Chromium and Dairy Nutrition: What Do We Know?

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BACKGROUND

Chromium (Cr) is a trace element that is most commonly encountered in the +3 and +6 oxidation states. Hexavalent Cr is a strong oxidizing agent and is used in numerous industrial processes, most notably in the manufacture of stainless steels. Trivalent Cr is the most stable oxidation state and is the form most likely to persist and have metabolic activity in biological systems. It is speculated that inorganic forms of Cr are poorly absorbed and only organic trivalent forms of Cr seem to have repeatable biological effects.

Chromium is well established as an essential trace element for man and laboratory animals (NRC, 1997). The only established metabolic role of Cr is its function in the glucose tolerance factor (GTF), which is believed to interact with the insulin-cell receptor complex in facilitating the action of insulin. The exact structure and function of GTF may never be elucidated; however, GTF appears to be composed of glycine, cysteine, glutamic acid, and nicotinic acid. Numerous claims are made relative to the biological activity or efficacy of various organic Cr compounds/complexes, based on the similarity of these compounds to GTF. However, there is very little information on the comparative bioavailability of various organic Cr compounds. Furthermore, the human and animal literature regarding Cr is becoming voluminous and many apparently disparate biological roles for Cr have been proposed. However, when viewed critically, most of the positive biological responses to Cr supplementation are consistent with the known function of Cr in improving insulin effectiveness via the GTF.

In 1997, the National Research Council published a review of the available data and essentially developed a position statement relative to the inclusion of supplemental Cr in the diets of commercial livestock. Unfortunately, most of the data for dairy animals became available after the compilation of that document. In the U.S., Cr is currently not approved for use in ruminant diets. For convenience, all Cr concentrations in this paper will be given as ppm (mg/kg) on a dry basis. For reference, the pig requires about 0.2 ppm Cr.

CHROMIUM ANALYSIS AND LEVELS IN FEEDSTUFFS

Analysis for Cr in foods and feeds is technically difficult, requiring graphite furnace atomic absorption spectroscopy, appropriate reference materials, and an ultra-clean lab. Exposure to metal surfaces in feed processing and handling and laboratory sample preparation greatly increases Cr contamination. Because of these problems, the information available on basal levels of Cr in animal feeds is scant and variable. Generally, forages and by-products seem to contain more Cr than grains (Table 1). The basal Cr concentrations reported for experimental diets for ruminants (range: 0.3 to 1.6 ppm) is usually higher than the supplemental Cr added to these diets (0.25 to 0.5 ppm). There is little information on the biological activity/availability of Cr in feedstuffs for livestock. Generally, the Cr in most ruminant feedstuffs should be considered poorly available. Some biological organisms, such as yeasts, are capable of bio-concentrating Cr. In fact, some high-Cr commercial products are made in this way. The bioavailability of Cr in these products is probably moderately high.

Table 1: Chromium content of feedstuffs

Feedstuff	Cr, ppm	Reference
Dehydrated alfalfa	0.20	Yang and Mowat (unpubl.)
Corn silage	2.03	Chang (1991)
Ryegrass	0.44	Jones and Buckley (1977)
Barley	0.83	Yang and Mowat (unpubl.)
Corn	0.91	Yang and Mowat (unpubl.)
Wheat bran	0.63	Yang and Mowat (unpubl.)
Meat meal	0.80	Jones and Buckley (1977)
Fish meal	0.63	Jones and Buckley (1977)
Soybean meal	0.15	Yang and Mowat (unpubl.)
Brewers yeast	1.00	Jones and Buckley (1977)
Brewers grain	0.23	Yang and Mowat (unpubl.)

[1] Adapted from Subiyatno, 1994

IMPLICATIONS OF CHROMIUM FOR LACTATING COWS

Stress resistance and immune function.

There is evidence in humans and laboratory animals that various stressors significantly increase urinary excretion of Cr, suggesting that Cr may be physiologically linked to the responses to or control of stress. Stress can cause sharp increases in the secretion of cortisol. High circulating concentrations of cortisol dramatically reduce tissue insulin sensitivity. The immediate effects include decreased entry of blood glucose into muscle and adipose tissue, increased glycogenolysis and gluconeogenesis, and increased mobilization of fatty acids from adipose tissue. Extended stress and insulin insensitivity results in reduced immune function.

Among the most promising effects of supplemental organic Cr has been improved resistance to or recovery from stress and increased immune function. Reduced morbidity and improvements in most growth performance criteria were observed during the first few weeks after arrival of market-transit stressed feeder calves (Chang and Mowat, 1992; Moonsie-Shageer and Mowat, 1993; Mowat et al., 1993; Kegley and Spears, 1995). Improved health and growth performance were invariably associated with improvements in stress and (or) immune criteria. In contrast, when physiologically adapted feeder calves were fed over longer feeding periods, growth performance was not affected by Cr supplementation (Chang and Mowat, 1992; Bunting et al., 1994).

The stress of late pregnancy, calving and early lactation elicits moderate immunosuppression in the dairy cow. The significance of this immunosuppression relative to vitamin E and Se status were detailed by Smith (1998) at this conference. Data regarding the effects of Cr on immunocompetence in the lactating cow are very limited. Using a small number of Holstein cows, Burton et al. (1993) demonstrated that some immune criteria were improved by supplementing with Cr (0.50 ppm as Cr-metalosate), most notably in the period immediately before and at calving. However, Subiyatno (1994) observed no changes in colostral immunoglobulin levels or in somatic cell counts in the first 16 weeks of lactation when Holstein cows were supplemented with Cr (0.50 ppm as Cr-amino acid chelate) beginning 2-wk prepartum. The production and metabolic data from this latter study are reported in Yang et al. (1996).

Villalobos et al. (1997) and Romero et al. (1997 unpublished) evaluated the frequency of placental retains in successive years in a Mexican dairy herd

Table 2: Effect of chromium picolinate supplementation on incidence of placental retention

	Villalobos et al., 1997		Romero et al., 1997, unpublished	
	Control	0.24 ppm Cr	Control	0.24 ppm Cr
Number of cows	25	25	40	40
Number of retains	14	4	20	6
Percentage	56	16	50	15

Within an experiment, means differ $P < 0.01$.

that had been experiencing a high incidence of this problem. Chromium picolinate (3.5 mg per head daily) was top-dressed onto silage based diets beginning 9 wk prior to expected calving date. As shown in Table 2, a dramatic reduction in placental retains was achieved. Information on dietary concentrations of key trace nutrients, such as Se and vitamin E, were not provided.

Lipid Metabolism and Metabolic Disorders

Perhaps the most consistently reported metabolic response to supplemental Cr is altered lipid metabolism. Reductions in circulating concentrations of cholesterol and(or) nonesterified fatty acids (NEFA) are frequently reported in humans and laboratory animals (NRC, 1997), as well as in ruminants (Bunting et al., 1994; DePew et al., 1998; Kitchalong et al., 1995; Yang et al., 1996). It is likely that the more dramatic hypolipidemic effects of organic Cr may be attributable simply to increased glucose tolerance with corresponding reductions in lipolysis. Although supplemental Cr has not consistently altered measured glucose tolerance (Bunting et al., 1994; Bunting et al., 1999; DePew et al., 1998; Kegley et al., 1997; Kitchalong et al., 1995; Subiyatno et al., 1996), the balance of these data suggests that supplemental Cr probably enhances glucose clearance in the ruminant.

In early lactation, increased insulin effectiveness may have significant health and performance implications. When cows are undergoing calving stress, are in negative energy balance, and/or are over-conditioned, excessive adipose mobilization may lead to accumulation of triglycerides in the liver and reduced liver function (Grummer, 1993). In addition, there is generally a strong association between fatty liver and the development of ketosis. Insulin generally reduces lipolysis (decreasing the supply of fatty acids to the liver), decreases hepatic ketogenesis and increases ketone body utilization. Supplemental Cr has been shown to reduce lipid concentrations in the livers of obese mice (Li and Stoecker, 1986). Although NEFA were not affected, Besong et al. (1996) observed a 45% reduction in plasma beta-hydroxybutyrate and an almost 50% reduction in liver triglyceride concentrations on day 30 of lactation in Holstein cows fed Cr (0.8 ppm as Cr-picolinate), beginning 30 days prepartum. Yang et al. (1996) also observed trends for reduced blood beta-hydroxybutyrate concentrations in multiparous but not primiparous cows.

Milk Yield

At first glance, there would seem to be little reason to anticipate that supplemental Cr would increase growth or milk production in ruminants. Insulin seems to have little anabolic effect on muscle tissue of growing ruminants. Moreover, glucose uptake by the mammary cells appears to be independent of the action of insulin. In addition, circulating insulin concentrations are generally higher in low-yielding compared with high-yielding dairy cows (Sartin et al., 1988). The collective data for studies using growing ruminants shows little promise for a growth or lean tissue promoting effect of supplemental Cr. In contrast, emerging data from lactation studies (Table 3) suggests that supplemental Cr may increase milk yield under certain metabolic circumstances. In the previously mentioned study of Yang et al. (1996), two experiments were reported in which supplemental Cr increased early lactation milk production in primiparous but not in multiparous cows. Although they did not report differences between primiparous and multiparous cows, Besong et al. (1996) also observed increased milk yield in the

Table 3: Milk production by cows given supplemental organic chromium.

	Yang et al., 1996 (two trials)				Besong et al., 1996*	
	Primiparous cows*		Multiparous cows			
	Control	Cr	Control	Cr	Control	Cr
No. of cows	15	15	20	20	12	12
Cr level	5 mg/d	5 mg/d	5 mg/d	5 mg/d	0.8 ppm	0.8 ppm
Duration, wk	16	16	16	16	8	8
Milk production. lbs	53.2	58.5	80.5	80.2	72.8	74.4

*$P < .05$

first 60 days of lactation in cows supplemented with Cr. To date, there are no published reports of the effects of Cr on performance for an entire lactation.

It is not yet clear how supplemental Cr may increase milk yield in early lactation. A slight reduction in the rate of mobilization of fatty acids from adipose tissue may simply help stabilize hepatic fat metabolism, reduce hepatic ketogenesis, and perhaps allow feed intake to increase more rapidly after calving. In the study of Besong et al. (1996), increased milk yield was accompanied by increased feed intake; however, feed intake was not affected by supplemental Cr in the study of Yang et al. (1996).

Yang et al. (1996) postulated that increased milk yield may be the result of the indirect effects of Cr on hepatic glucose production (gluconeogenesis). Conversion of propionate to glucose has increased during i.v. propionate infusion tests in early lactation heifers (Subiyatno et al., 1996) and stressed rams (Sano et al., 1996) fed supplemental Cr. In our work at LSU, we also observed proportional increases in glucose production following propionate infusion in animals given supplemental Cr (Bunting et al., 1999); however, we hypothesize alternative explanations for this finding. Moreover, gluconeogenesis is a metabolic event that is essentially opposed to increased insulin sensitivity. As suggested by Yang et al. (1996), Cr may promote the activity of IGF receptors, which have structural and functional homology to the insulin receptor. Such a direct effect on mammary synthetic capacity is more consistent with observed milk production responses. Also, trends for increased circulating IGF-I with Cr supplementation were observed in the propionate loading tests of Subiyatno et al. (1996).

Fertility

Organic Cr seems to have proven efficacy for increasing reproductive performance in swine (Trout, 1995). Increasing the level or effectiveness of insulin generally has positive effects upon the reproductive axis. Therefore, it seems quite plausible that dairy cow fertility also may be positively influenced by improved insulin effectiveness. The only available report regarding Cr and bovine fertility (Yang et al., 1996) suggests that supplementation with organic Cr may reduce days open in Holstein cows. However, the limited number of cattle in that study precludes further speculation.

IMPLICATIONS OF CHROMIUM FOR DAIRY CALVES

Convincing evidence exists that intensively-fed veal calves eventually become markedly insulin resistant, resulting in elevated concentrations of insulin and glucose in the blood (Hostettler-Allen et al., 1994). Under these conditions, there is the potential urinary spillage of blood glucose and reduced efficiency.

Although such exaggerated changes in insulin and blood glucose are unlikely in conventionally reared dairy calves, it is plausible that these calves also become marginally insulin insensitive as weaning nears. Furthermore, given the susceptibility of neonatal calves to poor immune function and disease, one might project these animals to be particularly responsive to supplemental Cr. Kegley and Spears (1997) fed only milk replacer to Holstein bull calves through 64 days of age. Although glucose kinetic data were inconclusive, immune function seemed to be improved by supplementing with 0.4 ppm Cr-nicotinate.

As has been true for growth performance variables for both growing dairy replacements and feedlot cattle, supplemental Cr has not affected the feed intake or growth performance of young dairy calves. This has been true whether the calves were conventionally reared on a milk/starter regimen (DePew et al., 1997; 1998; Crochet et al., 1999) or were given milk only (Bunting et al., 1999; Kegley et al., 1997) and irrespective of dietary nutrient content.

To date, the conventional i.v. glucose tolerance test has been the primary method of measuring the effects of nutritional modifications on glucose utilization in livestock. However this methodology has been only marginally successful in detecting the effects of Cr on glucose usage and insulin function in ruminants. DePew et al. (1997) were able to detect an effect of Cr on insulin function in preweaned dairy calves with a limited application of the Minimal Model i. v. glucose tolerance test (Bergman, 1997), which utilizes a computer modeling procedure that was developed for evaluating glucose effectiveness and insulin sensitivity in humans. Using this model, Bunting et al. (1999) were able to measure wide differences in glucose clearance between control and Cr-supplemented calves receiving an all milk diet. Interestingly, model output from this latter study suggested that Cr may have greater effects on insulin secretion than on insulin sensitivity.

FUTURE OF CHROMIUM IN DAIRY NUTRITION

Because Cr is essential for the normal functioning of insulin, all physiological functions in which insulin plays a critical role have the potential to be influenced by a deficiency of Cr. Consequently, it is valid to consider Cr an essential dietary micronutrient, at least for high producing or intensively-reared ruminants. Even with no measurable benefit to growth performance, supplemental Cr will likely have a place in the diet of the young dairy calf, given its inherent susceptibility to stress and disease. For other non-lactating species and classes of ruminants, however, the routine inclusion of supplemental Cr in the diet depends upon demonstration of cost-effective improvements in animal health.

Although the data are limited, the performance and multiple health-related benefits of organic Cr for the early lactation cow are compelling and physiologically reasonable. As such, it seems likely that supplemental Cr should be considered in future lactation rations on an appropriate cost-benefit basis. The cost sensitivity of supplemental Cr for lactating rations depends upon dietary levels of immunomodulatory micronutrients, such as Se and vitamin E, as well as dietary levels of lipotropic micronutrients, such as methionine, choline, and niacin. Given the complexity of analysis and bioavailability assessment for Cr, it is very unlikely that a true requirement will be determined for any class of ruminant livestock. A reasonable estimate would be one to two times the requirement of the pig, or between 0.25 and 0.5 ppm in ration DM. This would result in a daily per cow cost of 5 to 15 cents, depending on the source of Cr used. Remember, however, the FDA currently does not permit the supplementation of ruminant diets with Cr.

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