The effect of heat treatment on the nutritive value of milk for the young calf

The effect of ultra-high-temperature treatment and of pasteurization

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The advantages of sterilizing milk by the ultra-high-temperature (U.H.T.) process which involves heating milk to temperatures between 130° and 150° for a few seconds only has been discussed by Clegg (1956). As there is at present no satisfactory aseptic bottling technique, such milk is usually re-sterilized in-bottle at 110° for 30 min. Kon (1958) reviewed the extent to which the nutritive value of milk is affected by U.H.T. sterilization and concluded that the small losses in nutritive value that occur are of little importance when such milk forms part of a reasonably planned mixed diet. Little has been done, however, to obtain information on the performance of infants and young animals reared exclusively on U.H.T.-treated milk.

Henry & Porter (1959) showed that U.H.T. treatment (135° for 1–3 sec) did not affect the biological value or true digestibility of milk or whey proteins for the rat; de Groot & Engel (1956) showed that the Stork process (135° for 15 sec followed by in-bottle sterilization at 113° for 30 min) caused a small but not significant loss in biological value, and similar but significant changes were obtained by Henry & Kon (1938) with in-bottle sterilization alone and by Henry & Porter (1959) with in-bottle sterilization after U.H.T. treatment. Wagner (1953) claimed that the growth rate of rats given sterilized milk was considerably less than that of those given fresh milk, but no detrimental effect of sterilization of milk on growth of rats, when such milk comprised all or the major part of the diet, was found by Henry, Ikin & Kon (1938); Bernhard, Gschaedler & Sarasin (1953); Hodson (1954); Bixby, Bosch, Elvehjem & Swanson (1954); Mancini (1956); de Groot & Engel (1956) or Ogasa, Ishii, Kazuyori, Tanaka & Maeno (1959). Wagner (1952) also reported that sterilization resulted in the destruction of a large proportion of the vitamin A in milk; this claim was challenged by Kon (1952) who presented ample evidence from the literature that little destruction of vitamin A occurs during milk sterilization. Clearly not too much weight should be given to Wagner's claims unless they can be confirmed by other workers.

A comparison of the nutritive values of pasteurized milk (72° for 20 sec), and U.H.T-treated milk re-sterilized in-bottle, for baby pigs was made in Holland by de Groot & Engel (1956) who found small, not significant differences in growth rate in favour of the pasteurized milk. Trials involving a total of 866 infants from birth to 10 months of age made in Germany by Jochims & Wickhaus (1954) and Jochims (1957) indicated that milk sterilized by the Stork process was inferior to pasteurized milk as judged by average daily weight gains, dyspepsia and tolerance of overfeeding.

It is reasonable to suppose that the young calf would be the most sensitive test animal to detect any changes in cow's milk caused by heat treatment. The experiment reported in this paper compared the nutritive values of U.H.T.-treated milk and raw milk for the young calf and is part of an inquiry being made at this Institute to find the effect on the performance of the calf of milk powders that have been subjected to certain heat treatments during processing. These milk powders form a large proportion of milk 'substitutes' widely used in the feeding of young calves. Although it has been generally found that pasteurization does not impair the nutritive value of milk for the calf, the opportunity was taken to compare pasteurized milk with raw milk under our experimental conditions.

METHODS

Plan of experiment

The experiment was done in the autumn of 1958 after the calfhouse had been occupied by only a few calves during the summer months; the level of 'infection' in the calfhouse was therefore low (see Roy, Palmer, Shillam, Ingram & Wood, 1955). A randomized block design was used with three treatments in each of twelve blocks, nine of Ayrshire bull calves and three of Shorthorn, as follows:

Treatment no.	Initial diet	Subsequent diet
1	6 pints colostrum	Raw milk
2	6 pints colostrum	Pasteurized milk
3	6 pints colostrum	U.H.T.-treated milk

Diets

Colostrum. Colostrum obtained within 24 h of calving from Shorthorn and Ayrshire cows was used; 1-pint samples were stored separately in waxed paper cartons at $-25°$. Each calf was given initially 6 pints of colostrum consisting of 1 pint from each of six different batches. Calves within each block received the same blend of colostrum but there were differences in the blend between some of the blocks.

Milk. To avoid treating small amounts of milk daily and to ensure batches of similar composition, the procedure was as follows. At intervals, generally weekly, 45–75 gal of whole milk from the Institute tuberculosis-free herd were drawn from a bulk tank for treatment in the experimental dairy. The U.H.T. plant used was an APV plate heat-exchanger described in detail by Burton (1958). Two-thirds of the milk were placed in the holding tank of the U.H.T. plant, heated to 49°, homogenized at a pressure of 2500 lb/in^2 and cooled immediately. Half of this milk was then pasteurized by the Holder method at 63° for 30 min and cooled on a surface cooler. It was necessary to homogenize the raw and pasteurized milks in order to prevent oiling-off of the butter-fat during storage. The remaining one-third of the milk was placed in the holding tank of the U.H.T. plant, homogenized as described above, passed to the steam-heating section, sterilized at 135° for 1–3 sec and cooled immediately. To prevent dilution by water that had been passed through the homogenizer and heat exchanger before treatment of the milk, several gallons of milk were allowed to go to waste before the treated milks were collected at the outlet of the plant. In all, twelve batches of milk were treated by these methods.

The raw, pasteurized and U.H.T.-treated milks were then stored in 1-pint waxed cartons at -25° until required. The amount of milk required daily was slowly thawed and warmed to 37° before use; the daily allowance was calculated to give a live-weight gain of 1 lb/day (Roy, Shillam, Hawkins & Lang, 1958).

Analytical methods

Duplicate or triplicate samples taken from each batch of the three milks directly after treatment were analysed for fat and solids-not-fat content. The proximate composition, nitrogen partition and ultrafiltrable calcium were determined on two pooled samples of each of the three milks. Each of these pooled samples was a composite sample of six batches of milk that had been stored at -25°. The proximate composition was determined by the methods used by Rowland, Roy, Sears & Thompson (1953), nitrogen partition by the method of Aschaffenburg & Drewry (1959) and ultrafiltrable calcium on an ultrafiltrate of milk obtained by the method of Gregory (1954).

Calves

The calves were reared for 3 weeks; collection and general management were as in earlier experiments (Aschaffenburg, Bartlett, Kon, Terry, Thompson, Walker, Briggs, Cotchin & Lovell, 1949). If a calf scoured, the quantity of milk was reduced to that calculated to give maintenance of body-weight (Roy *et al.* 1958). When the consistency of the faeces returned to normal, the volume of milk was increased to the normal daily allowance. This practice was repeated when scouring recurred.

RESULTS

Performance of the calves

The results are given in Table 1. It is clear that, whereas pasteurized milk had no detrimental effect on the health or growth of the calves, milk that had been subjected to U.H.T. treatment was inferior to both raw and pasteurized milk. From Fig. 1, which gives the mean daily live weights over the 3-week period, it can be seen that the differences in growth rate were most marked during the first 10–12 days of life. This was no doubt due at least in part to the higher incidence during this time of scouring among the calves given U.H.T.-treated milk. Fig. 2 shows the percentage of calves on each treatment that scoured on each day during the 3-week period.

A multiple covariance analysis of live-weight gain/day on the variables, birth weight, colostrum and milk-solids consumption, incidence of scouring and incidence of a high rectal temperature was made; only the partial regression coefficient of live-weight gain on consumption of milk solids was significant. Treatment means were therefore adjusted by means of the simple regression coefficient of live-weight gain/day on consumption of milk solids given in Table 1. As the milk intake of the calves was considerably reduced when scouring occurred, this adjustment was in fact largely one for scouring. After adjustment, the mean growth rate of calves given U.H.T.-treated milk was only approximately 70% of that of calves given raw or pasteurized milk, the difference being highly significant. Even if treatment means were adjusted for the effect of the incidence of scouring on live-weight gain/day (by means of the simple

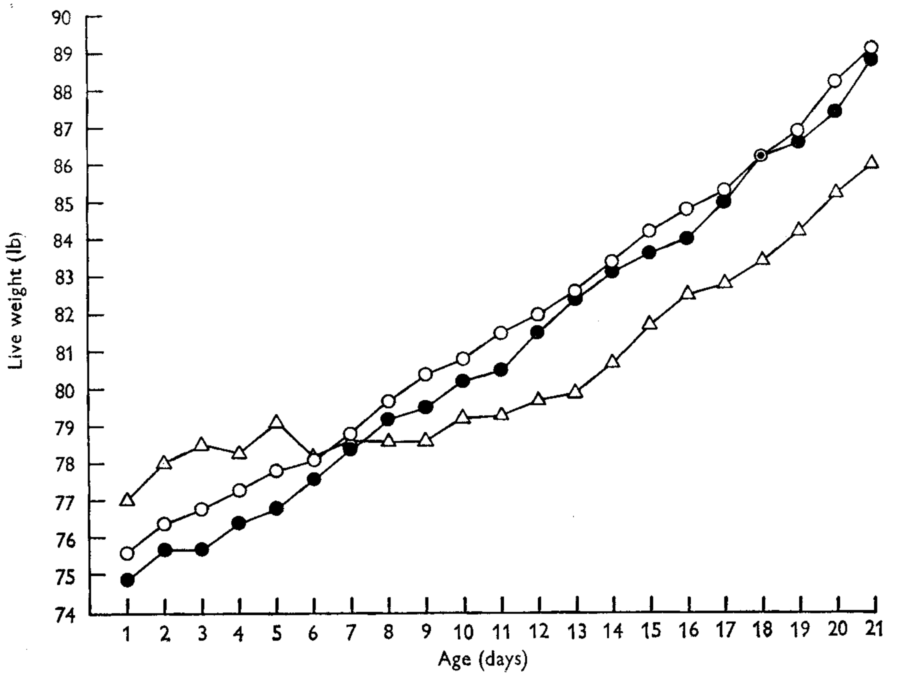

Fig. 1. Growth rate of calves given raw, pasteurized or U.H.T.-treated milk. ○, raw milk; ●, pasteurized milk; △, U.H.T.-treated milk.

Table 1. *Comparison of the performance (mean values with their standard errors) of calves given raw, pasteurized or* U.H.T.*-treated milk*

	Treatment no. and diet			
	1 Raw milk	2 Pasteurized milk	3 U.H.T.-treated milk	Significance of difference between treatments
No. of calves used	12	12	12	
Live-weight gain/day (lb)	0·66 ± 0·06	0·69 ± 0·06	0·42 ± 0·06	1 > 3**, 2 > 3**
No. of days on which calves scoured	1 ± 0·5	1 ± 0·2	3 ± 0·6	1 < 3*, 2 < 3*
No. of days on which calves had a high rectal temperature (> 102·8° F)	2 ± 0·6	3 ± 1·0	2 ± 0·7	—
Colostrum and milk-solids consumption in 21 days (lb)	24·59 ± 0·61	24·66 ± 0·61	23·72 ± 0·61	—
Adjusted live-weight gain/day (lb)†	0·64 ± 0·04	0·67 ± 0·04	0·46 ± 0·04	1 > 3**, 2 > 3**

Regression coefficient of live-weight gain/day on colostrum and milk-solids consumption = 0·0695 ± 0·0136***.

* Significant at 0·01 < *P* < 0·05. ** Significant at 0·001 < *P* < 0·01. *** Significant at *P* < 0·001.

† Adjusted for differences in consumption of milk solids between treatments (see p. 405).

regression coefficient -0.16 ± 0.07, significant at $0.01 < P < 0.05$), the mean growth rate of calves given U.H.T.-treated milk was again significantly less than that of those given raw or pasteurized milk.

Composition of raw, pasteurized and U.H.T.*-treated milks*

The mean fat and solids-not-fat contents of the three milks are given in Table 2. The U.H.T.-treated milk contained 1·8 % less total solids than the raw milk and 2·3 % less than the pasteurized milk.

The proximate compositions, given in Table 3, of the six pooled samples of the three milks, were very similar, but the amount of ultrafiltrable calcium in the U.H.T.-treated milk was about 15 % less than that in the raw milk.

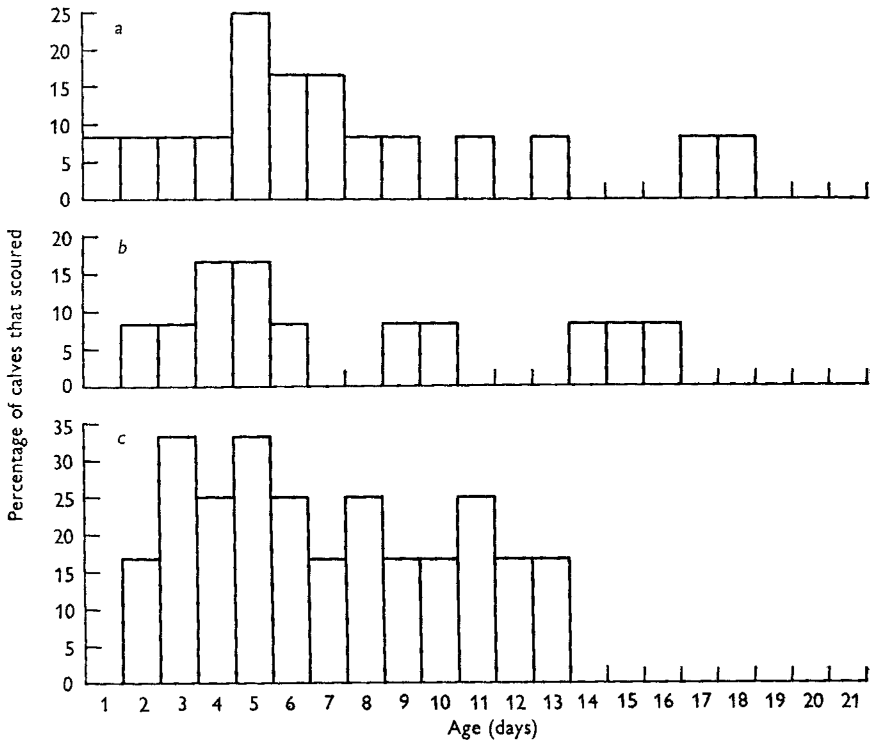

Fig. 2. Percentage of calves that scoured on each day. *a*, raw milk; *b*, pasteurized milk; *c*, U.H.T.-treated milk.

Table 2. *Fat and solids-not-fat content of the raw, pasteurized and* U.H.T.*-treated milks*

	Raw milk	Pasteurized milk	U.H.T.-treated milk
Total amount of milk processed (gal)	224	227	213
No. of samples analysed	25	26	24
Mean fat content (%)	3·91	3·96	3·84
Mean solids-not-fat content (%)	8·61	8·63	8·46

The values for nitrogen partition of the three milks given in Table 4 show that, although the content of total N in the milks was similar, the amount of non-casein protein N in the U.H.T.-treated milk was only 28% and in the pasteurized milk 90% of that in the raw milk. The effect of U.H.T. treatment on the content of total albumin N and its fractions was similar to that obtained by Larson & Rolleri (1955) in milk heated at 75–85° for 30 min; the β-lactoglobulin fraction was particularly affected, its content in U.H.T.-treated milk being only 10% of that in the raw milk.

Table 3. *Proximate composition and ultrafiltrable calcium of two pooled samples of each of the raw, pasteurized and* U.H.T.*-treated milks*

	Raw milk		Pasteurized milk		U.H.T.-treated milk	
	Batches 1–6	Batches 7–12	Batches 1–6	Batches 7–12	Batches 1–6	Batches 7–12
Fat (g/100 g)	3·85	4·32	3·80	4·28	3·92	4·25
Lactose (g/100 g) (anhydrous)	4·55	4·69	4·56	4·63	4·36	4·60
Protein (g/100 g)	3·37	3·44	3·35	3·41	3·39	3·42
Ash (g/100 g)	0·73	0·73	0·73	0·72	0·71	0·71
Phosphorus (mg/100 g)	92	99	92	96	92	95
Total calcium (mg/100 g)	118	123	117	119	121	119
Ultrafiltrable calcium (mg/100 g)	44·8	Sample lost	40·0	42·5	37·2	39·2

Table 4. *Nitrogen partition (mg N/100 g) of two pooled samples of each of the raw, pasteurized and* U.H.T.*-treated milks*

	Raw milk			Pasteurized milk			U.H.T.-treated milk		
Nitrogen partition	Batches 1–6	Batches 7–12	Percentage of total N*	Batches 1–6	Batches 7–12	Percentage of total N*	Batches 1–6	Batches 7–12	Percentage of total N*
Total N	516	520	100·0	522	526	100·0	521	516	100·0
Casein N	383	394	75·0	400†	409†	77·2	463†	458†	88·8
Non-casein N	133	126	25·0	122	117	22·8	58	58	11·2
Non-casein protein N	101	95	18·9	91	87	17·0	28	27	5·3
Total albumin N	68	69	13·2	63	63	12·0	15	16	3·0
β-lactoglobulin N	38	37	7·2	35	34	6·6	4	3	0·7
Residual albumin N‡	30	32	6·0	28	29	5·4	11	13	2·3
Proteose-peptone + globulin N	33	26	5·7	28	24	5·0	13	11	2·3
Non-protein N	32	31	6·1	31	30	5·8	30	31	5·9

* Mean for both pooled samples.
† Includes denatured non-casein N.
‡ Sum of α-lactalbumin, 'blood' serum albumin and two minor components (see Aschaffenburg & Drewry, 1959).

DISCUSSION

The results of this experiment show clearly that the performance of young calves reared on U.H.T.-treated milk for the first 3 weeks of life was considerably inferior to that of calves reared on raw or pasteurized milk. The higher incidence of scouring of calves given U.H.T.-treated milk did not solely account for the reduced growth rate, for after adjustment of mean live-weight gains/day for the effect of differences in incidence of scouring between treatments, weight gains of calves given raw or pasteurized milk were significantly greater than those of calves given U.H.T.-treated milk. As adjustment of live-weight gains was made for differences in the consumption of total solids in the milks, the observed differences in growth were not attributable to the slightly lower fat and solids-not-fat content of the U.H.T.-treated milk; the calves given U.H.T.-treated milk consumed only 1·8% less total solids than those given raw milk, yet their growth rate was 32% less. The lowered solids content of the U.H.T.-treated milk was probably due to dilution of the milk with water in the U.H.T. plant despite the precautions taken to prevent its occurrence. Loss of dry matter due to deposition in the heat-exchanger is unlikely, for Aschaffenburg, Burton, Rowland & Thiel (1958) were unable to detect any consistent changes in fat and solids-not-fat content of milk as a result of U.H.T. treatment, and Burton (1959) states that only small deposits, mainly of mineral salts, are left in heat exchangers when milk is treated at temperatures greater than 100°.

The observed differences in growth rate certainly did not result from differences in palatability of the diets, for U.H.T.-treated milk, despite its cooked, sulphurous smell, was as acceptable as raw or pasteurized milk. Over the 3-week period, refusals of milk offered averaged 1·5 pints/calf for calves given U.H.T.-treated milk compared with 2·7 or 2·2 pints/calf, respectively, for those given raw or pasteurized milk. de Groot & Engel (1956) considered that the slightly inferior weight gains of baby pigs 2–4 days old given milk sterilized by the Stork process compared with those of pigs given pasteurized milk could be partly attributed to differences in food intake during the 1st week of the trial. Thus, difficulties were found in accustoming baby pigs to the sterilized milk, but the authors gave no values for milk consumption. During the 5–6 weeks trial period the weight gains of their pigs given U.H.T.-sterilized milk were 97% of those given pasteurized milk, whereas the corresponding figure during the 1st week of the trial was only 73%. The more marked effect of U.H.T.-treated milk during the early postnatal life of pigs is in agreement with our present findings with calves and also with our unpublished results of studies on the effect on the performance of the young calf of milk powders subjected to certain heat treatments during processing. Similarly Noller, Ward, McGilliard, Huffman & Duncan (1956) observed that evaporated milk was not utilized as well as raw milk by calves of from 10 to 22 days of age, but equally well during the period 26–38 days of age.

It seems probable that the poor performance of calves given U.H.T.-treated milk was associated with the denaturation of about 72% of the non-casein proteins. As the non-casein protein N in raw milk comprised only about 19% of the total N, the observed effect on the calf is unlikely to be solely a result of quantitative changes in the amount of undenatured protein available for growth. This contention is borne out by the findings of Blaxter & Wood (1951) who concluded that for growth of the young calf, cow's milk contains an excess of protein relative to energy. The need for only very small amounts of the whey-protein fraction of colostrum for calf survival has been shown by Aschaffenburg, Bartlett, Kon, Roy, Walker, Briggs & Lovell (1951) and it may be that the whey proteins of milk similarly contain essential components, of which only small amounts are necessary for normal growth of the calf.

Sterilization (110° or 113° for 30 min) of raw or U.H.T.-treated milk generally causes a decrease of a few percentage units in biological value for the rat (Henry & Kon, 1938; de Groot & Engel, 1956; Henry & Porter, 1959) owing probably to injury to one or more essential amino-acids (Henry & Kon, 1938). However, Henry & Porter (1959) found that U.H.T. treatment alone produced no change in biological value of milk for the rat and concluded that such treatment caused no detectable loss or inactivation of the essential amino-acids in the whey proteins. However, the differences in age and physiological development between the rats, which were in a post-weaning state (at least 3 weeks of age), and the newborn calf must be borne in mind. Thus it is possible that U.H.T. treatment alone may cause sufficient destruction or inactivation of the essential amino-acids of the whey proteins to have a detrimental effect on the performance of the newborn calf but not of the 3-week-old rat. A shortage of certain amino-acids might arise during the first 10–12 days of life of the calf, if, at this time, there were insufficient or inappropriate proteolytic enzymes capable of dealing with the denatured protein.

It is known from the early work of Mortenson, Espe & Cannon (1935) and Dickey, Espe & Cannon (1939) that the boiling of milk has a marked effect in vivo on the rate of clotting and of liquefaction of the curd and also on the emptying time of the abomasum. It seems possible therefore that the poor performance of calves given U.H.T.-treated milk may have been associated with changes in the physical nature of the rennet clot formed in the abomasum. It is well established that calcium is associated with rennet coagulation, for Kastelic, Bentley & Phillips (1950) demonstrated that a synthetic milk containing 1·26 g calcium/l. was a satisfactory diet for the newborn calf, whereas when calves were given a milk in which the concentration of calcium was reduced to 0·73 g/l. to prevent coagulation by rennet, they did not grow normally and developed diarrhoea. However, the milk of low calcium content was satisfactory for the 2-week-old calf, a finding which the authors explained by assuming that by this age secretion of acid and pepsin had developed sufficiently to cause coagulation of the milk.

It is known that when milk is heated the concentration of soluble calcium decreases by up to 25% (Lampitt & Bushill, 1934; Verma & Sommer, 1950; Bernardoni & Tuckey, 1950; Harman & Slatter, 1950; Hilgeman & Jenness, 1951; Baker, Gehrke & Affsprung, 1954), a finding that we have confirmed in this experiment. Ionized calcium is also known to be reduced by a similar amount as a result of heat treatment (Christianson, Jenness & Coulter, 1954; Hostettler & Stein, 1958; Davies & White, 1959). Hostettler & Stein (1958) consider that the reduction in calcium-ion concentration in evaporated milk is due to the increased binding of calcium by the denatured proteins, a finding in accordance with that of Kannan & Jenness (1956) who showed that increased rennet-coagulation time of heated milk occurred only in the presence of denatured whey proteins.

Many previous experiments comparing raw and pasteurized milk have been complicated by the fact that some of the calves fed on raw milk reacted to the tuberculin test (Wilkie, Edwards, Fowler & Wright, 1937; Bartlett, Cotton & Mackintosh, 1938; Crichton & Biggar, 1938). Our finding that pasteurization of milk from a tuberculin-tested herd was without detrimental effect on the health or growth of calves free from tuberculosis confirms that of Wilson, Minett & Carling (1937). Thus the denaturation of 10% of the non-casein protein N by means of Holder pasteurization, a finding which is in agreement with that of 5–10% denaturation of albumin and globulin N in milk heated to 60–63° for 30 min reported by Menefee, Overman & Tracy (1941), Shahani & Sommer (1951), Larson & Rolleri (1955) and Davies & White (1959), was without effect on the growth of the calf.

Our findings of the relative inferiority of U.H.T.-treated milk for the young calf appear to have little significance in practice, for it seems unlikely that calves will ever be reared under farming conditions on milk that has been subjected to U.H.T. treatment. However, the results of this experiment are in agreement with our findings (to be published) that certain severe heat treatments, imposed on skim milk during the drying process, reduce the nutritive value of the dried product for the calf.

In view of the increasing use of sterilized milk for human consumption both in this country and especially in warmer climates, it appears to be desirable to obtain further evidence on the effect of U.H.T. treatment of milk on the performance of the young artificially fed human infant. The young calf, however, appears to be an extremely sensitive test animal for studying the effect of changes in the composition of cow's milk, its natural food, and one must be cautious when reasoning from one species to another. Moreover, in infant feeding, cow's milk is generally diluted with water and boiled before use.

SUMMARY

1. Thirty-six newborn bull calves were reared for the first 3 weeks of life on raw, pasteurized (63° for 30 min) or U.H.T.-treated (135° for 1–3 sec) milk.

2. The health and weight gains of calves given pasteurized milk and of those given whole milk were similar.

3. Live-weight gain of calves given U.H.T.-treated milk was significantly less and the incidence of scouring significantly greater than of calves given raw or pasteurized milk.

4. U.H.T. treatment of milk denatured 72% and pasteurization only 10% of the non-casein protein N.

5. The possibility is discussed that the poor performance during the first 10–12 days of life of calves given U.H.T.-treated milk is related to the denaturation of the whey proteins.

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