THE SYNTHESIS OF MILK

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Introduction

Milk is universaly recognized as nature's most nearly perfect food, and rightly so, because of its high nutrient content. We know that milk composition varies only slightly regardless of the environment to which animals are subjected.

One often wonders how multicolored cows can eat multi-colored feeds and produce white milk, which is quite unlike any other body fluid or secretion. The purpose of this paper is to review the present knowledge regarding milk synthesis by the cow's mammary glands.

How are the various milk components synthesized?

There are two useful methods for studying milk synthesis from blood precursors. Early research involved measuring arterio-venous differences in blood composition between the blood entering and that leaving the cow's udder, Espe (1946).

The second and most useful is the radio-isotope tracer technique. This consists of administering labeled compounds to the animal and measuring the radioactivity of the final products. Let's find out how the tiny epithelial cells of the alueoli (milk secreting cells) make milk from a wide variety of blood components.

A. **Carbohydrate**—Lactose is the principal carbohydrate found in milk. Barry (1959) labeled glucose on the first carbon and also on all six carbons and found that over one-half of the lactose came from blood glucose. Rogers & Kleiber (1956) found butyrate to be the source of glucose and a higher amount of butyrate goes to lactose than acetate and a lower amount to milk fat.

Wood (1958), using C14—acetate or glycerol injected into an artery leading to the udder demonstrated that traces of these compounds are incorporated into lactose and galactose has many times the activity of glucose. Wood believes that lactose is formed primarily by the reaction of free glucose with uridine dephosphoglucose (UDPG) and the latter is also formed by blood glucose. So far, no enzyme has been found to catalyze this reaction.

Barry (1959) suggested that UDP—Galactose supplies the galactose molecule and that Glu-1-PO4 is the galactosyl acceptor. Hansen, et al., (1962) proposed a similar mechanism. The enzyme catalyzing this reaction has been described but not confirmed (Gander et al., (1957).

Enzymes found in the mammary gland are hexokinase, phosphoglucomutase, UTP - Glu - 1-PO4-pyrophosphorylase and UDP-gal-4-epimerase. Hansen (1962) suggests that two or more pools of Glu-6-PO4 are in the mammary gland and one turns slowly and doesn't acquire much C14 from the labeled substrates. This low activity pool seems to be involved in lactose synthesis and may be from a non-secretory tissue of the gland. The C14 pattern of the UDP-Gal differes from the UDP-Glu and it is proposed that there may be a pathway allowing C14 to be introduced directly into UDP-Gal from triose phosphates such as Glyceraldehyde-3-PO4.

B. **Fats.**

1. **Fatty acids**—Fats in milk are derived unchanged from the blood stream or are manufactured in the mammary gland. Patton **et al.**, (1960) used gas chromatography to find C4, C6, and C8, through C-18 n-alkanoic acids, the C16 and cis and trans C18 n-alkanoic acids and the C18 n-alkadienoic and trienoic acids.

Short-chained fatty acids are found in milk at a level of 30 per cent, (Hilditch, 1956).

Folley (1956) injected acetate-C14 into the goat blood stream and found that the short-chained fatty acids were almost completely formed by acetate from the blood. The long chained fatty acids had almost no radioactivity.

When labeled stearic acid was fed to cows, the level of stearic and oleic acids reached 60 per cent of the milk fat (Barry, 1959). When labeled glucose and acetate were injected, little stearic and oleic acid was formed in the gland. Glascock (1958) labeled stearic acid in triglyceride and fed a cow. It was partly carried to the milk in a small fraction of the blood which didn't exchange with the bulk of the stearic acid of blood fat.

James and Peeters (1956) showed that traces of fatty acids with odd-numbered carbons in milk fat arise from acetate, with traces of propionate, from the blood.

Two theories of fat synthesis have been proposed by McCarthy **et al**, (1960):

(a.). The alteration of pre-existing triglyceride molecules.

(b). Supplemental (non-lipid) precursors

Popjak **et al.**, (1951) found acetate to be absorbed directly from the reticulo-rumen and is a source of part of the milk fat, and is active in forming fatty acids up to 16 carbons long.

Balch and Rowland (1959) proved acetate and butyrate to be important to butterfat synthesis, but not contributing factors.

According to Luick, (1960) milk fat may be synthesized in the mammary gland using glycerol and free fatty acids.

2. **Glycerol**—Intramammary synthesis of glycerol was denied bp Glascock (1958). Wood, et al., (1958) reported strong evidence for it.

Luick (1961) studied fat synthesis in dairy cows following intromamary infusion of C14 labeled glycerol, glucose, acetate, propionate, or bytyrate. The results indicate that glycerol is synthesized in the mammary gland from glucose but not acetate, propionate, or butyrate. The newly formed glycerol is incorporated into milk fat.

Luick and Kleiber (1961) reported that at least 70% of milk fat glycerol was synthesized from blood glucose. Wood (1958) said 17% of the glycerol carbons were derived from glucose in the mammary glands.

C. **Proteins**—Barry (1957) showed that free amino acids in the blood are the source of at least 90 per cent of the amino acids of milk proteins. There was no evidence that the mammary gland manufactures amino acids or that it converts blood protein to milk protein. It was found that the mammary gland must break blood proteins down to amino acids before they can be converted to milk proteins. The udder can select from 20 amino acids to do this.

Stein and Moore (1954) found that blood peptides can provide only about 10 per cent of each amino acid of milk protein.

Barry (1958) used tracers to show that at least 70 per cent of each of the two essential amino acids of casein came from the same two free amino acids of blood.

Kleiber and Black (1956) obtained evidence which indicated that enzymes for making proteins are present in the mammary gland.

Wood (1958) found that serine comes from blood glucose in the mammary gland.

Barry (1958) showed that alpha-lactalbumin comes largely from free amino acids of the blood, but immune globulin and serum albumin come from blood without change. The immune globulin of cow colostrum seems to be made from free amino acids by plasma cells held in the mammary gland.

D. **Mineral and Vitamins**—These are thought to diffuse directly from the blood into the secretory tissue of the gland, although the concentration of some compounds (e.g. - Calcium) is much greater in milk than blood. Kamal and Cragle (1962) found that Ca45 and P32 injected into the veins was the source of milk calcium and phosphorus as found in the plasma ultrafiltrable fraction.

E. **Energy**—Where does the energy for milk synthesis come from? Barry (1959) believes it is from the oxidation of acetate in the tricarboxylic acid cycle. There is evidence that the ruminant can not change glucose to acetyl-Coenzyme A and oxidize it in the tricarboxylic acid cycle.

Glucose is slowly oxidized by tissues, suggesting the pentose phosphate cycle, (Glock and McLean, 1958). In rats glucose is so oxidized via acetyl-Co A through the tricarboxylic acid cycle, but must of it is oxidized via the pentose phosphate cycle.

Summary

Milk synthesis is a complex process, but many questions have been answered. The precursors and the sites of milk nutrient synthesis are fairly well known. It is still a mystery how the tiny milk secreting cells of the udder can synthesize milk components from such diverse precursors.

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Concentrates and Roughages

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Recent reports by Geurin, **et al,** (1959); Anthony, **et al,** (1960). Wise, **et al,** (1961); Richardson **et al,** (1961); McCroskey **et al,** (1961), and many others have pompted many tials and much discussion as to the proper levels of concentrates and roughages in the diets of fattening cattle. These trials were conducted to determine the desirable lebel of hay to include with other ingredients of the typical California cattle fattening mixture.

PROCEDURE

TRIAL I. One hundred and twenty-seven Hereford steers were placed on pasture February 20, 1960. At this time one-half of the steers were implanted with a half dose of Synovex. The animals ran together on pasture until June 5, when they were brought into the feedlot. The steers were all implanted with Synovex and were started on the test mixtures on June 25. The steers that had been implanted on pasture were sorted and placed in the odd numbered pens and the steers being implanted for the first time were put in the even numbered pens. The 127 steers were divided into ten pens of twelve or thirteen animals each; four pens were placed on a 70% concentrate mixture, four pens on an 85% concentrate ration, and two pens were fed a 95% concentrate diet. The only difference in the mixture was the amount of hay included in the ground, mixed rations. (See Table I for feed mixture used.)

TABLE 1.
BEEF CATTLE TRAIL SUMMARY JUNE 25—OCTOBER 10, 1960 (107 DAYS)

Pen	Treatment (% Concentrates)	Animals	Average Wt. Initial	Average Wt. Final	A.D.G. lbs	Feed/Day lbs.	Feed/lb. Gain	Carcass Data Yield	Carcass Data Grade
1		13	803.0	1108.5	2.86	29.0	10.1	59.3	13 C.
2		13	756.9	1059.6	2.82	28.1	10.0	59.3	13 G.
4	70% 8,500 I.U. Vit. A.	13	768.0	1051.2	2.65	28.0	10.6	59.8	16 C.
8		13	758.7	1068.4	2.89	28.5	9.9	59.8	10 G.
5	85%	13	865.0	1220.3	3.32	28.8	8.7	61.5	24 C.
6	85%	12	816.8	1173.7	3.34	27.9	8.4	61.5	1 G.
7	95%	12	894.4	1254.4	3.36	27.7	8.2	61.8	23 C.
8	95%	13	859.2	1199.9	3.18	27.0	8.5	61.8	2 G.
9	85%	13	723.7	1015.8	3.00	24.3	8.1	60.4	19 C.
10	85%	12	767.6	1074.3	3.10	25.5	8.2	60.4	6 G.

All weights taken between 6:00 and 7:00 A.M. before feeding and a 5% shrink taken. Animals in odd numbered pens were implanted with Synovex February 20, when turend on pasture. All animals were implanted with Synoverex when started in feedlot June 25.

Concentrate mixture used: Steam rooled barley 71%, Steam rolled milo 5%, Dried beet pulp 9%, Cottonseed meal 5%, Dehy. alfalfa meal 1%, Oyster shell 5%, Salt 0.5%, and Molasses 8%. The roughage portion of the diet was Oat and Vetch hay. Steam bone meal and salt were fed free choice.