Progress. Mimeo. Bull. Western Regional Research Lab. (1951).

(37) Griffiths, F. P., Antonsen, R., Darwin, R., and Edminster, J. Chemical utilization of alfalfa. Nat. Farm Chemurgic Counc., Chemurgic Digest. 5:281-284. (1946).

(38) Griffiths, Francis P. Production and utilization of alfalfa. Econ. Bot. 3:170-183. (1949).

(39) Guilbert, H. R. Determination of carotene as a means of estimating the vitamin A value of forage. Ind. Eng. Chem., Anal. Ed. 6:452-454. (1934).

(40) Guilbert, H. R. Factors influencing the carotene content of alfalfa hay and meal. Jour. Nutrition. 10:45-62. (1935).

(41) Hackerott, H. T. Factors affecting carotene content of alfalfa. Unpublished Thesis. Kansas State College, Manhattan, Kansas. 70 pp. (1946).

(42) Halverson, A. W., and Hart, E. B. The stabilization of carotene in dehydrated legumes (alfalfa) and cereal grasses. Jour. Dairy Science. 30:245-253. (1947).

(43) Halverson, A. W., and Hart, E. B. Stabilizing carotene in foods. U. S. Patent No. 2, 491, 495. (1949).

(44) Ham, W. E., and Tysdal, H. M. Carotene content of alfalfa strains and hybrids with different degrees of resistance to leaf hopper injury. Jour. Amer. Soc. of Agron. 38:68-84. (1946).

(45) Hanke, A. R., and Perkins, A. T. Carotene and riboflavin in alfalfa. Poultry Sci. 21:195-199. (1942).

(46) Hauge, S. M. Vitamin A value of alfalfa cut at different stages of maturity. Jour. Assoc. Off. Agr. Chemists. 17:304-307. (1934).

(47) Hawley, J. E. Development and comparison of spectrographic methods for determination of zinc in plant material; survey of the zinc content of Kansas grown alfalfa. Unpublished Thesis. Kansas State College, Manhattan, Kansas. 50 pp. (1948).

(48) Hendry, G. W. Alfalfa in history. Jour. Am. Soc. Agron. 15:171-176. (1923).

(49) Hoffman, E. J., Lum, F. G., and Pitman, A. L. Retention of carotene in alfalfa stored in atmospheres of low oxygen content. Jour. Agr. Research. 71:361-373. (1945).

(50) Honstead, W. H., and Silker, Ralph E. Alfalfa dehydration. Unpublished radio manuscript. (1946).

This publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Service
has been archived. Current information is available from http://www.ksre.ksu.edu.

(51) Jackson, A. H., and Kummerow, F. A. The lipids of dehydrated alfalfa leaf meal. Jour. Am. Oil Chemists Soc. 26:26-28. (1949).

(52) Kemmerer, A. R. Report on carotene. Jour. Assoc. Off. Agr. Chemists. 24:859-865. (1941).

(53) Kephart, John C. Preservation of pigments in alfalfa. U. S. Patent No. 2, 474, 182. (1949).

(54) Kernohan, Geo. The determination of carotene. Science. 90:623. (1939).

(55) Kodras, R., Cooney, W. T., and Butts, J. S. Chick growth depressing factor in sun-cured and dehydrated alfalfa meals. Poultry Sci. 30:280-292. (1951).

(56) Koegle, John S. An investigation of the drying rates of alfalfa in a rotary kiln. Unpublished M.S. Thesis. Kansas State College, Manhattan, Kansas. 36 pp. (1949).

(57) Krider, J. L. Alfalfa—key to greater profits in swine feeding. Presented at American Dehydrators' Assoc. Convention, Univ. of Ill. 55 pp. (1947).

(58) Leonard, O. A. Mississippi Farm Res. 2:No. 11, 2. (1939).

(59) Lepkovsky, S., Shaeleff, W., Peterson, D., and Perry, R. Alfalfa inhibitor in chick rations. Poultry Sci. 29:208-213. (1950).

(60) Lillie, R. J., and Briggs, G. M. Folic acid studies. I. Biological assay of folic acid activity in common feedstuffs. Poultry Sci. 26:289-294. (1947).

(61) Meenen, F. E. Losses of carotene (pro-vitamin A) in curing alfalfa hay. Unpublished Thesis. Kansas State College, Manhattan, Kansas. 29 pp. (1945).

(62) Mitchell, H. L., and Hauge, S. M. Enzymic nature of the carotene-destroying system of alfalfa. Jour. Biol. Chem. 163:7-14. (1946).

(63) Mitchell, H. L., and King, H. H. Effect of dehydration on enzymic destruction of carotene in alfalfa. Jour. Biol. Chem. 166: 477-480. (1946).

(64) Mitchell, H. L., and King. H. H. Determination of carotene in alfalfa and cereal grasses. Anal. Chem. 20:637-638. (1948).

(65) Mitchell, H. L., Schrenk, W. G., and King, H. H. Effects of high-moisture storage on preservation of carotene in dehydrated alfalfa meal. Arch. Biochem. 16:343-348. (1948).

(66) Mitchell, H. L., Schrenk, W. G., and Silker, Ralph E. Unpublished data. Kan. Agr. Experiment Sta. (1949).

(67) Mitchell, H. L., and Silker, Ralph E. Stability of carotene in alfalfa. Effect of feed ingredients. Ind. Eng. Chem. 42:2325-2327. (1950).

(68) Moore, L. A. Determination of carotene in plant material. Ind. Eng. Chem., Anal. Ed. 12:726-729. (1940).

(69) Mussehl, F. E. Alfalfa in turkey rations. Poultry Husbandry Dept. Univ. of Neb. Leaflet No. 68. 6 pp. (1947).

(70) Nelson, E. M. Statement on carotene. Jour. Assoc. Off. Agr. Chemists. 28:544-547. (1945).

(71) Payne, L. F., Caldwell, M. J., and Hughes, J. S. Vitamin supplements for low grade alfalfa meal. Poultry Sci. 24:375-377. (1945).

(72) Pepkowitz, L. P. The photochemical destruction of carotene in the presence of chlorophyll. Jour. Biol. Chem. 149:465 71. (1943).

(73) Petering, H. G., Morgal, P. W., and Miller, E. J. Lipides isolated from alfalfa-leaf meal. Ind Eng. Chem. 33:1428-1432. (1941).

(74) Peterson, D. W. Some properties of a factor in alfalfa meal causing depression of growth in chicks. Jour. Biol. Chem. 183: 647-653. (1950).

(75) Peterson, D. W. Effect of sterols on the growth of chicks fed high alfalfa diets or a diet containing quillaja saponin. Jour. Nutrition. 42:597-607. (1950).

(76) Peterson, W. J., Hughes, J. S., and Freeman, H. F. Determination of carotene in forage. Ind. Eng. Chem., Anal. Ed. 9:71-72. (1937).

(77) Pumpelly, C. T., Mitchell, H. L., and Silker, Ralph E. Determination of carotene in alfalfa meal. Jour. Assoc. Off. Agr. Chemists. 34:821-827. (1951).

(78) Quackenbush, F. W. Report on carotene. Jour. Assoc. Off. Agr. Chemists. 32:480-484. (1949).

(79) Quackenbush, F. W. Report on carotene. Jour. Assoc. Off. Agr. Chemists. 33:647-651. (1950).

(80) Quackenbush, F. W. Report on carotene. Jour. Assoc. Off. Agr. Chemists. 34:387-390. (1951).

(81) Russell, W. C., Taylor, M. W., and Chichester, D. F. The effect of the curing process upon the carotene and vitamin A content of alfalfa. New Jersey Agr. Expt. Sta. Bull. 560. 8 pp. (1934).

(82) Schoenleber, L. G. Operation and performance of alfalfa dehydrators in central U. S., United States Dept. of Agr. Agricultural Engineering, Information Series No. 101, April, 10 p. (1950).

(83) Schoenleber, L. G. U.S.D.A. Engineering study highlights dehydration costs. Feedstuffs. p. 26, Nov. 17. (1951).

(84) Schneider, B. H. Feeds of the world. West Virginia Agr. Expt. Station. 299 pp. (1947).

(85) Schrenk, W. G., and King, H. H. Vapor pressure of water adsorbed on dehydrated alfalfa. Ind. Eng. Chem. 39:1165-1167. (1947).

(86) Schrenk, W. G., and Silker, Ralph E. Mineral composition of dehydrated alfalfa. Transactions of the Kansas Academy of Science. 53:422-426. (1950).

(87) Shearon, W. H., Jr., and Gee, O. F. Carotene and chlorophyll. Ind. Eng. Chem. 41:218-226. (1949).

(88) Sheldon, V. L., Blue, W. G., and Albrecht, W. A. Diversity of amino acids in legumes according to soil fertility. Science. 108:426-428. (1948).

(89) Silker, Ralph E., Schrenk, W. G., and King, H. H. Carotene content of alfalfa. Retention on dehydration and storage. Ind. Eng. Chem. 36:831-835. (1944).

(90) Silker, Ralph E., Schrenk, W. G., and King, H. H. Determination of carotene in dehydrated alfalfa. Ind. Eng. Chem., Anal. Ed. 16:513-515. (1944).

(91) Silker, Ralph E., Schrenk, W. G., and King, H. H. Storage of commercial dehydrated alfalfa meal. Ind. Eng. Chem. 39: 1160-1162. (1947).

(92) Silker, Ralph E., and King, H. H. Handling fresh alfalfa before dehydration. Ind. Eng. Chem. 39:1163-1165. (1947).

(93) Sprague, H. G. Convenient method of measuring quantities of chloroplast pigments. Science. 67:167-169. (1928).

publication from the Kansas State University Agricultural Experiment Station and Cooperative Extension Ser
been archived. Current information is available from http://www.ksre.ksu.edu.

(94) Stokes, J. L., Gunness, M., Dwyer, I. M., and Caswell, M. C. Microbiological methods for the determination of amino acids. II. A uniform assay for the ten essential amino acids. Jour. Biol. Chem. 160:35-49. (1945).

(95) Strain, H. H. Carotene. VIII. Separation of carotene by adsorption. Jour. Biol. Chem. 105:523-535. (1934).

(96) Taylor, M. W., and Russell, W. C. The stability of carotene in plant tissue. Jour. Nutrition. 16:1-13. (1938).

(97) Titus, H. W. Dehydrated alfalfa meal, a protective feed for poultry. Dehyd. Alfalfa Meal. 1:No. 2. (1946).

(98) Thompson, C. Ray. Stability of carotene in alfalfa meal. Effect of antioxidants. Ind. Eng. Chem. 42:922-925. (1950).

(99) Thompson, C. R., and Bickoff, E. M. A proposed modification of the AOAC method for carotene in alfalfa. Jour. Assoc. Off. Agr. Chemists. 34:219-224. (1951).

(100) Tswett, M. Adsorption analysis and chromatographic methods. Ber. Deut. Botan. Ges. 24:384-393. (1906).

(101) Tysdal, H. M. Report of the uniform alfalfa nurseries. (1942).

(102) U. S. Dept. of Agri., Agri. Statistics.

(103) Wall, M. E., and Kelley, E. G. Determination of pure carotene in plant tissue. Ind. Eng. Chem., Anal. Ed. 15:18-20. (1943).

(104) Warner, D. R., Harris, E., Pumphrey, V., and Alexander, M. A. Dehydrated alfalfa in lamb fattening rations. Feedstuffs. p. 12a. Nov. 17. (1951).

(105) Wilder, O. H. M., and Bethke, R. M. The loss of carotene in machine-dried alfalfa meal under variable conditions of storage. Poultry Sci. 20:304-312. (1941).

(106) Williams, H. H. Studies of the amino acid composition of feedstuffs. Feedstuffs. 23:No. 6, p. 17. (1951).

(107) Willstatter, R., and Stoll, A. Investigation on chlorophyll. English translation by Frank Milton Schertz and Albert R. Merz. The Science Press Printing Co. 385 pp. (1928).

(108) Zscheile, F. P., and Whitmore, R. A. Determination of carotene in alfalfa. Anal. Chem. 19:170-172. (1947).