Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 14 (1)
January 2021
DOI: http://dx.doi.org/10.36560/14120211280
Article link
http://sea.ufr.edu.br/index.php?journal=SEA&page=article&op=view&path%5B%5D=1280&path%5B%5D=pdf
Included in DOAJ, AGRIS, Latindex, Journal TOCs, CORE, Discoursio Open Science, Science Gate, GFAR, CIARDRING, Academic Journals Database and NTHRYS Technologies, Portal de Periódicos CAPES, CrossRef, ICI Journals Master List.

ISSN 2316-9281

Chromium in performance and metabolism of dairy cows

J. R. Assis[12]*

[1]Universidade Federal de Mato Grosso, Cuiabá-MT, Brasil
[2]Centro Universitário FASIPE, Sinop-MT, Brasil

*** Author for correspondence: joaorafael_zootecnista@hotmail.com**

Abstract. The need for refined adjustments to nutritional requirements in dairy cow production systems is a demand for productive efficiency. Dairy cows face severe physiological and metabolic changes as the end of pregnancy and the beginning of lactation, requiring greater attention in nutritional aspects. However, chromium supplementation has been suggested to improve the metabolism of carbohydrates, lipids and proteins. Thus giving potential use for dairy cows. In this context, the objective was to conduct a literature review on the effects of chromium supplementation on the productive performance and metabolism of dairy cows. Therefore, chromium supplementation appears to improve milk production without affecting milk constituents. And apparently chromium supplementation reduces the blood concentration of NEFA. These results can be explained by a possible improvement in insulin metabolism, promoting an increase in insulin sensitivity in adipose tissue, consequently reducing lipolysis. What can change the energy partition in the mammary gland improving the processes of milk synthesis. However, many experimental results are contradictory in the literature, which can be explained by different stages of lactation, chromium source, stress conditions, supplementation period, type and content of carbohydrates in the diet. So in fact, there is a need to conduct a meta-analysis study with the available database to elucidate the real effect of chromium on the performance and metabolism of dairy cows.
Keywords: Micromineral, Insulin sensitivity, Milk production

Introduction

Chromium (Cr) was first described as an essential mineral for normal glucose metabolism in rats by Schwarz and Mertz (1959) and in humans by Jeejebhoy et al. (1977). Apparently, the positive responses of Cr supplementation seem to be related to the change in the energy partition (Vargas-Rodriguez et al., 2014; Leiva et al., 2015) due to a potentiating effect of the action of insulin (Vincent, 2001).

Traditionally, conventional diets were supposed to meet the nutritional requirements of Cr in farm animals. However, studies suggest that Cr supplementation affects glucose and / or lipid metabolism (Gentry et al., 1999; Hayirli et al., 2001; Sumner et al., 2007). Fact that can be used to modulate animal metabolism and improve the production of ruminants.

The demand for Cr is typically increased during different forms of stress such as nutritional, metabolic and physical (Pechova and Pavlata, 2007). During the prepartum, delivery, lactogenesis and galactopoiesis periods, great metabolic stress is generated, causing immunosuppression and metabolic overload in dairy cows (Spears, 2000; NRC, 2001; Gulpete, 2018). Cr is involved in many metabolic functions (Mertz, 1993; Bryan et al., 2004; Vargas-Rodriguez et al., 2014) and is essential for the normal metabolism of carbohydrates, lipids and proteins (Vincent, 2004).

Therefore, Cr supplementation in dairy cows can have positive effects on metabolism and productive performance. Thus, the aim was to conduct a literature review to assess the effects of Cr on the metabolism and performance of dairy cows.

Therefore, Cr supplementation in dairy cows can have positive effects on metabolism and productive performance. Thus, the aim was to conduct a literature review to assess the effects of Cr on the metabolism and performance of dairy cows.

Contextualization and Analysis

Chromium

Cr is a mineral that can be found in very low concentrations in natural ingredients commonly used in diets for farm animals (Bailey, 2014). It can be naturally detected in different oxidation states from -2 to +6, however with a greater predominance of hexavalent (Cr^{6+}) and trivalent (Cr^{3+}) Cr. Trivalent

chromium is the most stable form found in living beings, considered a highly safe form of chromium (Lindeman, 1996). However, hexavalent chromium is mainly of industrial origin and is associated with chromium toxicity (Amata, 2013). Currently several forms of organic Cr are described in the literature as Cr-Propionate, Cr-methionine, Cr-picolinate, Cr-nicotinic acid complex and Cr-yeast.

According to Gäbel et al. (1987), the absorption of Cr in the rumen is negligible and the recovery of Cr in the rumen varies between 92 to 99%. Although most studies are conducted with rats, it has been suggested that Cr absorption occurs in the proximal part of the jejunum (Khan et al., 2014), duodenum and in the ileum (Chen et al., 1973).

Different factors can affect the absorption of Cr, however it is well accepted that the absorption and bioavailability of organic sources are better than inorganic sources (Lukaski, 1999; Zha et al., 2009). In the literature it is reported that the bioavailability of inorganic Cr is between 1 and 3%, while organic Cr is about 10 to 30 times more available (Forbes and Erdman, 1983). The low bioavailability of inorganic Cr is probably related to the formation of non-soluble Cr oxides (Chen et al., 1973; Pechova and Pavlata, 2007), due to interference in the ion forms of other minerals (Pechova and Pavlata, 2007), bonding Cr to natural forage compounds (Borel and Anderson, 1984; Pechova and Pavlata, 2007), or the slow conversion of inorganic Cr to bioactive form (Ranhotra and Gelroth, 1986).

Chromium role in metabolism

Currently, it is described that chromium acts on the activation of insulin via cromodulin, an oligopeptide consisting of glycine, cysteine, aspartate and glutamate (Yamamoto, et al., 1987). This oligopeptide is a cofactor for the action of insulin, mediated by stimulating the activity of protein tyrosine kinase, an insulin receptor (Ducros, 1992; Davis et al., 1996; Davis and Vincent, 1997). The stimulating effect of chromodulin seems to occur without affecting insulin concentration, indicating that this oligopeptide has an intrinsic role in insulin sensitivity (Khan et al., 2014), promoting a self-amplifying mechanism of insulin signaling (Vincent, 2000).

In adipose tissue, it is suggested that the action of insulin is mediated by the activation of phosphotyrosine phosphatase in the adipositary membrane (Ducros, 1992; Vincent, 2000; Davis et al., 1996) increasing glucose uptake. Additionally, the activation of this intracellular signaling pathway increases the rate of glucose uptake and positively regulates the levels of mRNA of the insulin receptor, type 4 glucose transporter (GLUT4), glycogen synthase and uncoupling protein-3 in skeletal muscle cells (Davis et al., 1996), consequently improving insulin sensitivity, increasing the rate of glucose and amino acid uptake.

Productive performance

Diets for dairy cows can contain sufficient concentrations of Cr to meet the demands during a normal production period, but can become deficient in critical situations such as, late pregnancy, delivery, early lactation, weaning and transport (Sano et al., 1991; Mousaie et al., 2014; Vargas-Rodriguez et al., 2014; Yuan et al., 2014).

In the experiment by Kafilzadeh et al. (2012), supplementing chromium in multiparous dairy cows at the beginning of lactation, reported that MP was not affected. Soltan (2010) and Nikkhah et al. (2011) investigating the effect of Cr supplementation on the performance of multiparous dairy cows reared under heat stress at the beginning of lactation, reported that MP and DMI in cows supplemented with Cr were greater than the control group. Similarly in the experiment by Al-Saiady et al. (2004) with multiparous dairy cows in mid-lactation raised under thermal stress, it was reported that DMI and PM were higher for the group of cows supplemented with Cr. However, experiments using Cr supplementation for dairy cows demonstrate inconsistent results (Table 1).

Composition of milk in lactating dairy cows

Several experiments evaluated the effects of Cr supplementation on the milk composition of dairy cows (Table 2). In general, it is reported that the fat, lactose, protein and non-fat solid content of milk was not affected by the addition of Cr in the diet (Yang et al., 1996; Soltan, 2010; Vargas-Rodriguez et al., 2014; Yasui et al., 2014). However, Kafilzadeh et al. (2012) reported that the lactose content in milk increased when the diet of multiparous dairy cows at the beginning of lactation was supplemented with Cr. Al-Saiady et al. (2004) reported that Cr levels in the diet did not affect the milk composition of multiparous dairy cows stressed by heat in the middle of lactation. In contrast Nikkhah et al. (2011) reported an increase in protein, fat and lactose content with Cr supplementation for cows under heat stress. However, other investigations have described that Cr supplementation did not influence the fat, protein and lactose content of milk in primiparous dairy cows (Yang et al., 1996; Bryan et al., 2004; Smith et al., 2005).

Blood parameters

There are conflicting reports regarding the effects of Cr supplementation on the serum parameters of dairy cows (Table 3). Kafilzadeh et al. (2012) investigated the effect of Cr supplementation on the serum parameters of multiparous dairy cows at the beginning of lactation and reported that Cr supplementation caused an increase in glucose and insulin and decreased concentrations of non-esterified fatty acids (NEFA), but not there was an effect on cortisol by Cr supplementation. Soltan (2010) reported that Cr supplementation decreased the level of cortisol and NEFA in multiparous dairy cows in the prepartum period, although glucose and insulin concentrations were not affected.

Table 1: Effects of chromium supplementation on performance of lactating dairy cows.

Parity, lactation stage and period (day)	Chromium source and level	Results	Reference
Primiparous and multiparous, prepartum (42 days), and postpartum (21 days)	Chromium maethionine (0, 6.25 mg/day)	MP did not change	Bryan et al. (2004)
Multiparous, prepartum (21 days)	Chromium propionate (0, 8 mg/day)	DMI and BW did not change	Yasui et al. (2014)
Multiparous, early lactation (63 days)	Chromium propionate (0, 8 mg/day)	DMI, MP and BW did not change	Yasui et al. (2014)
Multiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	DMI, FBW, and MP did not change	Yang et al. (1996)
Primiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	FBW decreased, but DMI and MP did not change	Yang et al. (1996)
Primiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	MP increased, but DMI and FBW did not change	Yang et al. (1996)
Multiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	DMI, FBW, and MP did not change	Yang et al. (1996)
Primiparous and multiparous, early lactation (225 days)	Chromium propionate (0, 2.5 g/day)	MP and FBW did not change	Leiva et al. (2015)
Primiparous and multiparous, early lactation (28 days)	Chromium methionine (0, 0.03, 0.06 mg/kg metabolic BW)	DMI, MP, and BW increased	Smith et al. (2005)
Primiparous and multiparous, prepartum (21 days)	Chromium methionine (0, 0.03, 0.06 mg/kg metabolic BW)	DMI and BW did not change	Smith et al. (2005)
Multiparous, prepartum (21 days) and postpartum (21 days), early lactation	Chromium methionine (0, 8 mg/day)	MP did not change	Kafilzadeh et al. (2012)
Primiparous and multiparous, early lactation (49 days)	Chromium methionine (0, 0.05, 0.10 mg/kg of metabolic BW)	Fat corrected milk (4%) and DMI increased	Nikkhah et al. (2011)
Multiparous, prepartum (21 days)	Reared under heat stress Chromium methionine (0, 6 mg/day)	FBW did not change	Soltan (2010)
Multiparous, early lactation (84 days)	Reared under heat stress Chromium methionine (0, 6 mg/day)	MP increased, and DMI in 5–12 weeks postpartum increased, but BW did not change	Soltan (2010)
Multiparous, prepartum (21 days)	Reared under heat stress Chromium propionate (0, 10 mg/day)	DMI did not change	McNamara and Valdez (2005)
Multiparous, early lactation (90 days)	Chromium propionate (0, 10 mg/day)	MP and DMI increased	McNamara and Valdez (2005)
Primiparous and multiparous, early lactation (35 days)	Chromium propionate (0, 8 mg/day)	DMI increased, but MP did not change	Vargas-Rodriguez et al. (2014)
Multiparous, mid lactation (130 days)	Chelated chromium (0, 4 g/day) Reared under heat stress	MP and DMI increased	Al-Saiady et al. (2004)
Primiparous and multiparous, prepartum (28 days) e pospartum (28 days)	Chromium methionine (0, 0.03, 0.06, 0.12 mg/kg metabolic BW)	Increased DMI and MP increase at a dose of 0.03	Hayirli et al. (2001)

DM = dry matter, DMI = dry matter intake, MP = milk production, BW = body weight, FBW = final body weight, Metabolic BW = $BW^{0.75}$.

Table 2: Effects of chromium supplementation on milk composition of lactating dairy cows.

Parity, lactation stage and period (day)	Chromium source and level	Results (%)	Reference
Primiparous and multiparous, prepartum (42 days), and postpartum (21 days)	Chromiummethionine (0, 6.25 mg/day)	Fat, protein, lactose, and solid not fat did not change	Bryan et al. (2004)
Multiparous, early lactation (63 days)	Chromium propionate (0, 8 mg/day)	Fat, protein, lactose, and solid not fat did not change	Yasui et al. (2014)
Primiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	Fat, protein, lactose, and solid not fat did not change	Yang et al. (1996)
Multiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	Fat, protein, lactose, and solid not fat did not change	Yang et al. (1996)
Primiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	Fat, protein, lactose, and solid not fat did not change	Yang et al. (1996)
Multiparous, early lactation (154 days)	Chelated chromium (0, 0.5 mg/kg DM)	Lactose and solid not fat decreased, but fat and protein did not change	Yang et al. (1996)
Primiparous and multiparous, early lactation (28 days)	Chromium methionine (0, 0.03, 0.06 mg/kg of metabolic BW)	Fat, protein, lactose, and solid not fat did not change	Smith et al. (2005)
Multiparous, prepartum (21 days), postpartum (21 days), and early lactation	Chromium methionine (0, 8 mg/day)	Lactose and solid not fat decreased, but fat and protein did not change	Kafilzadeh et al. (2012)
Primiparous and multiparous, early lactation (49 days)	Chromium methionine (0, 0.05, 0.10 mg/kg of metabolic BW)	Fat, protein, lactose, and solid not fat did not change	Nikkhah et al. (2011)
Multiparous, early lactation (84 days)	Reared under heat stress Chromium methionine (0, 6 mg/day)	Fat, protein, lactose, and solid not fat did not change	Soltan (2010)
Multiparous, early lactation (81 days)	Chromium propionate (0, 10 mg/day)	Fat, protein, lactose, and solid not fat did not change	McNamara and Valdez (2005)
Primiparous and multiparous, early lactation (35 days)	Chromium propionate (0, 8 mg/day)	Fat, protein, lactose, and solid not fat did not change	Vargas-Rodriguez et al. (2014)
Multiparous, mid lactation (130 days)	Chelated chromium (0, 4 g/day) Reared under heat stress	Fat, protein, lactose, and solid not fat did not change	Al-Saiady et al. (2004)
Primiparous and multiparous, prepartum (28 days) e pospartum (28 days)	Chromium methionine (0, 0.03, 0.06, 0.12 mg/kg metabolic BW)	Fat, protein, lactose, and solid not fat did not change	Hayirli et al. (2001)

DM = dry matter, BW = body weight, Metabolic BW = $BW^{0.75}$.

Table 3: Effects of chromium supplementation on blood parameters of dairy cows.

Parity and lactation stage	Chromium source and level	Results	Reference
Primiparous and multiparous, prepartum (42 days), and postpartum (21 days)	Chromium methionine (0, 6.25 mg/day)	NEFA decreased, but glucose and BHB did not change	Bryan et al. (2004)
Multiparous, prepartum	Chromium propionate (0, 8 mg/day)	Glucose, insulin, BHB, glucagon, and NEFA did not change	Yasui et al. (2014)
Multiparous, early lactation	Chromium propionate (0, 8 mg/day)	Glucose, insulin, BHB, glucagon, and NEFA did not change	Yasui et al. (2014)
Multiparous, prepartum (21 days) and postpartum (21 days), early lactation	Chromium methionine (0, 8 mg/day)	Glucose and insulin increased, NEFA decreased, but cortisol did not change	Kafilzadeh et al. (2012)
Primiparous and multiparous, early lactation (210 days)	Chromium propionate (0, 2.5 g/day)	NEFA increased, but glucose did not change	Leiva et al. (2015)
Primiparous and multiparous, early lactation (28 days)	Chromium methionine (0, 0.05, 0.10 mg/kg of metabolic BW) Reared under heat stress	Glucose, insulin, glucagon, NEFA, BHB, TG, cholesterol, HDL, and VLDL did not change	Nikkhah et al. (2001)
Multiparous, prepartum (21 days)	Chromium methionine (0, 6 mg/day) Reared under heat stress	Cortisol and NEFA decreased, but glucose and insulin did not change	Soltan (2010)
Multiparous, early lactation (14 to 84 days)	Chromium methionine (0, 6 mg/day) Reared under heat stress	Cortisol and NEFA in 2 and 4 weeks postpartum decreased, but glucose and insulin did not change	Soltan (2010)
Multiparous, mid lactation (120–130 days)	Chromium yeast, (0, 4 mg/day) Reared under heat stress	Glucose did not change	Al-Saiady. (2004)
Primiparous and multiparous, prepartum (21 days)	Chromium methionine (0, 0.03, 0.06 mg/kg of metabolic BW)	Glucose, insulin, glucagon, and NEFA did not change	Smith et al. (2008)
Primiparous and multiparous, early lactation (28 days)	Chromium methionine (0, 0.03, 0.06 mg/kg of metabolic BW)	Glucose, insulin, glucagon, and NEFA did not change	Smith et al. (2008)
Primiparous and multiparous, early lactation lactation (28 days)	Chromium propionate (0, 8 mg/day)	Glucose, insulin, glucagon, and NEFA did not change	Yuan et al. (2014)
Primiparous and multiparous, prepartum (28 days)	Chromium methionine (0, 0.03, 0.06, 0.12 mg/kg metabolic BW)	NEFA decreased, but glucose, BHB and insulin did not change	Hayirli et al. (2001)
Primiparous and multiparous, pospartum (28 days)	Chromium methionine (0, 0.03, 0.06, 0.12 mg/kg metabolic BW)	Insulin decreased, but glucose and NEFA, BHB did not change	Hayirli et al. (2001)
Multiparous, pospartum (15–22 days)	Chromium picolinate (0, 3.6, 7.2 and 10.8 mg/day)	Increased glucose and insulin	An-Qiang (2009)

DM = dry matter, BW = body weight, Metabolic BW = $BW^{0.75}$, NEFA = non-esterified fatty acid, BHB = beta-hydroxyl butyrate, TG = triglyceride, HDL = high density lipoprotein, VLDL = very low density lipoprotein.

However, it was reported that the concentrations of glucose, insulin, glucagon, beta-hydroxybutyrate (BHBA) and NEFA were not affected by Cr supplementation in multiparous dairy cows during the prepartum period (Yasui et al., 1996; Smith et al. ., 2008). Similarly, Yuan et al. (2014) studied the effect of Cr supplementation on some serum parameters in primiparous and multiparous dairy cows in mid-lactation, reported that the concentrations of glucose, insulin, glucagon and NEFA were not affected by Cr supplementation.

Final considerations

The effects of Cr supplementation for dairy cows are inconsistent, making it difficult to determine whether Cr supplementation improves the productive performance of dairy cows.

In some studies, the increase in milk production may be due to the nutritional correction of Cr deficiency or change in the energy partition in the metabolism, increasing the energy availability for milk synthesis. Another mechanism that should be taken into account is that Cr can improve gluconeogenesis, thus increasing the use of glucose for the synthesis of lactose in the mammary gland, consecutively increasing milk production, due to the osmoregulatory effect of lactose.

In general, the composition of the milk does not appear to change. However, in relation to blood parameters, NEFA is the one with the greatest change, promoting a reduction in concentrations. These results suggest that a possible action of Cr on insulin sensitivity in adipose tissue may occur, providing an increase in glucose uptake, consequently increasing lipogenesis and reducing liquid lipolysis. This effect can help explain the energy partition in the metabolism, culminating in increased milk production.

However, the discrepancies between the results of the experiments can be explained by differences in the lactation stage, chromium source, stress conditions, supplementation period, type and content of carbohydrates in the diet. Thus, it is suggested the need to conduct a meta-analysis study with the available published database, to assess the real effect of Cr on the performance and metabolism of dairy cows.

Acknowledgments

To thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting the doctoral scholarship and the National Council for Scientific and Technological Development (CNPq).

References

AL-SAIADY, M. Y.; AL-SHAIKH, M. A.; AL-MUFARREJ, SI.; AL-SHOWEIMI, T. A.; MOGAWER, H. H.; DIRRAR, A. Effect of chelated chromium supplementation on lactation performance and blood parameters of Holstein cows under heat stress. Anim Feed Sci Technol. 117:223–233, 2004. https://doi.org/10.1016/j.anifeedsci.2004.07.008

AN-QIANG, L.; ZHI-SHENG, W.; AN-GUO, Z. Effect of Chromium Picolinate Supplementation on Early Lactation Performance. Rectal Temperatures. Respiration Rates and Plasma Biochemical Response of Holstein Cows under Heat Stress. Pakistan Journal of Nutrition. 8:940-945, 2009.

AMATA, I. A. Chromium in Livestock Nutrition: A Review. G A R J Agri Sci. 2:289-306, 2013.

BAILEY, C. H. Improved meta–analytic methods show no effect of chromium supplements on fasting glucose. Biol Trace Elem Res 157:1–8, 2014. https://doi.org/10.1007/s12011-013-9863-9

BOREL, J. S.; ANDERSON, R. A. Chromium. In: Frieden E (ed) Biochemistry of the essential ultratrace elements. Plenum Press, New York, NY. 175–199, 1984.

BRYAN, M. A.; SOCHA, M. T.; TOMLINSON, D. J. Supplementing intensively grazed late-gestation and arly-lactation dairy cattle with chromium. J Dairy Sci. 87:4269–4277, 2004. https://doi.org/10.3168/jds.S0022-0302(04)73571-7

DAVIS, C. M.; SUMRALL, K. H.; VINCENT, J. B. A biologically active form of chromium may activate a membrane phosphotyrosine phosphatase (PTP). Biochemistry. 35:12963–12969, 1996. https://doi.org/10.1021/bi960328y

DAVIS, C. M.; VINCENT, J. B. Chromium oligopeptide activates insulin receptor tyrosine kinase activity. Biochemistry. 36:4382–4395, 1997. https://doi.org/10.1021/bi963154t

DUCROS, V. Chromiummetabolism. Biol Trace Elem. Res. 32:65–77, 1992. https://doi.org/10.1007/BF02784589

FORBES, R. M.; ERDMAN, J. J. W. Bioavailability of trace mineral elements. Ann Rev Nutr. 3:213–231, 1983. https://doi.org/10.1146/annurev.nu.03.070183.001241

GÄBEL, G.; MARTENS, H.; SUENDERMANN, M.; GALFI P. The effect of diet, intraruminal pH and osmolarity on sodium, chloride and magnesium absorption from the temporarily isolated and washed reticulo-rumen of sheep. Exp Physiol. 72:501–511, 1987. https://doi.org/10.1113/expphysiol.1987.sp003092

GENTRY, L. R.; FERNANDEZ, J. M.; WARD, T. L.; WHITE, T. W.; SOUTHERN, L. L.; BIDNER, T. D.; THOMPSON, D. L.; HOROHOV, D. W.; CHAPA, A. M.; SAHLU, T. Dietary protein and chromium tripicolinate in Suffolk wether lambs: effects on production characteristics, metabolic and hormonal responses, and immune status. J Anim Sci. Vol. 77, p. 1284–1294, 1999. https://doi.org/10.2527/1999.7751284x

GULTEPE, E. E.; UYARLAR, C.; BAYRAM, I. Supplementation of Cr Methionine during dry period of dairy cows and its effect on some production and biochemical parameters during early lactation and on immunity of their offspring. Biological Trace Element Research. 186:143-153, 2018. https://doi.org/10.1007/s12011-018-1279-0

HANG, F. J.; WENG, X. G.; WANG, J. F.; ZHOU, D.; ZHANG, W.; ZHAI, C. C.; HOU, Y. X.; ZHU, Y. H. Effects of temperature–humidity index and chromium supplementation on antioxidant capacity, heat shock protein 72, and cytokine responses of lactating cows. J Anim Sci. 92:3026–3034, 2014. https://doi.org/10. 2527/jas.2013-6932

HAYIRLI, A.; BREMMER, D. R.; BERTICS, S. J.; SOCHA, M. T.; GRUMMER, R. R. Effect of chromium supplementation on production and metabolic parameters in periparturient dairy cows. J Dairy Sci. 84:1218–1230, 2001. https://doi.org/10.3168/jds.S0022-0302(01)74583-3

JEEJEBHOY, K. N.; CHU, R. C.; MARLISS, E. B.; GREENBERG, G. R.; BRUCE-ROBERTSON, A. Chromium deficiency, glucose intolerance and neuropathy reversed by chromium supplementation in a patient receiving long-term total parental nutrition. Ame. J. Clinical Nutrition, 30:531-538, 1977. https://doi.org/10.1093/ajcn/30.4.531

KAFILZADEH, F.; SHABANKAREH, H. K.; TARGHIBI, M. R. Effect of chromium supplementation on productive and reproductive performances and some metabolic parameters in late gestation and early lactation of dairy cows. Biol Trace Elem Res. 149:42– 49, 2012. https://doi.org/10. 1007/s12011-012-9390-0

KHAN, N.; CHOI, J. Y.; NHO, E. Y.; JAMILA, N.; HABTE, G.; HONG, J. H.; HWANG, I. M.; KIM, K. S. Determination of minor and trace elements in aromatic spices by micro–wave assisted digestion and inductively coupled plasma-mass spectrometry. Food Chem. 158:200–206, 2014. https://doi.org/10.1016/j.foodchem.2014.02.103

LEIVA, T.; COOKE, R. F.; BRANDÃO, A. P.; ABOIN, A. C.; RANCHES, J.; VASCONCELOS, J. L. Effects of excessive energy intake and supplementation with chromium propionate on insulin resistance parameters, milk production, and reproductive outcomes of lactating dairy cows. Livest Sci. 180:121–128, 2015. https://doi.org/10.1016/j.livsci.2015.08.007

LINDEMANN, M. D. Organic Chromium – the missing link in farm animal nutrition? Feeding Times, 1:8-16, 1996.

LUKASKI, H. C. Chromium as a supplement. Ann Rev Nutr. 19:279–302, 1999. https://doi.org/10.1146/annurev.nutr.19.1.279

MCNAMARA, J. P.; VALDEZ, F. Adipose tissue metabolism and production responses to calcium propionate and chromium propionate. J Dairy Sci. 88:2498–2507, 2005. https://doi.org/10.3168/jds.S0022-0302(05)72927-1

MERTZ, W. Chromium in human nutrition: a review. J Nutr. 123:626, 1993.

MOUSAIE, A.; VALIZADEH, R.; NASERIAN, A. A.; HEIDARPOUR, M.; MEHRJERDI, H. K. Impacts of feeding selenium-methionine and chromium-methionine on performance, serum components, antioxidant status, and physiological responses to transportation stress of Baluchi ewe lambs. Biol Trace Elem Res. 162:113–123, 2014. https://doi.org/10.1007/s12011-014-0162-x

NIKKHAH, A.; MIRZAEI, M.; GHORBANI, G. R.; KHORVASH, M.; RAHMANI, H. R. Chromium improves production and alters metabolism of early lactation cows in summer. J AnimPhysiol AnimNutr. 95:81–89, 2001. https://doi.org/10. /j.1439-0396.2010.01007.x

NRC, NUTRIENT REQUIREMENTS OF DAIRY CATTLE, 7th edn. National Academy Press, Washington, DC, 2001.

PECHOVA, A.; PAVLATA, L. Chromium as an essential nutrient: a review. Vet Med. 52:1–18, 2007.

RANHOTRA, G. S.; GELROTH, J. A. Effects of high chromium baker's yeast on glucose tolerance and blood lipids in rats. Cereal Chem. 63:411–413, 1986.

SANO, H.; NAKAI, M.; KONDO, T.; TERASHIMA, Y. Insulin responsiveness to glucose and tissue responsiveness to insulin in lactating, pregnant, and nonpregnant, nonlactating beef cows. J Anim Sci. 69:1122–1127, 1991. https://doi.org/10.2527/1991.6931122x

SCHWARZ, K.; MERTZ, Z. Chromium (III) and glucose tolerance factor. Arch. Biochem. Biophysics. 85: 292-295, 1959.

SMITH, K. L.; WALDRON, M. R.; RUZZI, L. C.; DRACKLEY, J. K.; SOCHA, M. T.; OVERTON, T. R. Metabolism of dairy cows as affected by prepartum dietary carbohydrate source and supplementation with chromium throughout the periparturient period. J Dairy Sci. 91: 2011–2020, 2008. https://doi.org/10.3168/jds.2007-0696

SMITH, K. L.; WALDRON, M. R.; DRACKLEY, J. K.; SOCHA, M. T.; OVERTON, T. R. Performance of dairy cows as affected by prepartum dietary carbohydrate source and supplementation with chromium throughout the transition period. J Dairy Sci. 88:255–263, 2005. https://doi.org/10.3168/jds.S0022-0302(05)72683-7

SOLTAN, M. A. Effect of dietary chromium supplementation on productive and reproductive performance of early lactating dairy cows under heat stress. J Anim Physiol Anim Nutr. 94:264–272, 2010. https://doi.org/10. 1111/j.1439-0396.2008.00913.x

STOECKER, B. J. Chromium absorption, safety, and toxicity. J Trace Elem Exp Med. 12:163–169, 1999. https://doi.org/10.1002/(SICI)1520670X(1999)12:2<163::AIDJTRA13>3.0.CO,2-3

SUMNER, J. M.; VALDEZ, F.; MCNAMARA, J. P. Effects of chromium propionate on response to an intravenous glucose tolerance test in growing Holstein heifers. J Dairy Sci. 90:3467–3474, 2007. https://doi.org/10. 3168/jds.2006-623

VARGAS-RODRIGUEZ, C. F.; YUAN, K.; TITGEMEYER, E. C.; MAMEDOVA, L. K.; GRISWOLD, K. E.; BRADFORD B. J. Effects of supplemental chromium propionate and rumen-protected amino acids on productivity, diet digestibility, and energy balance of peak-lactation dairy cattle. J Dairy Sci. 97:3815–3821, 2014. https://doi.org/10. 3168/jds. 2013-7767

VINCENT, J.B. The bioinorganic chemistry of chromium (III). Polyhedron 20:1-26, 2001. https://doi.org/10.1016/S0277-5387(00)00624-0

VINCENT, J. B. The biochemistry of chromium. J Nutr. 130:715–718, 2000. https://doi.org/10.1093/jn/130.4.715

VINCENT, J. B. Recent advances in the nutritional biochemistry of trivalent chromium. Proc. Nutr. Soc. 63:41–47, 2004. https://doi.org/10.1079/PNS2003315

YAMAMOTO, A.; WADA, O.; ONO, T. Isolation of a biologically active low-molecular-mass chromium compound from rabbit liver. FEBS J. 165:627–631, 1987. https://doi.org/10.1111/j.1432-1033.1987.tb11486.x

YANG, W. Z.; MOWAT, D. N.; SUBIYATNO, A.; LIPTRAP R. M. Effects of chromium supplementation on early lactation performance of Holstein cows. Can J Anim Sci. 76:221–230, 1996. https://doi.org/10.4141/cjas96-034

YASUI, T.; MCART, J. A.; RYAN, C. M.; GILBERT, R. O., NYDAM, D. V.; VALDEZ, F.; GRISWOLD, K. E.; OVERTON, T. R. Effects of chromium propionate supplementation during the periparturient period and early lactation on metabolism, performance, and cytological endometritis in dairy cows. J Dairy Sci. 97:6400–6410, 2014. https://doi.org/10.3168/jds.2013-7796

YUAN, K.; VARGAS-RODRIGUEZ, C. F.; MAMEDOVA, L. K.; MUCKEY, M. B., VAUGHN, M. A.; BURNETT, D. D.; GONZALEZ, J. M.; TITGEMEYER, E. C.; GRISWOLD, K. E.; BRADFORD, B. J. Effects of supplemental chromium propionate and rumen-protected amino acids on nutrient metabolism, neutrophil activation, and adipocyte size in dairy cows during peak lactation. J Dairy Sci. 97:3822–3831, 2014. https://doi.org/10.3168/jds.2013-7770