Chromium Supplementation in Cattle Diets

Jerry W. Spears[1]
Department of Animal Science
North Carolina State University

Introduction

In the late 1950's Schwartz and Mertz (1959) reported that trivalent chromium (Cr) was an essential component of a factor in brewer's yeast that corrected impaired glucose metabolism in rats fed certain diets. Subsequent studies demonstrated that Cr functioned as a potentiator of insulin action (Vincent, 2001). Considerable research has been conducted with Cr in human nutrition and an adequate intake of Cr has been established for humans by the Institute of Medicine (DRI, 2001).

Chromium requirements for cattle have been estimated by the National Research Council (NRC). Traditionally, practical diets fed to domestic animals were assumed to provide sufficient Cr to meet animal requirements. However, in the past 15 years a number of studies in cattle and other species have indicated that Cr supplementation of diets can affect animal metabolism and production criteria.

Although considerable research has been conducted with Cr in cattle, only recently has Cr supplementation been allowed in cattle diets. The FDA CVM issued a regulatory discretion letter in July of 2009 which permitted the use of Cr propionate as a source of Cr in cattle diets. Chromium propionate is the only Cr source currently permitted for supplementation to cattle diets in the U.S. It can be added at levels up to 0.50 mg Cr/kg of complete diet.

This paper will discuss responses that have been observed to supplementation with various forms of Cr in dairy and beef cattle. In addition to Cr propionate (CrProp), Cr picolinate (CrPic), Cr methionine (CrMet), Cr amino acid chelate (CrAA), Cr yeast (CrY), Cr nicotinic acid complex (CrNic), and inorganic $CrCl_3$ have been evaluated experimentally in cattle. It is unclear how different sources of Cr compare in regard to bioavailability.

Chromium and Insulin Action

Glucose tolerance tests have been conducted in cattle to evaluate the effects of Cr on glucose and insulin metabolism. In these studies a glucose solution has been infused intravenously (iv) and circulating concentrations of glucose and insulin measured frequently until they returned to baseline values. The addition of CrPic (Bunting et al., 1994) or CrProp (Sumner et al., 2007) to diets of growing calves has increased glucose clearance rates following glucose infusion without affecting serum

[1] Contact at: Department of Animal Sciences, 123 Polk Hall, PO Box 7621, North Carolina State University, Raleigh, NC 27695-7621; Email: jerry_spears@ncsu.edu

insulin concentrations. Supplementing a milk replacer diet with 0.4 mg Cr/kg of dry matter (DM), from either $CrCl_3$ or a Cr nicotinic acid complex (CrNic) did not affect glucose clearance rate following a glucose infusion in young calves with undeveloped rumens (Kegley et al., 1997a). However, insulin concentrations were lower following glucose administration in calves supplemented with $CrCl_3$, suggesting increased insulin sensitivity in this group.

We recently examined the effect of level of supplemental Cr from CrProp on glucose metabolism in growing heifers. Chromium was supplemented at 0, 3, 6, or 9 mg Cr/head/day. These daily levels corresponded to 0, 0.47, 0.94, and 1.42 mg Cr supplemented/kg diet DM. Serum insulin concentrations and insulin:glucose ratios were much lower in all Cr-supplemented groups the first 15 minutes following glucose infusion (Figure 1). The lower release of insulin and decreased insulin:glucose ratio in Cr-supplemented heifers indicates that their tissues were more sensitive to insulin. Insulin concentrations and insulin:glucose ratios did not differ among heifers supplemented with 0.47, 0.94, and 1.42 mg Cr/kg DM. This suggests that Cr requirements of growing heifers do not exceed 0.47 mg Cr/kg DM.

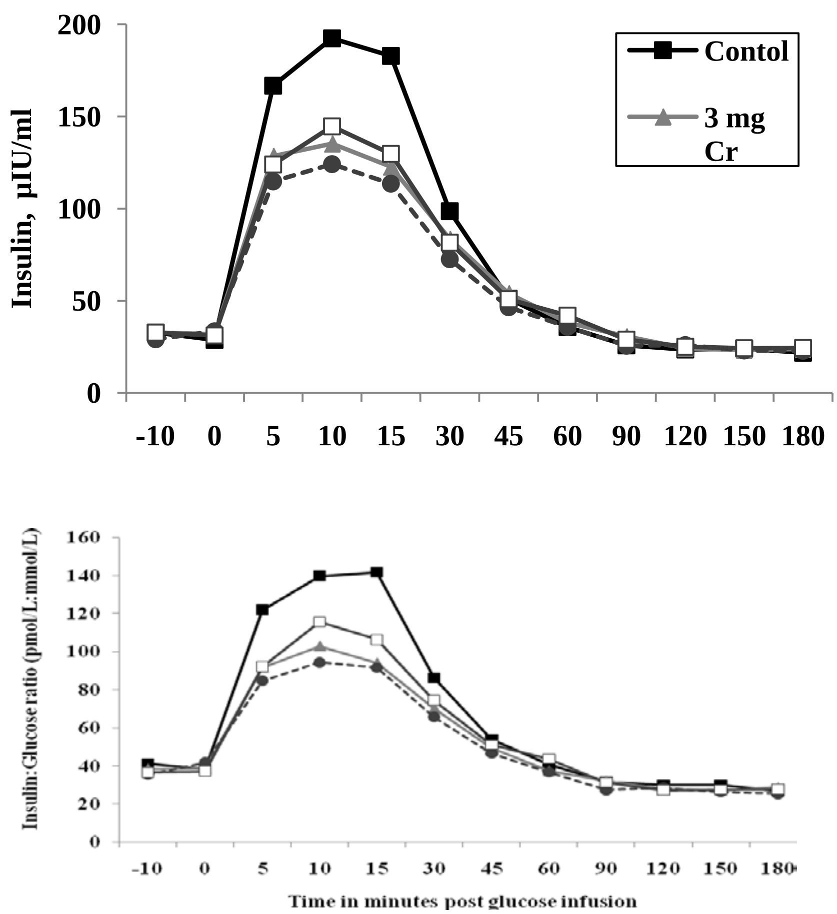


Figure 1. Effects of dietary chromium propionate on serum insulin concentrations and insulin:glucose ratios in heifers following a glucose tolerance test

There has been interest in the effect of Cr on insulin sensitivity in transition dairy cows because insulin resistance occurs in late gestation and continues during early lactation in both dairy (Sano et al., 1993) and beef cows (Sano et al., 1991). Subiyatno et al. (1996) found that supplementation of 0.5 mg Cr/kg diet, from CrAA, appeared to increase insulin sensitivity in primiparous dairy cows but not in multiparous cows at approximately 14 days prepartum. This was based on reduced insulin release and lower insulin:glucose ratios following iv glucose administration. Hayirli et al. (2001) supplemented multiparous cows with varying concentrations of CrMet from 21 days prepartum until 28 days postpartum, and conducted glucose tolerance tests at approximately 10 days prepartum and 28 days postpartum. Chromium supplementation did not affect glucose clearance or serum insulin concentrations prepartum. In postpartum cows, peak glucose concentrations and serum insulin concentrations were lower following iv glucose infusion in cows supplemented with 3.7 or 7.7 mg Cr/day compared with controls (Hayirli et al., 2001). Multiparous beef cows provided CrPic in a free choice mineral had lower insulin release following glucose infusion than control cows at approximately 30 days prepartum and 30 day postpartum (Stahlhut et al., 2006a). The lower serum insulin concentrations occurred without a change in glucose clearance indicating increased insulin sensitivity.

Dairy Cattle

Feed Intake and Milk Production

It is well documented that the transition period from 21 days prepartum to approximately 21 days postpartum is a critical period in regard to health and subsequent milk production of high producing dairy cows (Drackley, 1999). Most of the Cr supplementation studies with dairy cows have involved supplementation during the transition period. Supplementation of Cr prepartum has increased prepartum intake in some studies (Hayirli et al., 2001; Sadri et al., 2009) but not in others (Yang et al., 1996; Besong, 1996; Smith et al., 2005; McNamara and Valdez, 2005). Supplementation of 0, 3.9, 8.3 and 16.5 mg Cr/day from CrMet resulted in a linear increase in prepartum DM intake (Hayirli et al., 2001). Sadri et al. (2009) reported that supplementation with CrMet (approximately 10 mg Cr/day) increased prepartum DM intake when barley was used as the grain source but not when corn served as the prepartum grain source.

Supplementation of 0.5 mg Cr/kg diet from CrAA increased milk yield in primiparous dairy cows in two separate experiments (Table 1; Yang et al., 1996). Chromium was supplemented during both experiments from 6 weeks prepartum to 16 weeks postpartum.

Table 1. Effect of chromium (Cr amino acid chelate) supplementation on feed intake and milk production of primiparous cows[a,b]

	Control	+Cr	P-value
Exp 1			
n	6	6	
Milk, kg/d	24.3	27.5	0.06
DMI, kg/d	16.4	16.8	0.76
Cows open	3/6	0/6	0.05
Exp 2			
n	9	9	
Milk, kg/d	24.1	25.7	0.03
DMI, kg/d	15.1	15.5	0.43
Cows open	2/9	1/9	0.53

[a]Adapted from Yang et al., (1996).
[c]Chromium was supplemented from 6 weeks prepartum until 16 weeks postpartum in both experiments. In experiment 1, chromium was supplemented at 5.5 mg Cr/cow prepartum and 10 mg Cr/cow postpartum. In experiment 2, cows were supplemented with 4.25 mg Cr/cow prepartum and 7.75 mg Cr/cow postpartum.

Besong (1996) supplemented multiparous and primiparous cows with 0 or 0.8 mg Cr/kg diet, as CrPic, from 30 days prepartum to 8 weeks postpartum. Performance results were not presented by parity in this study but parity was included in the statistical model. Chromium supplementation increased average milk yield from 31.1 to 33.4 kg/day. Feed intake was higher in Cr-supplemented cows during weeks 2, 3, 4, 5, and 6 of lactation.

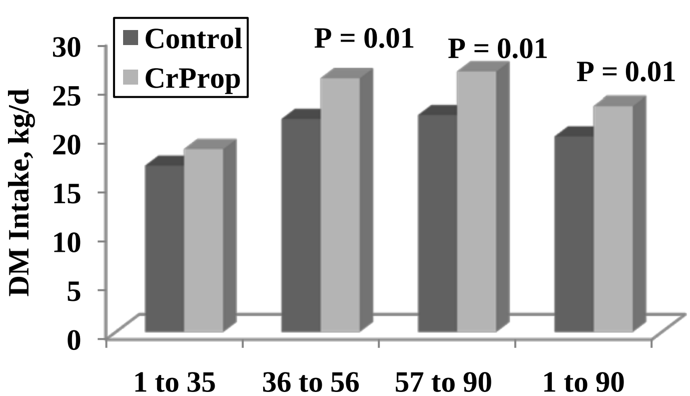
Multiparous cows supplemented with CrMet from 21 days prepartum through early lactation had higher DM intake and milk production during the first 28 days in milk (Table 2; Hayirli et al., 2001; Smith et al., 2005). Sadri et al. (2009) reported that grain source used in the pre and postpartum diets affected responses to supplemental CrMet. Chromium supplementation, at a level of approximately 10 mg/day, increased DM intake and milk production during the first 28 days in milk when barley was used as the grain source in the total mixed ration (TMR). Feed intake and milk production were not affected by Cr addition when corn was used in the TMR. Yang et al. (1996) observed no DM intake or milk production response to Cr supplementation with CrAA in multiparous cows. However, in these same experiments Cr supplementation improved milk yield in primiparous cows. Estimated net energy for lactation (1.59 Mcal/kg DM) was lower in the lactation diets used by Yang et al. (1996) compared to other studies (1.67 to 1.74 Mcal/kg DM) with multiparous cows fed harvested feeds. It is unclear if feed intake and milk production responses to supplemental Cr are affected by dietary energy level. However, Cr supplementation from either CrPic (Peterson, 2000) or CrMet (Bryan et al., 2004) did not affected milk production in grazing dairy cows where forage was the major source of energy.

Table 2. Effects of supplementation with chromium methionine during the transition period on feed intake and milk production in early lactation

	Supplemental chromium, mg/kg BW$^{0.75}$			
	0	0.03	0.06	0.09
Hayirli et al. (2001)				
Cows, n	10	10	10	11
DM intake, kg/d[a]	13.8	14.9	17.2	16.3
Milk, kg/d[b]	33.5	34.0	38.5	31.8
Smith et al. (2005)				
Cows, n	22	25	25	
DMI, kg/d[a]	18.2	18.9	19.7	
Milk, kg/d[c]	40.3	40.5	42.8	

[a]Linear effect of Cr ($P < 0.01$).
[b]Quadratic effect of Cr ($P < 0.05$).
[c]Linear effect of Cr ($P < 0.05$).

Supplementing with Cr during the transition period may increase feed intake and milk production later in lactation even if Cr supplementation is discontinued. McNamara and Valdez (2005) supplemented dairy cows with CrProp from 21 days prepartum until 35 days postpartum. After CrProp was removed from the diet on day 35, DM intake and milk production continued to be monitored through 90 days in milk (Figure 2). Numerical increases in DM intake and milk yield were observed in Cr-supplemented cows the first 35 days of lactation. However, differences in intake and milk production between control and Cr-supplemented cows were greater from days 36-90 of lactation even though Cr was no longer being supplemented.



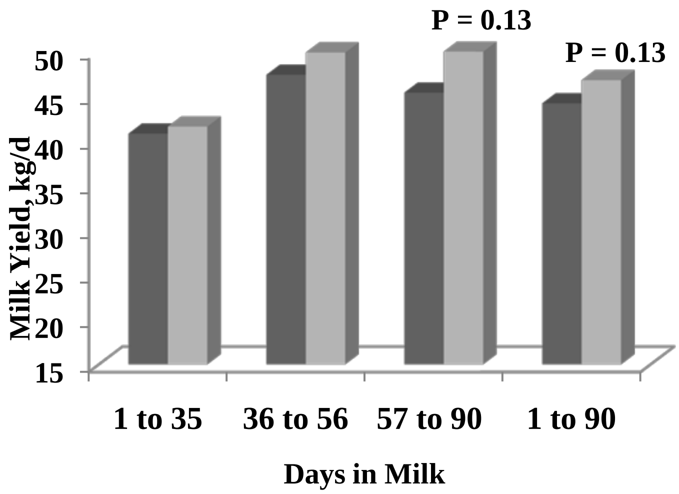


Figure 2. Effects of supplementing chromium propionate from 21 days pre until 35 days postpartum on DM intake and milk production. Adapted from McNamara and Valdez (2005).

Studies in humans and rodents suggest that stress increases Cr requirements. Recently, Cr has been evaluated in lactating dairy cows under heat stress conditions. In Saudi Arabia, supplementation of dairy cows in mid lactation with CrY (4 mg Cr/day) increased DM intake by 1.6 kg/day and milk production by 3.3 kg/day (Al-Saiady et al., 2004). Supplementation of heat-stressed dairy cows with CrPic during early lactation in China also increased DM intake and milk production (AnQiang et al., 2009).

Reproduction

Limited research indicates that Cr supplementation may improve reproduction in dairy cattle. Chromium supplementation reduced the number of open cows in one of two experiments with primiparous dairy cows (Table 1) but not in multiparous cows (Yang et al., 1996). Pregnancy rate tended to be higher in intensively grazed dairy cows supplemented with CrMet than in controls (Bryan et al., 2004).

Immunity and Health

Studies in periparturient dairy cows indicate that Cr supplementation of practical diets may affect cell-mediated and humoral immune responses. Lymphocytes from cows supplemented with 0.5 mg Cr/kg diet, from CrAA, had increased blastogenic responses to concavalin A stimulation (Burton et al., 1993). Furthermore, Cr supplementation prevented the decrease in blastogenic response that was observed in control cows 2 weeks prepartum. Chromium supplementation also improved primary and secondary antibody response to ovalbumin administration but not antibody response to human erythrocytes (Burton et al., 1993). The primary injection of ovalbumin and human erythrocytes was given 2 weeks prepartum and the secondary injection was administered 2 weeks postpartum. Supplementation with 5 mg Cr/day increased antibody responses following vaccination with tetanus toxin in dairy cows

(Faldyna et al., 2003). Neutrophil function has not been affected by dietary Cr (Chang et al., 1996; Faldyna et al., 2003).

Studies examining the effects of dietary Cr on health in dairy cows are limited. Supplementing 3.5 mg Cr/day (from CrPic) during the last 9 weeks of pregnancy reduced the incidence of retained placenta, in a dairy herd with a high incidence of retained placenta, from 56 to 16% (Villalobos-F et al., 1997). Chromium supplementation (CrAA) prepartum and during the first 16 weeks of lactation did not affect mammary gland health status (Chang et al., 1996).

Chromium may affect incidence of ketosis by enhancing insulin sensitivity. Insulin is an anabolic hormone that promotes lipogenesis and inhibits lipolysis. Supplementation of dairy cows with CrMet has reduced circulating nonesterified fatty acids (NEFA) concentrations at 7 to 10 days prepartum in some studies (Bryan et al., 2004; Hayirli et al., 2001) but not in others (Smith et al., 2008). Dairy cows supplemented with CrPic had lower plasma concentrations of β- hydroxybutyate than controls at 3 and 30 days postpartum (Besong, 1996). Liver triglyceride concentration were also lower in Cr-supplemented cows at 30 days postpartum (Besong, 1996). Chromium supplementation has not affected clinical cases of ketosis in lactation studies that have reported health-related disorders (Chang et al., 1996; Yang et al., 1996; Smith et al., 2005).

Beef Cattle

Health and Performance of Stressed Calves

Research at the University of Guelph in the 1990's suggesting that Cr supplementation could affect performance and morbidity in stressed calves generated considerable interest in Cr in ruminant nutrition. A summary of Cr studies with calves that had been stressed, due to transportation and other factors associated with shipping (weaning, feed restriction, etc), is presented in Table 3. Performance and morbidity results shown represent data from the first 28 days after arrival in the feedlot. Chromium supplementation in the form of CrY or CrAA reduced incidence of morbidity following transportation in some studies (Moonsie-Shageer and Mowat, 1993; Mowat et al., 1993), but not in other trials (Chang and Mowat, 1992; Chang et al., 1995; Mathison and Engstrom, 1995). As expected, performance of calves during the receiving phase also has been improved by Cr in studies where Cr supplementation reduced morbidity (Moonsie-Shageer and Mowat, 1993; Mowat et al., 1993). Chromium supplementation has tended to increase gain in some studies (Chang and Mowat, 1992; Wright et al., 1994) where morbidity was not affected by Cr.

Table 3. Influence of supplementing chromium during the receiving period on performance and morbidity in stressed calves

	Supplemental Cr, mg/kg DM				
	0	0.2	0.5	0.75	1.0
Chang and Mowat (1992)					
Cr source - CrY					
Animals, n	53	53			
ADG, kg	0.70	0.80			
DMI, kg	4.92	5.37			
Morbidity, %	20.3	19.7			
Moonsie-Shageer and Mowat (1993)					
Cr source - CrY					
Animals, n	21	21	21		21
ADG, kg	0.66^{a}	0.84^{b}	$0.70^{a,b}$		0.84^{b}
DMI, kg	3.99^{a}	4.66^{b}	3.91^{a}		4.57^{b}
Morbidity, %	52.4^{a}	14.3^{b}	33.3^{a}		47.6^{a}
Mowat et al. (1993)					
Cr sources – CrY & CrAA		0.5 CrY	0.5 CrAA		
Animals, n	18	17	18		
ADG, kg	0.62	0.71	0.70		
DMI, kg	4.03	4.10	4.41		
Morbidity, %	55.6^{a}	$33.3^{a,b}$	11.1^{b}		
Wright et al. (1994)					
Cr source - CrAA					
Animals, n	65	65			
ADG, kg	1.29	1.40			
DMI, kg	5.35	5.51			
Morbidity, %	57.3	49.3			
Chang et al. (1995)					
Cr source – CrY					
Animals, n	27			27	
ADG, kg	0.43			0.50	
DMI, kg	4.5			4.6	
Morbidity, %	44			41	
Mathison and Engstrom (1995)					
Cr source - CrAA					
Animals, n	95		96		
ADG, kg/d	1.16		1.16		
DMI, kg	4.74		4.72		
Morbidity, %	39		36		

[a,b]Means in a row not sharing a common superscript differ ($P < 0.05$).
ADG = average daily gain; DMI = dry matter intake.

The effects of dietary Cr on physiological response of calves to an experimental disease challenge have also been evaluated. Chromium supplementation was provided for 49 to 75 days before disease challenge in these studies. Calves supplemented with 0.4 mg Cr/kg diet (as either CrNic or $CrCl_3$) tended to have lower body temperatures at certain time points after intranasal inoculation with infectious bovine rhinotracheitis virus (IBRV) followed by *Pasteurella haemolytica* intratracheally 5 days later (Kegley et al., 1996). Supplementing calves with 0.4 mg Cr/kg diet, as CrNic, for 56 days before transportation did not affect body temperature or feed intake responses to an IBRV challenge (Kegley et al., 1997b). Rectal temperature responses also were not affected by CrY supplementation in calves inoculated with IBRV (Arthington et al., 1997).

Stress results in elevated blood concentrations of cortisol which is known to depress immune functions. Chromium supplementation in cattle decreased serum cortisol concentrations in some studies with stressed cattle (Chang and Mowat, 1992; Moonsie-Shageer and Mowat, 1993; Kegley et al., 1996), but not in others (Kegley and Spears, 1995; Kegley et al., 1997b). When serial blood samples were obtained from jugular-cannulated calves at 4-hour intervals for 6 days, Cr supplementation from CrY did not affect serum cortisol concentrations following inoculation with IBRV (Arthington et al., 1997).

Reproduction

Chromium has affected reproduction in beef cows grazing pastures. Providing CrPic in a free choice mineral improved pregnancy rate in beef cows (Stahlhut et al., 2006b). The improvement in reproduction was due to increased pregnancy rate in cows 5 years of age or younger (Table 4). Chromium did not affect pregnancy rate in beef cows 6 years of age or older. The improved pregnancy rate was associated with much lower plasma NEFA concentrations at approximately 21 and 79 days postpartum in Cr-supplemented cows (Stahlhut et al., 2006a). Chromium supplementation reduced postpartum body weight loss in 2 and 3-year old cows but not in older cows (Stahlhut et al., 2006b). Supplementation of CrY in a free choice mineral reduced the interval from calving to first estrus and tended to improve pregnancy rate in primiparous Zebu beef cows in Brazil (Aragon et al., 2001). Body weight gain was also greater in Cr-supplemented cows from parturition until their calves were weaned (Aragon et al., 2001). Reproductive responses to Cr may relate to its ability to increase insulin sensitivity. Insulin administration improved ovulation rate in energy-deprived heifers (Harrison and Randel, 1986).

Table 4. Effects of chromium supplementation on body weight (BW) change and pregnancy rate in beef cows[a]

	Treatment		
	Control	Chromium	P-value
BW change, kg (September-June)			
Overall[b]	-70.2	-56.7	0.01
≥ 6 years of age	-66.9	-73.1	0.33
4 and 5 –year olds	-69.3	-60.0	0.23
2 and 3-year olds	-74.4	-37.1	0.01
Pregnancy rate, %			
Overall	81	89	0.06
≥ 6 years of age	86(28)[c]	83(29)	0.76
4 and 5 –year olds	74(19)	90(20)	0.19
2 and 3-year olds	81(26)	96(24)	0.13

[a]Adapted from Stahlhut et al. (2006b). Study was conducted from approximately 75 d prepartum (September) until calves were weaned in June.
[b]Treatment x block interaction (P < 0.01).

Chromium in Feedstuffs

Variation among studies in response to Cr supplementation may relate to differences in Cr content or bioavailability from feedstuffs. Little is known regarding Cr concentrations in practical feedstuffs and even less is known regarding bioavailability of Cr from common feedstuffs. In many Cr studies with cattle the Cr content of the control diets have not been reported. Chromium analysis of diets is challenging due to the low levels of Cr normally present and problems with Cr contamination of feed samples during collection and preparation of samples for analysis (NRC, 2005). We have found most complete diets to contain less than 1 mg Cr/ kg diet DM.

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<u>SESSION NOTES</u>