The Nutritive Value of Colostrum for the Calf

1. The Effect of Different Fractions of Colostrum*

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Calf mortality causes serious losses in dairy herds. At the suggestion of the Agricultural Research Council several research centres in this country are studying the different aspects of the causes and possible prevention of these losses. The National Institute for Research in Dairying, in collaboration with the Royal Veterinary College, is taking part in this work and is giving special attention to the nutritional significance of colostrum.

The importance of colostrum to newborn calves has long been realized: animals deprived of colostrum stand less chance of survival than calves which receive their natural food. This was shown in classical experiments by Smith & Little (1922), who suggested that calves receive protection against fatal scours by the transfer of maternal antibodies through the colostrum. According to Smith (1930) antibodies to *Bacterium coli* 'of the scours type' are normally present in cow's colostrum. Howe (1925) first suggested that these antibodies are associated with the globulins of colostrum. Since then strong evidence has accumulated that these 'immune globulins' play an important part in the protection of the calf during early life. This subject has lately been reviewed in detail by E. L. Smith (1948).

Recently workers in the U.S.A. (cf. Lundquist & Phillips, 1942, 1943; Phillips, Lundquist & Boyer, 1941) have stressed the significance of vitamin A and of certain members of the vitamin B complex in the prevention of 'nutritional scours' in calves. Several attempts have since been made to protect calves from scours by the addition of supplementary vitamins to their diet (cf. Nevens & Kendall, 1947) but so far no conclusive proof of the efficacy of any particular vitamin has been forthcoming.

Vitamin A is associated with the fat of colostrum, whereas the antibodies are present in the aqueous phase. We therefore compared the value of these two fractions by giving calves diets containing only one of them. In addition, we attempted to raise calves on a colostrum substitute containing certain vitamins in high concentrations.

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METHODS

Diets

Basic diet

The study of the nutritional factors affecting the resistance of calves to scours necessitated the preparation of a diet capable of supporting the normal healthy growth of a calf that had been given colostrum, but failing to do so when colostrum was withheld. It was considered essential that this diet should not contain vitamins A and D in greater concentration than milk.

Diets containing different proportions of margarine fat, glucose and dried skim milk were given to calves which had suckled their dams for the first 4 days after birth. The following 'synthetic milk' proved satisfactory:

	%
Spray-dried skim milk	9·5
Non-vitaminized margarine	2·0
Glucose	2·5
Water	86·0

The diet was prepared daily by homogenizing the fat into the dried skim milk dispersed in water, adding the glucose and making up to volume. This diet, supplemented daily for each calf with 3500 i.u. of vitamin A and 700 i.u. of vitamin D, enabled calves to grow normally and in health. The daily allowance of this 'synthetic milk' was 1 lb./10 lb. live weight. The dried skim milk used in all experiments was commercially prepared under carefully controlled conditions by the spray-drying process and was packed at low moisture content into sealed containers (cf. Henry, Kon, Lea & White, 1948). Sufficiently large batches were acquired to ensure uniformity of the product throughout one complete experiment. The homogenizer was of the single-action type capable of handling as little as 1 pt.; it was operated at a pressure of 200 atm. A stirrer was fitted close to the inlet of the homogenizer so that the fluid entered the machine in a well-mixed condition.

Colostral diets

Colostrum

First- and second-day colostrum was collected separately from individual Shorthorn and Ayrshire cows. The colostrum from one cow was sometimes bulked before processing, but more often each day's yield was handled separately, and the resulting products were bulked afterwards.

Separation of the fat from the aqueous phase of colostrum

The non-fatty fraction of colostrum can be obtained with ease in an ordinary cream separator. Isolation of the pure fat from the resulting cream is, however, difficult when drastic operations, such as churning or extraction with solvents, are considered undesirable. Other methods of separation were, therefore, investigated. It was found that, when colostrum was exposed to a great centrifugal force in the separator bowl of a motor-driven Sharples supercentrifuge running at a speed of *c.* 24,000 r.p.m., a butter-like product could be obtained which contained at least 70% of fat. This 'crude

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fat' was, at first, considered adequate for incorporation in the diets but, at a later stage, further purification was found necessary.

Owing to the variations in consistency of different batches of colostrum, no standard procedure of separation could be laid down. The most efficient separation was obtained with the fat in the liquid state and with the colostrum entering the supercentrifuge at 50°. Care was taken not to exceed this temperature as more drastic heating was likely to change the properties of colostrum. The supercentrifuge was thoroughly pre-warmed by passing hot water through the bowl. It was, unfortunately, found that the cold air streaming through the two cover lids solidified the fat in the lower one, with the result that it tended to spill into the outer bowl cover after a few hundred ml. of colostrum had gone through. By circulating water at 50° through a metal coil soldered to the outer surface of the lower cover lid this difficulty was reduced, though not completely resolved. In general, batches of from 2 to 4 l., depending on the fat content, could thus be separated cleanly in a single run. The consistency of the 'crude fat' varied with the size of the openings through which the fat leaves the separator bowl. In most cases ring no. 8½ was satisfactory; when the crude fat resembled cream rather than butter, an increase of the ring size to no. 9 or, occasionally, to no. 9½ produced the desired butter-like material.

Preparation of clarified fat

When the freshly prepared 'crude fat' was liquefied and spun in an ordinary centrifuge, the fat did not separate cleanly from the aqueous layer. A clear separation was, however, obtained when the 'crude fat' had been aged at *c.* 4° for at least 12 hr. The 'clarified fat' then contained no more than traces of non-fatty material.

The aqueous phase

During the separation in the supercentrifuge, a portion of the proteins was deposited on the wall of the separator bowl. Many batches of colostrum were contaminated with blood and dirt which collected on the wall near the bottom of the bowl. The discoloured layer was discarded. The remainder was scraped off the bowl wall and redispersed in a portion of the non-fatty fraction in a Waring Blendor. This dispersion presented no difficulties if it was carried out immediately after the end of each run.

Preparation of the diets from the components

The products of separation of colostrum were used in making up the diets described below. Each prepared batch was subdivided into 300 ml. portions which were poured into 1 pt. waxed paper cartons, rapidly frozen solid, and kept in a cold room at −25° until required for the calves. Under these conditions the keeping quality of the products was excellent; no evidence of any deterioration was observed after storage for several months.

Diet 1 *containing the crude fatty fraction of colostrum.* 'Crude fat' was liquefied by warming, and homogenized with reconstituted dried skim milk (1 lb. made up to 10 lb. with water) so as to give a liquid containing *c.* 3·5% of fat.

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Diet 1 *A containing the clarified fatty fraction of colostrum.* This was prepared in the same manner as diet 1, using clarified fat instead of 'crude fat'.

Diet 2 *containing the non-fatty fraction of colostrum.* Non-vitaminized margarine was dispersed in the aqueous phase, to give a homogenized product containing *c.* 2% of fat.

Diet 3. *Reconstituted colostrum.* As the processes involved in separating the colostral constituents may have had an effect on their properties, a control diet was prepared in which the 'crude fat' was homogenized with the corresponding non-fatty fraction to a fat content of *c.* 3·5%.

Bulking of the diets for treatment

The diets described above were prepared from the colostrum of a number of cows of each breed. When a diet was required for the initial feeding of a calf, uniformity of treatment was ensured by bulking, after thawing, the contents of a fixed number of cartons from each of at least four animals. In a given block of treatments each calf received colostral components from the same cows, made up in the same fixed proportions.

Diet 3*A. Whole untreated colostrum*

During part of the experimental work 300 ml. portions of untreated, bulked, first- and second-day colostrum were also kept at $-25°$. With these samples the fat percentage was not adjusted; it varied from 3·6 to 5·6%.

Diet 4. *Colostrum substitute*

In addition to the stored diets a vitamin-supplemented colostrum substitute was freshly prepared as required. Lundquist & Phillips (1942, 1943) and Boyer & Phillips (1944) stressed the importance of several vitamins to newborn calves and recommended vitamin supplements to prevent scours. It was, therefore, decided to add various vitamins to the 'synthetic milk' already described to see whether it would replace colostrum. The 'synthetic milk' was supplemented during the first 2 days of feeding with 52,000 μg. of β-carotene and 150,000 i.u. of vitamin A. For this purpose crystalline β-carotene was dissolved in the smallest amount of chloroform necessary (*c.* 2 ml.) and added to a small quantity of arachis oil together with vitamin A in the form of mixed fish-liver oil with a potency of *c.* 106,000 i.u./g. The chloroform was removed in vacuo, and then by blowing out with nitrogen. The oil was then mixed with non-vitaminized margarine and homogenized with reconstituted dried skim milk and glucose to make a liquid diet containing *c.* 2% fat. In addition, each calf received daily for the first 10 days of its life 500 mg. of vitamin C and 50 mg. of nicotinic acid given by mouth.

The quantities of carotene and vitamin A given were well in excess of those which a calf would normally derive from colostrum. The amount of vitamin C was twice that suggested by Boyer & Phillips (1944), and the allowance of nicotinic acid was the same as that of these authors.

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Calves

Supply and housing

Only male calves were used, and in the preliminary experiments they were of the three breeds available in the district, Shorthorn, Ayrshire and Guernsey. Later the Guernsey calves were omitted owing to shortage of numbers. Suitable animals were obtained through the collaboration of owners of tubercle-free herds in the neighbourhood. The calves were removed from their dams at birth, dried and transported within a few hours in a covered van from the farm where they were born to the experimental calf pens at this Institute. Every effort was made to ensure that the calves had not had access to colostrum. The necessity to feed each calf immediately on arrival at the Institute made it impossible to start all the treatments in any given experiment at the same time. The experimental animals were, therefore, assigned beforehand to a place in a group, or block, containing as many animals as there were experimental treatments. The arrangement is shown in Table 1. Thus, if the experiment involved four treatments, the first block consisted of the first four calves to arrive, the treatment for each being decided by lot.

The calf house was capable of accommodating thirteen calves, it had ample light and ventilation, the size was adequate and each calf was housed in an individual pen 3 ft. 6 in. × 5 ft. 6 in. The walls between pens were solid and no direct contact was possible between calves. Artificial heat was provided by water radiators and the room temperature was kept at 15–18°, except during short spells of very cold weather when this temperature could not be maintained. The calves were bedded on straw and each pen was thoroughly cleansed and disinfected before being used for another calf.

Management

On arrival, the newborn calves were placed in pens selected at random. They received the initial experimental diet for 2 days (see Table 1) and then the 'synthetic milk' diet (p. 188) until they were 5 weeks old. During the later stages of the experiment this period was reduced to 3 weeks, as it was found that calves of this age had passed the danger period for fatal scours. The calves were fed thrice daily at roughly equal intervals for the first 14 days and twice daily thereafter.

Assessment of performance

Weight and body temperature were measured daily up to 10 days of age and then twice weekly. In addition, the occurrence of scours was recorded on a numerical basis, the score varying from 0 for liquid faeces to 5 for normal faeces. To provide a simple numerical record of the progress and physiological condition of each calf a performance score was prepared, based on changes in live weight, on body temperature and on the incidence of scouring. These three factors were given equal weight in calculating the performance score, and a calf normal in all respects, that is, which gained at least 1 lb. daily, had a temperature not exceeding 102·8° F. and did not scour, scored 10, whereas a calf that died scored zero.

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Autopsy was made at the Royal Veterinary College on all calves that died and also on some of those which showed signs of illness during life.

For the measurement of vitamin A and carotenoids, blood samples were taken at birth, and blood and liver samples at slaughter. The results will be discussed in a separate paper. The experimental diets were analysed for fat, solids-not-fat, vitamin A and carotenoids.

Table 1. *Composition of diets*

		Diet of the calf		
		First 2 days		Subsequently (given at the rate of 1 lb./10 lb. live wt. throughout)
Treatment	Fraction or substitute of colostrum tested	Fatty component	Non-fatty component	
1	Crude fatty fraction	Crude colostral fat 3·5 %	Reconstituted dried skim milk 7200 ml.	'Synthetic milk'* + 3500 i.u. vitamin A and 700 i.u. vitamin D daily
1A	Clarified fatty fraction	Clarified colostral fat 3·5 %	Reconstituted dried skim milk 7200 ml.	As above
2	Non-fatty fraction	Non-vitaminized margarine 2 %	Separated colostrum 7200 ml.	As above
3	Reconstituted colostrum	Crude colostral fat 3·5 %	Separated colostrum 7200 ml.	As above
3A	Whole untreated colostrum	Whole untreated colostrum 7200 ml.		
4	Colostrum substitute	Margarine 2 % + 150,000 i.u. vitamin A + 52 mg. β-carotene	Reconstituted dried skim milk + 500 mg. nicotinic acid + 50 mg. vitamin C daily	'Synthetic milk'* + 500 mg. nicotinic acid + 50 mg. vitamin C daily up to 10 days of age

* See p. 188.

RESULTS

Preliminary experiments on the effect of feeding 'synthetic milk' to calves deprived of colostrum

As stated above (p. 188), calves that had received colostrum for the first 4 days of life were able to survive and grow normally on the 'synthetic milk' diet. When this diet was given to calves deprived of colostrum, the following results were obtained:

Breed	Died	Lived
Ayrshire	2	3
Shorthorn	5	0
Guernsey	3	2
Total	10	5

These results indicated a chance of survival in the absence of colostrum sufficiently low to justify the use of the diet in the investigation. As far as can be judged from the small number of calves used the Shorthorns were the least resistant.

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Main experiment

Eight blocks of Shorthorn calves (thirty-two animals) and eight blocks of Ayrshire calves (thirty-four animals) received the diets described in Table 1. The results are summarized in Table 2 which shows the number of calves on each of the six treatments, the number of calves that died and the mean performance scores obtained by expressing the sum of the individual performance scores as a percentage of the sum of the possible scores.

Table 2. *Performance of Ayrshire and Shorthorn calves on different treatments*

	Treatment					
	1 Crude fatty fraction of colostrum	1A Clarified fatty fraction of colostrum	2 Non-fatty fraction of colostrum	3 Recon-stituted colostrum	3A Whole untreated colostrum	4 Colostrum substitute
Ayrshire calves						
No. used	4	4	8	8	6	4
No. died	0	1	1	2	0	2
Mean performance score (%)*†	72 ± 10	40 ± 15	79 ± 12	67 ± 15	93 ± 3	30 ± 19
Mean live-weight gain of surviving calves during the first 21 days (lb.)†	17 ± 4·1	8 ± 4·6	14 ± 2·3	16 ± 2·5	16 ± 2·3	13 ± 4·0
Shorthorn calves						
No. used	4	4	8	8	5	3
No. died	1	3	0	2	0	3
Mean performance score (%)*†	52 ± 18	20 ± 20	81 ± 4	65 ± 15	88 ± 4	0
Mean live-weight gain of surviving calves during the first 21 days (lb.)†	16 ± 2	9	14 ± 2·2	14 ± 3·2	10 ± 2·6	0
Calves of both breeds						
No. used	8	8	16	16	11	7
No. died	1	4	1	4	0	5
Mean performance score (%)*†	62 ± 10	30 ± 12	80 ± 6	66 ± 10	91 ± 3	17 ± 12
Mean live-weight gain of surviving calves during the first 21 days (lb.)†	17 ± 2·4	8 ± 3·3	14 ± 1·5	15 ± 2·0	13 ± 1·9	13 ± 4·0

* The mean performance score $= \frac{\Sigma \text{ actual scores}}{\Sigma \text{ possible scores}} \times 100$. (For particulars see p. 191).

† Values with their standard errors of the mean.

The results show that calves that received whole untreated colostrum did better than those on any of the other treatments: no deaths occurred, and a very high mean performance score was obtained. With the other control treatment, i.e. reconstituted colostrum, results were less favourable, owing mainly to four deaths for which we have no explanation. These deaths occurred suddenly after a short period of scouring when the calves had reached an age of about 10 days, and they differed from the usual cases of 'fatal scours' in which scouring commenced about 48 hr. after birth, and resulted in death on the 4th or 5th day of life. Calves that received the non-fatty fraction of colostrum did well: only one out of sixteen died, and the mean performance score exceeded that with the control diet of reconstituted colostrum. It will be noted that diet 2 contained only 2% of fat and that its caloric value was, therefore, lower than that of the control diets 3 and 3A.

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The statistical significance of differences between the group means of performance scores was determined by the '*t*' test ('Student', 1908, 1925), *P* values below 0·05 being regarded as significant and *P* values below 0·01 as highly significant. For the treatments so far discussed these differences were not significant.

The eight calves that received the crude fatty fraction made satisfactory progress: only one death occurred, and the mean performance score and live-weight gain differed but slightly from those of the calves that received reconstituted colostrum. Comparison by the '*t*' test with the calves that had done so well on whole untreated colostrum revealed, however, a highly significant difference. It seemed possible that the small amount of the aqueous phase still present in the 'crude fat' was responsible for the relatively good performance of the calves on treatment 1. For this reason the 'crude fat' was clarified. When, at a later stage of the experiment, this clarified fat was incorporated in the diet (treatment 1A), calves fared badly: four out of eight died, the mean performance score was only 30% and the survivors grew less well than calves in other groups. The '*t*' test revealed a significant difference between these calves and those that received reconstituted colostrum, and highly significant differences in a comparison with the calves that received whole untreated colostrum or the non-fatty fraction. The marked difference between the effects of the crude and the clarified fatty fractions is of considerable interest. These fractions differed in that the 'crude fat' contained a certain amount of non-fatty material. A rough calculation showed that, provided no preferential adsorption had occurred, the calves on treatment 1 received in the 'crude fat' an amount of non-fatty fraction of the order of 1% of that given to calves on the full dose in treatment 2. This suggested that the protective factor present in the aqueous phase of colostrum was effective in very small doses, a suggestion followed up in further experiments reported in the accompanying paper (Aschaffenburg, Bartlett, Kon, Walker, Briggs, Cotchin & Lovell, 1949).

The high percentage of deaths on the colostrum substitute (treatment 4) and the low mean performance score of the calves, confirm recent findings that vitamin supplementation is ineffective in reducing the incidence of scours (Hibbs & Krauss, 1947; Nevens & Kendall, 1947; Hansen, Phillips & Rupel, 1946).

No marked differences were observed when the results were evaluated for each of the two breeds separately. There was again some indication that Shorthorn calves were slightly more susceptible than Ayrshires.

Autopsy findings

A summary of all autopsy findings is given in Table 3. Of the fifteen calves that died, thirteen died of 'fatal scours', characterized by *Bact. coli* septicaemia. In most cases *Bact. coli* was isolated from heart-blood and bone-marrow as well as from the lumen of the intestine and from the mesenteric lymph nodes.

Some of the calves that had shown illness during life, but had recovered, were also subjected to post-mortem examination at 5 weeks of age. There was an indication that *Bact. coli* had invaded the tissues during life; the organism was isolated from the mesenteric lymph nodes as well as from the intestine, whereas in normal healthy calves it could only be isolated from the intestine.

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Table 3. *Summary of autopsy findings*

	Treatment					
	1 Crude fatty fraction of colostrum	1A Clarified fatty fraction of colostrum	2 Non-fatty fraction of colostrum	3 Reconstituted colostrum	3A Whole untreated colostrum	4 Colostrum substitute
Total no. of calves used	8	8	16	16	11	7
Total no. of calves taken for autopsy	7	6	7	9	0	7
Findings at autopsy						
Fatal scours	1	4	1	4	—	3
Deaths due to other causes	—	—	—	—	—	2
Non-fatal illnesses*	6	2	5	3	—	2
Normal throughout	—	—	1	2	—	—

* Any departure from normality during the life of the calf, e.g. scours, high body temperature, listlessness and poor appetite.

SUMMARY

1. Thirty-four Ayrshire and thirty-two Shorthorn newborn bull calves, grouped into blocks of four or five, received in replicate experiments for 2 days an allowance of colostrum, of its fractions or of a substitute, followed for 3–5 weeks by a standard diet based on dried skim milk.

2. Only those calves whose initial diet contained the aqueous phase of colostrum made satisfactory progress; other calves failed to grow and many of them died.

3. Normally about 7 l. of the aqueous phase of colostrum was given, but about 1% of this quantity contained as an admixture in a crude fatty fraction allowed calves to live and grow; pure colostral fat proved ineffective.

4. The 'colostrum substitute' consisting of reconstituted dried skim milk and margarine fat, fortified with several vitamins in high concentrations, did not protect calves against fatal scours.

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The Nutritive Value of Colostrum for the Calf

2. The Effect of Small Quantities of the Non-fatty Fraction

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The experiments described in the preceding paper (Aschaffenburg, Bartlett, Kon, Terry, Thompson, Walker, Briggs, Cotchin & Lovell, 1949) have shown that, under our conditions, the factor most essential for the survival of the newborn calf is contained in the non-fatty fraction of colostrum, and that it might be active in very small amounts. It was, therefore, decided to do further experiments with quantities of the non-fatty fraction smaller than the 7200 ml. originally given to each calf. A preliminary experiment indicated that moderately reduced quantities were still fully protective, and the effects of more drastic reduction were then tested on a larger scale. A subsidiary test of the effects of heat treatment on the protective power of colostrum was also made.

METHODS

Preliminary experiment

Each of the last two blocks of Shorthorn and Ayrshire calves in the experiment described on p. 193 of the preceding paper (Aschaffenburg *et al.* 1949) was enlarged by the addition of two calves, one of which was given 3000 ml. (treatment 2A), the other 900 ml. (treatment 2B) of the non-fatty fraction of colostrum instead of 7200 ml. (treatment 2). The quantity of 900 ml. was given in the first feed, that of 3000 ml. during the first 24 hr., otherwise the original procedures were followed.

Main experiment

The experimental details were mostly as already described, but Shorthorn calves only were used, as they appeared slightly less resistant than Ayrshire calves. Instead of

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