A STUDY OF THE SUGAR CONTENT OF THE BLOOD OF DAIRY CATTLE

by

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INTRODUCTION

The blood sugar of animals has been studied extensively in recent years because of its relation to metabolism and disease. In dairy cattle these studies have been largely confined to investigations of the causative factors of milk fever. Investigations of factors other than disease which influence the blood sugar content of dairy animals are very limited.

The sugar of the blood is generally accepted as existing in the form of glucose, a simple monosaccharide. Carbohydrates are used principally for energy by the animal organism. They also serve other purposes such as building body compounds, body fat, milk fat and lactose. They may also be combined with ammonia to form some amino acids when the body is in need of these compounds. In addition glucose is stored in the liver as glycogen. This glycogen in turn may be readily broken down into glucose again and is available as a source of energy for the animal organism.

The activity of converting glycogen into glucose is influenced by the secretion of the adrenal glands. An increased secretion of adrenaline causes glycogen to be changed into glucose resulting in an increase in the concentration of blood sugar. Insulin, the hormone secreted by the pancreas, produces an increased oxidation of glucose in the

tissues which tends to cause a reduction in the blood sugar concentration.

Blood sugar concentration in the animal organism is controlled by a very delicate mechanism and many factors are involved in its behavior. Many intermediary products of carbohydrate metabolism appear in the blood stream which are either excreted or synthesized into compounds readily available to the body.

This investigation has dealt primarily with some of the factors influencing the normal blood sugar content of dairy animals. Through this study it was hoped that a more satisfactory understanding could be had of the blood sugar content of dairy animals under normal conditions of herd management. It is desirable to have figures for the normal concentration of the sugar of the blood so that comparisons with abnormal conditions can be made, as well as comparisons with other species of animals and as a basis for comparison with other workers.

Since the lactose in milk is derived from the sugar of the blood, it is important to know the blood sugar level of lactating as compared with non-lactating animals. It was felt that a more complete knowledge of the blood sugar concontent of dairy animals would aid in solving some of the complicated processes of carbohydrate metabolism and milk secretion.

REVIEW OF LITERATURE

Studies on the Blood Sugar Content of Dairy Cattle.

Moussu and Moussu 1927 (27) reported the average blood sugar content of the bovine as ranging from .06 per cent to .08 per cent. Their conclusions were based on determinations made on 10 cows of different breeds. After treatment of cows in milk fever they found that the blood sugar content was increased and attributed this increase to excitement of the animals. Fish 1927 (8) concluded that the average blood sugar content for dairy cattle is 52 mgm. per 100 cc. of blood. Scheicher 1928 (29) gave a concentration of .0744 per cent as the average. Schwartz as reported by Scheicher 1928 (29) stated that the normal blood sugar content of dairy cattle remained constant at .082 per cent.

Widmark and co-workers as reported by Fish 1928 (9) found a normal blood sugar content for milking animals of 60 mgm. per 100 cc. of blood and the average for dry cows and heifers as 80 mgm. Fish 1928 (9) on the other hand stated that the average blood sugar content of dry and lactating animals showed no differences.

Hayden 1929 (19) reported figures to show an average blood sugar content of 41.15 mgm. per 100 cc. of blood. These figures were obtained from 253 samples on 23 cows over

a period of 11 months.

Finally as a summary of the work done to date, Fish 1929 (10) concluded that the blood sugar content of dairy cattle ranges from 40 to 60 mgm. per 100 cc. of blood.

The results of the various workers cited show marked variation. These differences may be due to two causes. First, in practically all of the work reviewed small numbers of animals have been studied. In several instances the numbers were too few to substantiate definite conclusions. Secondly, various workers have used different methods in determining the blood sugar. In this connection it is well to note that Herbert and Groen 1929 (21) have shown that various methods give widely different results for the distribution of sugar between corpuscles and plasma. They found that the MacLean, Hagedorn and Jensen (original) methods agreed on a higher sugar value for blood plasma than for corpuscles and gave lower readings than the Folin-Wu or Shaffer-Hartmann methods. Folin 1928 (13) gave conclusive evidence that his new blood sugar method consistently gave a lower reading than the Folin-Wu method. Benedict 1928 (2) also has shown that his improved blood sugar method gives lower results than the Folin-Wu method. It is therefore evident that different methods have considerable influence on the results obtained. It is generally held that the methods giving the lower results come

closer to giving the true sugar value of the blood.

Nature of Blood Sugars.

According to Mathews 1925 (25), sugar as it is absorbed into the blood goes into solution as a simple dialyzable form of monosaccharide. This sugar distributes itself in the corpuscles and plasma in varying amounts. Stammer 1926 (32) stated that there is a greater portion of the blood sugar in the plasma. He stated further that the arterial blood has a slightly greater concentration of sugar than does the venous or capillary blood. The venous blood sugar concentration appears to be the same as that of the capillary blood. That the sugar concentration is increased by injection of starch and sugar is clearly brought out by Mathews 1925 (24).

Relation of the Liver to Blood Sugar

During the height of carbohydrate absorption in the body, the blood of the portal vein has a higher concentration of sugar than the hepatic vein indicating a disappearance of glucose in the liver. This process of building glucose into glycogen in the liver is called glycogenolysis. The liver acts as a storehouse of carbohydrate material in the body. Approximately half of the total glycogen content

of the body is contained in the liver. The glycogen content of the liver and muscles, according to Mathews 1925 (25), is affected by the sugar content of the diet. A large intake of carbohydrate increases the liver glycogen content. Cori and Cori 1929 (7) clearly pointed out that the blood sugar level has much to do in determining the rate of glycogen formation in the liver.

Glycogenesis or the conversion of glycogen into glucose takes place when the body is in need of more sugar than is present in the blood stream. Bodansky 1927 (4) is of the opinion that this process is under the control of the sympathetic nervous system and the secretion of the adrenal glands. As the body becomes in need of a large amount of available energy, the liver is stimulated to convert stored glycogen into glucose which can be used readily.

The glycogenic function of the liver plays an important role in maintaining a proper blood sugar level. The liver may either act as a source of sugar when the blood sugar level is low or as a storehouse for excess blood sugar.

Relation of the Muscles to Blood Sugar

Approximately half of the glycogen in the animal body is in the muscles. The muscle glycogen is controlled in much the same way as the liver glycogen. It can be con-

verted into glucose rapidly or it may be increased in amount when there is an excess of glucose in the blood.

A considerable portion of the muscle glycogen is utilized in muscular activity. It is converted into glucose and oxidized, liberating energy and the end products of muscular action. Blatherwick, Bell and Hill 1924 (3) have offered evidence to show that when glycogen is broken down into glucose by the muscles, it is combined in some way with the blood phosphate to form an intermediate product. They give the following steps as the probable transformation: glycogen ⟷ hexose-diphosphate ⟷ lactic acid. The lactic acid is in turn partially converted into glucose and partly into carbon dioxide and water. That the presence of insulin accelerates the transformation and oxidation of glucose is their belief. Cori and Cori 1928 (6) have stated that insulin accelerates the transformation into muscle glycogen thus reducing the glucose content of the blood.

From these findings, it is clear that the muscles act much in the same way as the liver in respect to its glycogen. In addition they have a greatly increased power to transform glucose into energy and the by-products of muscular activity. Especially is this true when insulin is present.

Relation of Blood Sugar to Lactose Formation

That milk sugar is synthasized from the sugar of the blood is the general belief. Heineman 1921 (20) stated that milk sugar is derived from the glucose in blood and is transferred by the specific action of the mammary gland. Fish 1927 (8) stated that lactose is one of the most constant constituents in milk and that it is derived from the blood sugar. He suggested that the mammary gland converts part of the blood glucose into galactose which in turn combines with glucose to form the disaccharide lactose. Turner 1929 (33) in his studies on milk secretion stated that in lactating cows the difference in the concentration of blood sugar going to the udder and that leaving was 18 per cent. In dry animals no such differences were observed. Cockefair 1928 (5) found that there was sufficient difference in the sugar concentration of the blood of the mammary and juglar veins to account for the lactose found in milk. Harding and Downs 1929 (16) found that there was no difference in the blood sugar concentration of lactating and non-lactating women. The work of Gaines (14) clearly shows that the lactose of milk is very constant.

As to what effect a high or low blood sugar level has on the lactose of milk is not definitely known. The work of Scheicher 1928 (29) would indicate that the ratio be-

tween milk sugar and blood sugar remains constant during lactation. The ratio ranges from .011-.016 with a mean of .013. As production falls below 1 to 2 liters per day, the milk sugar decreases and the quotient rises to .028.

Banu and Heresco as reported by Scheicher 1928 (29) concluded from their studies that no change in the sugar content of milk was produced by feeding or by introducing hypoglycemia through the use of insulin.

Schwartz and Mezler-Andelberg as reported by Scheicher 1928 (29) obtained results that indicated a gradual rise in the blood sugar level as the stage of lactation advanced. They also found that there is a temporary lowering of blood sugar at freshening time.

The results obtained by these various investigators show some difference of opinion as to the relationship of blood sugar to milk sugar. At present too little is known about this relationship to make definite conclusions and further studies are to be encouraged.

The Utilization of Blood Sugar for Energy and Body Fat Formation

A considerable portion of the sugar in the blood is oxidized to produce energy and heat in the animal organism. This oxidation takes place in the body tissues. The energy derived goes to supply fuel for the vital processes which

are continually in action. The heat which is produced upon this oxidation goes to maintain the body temperature.

When the blood sugar concentration is low and there is an insufficient supply of carbohydrate in the body, some amino acids may be deamonized and a portion used for energy. It is a well known fact that in periods when there is an excess of carbohydrate material in the blood, a considerable portion of it is built into body fat and stored as reserve food material. It is not an established fact that fat can be broken down into carbohydrate material and used as such.

Relation of the Kidney to Blood Sugar

The kidney is one of the principle excretory organs of the animal body. Its principle functions are to excrete waste products from the body to maintain proper concentration of blood and to maintain proper salt and water balances. Under normal conditions small amounts of reducing materials are present in the urine. Folin 1922 (11) stated that these reducing materials are a variety of carbohydrate products and derivatives of katabolism.

In abnormal conditions such as diabetes excessive amounts of reducing sugars appear in the urine. When there is an excessive amount of sugar in the blood stream, more than the liver and muscles and other tissues can take up,

the kidney in its efforts to maintain a proper concentration excretes sugar in the urine. Thus we see the kidney acting as a threshold in maintianing the proper blood sugar level. When the concentration of the blood reaches this level sugar is excreted.

Relation of Feed to Blood Sugar

Langfeldt 1921 (22) stated that the blood sugar remains fairly constant on normal ingestion of feed. On addition of glucose to the normal diet he stated that a rapid increase in the blood sugar concentration resulted which soon returned to normal. Sharp (30) reported that on fasting, humans, cats, swine and guinea pigs exhibit a decreased blood sugar content. Feeding at the end of a period of fasting causes an increase in the concentration of blood sugar. He further stated that fasting of rabbits caused a continuous increase in the blood sugar content.

Armsby 1922 (1) related that the carbohydrate supply from the digestive tract is very irregular and that this irregularity is regulated by the absorption of glucose by the liver. Thus it is evident that the effects of increased ingestion of carbohydrate material is partly taken care of by the liver. Folin, Trimble and Newman 1927 (12) have shown conclusively that glycogen formation in the liver in response to intravenous injections of glucose is slow and

that large amounts of the sugar is taken up by the skin. They stated that as the blood sugar goes down after injection the sugar in the skin filters back into the blood.

It is quite evident that as fairly large amounts of sugar are introduced into the blood, either through the digestive tract or by intravenous injection, a rise of the blood sugar content results. This increased concentration soon recedes to normal, due to the activity of the liver, muscles, kidney and skin.

Just how the introduction of large amounts of sugar into the blood affects milk sugar formation is an entirely different question. Scheicher 1928 (29) observed that neither the sugar of the blood nor lactose of milk increased on feeding three-fourths kilogram of molasses daily. Roadhouse and Henderson 1930 (28) concluded from results of feeding molasses to dairy cows that an addition of five to six pounds of molasses daily to the basal ration produced no increase in the lactose of milk. Meigs 1922 (26) stated that inadequate rations fed to lactating cows produced no change in the lactose content of their milk. He stated further that addition of carbohydrates to the normal ration caused no change in the composition or yield of milk. He concluded that lactose of milk is a very constant constituent and is not affected by any of the dietary changes thus far studied.

The foregoing paragraphs are an attempt to review briefly the question of carbohydrate metabolism in the animal body. A brief discussion of some of the factors affecting the blood sugar content is given to show the need of further study in this field. The studies of blood sugar of dairy cattle are rather limited and much is to be gained through further work. The relation of the feed to blood sugar and milk sugar as well as the relationship of blood sugar to milk sugar are quite unsettled questions.

With some of the above problems in mind this thesis was outlined. Its purpose was to establish a standard for comparison and to study the effect of various factors on the concentration of sugar in the blood of dairy animals.

EXPERIMENTAL PROCEDURE

The experimental results comprise a study of certain physiological factors affecting the blood sugar content of dairy animals. Such factors as age, breed and lactation were considered. In addition data are given to show the variation in the blood sugar concentration of animals during the day. Studies were made on the influence of fasting and ingestion of sugar on the blood sugar concentration of the animal organism.

The blood used in the analysis was drawn from the ear veins by means of a capillary pipette and transferred to a

10 per cent sodium tungstate solution which served to precipitate the protein material. The size of the sample was 0.1 cc. The blood was mixed with the tungstate solution and centrifuged. Four cubic centimeters of the water-clear solution was used in making the determinations. In all cases the analyses were completed within three hours after the samples of blood were taken.

Method of Analysis

Folin's new micro method of analysis involving the use of 0.1 cc. of blood was used. The principle of the method is based on the reducing properties of the blood sugar. It reduces potassium ferricyanide to ferrocyanide. On addition of an iron solution a permanent Prussian blue color is developed which is read colorimetrically.

Animals Used

One hundred and forty different animals were used in these studies. They were all in the college herd and maintained under normal conditions of herd management. The age of the animals ranged from calves to mature cows and consisted of representatives of the Ayrshire, Guernsey, Jersey and Holstein breeds. Many of the mature animals were in milk. In all trials the animals were fed the normal herd ration excepting those studied in the fasting and sugar in-

gestion trials.

Influence of Age on the Blood Sugar Content

Data collected comprise 20 observations made on animals in each of 11 different age intervals at intermittant periods from October 1929 to March 1930. The age intervals were so selected as to incorporate a relatively large number of observations of animals at the different ages. The animals of the four major dairy breeds were included. The mean blood sugar content of each interval as well as the probable error, standard deviation and coefficient of variability were calculated. The complete data are assembled in Table I. All figures are expressed in mgm. of sugar per 100 cc. whole blood.

It is apparent that there is a close inverse relationship between the blood sugar content and the age of dairy animals during the early stages of life. At birth the concentration of blood sugar is high, at an average of 100.4 $\pm$ 1.666 mgm. sugar per 100 cc. whole blood. As the animal grows older its blood sugar content decreases until it averages about 54 mgm. at producing age or approximately two years old. After the individual comes into production little change occurs in its blood sugar concentration through advancement in age.

Figure I shows graphically the relation of the blood

sugar content to age. The decrease appears to be quite rapid and uniform during the first two years of life.

Table I

Influence of Age on the Blood Sugar Content of Dairy Cattle

Age Interval	No. of determinations	Mean mgm per 100 cc*	Std. dev. mgm. per 100 cc.	Coeff. var. Per cent
1- 6 da incl	20	100.40 ± 1.666	11.16	11.11
1- 4 wk. "	20	88.20 ± 1.215	8.12	9.09
1- 3 mo. "	20	80.20 ± 1.203	8.04	9.90
4- 7 mo. "	20	75.40 ± 0.794	5.26	6.98
8-11 mo. "	20	69.60 ± 1.122	7.44	10.69
12-15 mo. "	20	67.80 ± 0.820	5.44	8.02
16-19 mo. "	20	62.20 ± 1.000	6.63	10.66
20-23 mo. "	20	55.00 ± 0.685	4.54	8.25
24-47 mo. "	20	54.60 ± 0.770	5.10	9.16
48-71 mo. "	20	53.60 ± 0.784	5.20	9.70
72-96 mo. "	20	53.40 ± 0.668	4.43	8.30

*Folin's new blood sugar method was used in making all determinations in this study.

More variation from the mean sugar content is evident in calves at birth than in older heifers and cows. This greater variation is probably due to the fact that some calves struggled more violently than others before the sample of blood could be taken which probably resulted in an increase in the concentration of blood sugar.

Animals between the ages of two and eight years of age show little difference in their blood sugar content. Two hundred and five observations made on animals within this age range gave a mean blood sugar concentration of 53.97 ± 0.914 mgm. per 100 cc. whole blood. The standard deviation

from the mean was calculated to be 5.88. The highest blood sugar value for an animal that was considered as normal was 68 mgm. sugar per 100 cc. whole blood, while the lowest normal reading was 36 mgm. This would indicate that there may be considerable difference in the blood sugar content of individual animals.

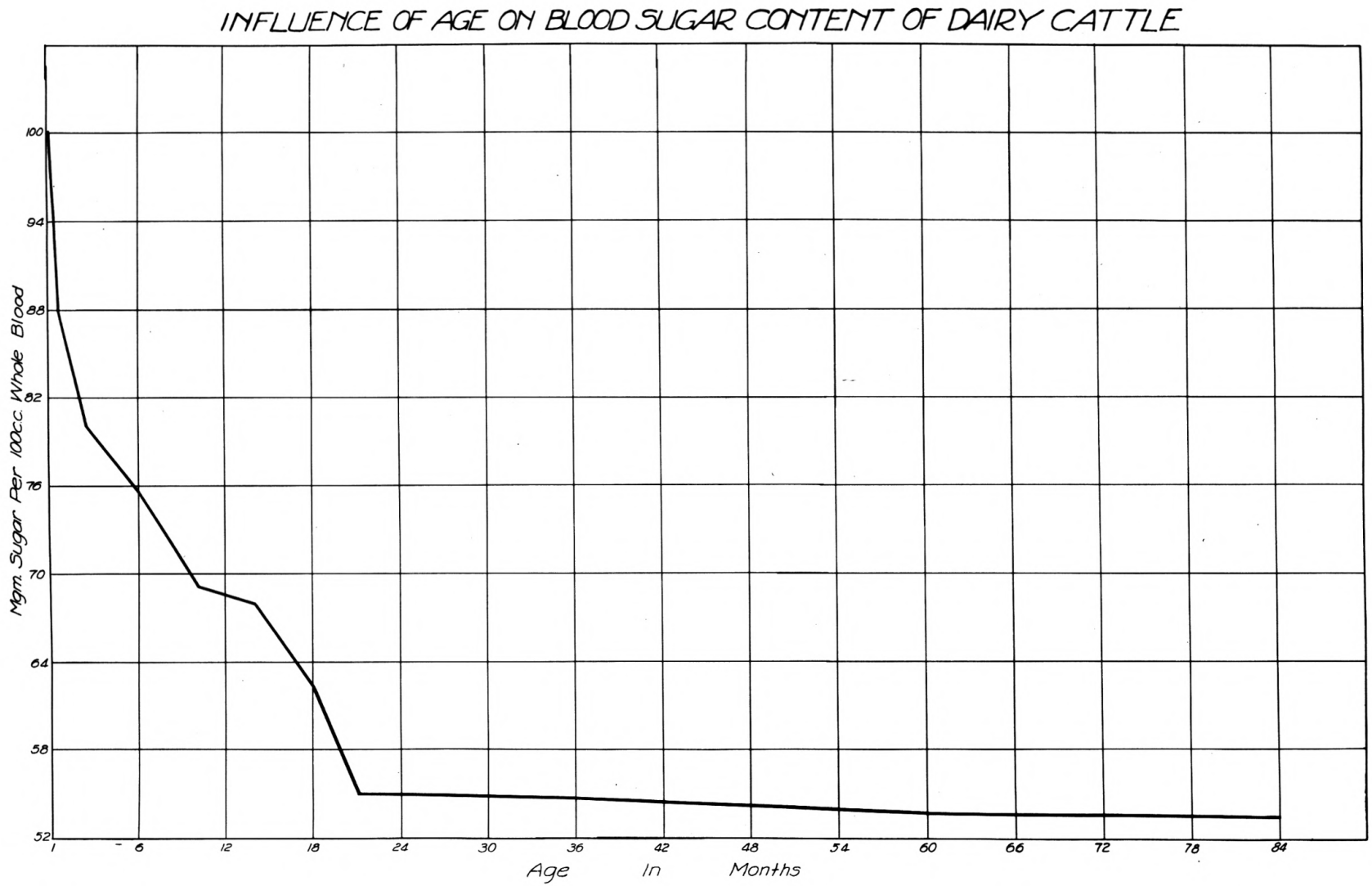
INFLUENCE OF AGE ON BLOOD SUGAR CONTENT OF DAIRY CATTLE
Mgm. Sugar Per 100cc Whole Blood
100
94
88
82
76
70
64
58
52
1
6
12
18
24
30
36
42
48
54
60
66
72
78
84
Age In Months

Figure I

Influence of Breed on the Blood Sugar Content

The mature cows of the herd were used to study the influence of breed on the blood sugar content. Only mature animals were used in order that the age factor would be excluded. The animals studied were in different stages of lactation.

As shown in Table II no significant difference is apparent in the blood sugar content of the breeds of dairy cattle studied. Ayrshires appear to show considerably more deviation from the mean that any of the other breeds considered in this study. This cannot be explained unless it is due to their increased activity at the time of sampling. In general they offered more resistance to the act of bleeding than cows of the other breeds. The Jerseys, as a breed, show much less variation and have a slightly lower mean blood sugar content. However, the differences in the mean blood sugar content of the various breeds are quite insignificant.

Table II

Blood Sugar Content of Mature Cows from Four Dairy Breeds

Breed	No. of determinations	Mean mgm per 100 cc*	Std. Dev. mgm. per 100 cc.	Coeff. Var. per cent
Ayrshire	41	53.12 ± 0.854	8.12	15.28
Guernsey	42	53.64 ± 0.711	6.83	12.73
Holstein	69	52.84 ± 0.442	5.44	12.95
Jersey	24	52.50 ± 0.459	3.33	6.36

Influence of Lactation on the Blood Sugar Content

Twenty observations were made on cows in each of 8 different lactation intervals to note the influence of lactation on their blood sugar content. The limits of the lactation intervals were 1-6 days, 1-4 weeks, 1-2, 3-4, 5-6, 7-8, 9-10 and 11-12 months inclusively. The last interval included dry animals only. Mature animals of the four dairy breeds were included in this trial.

The results of this study are shown in Table III. There was an increase amounting to 3.6 mgm. blood sugar per 100 cc. of whole blood from the time cows began milking until their period of lactation ended. This was an increase amounting to 7.0 per cent and was considered as slightly significant. The concentration of blood sugar appeared to be greatest during the seventh and eighth month of lactation. Figure II shows graphically the relation of stages of lactation to the concentration of blood sugar.

Table III

Influence of Lactation on Blood Sugar Content of Dairy Cattle

Lactation Interval	No. of determinations	Mean mgm per 100 cc	Std. Dev. mgm. per 100 cc.	Coeff. Var. Per cent
1- 6 da incl	20	51.20 ± 1.237	6.21	12.12
1- 4 wk. "	20	51.00 ± 0.845	5.60	10.98
1- 2 mo. "	20	52.00 ± 0.965	6.40	12.31

Table III - Continued

Lactation Interval	No. of determinations	Mean mgm per 100 cc	Std. Dev. mgm. per 100 cc.	Coeff. Var. Per cent
3- 4 mo.incl	20	52.20 ± 0.521	3.45	6.61
5- 6 mo. "	20	52.00 ± 0.588	3.90	7.50
7-8 mo. "	20	54.80 ± 0.728	4.83	8.81
9-10 mo. "	20	53.20 ± 0.881	5.15	9.68
Over 11 Mo(dry)	20	53.40 ± 0.436	2.89	5.41

Greater variation from the mean blood sugar concentration is noticable in the first three months of lactation than in later months. When dairy animals began lactating they exhibited considerable variation in their concnetration of blood sugar. As lactation advanced less variation was observed.

There is no apparent difference in the blood sugar content of dry and milking animals. The variation in the concentration of blood sugar of dry animals seems to be less as shown by a smaller percentage of deviation from the mean. The coefficient of variation for dry animals was calculated as 5.41 while that for cows milking 9-10 months was 9.68. It is evident form these results that while milking cows tend to show more variation in their blood sugar concentration they remain on about the same level as non-lactating animals.

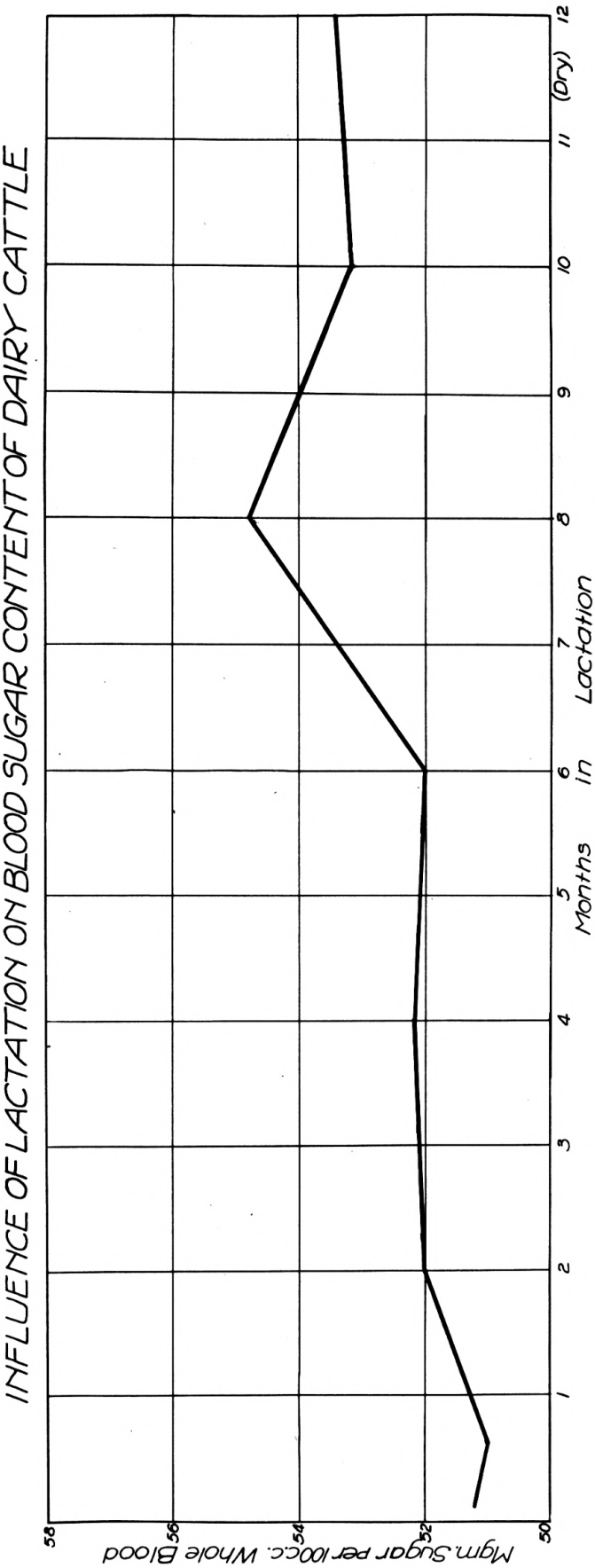
INFLUENCE OF LACTATION ON BLOOD SUGAR CONTENT OF DAIRY CATTLE
Mgm. Sugar per 100 c.c. Whole Blood
58
56
54
52
50
1
2
3
4
5
6
7
8
9
10
11
12 (Dry)
Months in Lactation

Figure II

Variation in Blood Sugar Content of Dairy Animals During the Day

Five groups consisting of a total of 22 animals were observed in studying the variation of the blood sugar content of dairy animals during the day. The groups were selected according to their stage of lactation. The animals were maintained under normal herd conditions.

Samples of blood were drawn for analysis at 7 and 10a.m. and at 1, 3 and 5 p.m. Grain and silage were fed at 6:30a.m. and at 4 p.m. Hay was given at 7 a.m. and 4:30 p.m. The animals were milked at 5 a.m. and 4:45 p.m.

Table IV gives a history of the animals involved in this study. Group I was observed on December 28, 1929. Although the weather was mild and warm the cows remained in the barn throughout the day. This group consisted of five mature animals all of which had been milking for about three months. None of these animals were with calf. Their average daily milk production was 30.3 pounds.

Group II was observed on December 30, 1929. The day was mild and warm and the cows were turned in the paddock from 9:30 to 12 a.m. The average lactation and gestation period of this group of four animals were six and two months respectively. Their average daily milk production amounted to 19.1 pounds.

Group III was observed on January 3, 1930. These cows were allowed to exercise in the paddock from 9:30 to 12 a.m. The group consisted of four cows which had been milking for an average of 9.5 months. Their average period of gestation was 4.5 months while the average milk production was 10.8 pounds.

Group IV was observed on January 4, 1930. The cows were kept inside because of the cold and disagreeable weather. The four dry animals in this group were in approximately the seventh month of their gestation.

Group V was observed on January 8, 1930 and consisted of five heifers of which only two were bred. They remained in the barn throughout the day.

Table IV

History of Animals Used in Study of Variation in Blood Sugar Content at Intervals During the Day

Group	No. of Animals	Breed	Average Age	Average Stage Lactation	Average Stage Gestation	Average Production
I	5	A-1 J-2 G-1 H-1	6yr.8mo	3.16 mo.	Open	30.3#
II	4	A-0 J-1 G-1 H-2	4yr.1mo	6.00 mo.	2 mo.	19.1#
III	4	A-1 J-1 G-1 H-1	5yr.5mo	9.56 mo.	4.5 mo.	10.8#
IV	4	A-1 J-0 G-0 H-3	5yr.6mo	dry	7 mo.	
V	5	A-1 J-1 G-1 H-2	1yr.4mo		2.5 mo.*	

* Three heifers not bred

Table V gives the average blood sugar content of the various groups studied. It will be noted that there is a relatively small variation in the blood sugar content throughout the day. The variation which is apparent in the different groups is not uniform. On averaging the readings of all the animals studied a variation of not more than 2.8 mgm. sugar per 100 cc. whole blood was observed. This variation is not considered as significant. Individual animals displayed considerable variation in their blood sugar concentration but these variations were not uniform.

The results obtained would indicate that the rate of absorption of carbohydrate material from the digestive tract remains fairly constant and continuous throughout the day. The act of milking does not appear to have an effect on the concentration of blood sugar.

Table V

Variation in Blood Sugar Content at Intervals During the Day

No. Cows	Ave. Stage lactation	Milligram sugar per 100 cc. whole blood 7 a.m.	10 a.m.	1 p.m.	3 p.m.	5 p.m.
5	3.16 mo.	55.1	51.7	52.7	56.8	54.7
4	6.00 mo.	46.7	42.0	43.0	42.6	44.0
4	9.56 mo.	49.0	46.0	47.9	47.8	48.2
4	dry	47.6	49.0	48.5	51.4	50.8
5	heifer	57.0	54.6	55.8	55.8	49.8
Average		51.1	48.7	49.6	51.5	49.5

Influence of Fasting on the Blood Sugar Content

Five dairy heifers were used in studying the influence of fasting on their blood sugar content and live weight. These heifers ranged from one and a half to two years of age and consisted of two Holsteins, one Ayrshire, one Guernsey and one Jersey. All five of the heifers were bred. They were kept in a paddock with shed adjoining throughout the trial and fresh water was available at all times. The actual fasting trial lasted for a period of nine days.

Samples of blood were taken for analysis at 8 o'clock each day and the live weights were recorded immediately after At the end of the fasting period feed was given in small amounts. The amount was increased regularly until the animals were receiving a full ration.

Table VI gives the blood sugar content and live weight of the heifers for each day of the trial. Figure III shows the results of the averages graphically. It will be observed that as the fasting period advanced the blood sugar decreased in its concentration. This decrease was continuous and uniform until the morning of the sixth day. On the evening before the heifers broke through the fence and consumed some roughage which will undoubtedly explain the rise in the blood sugar content on that date. On continued fasting the concentration of blood sugar decreased to more than

50 per cent of the initial content. The lowest average blood sugar value was 28.5 mgm. per 100 cc. whole blood observed on the seventh day as contrasted with the average initial content of 61.2 mgm. sugar per 100 cc. whole blood.

It will be observed also that the average live weight of the heifers in question decreased 120 pounds below their initial weight. After seven days of fasting the animals appeared gaunt and inactive. Their feces were watery and contained mucous material, though it is unlikely that all of the food material had been removed from the digestive organs in the short period involved.

After addition of feed on the morning of the ninth day, the blood sugar concentration increased to approximately the initial content. This increase did not take place immediately but rather over a period of four days. It was noted that the animals did not eat their feed with much relish. Three days were required for them to consume a full ration. As would be expected, the live weight of the heifers increased on addition of feed.

The results of this trial indicate that dairy cattle like other herbivora are partially dependent upon the absorption of carbohydrates from the digestive tract for the maintenance of the blood sugar concentration.

Table VI

Influence of Fasting on Blood Sugar Content and Live Weight of Dairy Heifers

Date	Treatment	I Holstein Blood Sugar mg per 100cc	I Holstein Live Weight pounds	II Holstein Blood Sugar mg per 100cc	II Holstein Live Weight pounds	III Ayrshire Blood Sugar mg per 100cc	III Ayrshire Live Weight pounds	IV Guernsey Blood Sugar mg per 100cc	IV Guernsey Live Weight pounds	V Jersey Blood Sugar mg per 100cc	V Jersey Live Weight pounds	Average Blood Sugar mg per 100cc	Average Live Weight pounds
	Normal												
3-29-30	Feeding	62.5		65.8		66.7		71.4		62.5		65.8	
3-30-30		62.5		64.5		65.8		62.5		62.9		63.8	
3-31-30	Last Feed												
	7:30 a.m	61.0	1107	57.2	1056	62.5	760	64.5	716	61.0	750	61.2	878.
4- 1-30		46.1	1026	60.8	998	55.6	722	57.1	665	52.6	716	54.4	825.4
4- 2-30		54.9	1016	65.4	980	55.6	700	48.1	654	42.2	703	53.2	810.6
4- 3-30		50.0	1005	44.4	960	44.8	700	46.7	648	37.7	692	44.7	801.0
4- 4-30		39.7	984	42.5	956	47.6	678	42.0	644	40.5	689	42.5	790.2
*4-5-30		33.0	975	36.5	939	36.1	666	34.5	638	44.0	687	36.8	781.0
4- 6-30		41.7	970	45.5	952	47.6	590	44.4	656	41.2	695	44.1	772.6
4- 7-30		27.6	956	28.6	932	29.4	664	30.1	630	27.0	672	28.5	771.0
4- 8-30		37.9	938	39.7	915	35.7	671	35.7	630	34.2	665	36.6	764.0
	1st Feed												
4- 9-30	8:30 a.m	45.4	928	42.6	920	40.0	655	34.1	620	37.7	660	40.0	756.6
4-10-30		58.1	980	61.7	945	51.5	656	61.7	650	50.0	688	56.6	784.9
4-11-30		62.5	988	60.6	980	58.8	676	60.2	652	52.6	680	58.9	795.2
4-12-30		58.5	986	58.8	950	59.2	682	57.1	666	50.0	690	56.7	795.0
4-13-30		57.4	982	57.8	964	68.0	676	62.5	662	57.1	682	60.6	793.2
4-14-30		57.5	984	61.7	960	60.2	684	59.9	660	62.5	685	60.4	794.6
4-15-30		61.7	1005	64.5	978	59.5	705	57.8	668	57.1	686	60.1	808.4
4-16-30		58.5	1020	58.8	983	69.0	706	58.1	666	55.6	681	60.0	811.2

* Obtained some feed at 5 p.m.

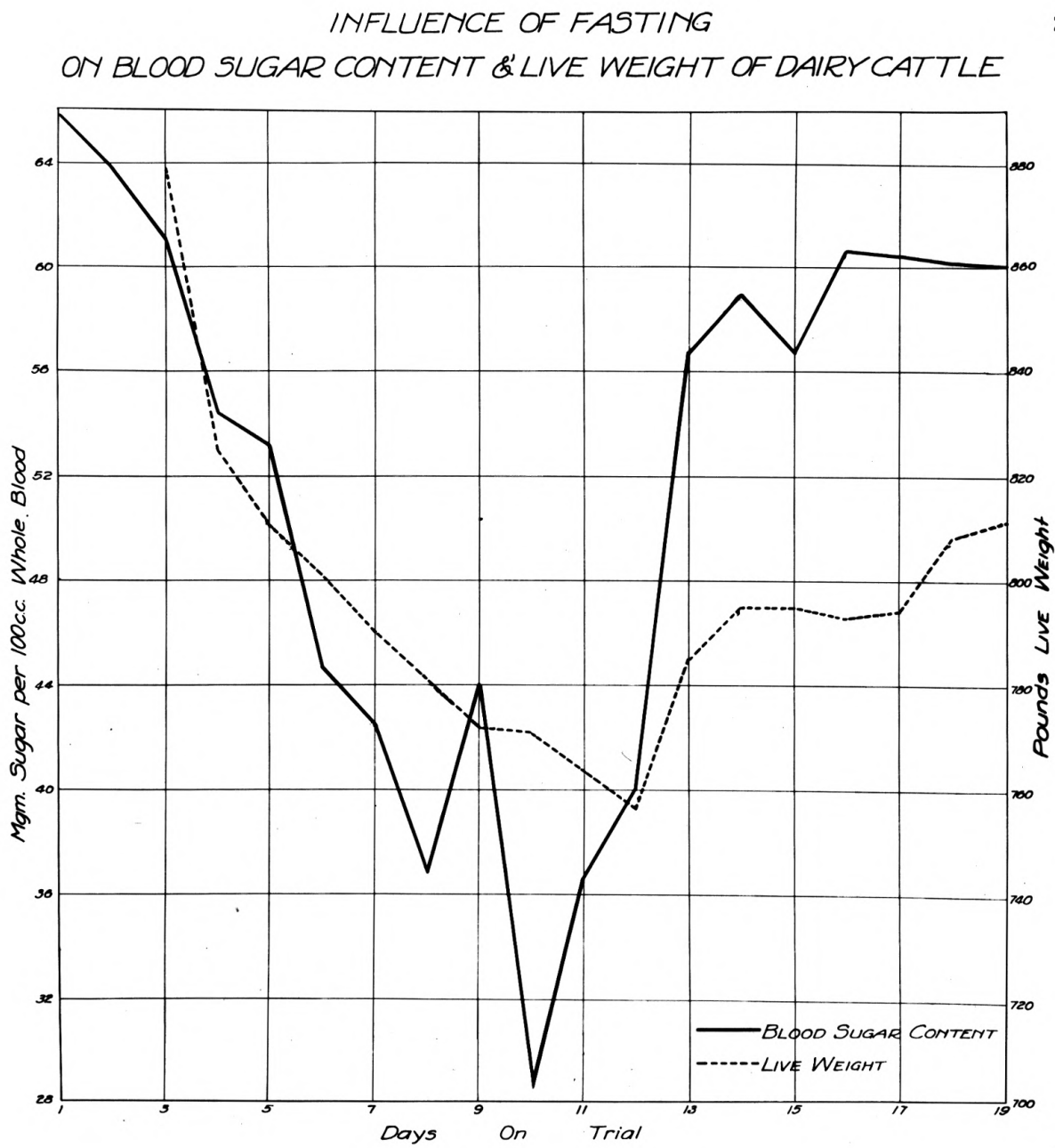
INFLUENCE OF FASTING
ON BLOOD SUGAR CONTENT & LIVE WEIGHT OF DAIRY CATTLE
Mgm. Sugar per 100c.c. Whole Blood
Pounds Live Weight
Days On Trial
Blood Sugar Content
Live Weight
64
60
56
52
48
44
40
36
32
28
880
860
840
820
800
780
760
740
720
700
1
3
5
7
9
11
13
15
17
19

Figure III

Influence of Feeding Sugar on the Blood Sugar Content

Seven trials were run to study the effect of feeding large amounts of sugar on the blood sugar content of dairy cattle. In the first two trials, the animals were deprived of feed for 12 hours. In the remaining trials they were fed the sugar solution in addition to their regular morning feed.

The animals in the various trials were fed different amounts of sugar, the amount being determined by their size and capacity. The sugar used was ordinary corn glucose. This sugar was put into solution in warm water and fed to the cows by means of a stomach pump. Since the sugar solution was pumped slowly into the animals, much of it probably went immediately into the true stomach.

The solutions were administered at 9:10 a.m. in each trial. Samples of blood were taken for analysis at 9 a.m. before the sugar ingestion and at 9:30, 10 and 11 a.m. and 1 and 4 p.m. Samples of urine were taken when possible and analyzed qualitatively for the presence of sugar.

Table VII gives the complete data for each trial. The results show a marked increase in blood sugar concentration immediately following the feeding of sugar and it required six to seven hours for the blood sugar content to return to normal. The increase following the feeding of sugar was

very rapid. The sugar content reached its highest point within 2 hours after the solution was given. In the case of heavy producing animals this peak appeared somewhat earlier than in dry animals or those which had been milking for several months. Also the initial blood sugar content appeared to be lower in those animals which had been fasted prior to the feeding of sugar. It was possible in these trials to increase the blood sugar content as much as 200 per cent.

In all cases the qualitative test for sugar in the urine gave negative results for the urine collected prior to the administration of sugar. With the exception of one trial sugar appeared in the urine within 2 - 4 hours after the solutions were given. In the second trial sugar was not found to appear in the urine. It will be noted that the blood sugar content did not increase to the extent that it did in the other trials, which would indicate that the concentration of blood sugar was not great enough to cause an excretion of sugar in the urine. The blood sugar content probably must more than double itself before sugar will be excreted in the urine.

It is quite evident that the feeding of soluble carbohydrates in large amounts, produce a decided increase in the concentration of blood sugar. When there is a large excess

amount of sugar present in the blood stream the kidneys have a tendency to excrete it into the urine.

Table VII

Influence of Feeding Sugar on the Blood Sugar Content of Dairy Animals

Cow Number and Breed	Treatment	Constituents Studied	mgm. sugar per 100 cc. whole blood					
			9 a.m.	9:30 a.m.	10 a.m.	11 a.m.	1 p.m.	4 p.m.
I Holstein Dry Wt. 1400#	Fasted 12 hr. 8#* sugar in solution administered at 9:10 a.m.	Blood Sugar	43.1	108.7	133.3	156.2	114.9	54.0
		Urine Sugar	-			+	+	-
II Holstein Dry Wt. 1200#	Fasted 12 hr. 6#* sugar in solution administered at 9:10 a.m.	Blood Sugar	47.8	78.7	69.0	105.3	91.0	59.5
		Urine Sugar	-			-	-	
III Guernsey Milking 8.5# Wt. 1050#	7#* sugar in solution administered at 9:10 a.m.	Blood Sugar	67.6	84.7	94.3	133.3	64.5	52.6
		Urine Sugar	-			+		
IV Guernsey Milking 9.5# daily Wt. 1000#	7#* sugar in solution administered at 9:10 a.m.	Blood Sugar	50.0	84.0	113.6	166.7	52.4	50.0
		Urine Sugar	-			+	+	
V Holstein Milking 40# daily Wt. 1200#	8#* Sugar in solution administered at 9:10 a.m.	Blood Sugar	59.2	137.0	166.7	88.5	83.3	63.3
		Urine Sugar	-			+	+	
VI Guernsey Milking 25# daily Wt. 950#	6#* Sugar in solution administered at 9:10 a.m.	Blood Sugar	54.0	117.6	105.3	100.0	76.9	58.8
		Urine Sugar	-		-	+	+	
VII Guernsey Milking 23.3# daily Wt. 1100#	8#* Sugar in solution administered at 9:10 a.m.	Blood Sugar	50.0	77.5	100.0	90.9	71.9	57.1
		Urine Sugar	-			+	+	

* Sugar solution given by means of a stomach pump

Influence of Oestrum and Parturition on the Blood Sugar Content

Data were obtained from three animals during the period of oestrum. Samples of blood were taken for analysis on one day before, twice during and one and two days after the oestrus period.

The results of these observations are given in Table VIII. It was apparent that during the oestrus period the blood sugar content increased materially. There was an increase of from 15 - 20 mgm. sugar per 100 cc. whole blood. This increase which was only temporary was probably due to excitement. After the oestrus period had passed the sugar content returned to normal.

Two animals were studied during parturition to note its effect on the concentration of blood sugar. Samples of blood were taken one day prior, twice during and one and two days after parturition. The samples obtained during parturition were taken just before and immediately after the calf was delivered.

The results of this study are also given in Table VIII. The results indicate that parturition caused an increase in the concentration of blood sugar. This increase was temporary, however, and was probably due to increased glandular acticity.

Table VIII

Influence of Oestrum and Parturition on the Blood Sugar Content

Number of Animal	Disturbance	mgm. sugar per 100 cc. Whole Blood: 1 day before	First Part	Last Part	1 day after	2 days after
I	Oestrum	54.9	74.1		50.0	52.6
II	Oestrum	50.0	66.7	66.7	51.5	
III	Oestrum	53.2	73.3	55.6	57.8	
I	Parturition	55.9	70.9	73.0	48.1	50.5
II	Parturition	39.2	63.7	52.7	54.9	36.2

DISCUSSION

The blood sugar content of dairy animals is materially influenced by the age of the individual. Calves at birth have a much higher concentration of blood sugar than their dams. At birth the blood sugar concentration is approximately 100 mgm. per 100 cc. whole blood, while that of the dam is near 54 mgm. As age advances the blood sugar content decreases until at producing age no further reduction is observed. After animals reach producing age or about 2 years old, the blood sugar content remains remarkably constant for the duration of life.

Calculations made from 205 observations on animals between the ages of 2 and 8 years gave a mean blood sugar concentration of 53.97 $\pm$ 0.914 mgm. per 100 cc. whole blood. The coefficient of variability was figured to be 10.93 per cent.

During the week of birth calves had a greater variation in the sugar concentration of their blood than when older. This increased variation may have been due to excitement of the animals at the time of bleeding. Excitement at the time of bleeding was less apparent in older animals.

Under normal conditions the age factor must be considered when discussing the concentration of the sugar of the blood of dairy animals.

The influence of breed on the concentration of the sugar of cow's blood is negligible. The fluctuation from the mean content is more noticable in the Ayrshire breed. However, under normal conditions of sampling this variation may be considered as insignificant.

A significant but small increase in the blood sugar content appears to occur as the stage of lactation of dairy animals advance. This increase amounts to approximately 7.0 per cent and is at its height when animals are 7 - 8 months along in their lactation. Apparently there is more individual variation in the concentration of blood sugar soon after parturition than in later months of lactation. Likewise, the variation in the concentration of blood sugar in milking animals appears to be greater than in non-lactating animals. It would seem from the results obtained that the concentration of blood sugar of lactating and non-lactating animals are the same.

The degree to which the blood sugar content is influenced by lactation is small and much importance cannot be attached to it.

The variation in the blood sugar content of dairy animals during the day is too small to attach much significance to it. An average of blood sugar readings made on 22 animals gave less variation than 3 mgm. per 100 cc. whole blood from 7 a.m. to 5 p.m.

The rate of glucose absorption into the blood stream from the digestive tract must be relatively uniform. There is no apparent high concentration of blood sugar after ingestion of food in cattle like there is apparent in humans. Due to the fact that the intake of food in ruminants is less rapid and that the food does not necessarily go into the true stomach immediately, the rate of absorption is probably more uniform than in humans.

It is not likely that the act of milking has any effect on the concentration of blood sugar. In the studies made the samples taken at 5 o'clock were taken soon after the animals had been milked. In no case where the animals were in milk, was there a decided increase or decrease in the concentration of blood sugar immediately after milking.

In general it would seem likely that where one is making a large number of observations the samples for

analysis could be taken at any time of the day. It would be advisable, however, to take samples at the same time each day in order to exclude the factor of individual variation where a small number of observations are made.

That the blood is partially dependent upon the absorption of carbohydrate material from the digestive tract for its concentration of sugar is clearly borne out. Approximately half of the sugar content of the blood comes from absorbed carbohydrates. When dairy animals are fasted their blood sugar content decreases to at least 50 per cent of the initial content. Results show that the decrease in the concentration of blood sugar of fasted animals takes place rapidly. It cannot be expected that on continued fasting the blood sugar content will continue to decrease, but will remain fairly constant at a lower level due to the fact that sugar is also being supplied from other sources.

A marked increase in the blood sugar content of the dairy cow occurs after ingestion of large amounts of readily soluble carbohydrate material. The amount of increase observed in this study was as much as 200 per cent. The greatest increase occurred within 2 hours after the introduction of the sugar. At that time in practically all cases sugar was found in the urine. Within 7 hours after the ingestion of the sugar solution the blood sugar content had returned to normal. The results obtained in the 7 trials studied

indicate that the highest concentration of blood sugar following ingestion occurred earlier in heavy producing cows than in dry cows or cows that were nearing the end of their lactation.

It is apparent that the liver mechanism does not have the power to rapidly take care of large excessive amounts of glucose that may be absorbed into the blood stream. The kidney serves as a threshold for elimination sugar when present in excessive amounts in the blood stream.

The picture presented by the concentration of blood sugar in dairy animals as a result of sugar ingestion is much like that of sugar tolerance tests in humans. However, the period that it takes to remove the excess sugar from the blood is somewhat longer in the case of dairy cattle.

During the oestrus period the concentration of blood sugar shows a temporary increase. This increase, in so far as this study would indicate, amounts to as much as 15 - 20 mgm. sugar per 100 cc. whole blood. The increase seems to occur for several hours during the active part of oestrum. Within a day after the oestrus period, the concentration of blood sugar had returned to normal. The reason for this increase is not definitely known but it is probably due to excitement resulting in an increased secretion of adrenaline.

Likewise, this study shows the concentration of blood

sugar at the time of parturition to be as much as 20 mgm. higher than at normal. It is likely that the great excitement which the animal is in during parturition is the cause of this increase. Following parturition the blood sugar content soon returns to normal.

It should be stated here that the results given on the influence of oestrum and parturition periods were obtained from a small number of animals. Observations on a large number of animals may give different results.

CONCLUSIONS

The blood sugar content of dairy animals is materially influenced by the age of the individual. The sugar content of the blood of calves decreased from 100.4 $\pm$ 1.666 mgm. at birth to approximately 55.00 $\pm$ 0.685 mgm. per 100 cc. whole blood at 2 years of age, after which no significant change was observed due to advancement in age. The mean blood sugar content of mature dairy animals amounted to 53.97 $\pm$ 0.914 mgm. sugar per 100 cc. whole blood.

There was no significant difference in the blood sugar content of the various breeds of dairy cattle studied.

Lactation exhibited little influence on the concentration of blood sugar in dairy animals. A rise of less than 4 mgm. sugar per 100 cc. whole blood was observed from the time animals began milking until their period of lactation

ended.

The data given indicate no significant difference in the blood sugar content of dry and milking animals.

The variation in the concentration of blood sugar during the day was slight. However, considerable variation was observed in individual animals, although these variations were not uniform.

Fasting caused a decided decrease in the blood sugar content and live wieght of dairy heifers. A decrease amounting to as much as 50 per cent of the initial blood sugar content was observed when heifers were fasted for 9 days.

The concentration of blood sugar in dairy cows was increased as much as 200 per cent through feeding large amounts of glucose. The presence of sugar in the urine was apparent when the concentration of blood sugar was at its greatest height.

So far as these results show oestrum causes an increase in the blood sugar content of cows which may amount to as much as 20 mgm. sigar per 100 cc. whole blood.

Results on two animals indicated that parturition causes an increase of as much as 20 mgm. sugar per 100 cc. whole blood in the concentration of blood sugar.

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