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A 100-Year Review: Advances in goat milk research[1]

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ABSTRACT

In the century of research chronicled between 1917 and 2017, dairy goats have gone from simply serving as surrogates to cows to serving as transgenic carriers of human enzymes. Goat milk has been an important part of human nutrition for millennia, in part because of the greater similarity of goat milk to human milk, softer curd formation, higher proportion of small milk fat globules, and different allergenic properties compared with cow milk; however, key nutritional deficiencies limit its suitability for infants. Great attention has been given not only to protein differences between goat and cow milk, but also to fat and enzyme differences, and their effect on the physical and sensory properties of goat milk and milk products. Physiological differences between the species necessitate different techniques for analysis of somatic cell counts, which are naturally higher in goat milk. The high value of goat milk throughout the world has generated a need for a variety of techniques to detect adulteration of goat milk products with cow milk. Advances in all of these areas have been largely documented in the *Journal of Dairy Science* (JDS), and this review summarizes such advances.
Key words: adulteration, composition, nutrition, somatic cells, safety

INTRODUCTION

Previously considered the "poor man's cow," the goat—and goat milk products—began gaining attention in the United States in the 1960s because of health and nutritive values attributed to goat milk and milk products. Touted for its easy digestibility and lower allergenic properties compared with cow milk, goat milk has been considered a nutraceutical for decades, but many early reports were anecdotal. The *Journal of Dairy Science* (**JDS**) played a large role in documenting the true differences between cow and goat milk. Haenlein (1980) even credited JDS as "a major US research organ on dairy goats as well as on dairy cows." In the 100-year period since 1917, JDS has published more than 850 research manuscripts related to goat milk and milk products. However, these numbers do not reflect the full scope of research related to dairy goats, or the role that goat milk and milk products have played in advancing the global dairy industry in the past century. With particular focus on JDS publications, this paper is dedicated to those discoveries (Appendix Table A1).

ADVANCES IN GOAT MILK RESEARCH FROM 1917 TO 2017

Goat Milk and Human Nutrition

The importance of goats for human nutrition has likely been recognized since the beginning of domestication. Indeed, the first publications related to goat milk, published in *The Lancet*, tended to focus on infant feeding and some of the risks and benefits associated with it (Dalebrook, 1902; Blackham, 1906; Cahill, 1906; Wright, 1906). One letter to the editor of *The Lancet* claimed that "goats practically never have tubercle, therefore their milk can be given without pasteurizing… their milk is said to be better for infants than cow's milk because the curd is finer" (Edmunds, 1914). Prompted by the observation that goat milk rarely forms a cream layer, though its fat content was similar to that of cow milk, Schultz and Chandler (1921) reported that 91% of goat milk fat globules were <4 μm in diameter. Previous work by Bitting (1902) reported that 90% of cow milk fat globules were >4 μm in diameter. Although it soon became clear that goat milk was also susceptible to microbial contamination, the softer curd and higher proportion of small fat globules have been selling points of goat milk ever since these early works.

In the early 1900s, vitamins and minerals were almost exclusively studied in rats, chicks, and monkeys. Approximately 15 years before the early "Our Industry Today" report by Elvehjem (1953), work in his laboratory revealed that rats grew more slowly on goat milk than on cow milk. By then, several cases of severe anemia had been associated with goat milk feeding of human infants, and the term "goat's milk anemia" was

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coined. Elvehjem (1953) reported that goat milk provided inferior amounts of vitamin B_{12} and that levels of folic acid in goat milk and cow milk were "about equal" (which has since been shown untrue). However, because improvement in rat growth was seen with folic acid supplementation, a sparing effect of folic acid on vitamin B_{12} was indicated. Still in the early days of understanding the role of folic acid and B_{12} in human health, Collins et al. (1953a,b) published 2 companion papers in JDS, the former related to cow colostrum and milk, and the latter to goat colostrum and milk. Because vitamin B_{12} levels in sheep milk could be increased by the addition of cobalt or trace minerals (containing cobalt), Harper et al. (1951) wanted to evaluate the effect of such diet supplementation in goats. Goats that received trace-mineralized salt (containing cobalt) had a higher level of vitamin B_{12} in their colostrum and milk during the first week postpartum compared with those receiving only iodized salt. Trace-mineralized salt or a 50-mg supplement of cobalt per goat per day had no influence on the level of B_{12} in goat milk after this time. The addition of trace minerals to the diet of the goat did not influence the free folic acid level of the goat milk. The authors admitted that the information reported in the JDS work was "more accurate" than that reported in their previous work (Collins et al., 1951).

It was not realized until later that goat milk was deficient, with respect to human nutrition, in folic acid and vitamins B_{12} and B_6, nutrients that are essential for normal human infant development (Ford and Scott, 1968; Parkash and Jenness, 1968). Nonetheless, goat milk products gained considerable attention in the 1970s because of their perceived health and nutritive value. Jenness (1980) provided a good review of goat milk nutritive value based upon the literature of the time. Similar to cow milk, goat milk is an adequate-to-excellent source of protein, calcium, niacin, pantothenic acid, phosphorus, potassium, riboflavin, thiamin, and vitamin A to the human diet (Parkash and Jenness, 1968; Jenness, 1980). Neither cow nor goat milk is a good source of iron, vitamin C, or vitamin D (unless fortified). In contrast to cow milk, goat milk contains inadequate levels of vitamin B_6, vitamin B_{12}, and folic acid for infant nutrition (Ford and Scott, 1968; Parkash and Jenness, 1968; Jenness, 1980). Folic acid and vitamin B_{12} deficiencies became a focus of research in the 1970s regarding megaloblastic anemia in children exclusively fed goat milk (Davidson and Townley, 1977) and continue to be of concern today (Ziegler et al., 2005; Basnet et al., 2010).

One of the main characteristics of goat milk that has contributed to its appeal as an alternative to cow milk is its lower allergenic properties compared with cow milk. Even today, families are known to switch to goat milk or to buy a dairy goat to avoid cow milk consumption. Yet mostly anecdotal evidence for the lower allergenicity of goat milk was reported until the 1990s (Loewenstein et al., 1980; Haenlein, 2001). With an incidence of 2 to 3% in the first year of life, cow milk allergy is the most common food allergy in early childhood, but the remission rate is approximately 85 to 90% by adulthood (Høst, 2002). In an outstanding review published in JDS, Jenness (1980) noted that in many cases, allergy to cow milk proteins was not improved by shifting patients to goat milk, and he recognized that α_{S1}-casein may play a role. It was not until Ballabio et al. (2011) published in JDS that the clear relationship was established. By running individual milk samples from 25 goats with different α_{S1}-CN genotypes through SDS-PAGE and immunoblotting using monoclonal antibodies specific for bovine α-CN and sera from children allergic to cow milk, Ballabio et al. (2011) showed that goat milk allergenicity is a function of α_{S1}-CN genetic polymorphism. Lower reactivity was shown for samples with null α_{S1}-CN genotypes (0_10_1 or 0_1F). Their work confirmed that caution must be taken before goat milk is suggested as an alternative to cow milk for patients with cow milk allergy. They went further to indicate that goat milk from particular α_{S1}-CN genotypes could serve as protein sources for hypoallergenic formulas (Ballabio et al., 2011). The findings were echoed by Lisson et al. (2014), who confirmed that although genetic variants of caseins differ in their allergenicity, cross-reactivity of IgE antibodies of goats and buffaloes with cow milk caseins limit feeding goat or buffalo products to cow milk-allergic patients.

In "Past, present, and future perspectives of small ruminant dairy research," Haenlein (2001) provided an outstanding review of over 135 manuscripts related to, primarily, goats and sheep. Haenlein noted that research before 2001 was scarce on the unique qualities of goat and sheep milk compared with cow milk; largely it had been assumed that technical research on cows could be extrapolated to small ruminants. Haenlein summarized differences in anatomy, physiology, nutrition, metabolism, and pathology of goats and sheep, as well as differences in their milk and milk products and economic profitability. Although not mentioned in his manuscript, perhaps a dairy goat check-off program could help narrow the gap of disparity in research dollars spent on cows and dairy goats. Particularly compelling was Haenlein's statement regarding the potential of goat or sheep milk to combat under- and malnutrition of people in poor areas and countries. Only 21 out of the 24 countries Haenlein included in his summary met the recommended level of calcium intake (1,000 mg/d). All but 5 countries met the recommended level of protein consumption (50 g/d) in the form of animal