FACTORS INFLUENCING THE BLOOD-SUGAR LEVEL OF DAIRY CATTLE[1]

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INTRODUCTION

The sugar of the blood of dairy animals has been the subject of considerable investigation in its relation to milk secretion and disease. It is the precursor of the lactose of milk. Meigs (*11*) [2] has presented a thorough review of the literature on this little-known phase of metabolism. There is good evidence to show that milk sugar is derived from the glucose of the blood, though the process by which the transformation takes place in the mammary gland remains obscure.

In recent years the behavior of the blood sugar has been studied in dairy cattle under certain abnormal conditions. Several investigators have presented figures on the normal concentration of this constituent. Hayden and Sholl (*5*) after 75 tests with 44 cows concluded that the average concentration of sugar in the blood of dairy cows is 51.75 milligrams per 100 cubic centimeters. Moussu and Moussu (*9*), working with only 10 cows of different breeds, gave a range of 0.061 to 0.08 per cent, while Hayden and Fish (*4*), as a result of 68 analyses, gave an average figure of 46.52 milligrams per 100 cubic centimeters with a range of 30 to 70 milligrams. In a later and more extensive piece of work, Hayden (*3*) reported the low average of 41.15 milligrams of sugar per 100 cubic centimeters of blood for 253 samples taken from 23 cows over a period of 11 months.

Scheicher (*12*), in studying the ratio of blood sugar to lactose in dairy cattle, observed that the sugar concentration of the blood ranged between 0.055 and 0.10 per cent and averaged 0.0744 per cent, while Anderson and his associates (*1*) in a recent investigation gave a range of 43.2 to 142.0 milligrams for animals of all ages and an average of 51.2 milligrams for animals in the older group.

It is evident from these results that the blood-sugar level of dairy animals, while tending toward a mean value somewhere near 50 milligrams per 100 cubic centimeters of blood, is subject to wide variations. The causes of these variations have not been discussed to any extent in articles reporting investigations in this field. Undoubtedly, however, they are due, in part, to the fact that the rate at which sugar enters the blood and the rate at which it leaves the blood vary under different conditions. The actual amount of sugar in the blood at any time depends on the relative intensity of these two opposing sets of conditions.

Figuratively speaking, there are three streams of sugar supplying the blood. One enters from the intestines, another arises from the hydrolysis of glycogen, and a third from the synthesis of sugar from

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[2] Reference is made by number (italic) to Literature Cited, p. 364.

other compounds. The first of these can be controlled to a considerable extent by limiting the amount and kind of carbohydrates in the feed. In the case of dairy animals where the digestion is slow and more or less continuous, the rate of absorption of monosaccharides from the digestive tract under ordinary conditions probably does not vary sufficiently to produce any marked fluctuation in the blood-sugar level. The second stream, namely, that arising from the hydrolysis of glycogen, is largely under the control of the nervous system. When an animal is excited, the rate of conversion of glycogen into glucose is increased through the action of the adrenal glands. Excitement may produce a pronounced increase in the sugar level of the blood in a short time. The third source of sugar, namely, the synthesis of sugar from other compounds, is controlled by the processes of metabolism. This source of sugar probably produces very little fluctuation in the blood-sugar level under ordinary conditions.

Sugar is being steadily withdrawn from the blood and oxidized to furnish energy for maintaining the various functions of the body. The amount varies greatly, depending on the degree of muscular activity. Sugar is also removed from the blood to provide the lactose in the milk of lactating animals. Under normal conditions any sugar in excess of that needed for the production of energy and lactose is stored as glycogen or converted into fat, in which form it is stored as reserve energy.

A knowledge of sugar metabolism and the factors that affect the blood-sugar level is important in studying the problem of milk secretion. It was in part for the purpose of securing such information that the experiments described in this paper were undertaken.

EXPERIMENTAL METHODS

One hundred and forty animals were used in these studies. All belonged to the college herd and were maintained under normal conditions of herd management. They were fed at 6 a. m. and 4 p. m. each day, and milked at 5 a. m. and 4 p. m.

The animals were selected and handled in such a way that information could be obtained concerning the influence of the following factors on the blood-sugar concentration: Age, breed, lactation, fasting, introduction of relatively large amounts of glucose into the stomach, and excitement. In many cases a single determination was used in more than one comparison. In studying the influence of any one factor, care was taken to see that other conditions affecting the blood-sugar level were maintained as nearly constant as possible.

In recent investigations (*6*, *10*) it has been shown that the various methods now in use for the determination of blood sugar may yield somewhat different results. Folin's new micro method (*2*), which appears to give results in close agreement with the actual sugar content, and which requires only 0.1 cubic centimeter of blood for each determination, was used in this work. The blood was drawn from the ear by means of a capillary pipette and rinsed into a 10 per cent sodium tungstate solution. In all cases the samples were centrifuged and prepared for analysis within one hour after the blood was drawn. The majority of the samples were collected at approximately 9 a. m.

FACTORS STUDIED

AGE

The data collected comprise 20 observations made on not less than eight animals in each of 11 age intervals. Animals of the four major dairy breeds were used. The mean blood-sugar values were calculated, and the results are assembled in Table 1.

TABLE 1.—*Influence of age on the blood sugar* [1] *of dairy cattle*

Age class of animals (inclusive)	Mean value for blood sugar [2]	Age class of animals (inclusive)	Mean value for blood sugar [2]
	Mg per 100 cm³		*Mg per 100 cm³*
1 to 6 days	100.4±1.685	16 to 19 months	62.2±1.000
1 to 4 weeks	88.2±1.226	20 to 23 months	55.0± .685
1 to 3 months	80.2±1.212	24 to 47 months	54.6± .770
4 to 7 months	75.4± .794	48 to 71 months	53.6± .785
8 to 11 months	69.6±1.123	72 to 96 months	53.4± .669
12 to 15 months	67.8± .821		

[1] 20 determinations of blood sugar on not less than eight animals were averaged for each age interval.
[2] gm and cm³ are the abbreviations recently adopted by the Government Printing Office for milligrams and cubic centimeters, respectively.

It is apparent that during the early stages of life there is a close inverse relationship between the blood-sugar content and the age of dairy cattle. A mean of 100.4 ± 1.685 milligrams sugar per 100 cubic centimeters of blood was obtained in this study for calves less than 1 week of age. As the animal grows older its blood-sugar concentration decreases until it averages approximately 54 milligrams, when the animal is 2 years old. After this age is reached, the blood-sugar level does not seem to be influenced to any appreciable degree by an increase in age.

Two hundred and twenty-two observations made during the winter months on 74 animals between 2 and 8 years of age gave a mean blood-sugar concentration of 53.03 ± 0.297 milligrams per 100 cubic centimeters of blood, with values ranging from 35 to 74 milligrams.

BREED

The mature cows in the herd were used for the study of the influence of breed on blood-sugar content. By using only mature aninals it was sought to exclude the age factor. Stage of lactation was not considered since these studies have shown it to have little influence on the blood-sugar concentration.

No significant difference was observed in the blood-sugar content of the various breeds. An average of 44 determinations on each of the four major breeds gave the following means: Ayrshire, 53.1 ± 0.856; Guernsey, 53.6 ± 0.711; Holstein, 52.8 ± 0.440; and Jersey, 52.5 ± 0.459.

MILK YIELD

Hewitt (7) has recently reported results with dry and lactating cows. Eight determinations on three dry cows gave an average of 90.4 milligrams blood sugar, while a similar number on three lactating cows gave an average of 50.7 milligrams. From this he concluded that the blood-sugar level in dry cows is decidedly higher than for cows in milk. Theoretically, the withdrawal of sugar from the blood

to form the lactose of milk might lower the blood-sugar level in lactating cows. It does not seem probable, however, that this factor alone would explain the wide difference observed.

In order to study the influence of milk yield on blood-sugar level, all the available data in these studies were grouped according to daily milk yield, as shown in Table 2. The results on heifers were not grouped with those on dry cows, since, as already shown, young animals have a higher blood-sugar level than mature animals. The difference in the means of the dry and the heaviest producing group (1.9 ± 1.16) is less than twice its probable error, which is not generally regarded as significant. However, a small difference is apparent in the figures presented, and a slight negative correlation (0.190 ± 0.038) was obtained in correlating blood sugar and milk production for the three producing groups in Table 2.

TABLE 2.—*Influence of milk yield on blood-sugar level in dairy cattle*

Daily milk yield	Determinations	Cows	Mean value for blood sugar
	Number	*Number*	*Mg per 100 cm³*
Dry	42	20	52.6±0.843
1 to 15 pounds	27	21	52.9± .455
16 to 35 pounds	64	33	51.6± .514
Over 35 pounds	32	15	50.7± .799

While these results are lower than those reported by Schlotthauer (*13*), in general, they confirm his finding that heavy producing cows have a slightly lower blood-sugar level.

FEEDING

It is a well-recognized fact that the blood-sugar level may be influenced by the rate of absorption from the intestines. In animals in which the process of digestion is rapid and more or less intermittent, the blood-sugar level varies considerably throughout the day. After a meal of readily digested carbohydrates it increases for a time, but returns to a lower level as the rate of absorption decreases. To observe whether or not such a fluctuation occurred in dairy cows fed in the normal way, the blood sugar was determined at intervals during the day. The cows were fed at 6 a. m. and 4 p. m. Blood samples were taken at 7 and 10 a. m. and at 1, 3, and 5 p. m.

TABLE 3.—*Variation in blood-sugar content in 22 dairy cattle at intervals throughout the day*

Hour of day	Time elapsed since feeding	Mean value for blood sugar
	Hours	*Mgm. per 100 c. c.*
7 a. m.	1	51.4±0.834
10 a. m.	4	49.0± .655
1 p. m.	7	50.7± .733
3 p. m.	9	52.9± .475
5 p. m.	1	50.5± .882

The results, which are summarized in Table 3, indicate that no significant difference in the blood-sugar level of the dairy cow is produced by feeding. This is undoubtedly due to the rather slow and continuous process of digestion resulting from the complex nature of the bovine stomach.

It will be observed from Table 3 that there is a small increase at 3 p. m., which probably can be accounted for by the increased activities about the barn at this time in preparation for the afternoon feeding.

That the rate of absorption of sugar from the digestive tract does influence the blood-sugar level in dairy cows is indicated by the results of the two following experiments—the first on the influence of fasting, and the second on the sugar tolerance of the dairy cow.

FASTING

Five dairy heifers were used in studying the influence of inanition on the blood-sugar content. These heifers ranged in age from 1½ to 2 years and comprised 2 Holsteins, 1 Ayrshire, 1 Guernsey, and 1 Jersey. Throughout the trial they were kept in a paddock with shed adjoining. Water was available at all times.

Samples of blood for analysis were drawn daily, beginning two days before the fasting period, and the live weights of the animals determined. At the conclusion of the 9-day fasting period the heifers were gradually returned to normal feeding conditions.

Figure 1 shows the results in graphic form. It will be observed that as the fasting period advanced the concentration of the blood sugar decreased. This decrease was continuous and uniform until the morning of the seventh day, when a substantial increase occurred. This increase may be explained by the fact that the heifers broke through the fence and obtained some roughage the evening before. As the fasting continued the blood sugar decreased more than 50 per cent of its initial content. The lowest average value observed was 28.5 milligrams per 100 cubic centimeters blood for the eighth day of the trial, as compared with an average initial content of 61.2 milligrams.

After nine days without feed the heifers appeared gaunt and inactive. Their feces were watery and contained mucous material, though it is unlikely that all of the contents had been removed from the digestive tract in the short time involved.

The blood-sugar content of the heifers did not return to normal immediately after they were fed, but increased rather slowly for several days. The average live weight of these heifers decreased 120 pounds.

ADMINISTRATION OF GLUCOSE

In order to secure more rapid absorption of carbohydrate from the digestive tract, trials were run in which sugar was dissolved and given by means of a stomach pump. The animals in the various tests were fed different amounts of glucose according to their size and capacity. The glucose used was dissolved in water at body temperature and introduced slowly by means of a stomach pump. That much of the solution found its way immediately into the abomasum and was readily available for absorption is indicated by the prompt rise in blood sugar that occurred in a majority of the animals under observation.

The solutions were administered at 9 a. m., immediately after an initial blood sample had been taken. Samples were then secured at 30 minutes, 1, 2, 4, and 7 hours after dosage. In the first two trials the animals had been deprived of feed for 12 hours. In the remainder

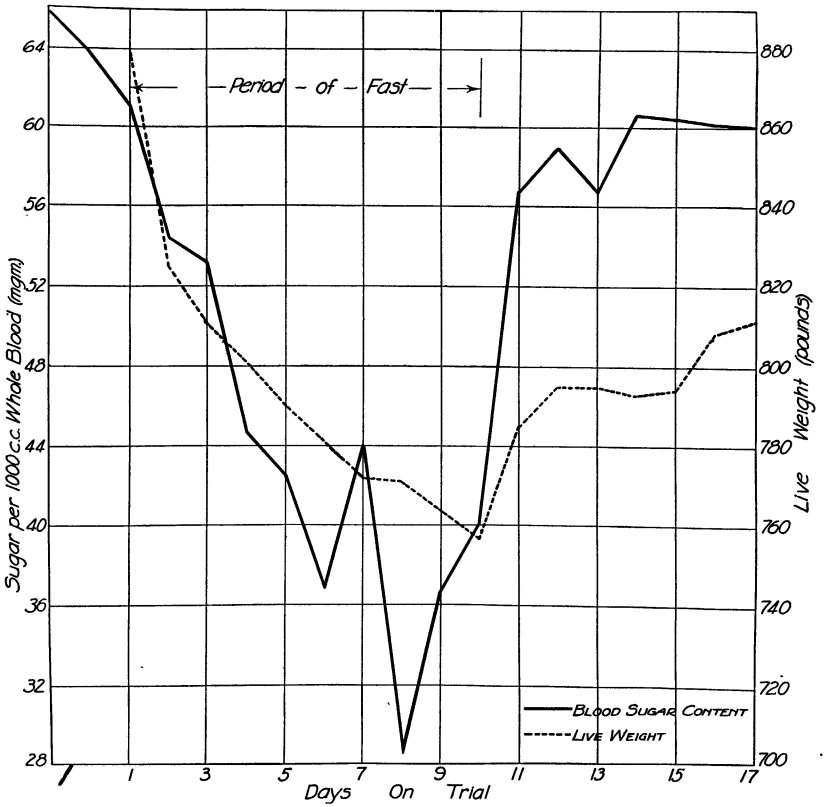

FIGURE 1.—Influence of fasting on the blood-sugar level and live weight of dairy cattle. The sudden rise in blood sugar on the seventh day was undoubtedly caused by the fact that the heifers broke through the fence and obtained some roughage the evening before

no attempt was made to withhold any part of the regular ration prior to giving the sugar.

TABLE 4.—*Effect of the administration of glucose on the blood-sugar level of dairy cows*

Breed and daily milk record of animal	Glucose administered	Milligrams sugar per 100 cubic centimeters whole blood at time indicated					
		Before dosage	30 minutes after dosage	1 hour after dosage	2 hours after dosage	4 hours after dosage	7 hours after dosage
	Pounds						
Holstein, dry	8	43.1	108.7	133.3	156.2	114.9	54.0
Holstein, dry	6	47.8	78.7	69.0	105.3	91.0	59.5
Guernsey, 9 pounds	7	67.6	84.7	94.3	133.3	64.5	52.6
Guernsey, 10 pounds	7	50.0	84.0	113.6	166.7	52.4	50.0
Holstein, 40 pounds	8	59.2	137.0	166.7	88.5	83.3	63.3
Guernsey, 25 pounds	6	54.0	117.6	105.3	100.0	76.9	58.8
Guernsey, 24 pounds	8	50.0	77.5	100.0	90.0	71.9	57.1

The results (Table 4) show a marked increase in blood-sugar concentration after dosage. This increase reached a maximum within approximately 2 hours, and 6 or 7 hours were required for the concentration to return to normal. In some of these trials it was possible to increase the blood-sugar content more than threefold.

That all this increase was not due to excitement resulting from the use of the stomach tube was shown by a repetition of the experiment in which water was used in place of the sugar solution. The average determination on four animals before the water was introduced was 65.3 milligrams of blood sugar. Thirty minutes after dosing the quantity had increased to 69.5 milligrams; one hour later it had decreased to 62.2 milligrams.

In every case the qualitative test (*8*) for sugar in the urine gave negative results for urine samples collected prior to the administration of glucose. Except in one trial, in which the blood sugar did not materially increase, sugar appeared in the urine within two to four hours after the solution was given. This glycosuria, which was to be expected under the conditions of the experiment, indicates that the "sugar threshold" value of the kidneys had been temporarily exceeded.

It is evident from these results that when soluble carbohydrate is given in such a way as to permit rapid absorption from the intestinal tract, a marked increase in the level of blood sugar results. This method of increasing the blood-sugar level has been used by the writers in studying the factors influencing lactose formation by the dairy cow.

EXCITEMENT

In order to determine the effect of excitement, the blood sugar of four cows was determined before and after a dog was brought into the barn. The nervousness of the cows resulted in an average increase in the blood sugar, ranging from 58.5 to 65.9 milligrams. When the dog was allowed to bark the blood sugar was further increased to 89.1 milligrams. All four cows showed a definite increase in this constituent.

Any undue excitement of an animal while the sample of blood is being taken for analysis may produce a marked increase in the blood sugar. This is particularly true when the animal is bled from the jugular vein. Unless one has had considerable practice in securing the blood in this manner, the animal may be rendered extremely nervous before the sample is finally obtained. In the work reported in this paper, the method used required only 0.1 cubic centimeter of blood, which could be taken quite conveniently from the ear, with a minimum of discomfort to the animal. The uniformity of the results recorded in Tables 1 to 4 may probably be attributed to this and the uniform conditions under which the samples were taken.

OESTRUS

A limited number of observations were made on cows during oestrus. In each case studied there was a distinct rise in the blood sugar, amounting in two instances to as much as 40 per cent. Hewitt (*7*) has reported blood-sugar values as high as 362 milligrams for heifers during oestrus. Observations made on five heifers in this herd gave no value in excess of 90 milligrams.

TEMPERATURE

As already stated, the results recorded in these studies were secured during the winter months, when the cows stayed in the barn a large part of the time and were maintained under uniform conditions. Some determinations made since in another study during extremely warm July and August weather gave results considerably higher than any observed heretofore. Further investigation will be required to determine definitely whether the increase in the blood-sugar level was due to the high temperature prevailing at the time the tests were made or to other factors.

SUMMARY

In the course of this investigation, blood samples from 140 dairy cattle were analyzed for sugar content. The following results were obtained.

Calves shortly after birth had a blood-sugar content of about 100 milligrams per 100 cubic centimeters. As the age of the animal increased the blood sugar decreased until the animal was approximately 2 years of age, after which little further change was observed. A mean blood-sugar content of 53.03 ± 0.297 milligrams per 100 cubic centimeters of blood was obtained on 222 samples from 74 animals between 2 and 8 years of age, with a range of 35 to 74 milligrams.

No significant difference was observed in the blood-sugar level of the four breeds studied.

Cows giving a liberal flow of milk were found to have slightly less blood sugar than dry cows or those yielding a small quantity of milk.

There was no increase in blood sugar after feeding. A slight increase was observed at 3 p. m., which probably may be accounted for by the increased activities about the barn prior to the afternoon feeding.

Fasting caused a decrease in the blood-sugar content of dairy heifers amounting approximately to 50 per cent.

The administration of glucose in solution produced increases in the blood-sugar content amounting to as much as 200 per cent.

Excitement was found to produce a marked increase in blood sugar.

The blood-sugar values of cows and heifers were higher during oestrus than at other times.

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