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Title:

Dietary nano-chromium tripicolinate increases feed intake and decreases plasma cortisol in finisher gilts during summer

Date:

2014-11-16

Citation:

Hung, A. T., Leury, B. J., Sabin, M. A., Collins, C. L. & Dunshea, F. R. (2014). Dietary nano-chromium tripicolinate increases feed intake and decreases plasma cortisol in finisher gilts during summer. *Tropical Animal Health and Production*, 46 (8), pp.1483-1489.
<https://doi.org/10.1007/s11250-014-0673-7>.

Persistent Link:

<https://hdl.handle.net/11343/220601>

1 **Dietary nano-chromium tri-picolinate increases feed intake and**
2 **decreases plasma cortisol in finisher gilts during summer**

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20 Key words: Chromium, Nanotechnology, feed intake, cortisol, pigs, heat stress

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22

23 **Abstract**

24 Chromium (Cr) is an essential mineral element and has been used in pig diets to
25 improve growth performance, insulin sensitivity, immune response, carcass traits and
26 to reduce heat or other stress responses. The aims of this study were to determine the
27 impact of nano-sized chromium tripicolinate (nCrPic) on growth performance, feed
28 efficiency and carcass characteristics of finisher gilts during the summer period. A
29 total of sixty finisher Large White x Landrace gilts were stratified on initial weight
30 and then within strata randomly allocated into two treatment groups in three replicates
31 during mid-summer for 28 days. All pigs were housed in individual pens and had *ad*
32 *libitum* access to feed and water. Pigs were fed either a control finisher diet (wheat
33 based diet containing 13.8 MJ DE/kg and 0.56 g available lysine/MJ DE) or a control
34 diet containing 400 ppb Cr as nCrPic. Dietary nCrPic supplementation increased feed
35 intake by 6% over the entire study (P=0.05). In particular, dietary nCrPic increased
36 ADFI by 8% (P=0.02) during the final 2 weeks of the study. Moreover, dietary nCrPic
37 tended to improve ADF over the entire study (P=0.09). However, there were no
38 significant effects of nCrPic on FCR, final weight, hot standard carcass weight
39 (HCWT), P2 depth or dressing percentage. Plasma cortisol was decreased by 25%
40 (P=0.06) by dietary nCrPic supplementation. However, there were no effects of
41 nCrPic on plasma glucose, insulin and nonesterified fatty acids (NEFA), might
42 because of the higher feed intake. In conclusion, this study demonstrates that dietary
43 nCrPic supplementation at 400 ppb can increase feed intake in finisher gilts during

44 mid-summer suggesting that nCrPic can ameliorate some of the negative effects of
45 heat stress in pigs, possibly via decreased of circulating cortisol.

46

47 **Introduction**

48 A hot environment has negative impacts on production, reproduction, metabolism,
49 health status and immune response. Despite advances in the construction and design
50 of animal housing facilities and cooling technologies (Armstrong. 1994), animal
51 production can still be severely affected by heat stress (St-Pierre et al. 2003). The
52 heat-induced economic burden is due to a combination of increased mortality and
53 decreased growth performance, nutrient utilization, sow performance, and carcass
54 quality (St-Pierre et al. 2003). Consequently, climate change threatens the global
55 protein supply chain and may decrease the competitiveness of the pig industry
56 (Godfray et al. 2010). Heat-stressed animals decrease their feed intake, presumably in
57 an effort to reduce heat production and the resultant reduced nutrient intake is
58 responsible, at least in part, for the reduction in performance (Quiniou et al. 2000).
59 Finishing pigs are particularly susceptible to high temperatures due to their decreased
60 evaporative critical temperature and the high stocking density often found during this
61 phase of production (Kouba et al. 2001; Spencer et al. 2005).

62

63 Cr is an essential mineral and has been included in pig diets to improve growth
64 performance, insulin sensitivity, immune response, carcass traits and to reduce the

65 impact of heat or other stressors (Hung et al. 2010). The interest in Cr
66 supplementation during the finisher phase of pig production is primarily for its
67 potential impact to improve body composition, and to a lesser extent, for any
68 associated improvement in performance. However, the effect of Cr on growth
69 performance is inconsistent. For example, Cr supplementation studies conducted with
70 pigs have been shown to either result in improve (Page et al. 1993; Lindemann et al.
71 1995; Mooney and Cromwell, 1995, 1997), or have no effect (Evock-Clover et al.
72 1993; Xi et al. 2001; Matthews et al. 2003) on growth performance. A meta-analysis
73 conducted by Sales and Jančík (2011) reported that dietary Cr can increase average
74 daily gain (ADG) and feed efficiency (FCR), whereas there is no effect on average
75 daily feed intake (ADFI). At least some of the variation in response to Cr may be
76 related to the low and variable digestion, absorption and availability of Cr and there is
77 potential to improve this by producing nano- or micro-sized Cr. Lien et al. (2009)
78 reported that nano-sized Cr had 1.66 fold greater digestibility than normal size.
79 Gonzales-Eguia et al. (2009) also indicated that availability of copper is higher in
80 nano sized particle copper. Moreover, the study reported by Hung et al. (2014) also
81 found benefits of Cr inclusion in finisher diets, particularly when CrPic was ground to
82 a small particle size (nCrPic). Carcase P2 was decreased and longissimus muscle area
83 increased when gilts were fed a high-fat finisher diet supplemented with 400 ppb
84 nCrPic. A meta-analysis conducted by Hung et al. (2010) reported that dietary nCrPic
85 can increase loin muscle area and decreased fat depth to a greater extent than normal

86 (ca. 0.5 mm) sized CrPic. Previous studies have demonstrated the potential of Cr to
87 reduce the negative effects of heat stress in broiler and layer poultry (Sahin et al.
88 2002a; Sahin et al. 2002b; Al-Saiady et al. 2004; 2005). In a rodent model, dietary
89 nCr improved growth rate and feed efficiency in heat-stressed rats (Zha et al. 2009).
90 The risk of high rigour temperature of beef carcasses increases with increasing insulin
91 resistance (Warner et al. 2014) and it has been proposed that the ability of dietary Cr
92 to improve insulin sensitivity may provide a means of ameliorating heat shortening in
93 beef cattle (DiGiacomo et al. 2014) and heat stress in dairy cattle (Dunshea et al.
94 2013). However, there are no studies investigating the effect of Cr on heat stress or
95 during hot condition in finishing pigs. Therefore, this study was conducted the impact
96 of nCrPic on growth performance, feed efficiency and carcass characteristics of
97 female finisher pigs during summer.

98

99 **Methods and Materials**

100 *Animals and treatments*

101 All animal procedures were approved by the Rivalea Pty Ltd. Corowa, NSW,
102 Australia (Rivalea Australia) Animal Ethics Committee. Sixty Large White ×
103 Landrace cross breed finishing gilts (PrimeGroTM Genetics) from the Research and
104 Development facility at Rivalea Australia were selected at approximately 17 weeks of
105 age (initial live weight 67.7± 0.46 kg, mean± standard error (SE), kg). Pigs were
106 stratified on weight and then within strata randomly allocated into two treatments in

107 three replicates during the mid-summer (January-February, 2011). The average
108 maximum temperature during the experiment was 29.7 °C, with a total of 24 days
109 where the daily maximum temperature was above 28 °C. All pigs were housed in
110 individual pens in a shed with no additional cooling and had *ad libitum* access to feed
111 and water. The experiment included one-week acclimatization and 28 days
112 experimental period. During the acclimatization period, pigs were fed with
113 commercial standard grower diet (Rivalea Australia). During experimental period,
114 pigs were fed a control finisher diet (wheat based diet containing 13.9 MJ digestible
115 energy (DE)/kg and 0.52 g available lysine/MJ DE) or control diet plus 400 ppb Cr as
116 nCrPic (Table1). The nCrPic was prepared according to our previous study (Hung et
117 al. 2014). Briefly, the raw CrPic material was ground and then passed through
118 appropriate sized end-plates sieves to collect nCrPic.

119

120 *Husbandry and management*

121 Pigs were housed in individual pens in the Rivalea Research and Development boar
122 test facility. Individual live weights were obtained at day 0, 14 and 28 of the study.
123 Feed intake was recorded weekly throughout the experimental period as estimated by
124 feed disappearance. In addition back fat thickness was measured via real time
125 ultrasound (Pork Scan Pty. Ltd. Australia) at the P2 site (65 mm from the midline over
126 the final rib) and leg (60 mm to the right of the midline base of the tail) on day 0 and
127 28. At the end of experiment, pigs were slaughtered at a commercial abattoir to

128 determine hot carcass weight (HCWT) and dressing percentage. HCWT was
129 standardized as head on (including tongue); kidneys removed (kidney fat remaining),
130 fore and hind trotters on.

131

132 *Blood sampling*

133 Pigs were fasted for 16 hours prior to blood collection. Fifteen animals were selected
134 randomly from each treatment (five pigs/ replicate) for blood collection on day 27.
135 After collection of blood, the samples were placed on ice for 1 h, and then centrifuged
136 for 15 min at 1,500×g. Plasma was collected and frozen (-20 °C) until subsequent
137 analysis for glucose, insulin, and NEFA concentrations. Plasma insulin (Millipore
138 Corporation, USA) and cortisol (Diagnostica, Finland) levels were used commercial
139 kit and determined by radioimmunoassay. Plasma glucose (Thermo Fisher Scientific
140 Inc. USA), and NEFA (NEFA-C kit, Wako Chemical Industries Ltd, Osake, Japan)
141 concentrations were determined by enzymatic colorimetric procedures.

142

143 *Statistical analyses*

144 Data were analysed by analysis of variance using GENESTAT release 11.1 (VSN
145 International Ltd. UK). Initial live weight was used as a covariate for ADG, final live
146 weight and HCWT and initial P2 were used as covariate for final P2. The quantitative
147 insulin sensitivity check index (QUICKI baseline) was calculated using the formula,
148 $QUICKI=1/(\log \text{ fasting insulin, } \mu\text{U/ mL} + \log \text{ fasting glucose, mg/dL})$ (Katz et al.,

149 2000). Normal QUICKI values are around 0.45 with values closer to 0.30 indicating
150 insulin resistance, an increase in QUICKI is associated with increased insulin
151 sensitivity (Katz et al., 2000). The homeostatic model assessment (HOMA) was
152 calculated using the formula, $HOMA = (\text{fasting insulin} \times \text{fasting glucose}) / 22.5$ (Katz
153 et al., 2000). A decrease in HOMA is associated with reduced insulin resistance.

154

155 **Results**

156 *Growth performance*

157 While there were no significant effect of nCrPic on ADFI during the first 14 days
158 (2.31 vs 2.37 kg/day for control and nCrPic diet, respectively, $P=0.43$), as the study
159 progressed dietary nCrPic increased ADFI such that during the final 2 weeks of the
160 study ADFI was 9% higher in pigs supplemented with dietary nCrPic (2.53 vs 2.75
161 kg/day, respectively, $P=0.02$) (Table 2). Consequently, ADFI over the entire study was
162 increased by 6% by dietary nCrPic (2.42 vs 2.56 kg/day, respectively, $P=0.05$). There
163 were no significant effects of nCrPic on ADG during the first 14 days (0.88 vs 0.95
164 kg/day, respectively, $P=0.12$) or over the period from 14 to 28 days (1.00 vs 1.02
165 kg/day, respectively, $P=0.59$). However, ADG tended to be increased by 5% dietary
166 nCrPic when measured over the entire study (0.94 vs 0.99 kg/day, $P=0.09$). Dietary
167 nCrPic had no effect on FCR in the current study (Table 2).

168

169 *Carcase characteristics*

170 In line with effects on ADFI and ADG, dietary nCrPic tended to increase live weight
171 at the completion of the study (94.0 vs 95.4 kg respectively, P=0.09) (Table 3).
172 However, dietary nCrPic did not significantly alter HSCW (70.2 vs 71.1 kg, P=0.14)
173 or dressing percentage (74.4 vs 74.4 %, P=0.71). The depth of back fat at the P2 site
174 (P=0.94) or over the leg (P=0.45) at the end of the study did not differ with treatment
175 (Table 3).

176

177 *Plasma metabolites*

178 Dietary nCrPic tended to decrease cortisol level (17.8 vs 15.2 nM/L, for control and
179 nCrPic diet, respectively, P=0.06) (Table 4). However, there was no effect of dietary
180 nCrPic on plasma glucose (P=0.48), insulin (P=0.96), NEFA (P=0.69) concentration
181 or the HOMA (P=0.91) and QUICKI (P=0.98) measures on day 27 of the study
182 (Table 4).

183

184 **Discussion**

185 Thermal stress reduces animal productivity and decreases ADFI in farm animals and
186 therefore it is desirable to develop nutritional strategies, likely based on physiological
187 and/or metabolic adaptations to help maintain pig performance during summer. The
188 major finding from the present study was that dietary nCrPic supplementation during
189 a hot summer period can increase ADFI with resultant improvements in ADG and
190 slaughter weigh. High ambient temperatures can reduce the efficiency and

191 profitability in pig production (Nardone et al. 2010) with pigs being particularly
192 susceptible during the late finishing phase due to their lower evaporative critical
193 temperature. Evaporative heat loss from the respiratory tract is the major mechanism
194 by which pigs dissipate heat (Giles et al. 1988; Marai et al. 2007). When pigs reach
195 the point where evaporative heat loss from the respiratory tract and skin is at a
196 maximum, the upper critical temperature is also reached (Giles et al. 1988). Beyond
197 this point, pigs will voluntarily reduce ADFI in order to reduce their heat production.
198 For example, Le Bellego et al. (2002) reported that pigs reduced ADFI by 55 g per °C
199 above 22 °C and ceased eating when their body temperature reached about 41.3 °C.
200 The reduction in ADFI during high ambient temperatures was more pronounced in
201 pigs during the finishing phase than during the growing phase (78 vs 35 g /day per °C
202 above 22 °C for finishing phase and growing phase pig, respectively) (Le Bellego et al.
203 2002). This is because the upper critical temperature decreases with the increasing of
204 live weight (Giles et al. 1988; Quiniou et al. 2000) which may explain why the
205 improvement in ADFI became more pronounced as the present study progressed. An
206 improvement in growth performance, after CrPic supplementation during heat stress,
207 also been observed in poultry. For example, dietary supplementation of CrPic
208 ameliorated the detrimental effects of heat stress on growth and egg production (Sahin
209 et al. 2002a; Sahin et al. 2005). Also, supplementation of CrPic at levels from 200 to
210 1200 µg/kg linearly increased feed intake, live weight gain, and egg production rate of
211 laying quail reared under heat stress condition (Sahin et al. 2002a). Finally, dietary Cr

212 Yeast (4 g/head per day) increased feed intake in Holstein cows under heat stress
213 (Al-Saiady et al. 2004). These data suggested that dietary Cr may be able to use in
214 farm animals to alleviate the negative effects of high environment temperature.

215

216 The results from our previous study (Hung et al. 2014), in conjunction with other
217 literatures (Wang and Xu, 2004; Wang et al. 2007; Wang et al. 2009a) suggested that
218 dietary nano Cr could reduce the body fat content in pigs. However, in the present
219 study, there was no effect of dietary nCrPic on P2 backfat and leg fat depth of pigs.
220 Versteegen et al. (1973) indicated that pigs reared in hot environment typically yield
221 carcasses with a higher percent lean. The reduction in fat content of pigs under heat
222 stress was due to a reduction in total energy intake in the hot environment. Dietary
223 nCrPic increased feed intake during the day 14 to 28 in this study suggested that pigs
224 feed with nCrPic increased total energy intake in the late finishing period compared
225 with the control group. Increased energy intake without changed the P2 back fat and
226 leg fat depth implied that pigs fed with nCrPic had better efficiency to metabolized fat.
227 It should be noted that, by commercial standards, the pigs in the current study were
228 already very lean and had a low P2 backfat.

229

230 Heat stress likely affects many aspects of metabolism, including alterations in
231 substrate uptake and utilization, much of which is not yet fully understood. Metabolic
232 adaptations during high ambient temperatures likely occur in order to increase

233 survival probability. Denbow et al. (1986) reported insulin concentration are lower in
234 summer than in winter and spring in Holstein cattle, possibly as a result of reduced
235 feed intake. In lactating sows, plasma insulin was lower during high ambient
236 temperature compared to sows housed under thermo-neutral conditions despite similar
237 glucose concentrations (de Bragança and Prunier, 1999). Conversely, Achmadi et al.
238 (1993) reported that heat-exposure had no effect on fasting insulin level. Circulating
239 glucose concentrations were increased in pigs (Prunier et al. 1997) and cattle
240 (Denbow et al. 1986), but decreased in sheep (Achmadi et al. 1993) and cattle
241 (Shwartz et al. 2009; Wheelock et al. 2010), and unchanged in pigs in another study
242 (de Bragança and Prunier, 1999) under hot conditions. Heat exposure increased
243 plasma NEFA in sheep (Sevi et al. 2002), but decreased NEFA in lactating cattle (Itoh
244 et al. 1998; Shwartz et al. 2009; Wheelock et al. 2010). These differences between
245 basal hormone and metabolite concentrations may relate to differences in
246 experimental conditions such as ambient temperature and feeding manner,
247 physiological status, and animal species. Importantly, it worth to understand the
248 degree to which feed intake is impacted by high ambient temperatures as reduced feed
249 intake generally results in increased NEFA and decreased glucose and insulin. Also,
250 insulin resistance increase with fatness and the rate of fat deposition in pigs (Dunshea
251 and Cox et al. 2008). There is now increasing evidence that insulin resistant and
252 diabetic individuals suffer from thermal intolerance, exhibiting an inability to control
253 body temperature (Ohtsuke et al. 1995). In part this is because skin blood flow and

254 skin thickness are reduced in diabetic individuals (Forst et al. 2006), thereby reducing
255 the ability of thermoregulation. If dietary nCrPic can improve insulin sensitivity then
256 it may explain why feed intake is improved with dietary nCrPic during summer and
257 that the effect was greater during latter part of the study when the pigs would be fatter.

258

259 Chromium is a trace mineral that is widely distributed throughout the body, being
260 necessary for maintenance of insulin function and glucose uptake by insulin-sensitive
261 tissues (Anderson et al. 1985). However, the effects of dietary Cr on fasting glucose
262 concentrations in pigs are inconsistent. Some studies reported that dietary Cr
263 significantly reduces fasting glucose (Lien et al. 2001; Wang et al. 2001; Wang et al.
264 2009b), whereas others reported no effect (Amoikon et al. 1995; Matthews et al.
265 2001). Amoikon et al. (1995) reported that CrPic increased insulin sensitivity as
266 assessed by increased glucose clearance rate and decreased glucose half-life during a
267 glucose tolerance test and insulin challenge test in pigs. It is reported that CrPic can
268 increase the rate of insulin internalizations and uptake of glucose into skeletal muscle
269 cells (Evans and Bowman, 1992). Under heat stress condition, dietary CrPic
270 decreased glucose level in quails (Quiniou et al. 2000) and broiler chickens (Samanta
271 et al. 2008) indicating improved glucose clearance and insulin sensitivity. Zha et al.
272 (2009) indicated that heat-stressed male Sprague-Dawley rats fed with nano-Cr had
273 lower insulin. However, supplementation of CrPic linearly increased insulin
274 concentration at levels from 200 to 1200 µg/kg (Sahin et al. 2002a). Yari et al. (2010)

275 suggested that an improvement in peripheral insulin sensitivity as evidence by an
276 intravenous GTT revealed linear reductions in AUC of insulin during 0-90 and 0-120
277 minute after glucose infusion in calf fed with Cr-L-methionine in summer. As
278 reported by Hung et al. (2014), dietary increased insulin sensitivity as indicated by a
279 decrease in both fasting insulin and HOMA, and an increase in QUICKI. In the
280 present study, however, dietary nCrPic had no significant effect on glucose, insulin,
281 NEFA, HOMA, and QUICKI in finisher gilts during summer. The lack of effect on
282 these measures of insulin sensitivity and intermediary metabolism may be due to the
283 increase in feed intake over the latter phase of the study which would have the effect
284 of increasing plasma glucose and insulin, and lowering plasma NEFA (ie. opposite
285 effects of improving insulin sensitivity in the face of no change in feed intake).

286

287 Circulating cortisol concentration was tended to decrease by dietary nCrPic
288 supplementation. A reduction in plasma cortisol is a classic metabolic consequence of
289 Cr in farm animals suggesting there was a reduction in stress, especially when animals
290 are challenged with stressors such as a thermal-stress. For example, in heat-stressed
291 broiler chickens, dietary CrPic decreased serum cortisol concentration (Samanta et al.
292 2008). While, Sahin et al. (2002a) reported that dietary CrPic linearly decreased
293 serum corticosterone concentration across the range of 200-1200 $\mu\text{g}/\text{kg}$ in
294 heat-stressed laying quail. A stress-induced increase in circulating cortisol may
295 contribute to increase hepatic gluconeogenesis and heat production, thereby escalating

296 the heat load of the animal (McDonald et al. 2011). Farm animals tend to reduce feed
297 intake to adapt to high environment temperature (Nardone et al. 2010). Zha et al.
298 (2009) suggested that nCrPic can balance circulating cortisol and insulin level to
299 maintaining homeostasis. The anorexigenic actions of cortisol can mediated via
300 reducing circulating ghrelin levels as well as GHSR1a-LR (biologically active ghrelin
301 receptor) expression and/or suppressing neuropeptide Y expression (Janzen et al.,
302 2013). These data suggest that the improvement in feed intake in dietary nCrPic
303 supplemented pigs may be via the decreased cortisol secretion. Alternatively, the
304 reduction in cortisol in pigs supplemented with dietary nCrPic may mean they are
305 under less stress.

306

307 **Conclusion**

308 These data clearly show that dietary nCrPic supplementation at 400 ppb can increase
309 feed intake and tended to increase ADG in finisher gilts during mid-summer
310 suggesting that nCrPic can ameliorate some of the negative effects of heat stress in
311 pigs possibly via decreased circulating cortisol. However, this study failed to detect
312 any effects of dietary nCrPic on the levels of plasma glucose, insulin, NEFA, HOMA
313 and QUICKI under these conditions, might because of the increased feed intake.
314 Further studies are required to examine the growth performance and physiological
315 response in animal under heat stress condition.

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321 **The authors declare that they have no conflict of interest**

322

Reference

- Achmadi, J., Yanagisawa, T., Sano, H. and Terashima, Y., 1993. Pancreatic insulin secretory response and insulin action in heat-exposed sheep given a concentrate or roughage diet, *Domestic Animal Endocrinology*, 10, 279-287.
- Al-Saiady, M. Y., Al-Shaikh, M. A., Al-Mufarrej, S. I., Al-Showeimi, T. A., Mogawer, H. H. and Dirrar, A., 2004. Effect of chelated chromium supplementation on lactation performance and blood parameters of Holstein cows under heat stress, *Animal Feed Science and Technology*, 117, 223-233.
- Amoikon, E. K., Fernandez, J. M., Southern, L. L., Thompson, D. L., Ward, T. L. Jr. and Olcott, B. M., 1995. Effect of chromium tripicolinate on growth, glucose tolerance, insulin sensitivity, plasma metabolites, and growth hormone in pigs, *Journal of Animal Science*, 73, 1123-1130.
- Anderson, R. A., Bryden, N. A. and Polansky, M. M., 1985. Serum chromium of human subjects: effects of chromium supplementation and glucose, *The American journal of clinical nutrition*, 41, 571-577.
- Armstrong, D. V., 1994. Heat Stress Interaction with Shade and Cooling, *Journal of Dairy Science*, 77, 2044-2050.
- de Bragança, M. M. and Prunier, A., 1999. Effects of low feed intake and hot environment on plasma profiles of glucose, nonesterified fatty acids, insulin, glucagon, and IGF-I in lactating sows, *Domestic Animal Endocrinology*, 16, 89-101.
- Denbow, C. J., Perera, K. S., Gwazdauskas, F. C., Akers, R. M., Pearson, R. E. and McGilliard, M. L., 1986. Effect of Season and Stage of Lactation on Plasma Insulin and Glucose Following Glucose Injection in Holstein Cattle, *Journal of Dairy Science*, 69, 211-216.
- DiGiacomo, K., Leury, B. J. and Dunshea, F. R., 2014. Possible metabolic causes of heat shortening in cattle and potential strategies base on these mechanisms, *Animal Production Science*, 54, 430-443.
- Dunshea, F. R., Leury, B. J., Fahri, F., DiGiacomo, K., Hung, A., Chauhan, S., Clarke, I. J., Collier, R., Little, S., Baumgard, L. and Gaughan, J. B., 2013. Amelioration of thermal stress impacts in dairy cows, *Animal Production Science*, 53, 965-975.
- Evans, G. W. and Bowman, T. D., 1992. Chromium picolinate increases membrane fluidity and rate of insulin internalization, *Journal of inorganic biochemistry*, 46, 243-250.
- Evoock-Clover, C. M., Polansky, M. M., Anderson, R. A. and Steele, N. C., 1993.

- Dietary chromium supplementation with or without somatotropin treatment alters serum hormones and metabolites in growing pigs without affecting growth performance, *The Journal of nutrition*, 123, 1504-1512.
- Giles, L. R., Dettmann, E. B. and Lowe, R. F., 1988. Influence of diurnally fluctuating high temperature on growth and energy retention of growing pigs, *Animal production*, 47, 467-474.
- Godfray, H. C., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Nisbett, N., Pretty, J., Robinson, S., Toulmin, C. and Whiteley, R., 2010. The future of the global food system, *Philosophical Transactions of the Royal Society of London*, 365, 2769-2777.
- Gonzales-Eguia, A. Fu, C. M., Lu, F. Y. and Lien, T. F., 2009. Effects of nanocopper on copper availability and nutrients digestibility, growth performance and serum traits of piglets. 126:122-129.
- Hung, T. Y., Leury, B. J., Lien, T. F., Lu, J. J. and Dunshea, F. R., 2010. Potential of nano-chromium to improve body composition and performance of Pigs. In: *Proceeding of the 14th AAAP Animal Science Congress, Pingtung, Taiwan*. 108-112.
- Hung, A. T., Leury, B. J., Sabin, M. A., Lien, T. F. and Dunshea, F. R., 2014. Dietary chromium picolinate of varying particle size improves carcass characteristics and insulin sensitivity in finishing pig fed low and high fat diet, *Animal Production Science*, (Published online)
- Itoh, F., Obara, Y., Rose, M. T., Fuse, H. and Hashimoto, H., 1998. Insulin and glucagon secretion in lactating cows during heat exposure, *Journal of Animal Science*, 76, 2182-2189.
- Janzen, W. J., Duncan, C. A. and Riley, L. G., 2012. Cortisol treatment reduces ghrelin signaling and food intake in tilapia, *Oreochromis mossambicus*. *Domestic Animal Endocrinology*. 43:251-259.
- Katz, A., Nambi, S.S., Mather, K., Baron, A. D., Follmann, D. A., Sullivan, G. and Quon, M. J., 2000. Quantitative insulin sensitivity check index: a simple, accurate method for assessing insulin sensitivity in humans, *The Journal of Clinical Endocrinology & Metabolism*, 85, 2402-2410.
- Kim, B. G., Lindemann, M. D. and Cromwell, G. L., 2009. The effects of dietary chromium(III) picolinate on growth performance, blood measurements, and respiratory rate in pigs kept in high and low ambient temperature, *Journal of Animal Science*, 87, 1695-1704.
- Kouba, M., Hermier, D. and Le Dividich, J., 2001. Influence of a high ambient temperature on lipid metabolism in the growing pig, *Journal of Animal Science*,

79, 81-87.

- Le Bellego, L., van Milgen, J. and Noblet, J., 2002. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs, *Journal of Animal Science*, 80, 691-701.
- Lien, T. F., Wu, C. P., Wang, B. J., Shiao, M. S. and Lu, J. J., 2001. Effect of supplemental levels of chromium picolinate on the growth performance, serum traits, carcass characteristics and lipid metabolism of growing-finishing pigs, *Animal Science*, 72, 289-296.
- Lien, T. F., Yeh, H. S., Lu, F. Y. and Fu, C. M. 2009. Nanoparticles of chromium picolinate enhance chromium digestibility and absorption. *Journal of the Science of Food and Agriculture*. 89:1164-1167.
- Lindemann, M. D., Wood, C. M., Harper, A. F., Kornegay, E. T. and Anderson, R. A., 1995. Dietary chromium picolinate additions improve gain:feed and carcass characteristics in growing-finishing pigs and increase litter size in reproducing sows, *Journal of Animal Science*, 73, 457-465.
- Marai, I. F. M., El-Darawany, A. A., Fadiel, A. and Abdel-Hafez, M. A. M., 2007. Physiological traits as affected by heat stress in sheep--A review, *Small Ruminant Research*, 71, 1-12.
- Matthews, J. O., Higbie, A. D., Southern, L. L., Coombs, D. F., Bidner, T. D. and Odgaard, R. L., 2003. Effect of chromium propionate and metabolizable energy on growth, carcass traits, and pork quality of growing-finishing pigs, *Journal of Animal Science*, 81, 191-196.
- Matthews, J. O., Southern, L. L., Fernandez, J. M., Pontif, J. E., Bidner, T. D. and Odgaard, R. L., 2001. Effect of chromium picolinate and chromium propionate on glucose and insulin kinetics of growing barrows and on growth and carcass traits of growing-finishing barrows, *Journal of Animal Science*, 79, 2172-2178.
- McDonald, P., Edwards, R. A., Greenhalgh, J. F. D. and Morgan, C. A., 2011. *Animal nutrition* 7th ed. (Pearson, Harlow).
- Mooney, K. W. and Cromwell, G. L., 1995. Effects of dietary chromium picolinate supplementation on growth, carcass characteristics, and accretion rates of carcass tissues in growing-finishing swine, *Journal of Animal Science*, 73, 3351-3357.
- Mooney, K. W. and Cromwell, G. L., 1997. Efficacy of chromium picolinate and chromium chloride as potential carcass modifiers in swine, *Journal of Animal Science*, 75, 2661-2671.
- Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S. and Bernabucci, U., 2010. Effects of climate changes on animal production and sustainability of livestock systems,

- Livestock Science, 130, 57-69.
- Page, T. G., Southern, L. L., Ward, T. L. and Thompson, D. L. Jr., 1993. Effect of chromium picolinate on growth and serum and carcass traits of growing-finishing pigs, *Journal of Animal Science*, 71, 656-662.
- Prunier, A., de Bragança, M. M. and Le Dividich, J., 1997. Influence of high ambient temperature on performance of reproductive sows, *Livestock Production Science*, 52, 123-133.
- Quiniou, N., Dubois, S. and Noblet, J., 2000. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight, *Livestock Production Science*, 63, 245-253.
- Sahin, K., Ozbey, O., Onderci, M., Cikim, G. and Aysondu, M. H., 2002. Chromium Supplementation Can Alleviate Negative Effects of Heat Stress on Egg Production, Egg Quality and Some Serum Metabolites of Laying Japanese Quail, *The Journal of nutrition*, 132, 1265-1268.
- Sahin, K., Sahin, N., Onderci, M., Gursu, F. and Cikim, G., 2002. Optimal dietary concentration of chromium for alleviating the effect of heat stress on growth, carcass qualities, and some serum metabolites of broiler chickens, *Biological Trace Element Research*, 89, 53-64.
- Sahin, N., Sahin, K., Onderci, M., Gursu, M. F., Cikim, G., Vijaya, J. and Kucuk, O., 2005. Chromium picolinate, rather than biotin, alleviates performance and metabolic parameters in heat-stressed quail, *British Poultry Science*, 46, 457-463.
- Sales, J. and Jančík, F., 2011. Effects of dietary chromium supplementation on performance, carcass characteristics, and meat quality of growing-finishing swine: A meta-analysis, *Journal of Animal Science*, 89, 4054-4067.
- Samanta, S., Haldar, S. and Ghosh, T. K., 2008. Production and carcass traits in broiler chickens given diets supplemented with inorganic trivalent chromium and an organic acid blend, *British Poultry Science*, 49, 155-163.
- Sevi, A., Rotunno, T., Di Caterina, R. and Muscio, A., 2002. Fatty acid composition of ewe milk as affected by solar radiation and high ambient temperature, *Journal of Dairy Research*, 69, 181-194.
- Shwartz, G., Rhoads, M. L., VanBaale, M. J., Rhoads, R. P. and Baumgard, L. H., 2009. Effects of a supplemental yeast culture on heat-stressed lactating Holstein cows, *Journal of Dairy Science*, 92, 935-942.
- Spencer, J. D., Gaines, A. M., Berg, E. P. and Allee, G. L., 2005. Diet modifications to improve finishing pig growth performance and pork quality attributes during periods of heat stress, *Journal of Animal Science*, 83, 243-254.

- St-Pierre, N. R., Cobanov, B. and Schnitkey, G., 2003. Economic Losses from Heat Stress by US Livestock Industries, *Journal of Dairy Science*, 86, 52-77.
- Verstegen, M. W., Close, W. H., Start, I. B. and Mount, L. E., 1973. The effects of environmental temperature and plane of nutrition on heat loss, energy retention and deposition of protein and fat in groups of growing pigs, *British Journal of Nutrition*, 30, 21-35.
- Wang, M. Q., He, Y. D., Lindemann, M. D. and Jiang, Z. G., 2009a. Efficacy of Cr (III) supplementation on growth, carcass composition, blood metabolites, and endocrine parameters in finishing pigs, *Asian-Australasian Journal of Animal Sciences*, 22, 1414-1419.
- Wang, M. Q. and Xu, Z. R., 2004. Effect of chromium nanoparticle on growth performance, carcass characteristics, pork quality and tissue chromium in finishing pigs, *Asian-Australasian Journal of Animal Sciences*, 17, 1118-1122.
- Wang, M. Q., Xu, Z. R., Li, W. F. and Jiang, Z. G., 2009b. Effect of chromium nanocomposite supplementation on growth hormone pulsatile secretion and mRNA expression in finishing pigs, *Journal of Animal Physiology and Animal Nutrition*, 93, 520-525.
- Wang, M. Q., Xu, Z. R., Zha, L. Y. and Lindemann, M. D., 2007. Effects of chromium nanocomposite supplementation on blood metabolites, endocrine parameters and immune traits in finishing pigs, *Animal Feed Science and Technology*, 139, 69-80.
- Wang, S., Sun, C., Kao, Q. and Yu, C., 2001. Effects of chromium and fish oil on insulin resistance and leptin resistance in obese developing rats, *Wei Sheng Yan Jiu*, 30, 284-286.
- Warner, R. D., Dunshea, F. R., Gutzke, D., Lau, J. and Kearny, G., 2014. Factors influencing the incidence of high rigor temperature in beef carcasses in Australia, *Animal Production Science*, 54, 363-374.
- Wheelock, J. B., Rhoads, R. P., VanBaale, M. J., Sanders, S. R. and Baumgard, L. H., 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows, *Journal of Dairy Science*, 93, 644-655.
- Xi, G., Xu, ZR., Wu, S. H. and Chen, S. J., 2001. Effect of chromium picolinate on growth performance, carcass characteristics, serum metabolites and metabolism of lipid in pigs, *Asian-Australasian Journal of Animal Sciences*, 14, 258-262.
- Yari, M., Nikkhah, A., Alikhani, M., Khorvash, M., Rahmani, H. and Ghorbani, G. R., 2010. Physiological calf responses to increased chromium supply in summer, *Journal of Dairy Science*, 93, 4111-4120.
- Zha, L., Zeng, J., Sun, S., Deng, H., Luo, H. and Li, W., 2009. Chromium(III)

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Biological Trace Element Research, 129, 157-169.

Table 1. Ingredient and nutrient composition of experimental diets

Ingredient	
Wheat	68.46
Millmix	16.5
Canola meal 36%	6.0
Meat meal	2.6
Water	1
Porzyme 9310	0.02
Natuphos 5000	0.01
Tallow-mixer	3.07
Salt	0.2
Limstone	1.5
Lysine-HCl	0.35
DL-methionine	0.01
Threonine	0.11
Copper proteinate Micro	0.1
Growth Premix ^{a,b}	0.07
Total	100
Calculated nutrient composition	
DE, MJ/kg	13.9
Fat, %	4.9
Crude protein, %	16.0
Calcium, %	0.89
Available Phosphorus, %	0.36
Available lysine/MJ DE	0.52

^a Provided the following trace mineral per kilogram of diet: Se, 0.2 mg; Fe, 60; Mn, 25 mg; Zn, 50 mg; I, 0.2 mg; Cu, 10 mg.

^b Provided the following vitamins per kilogram of diet: Vitamin A, 2.5 mg; Vitamin D3, 1mg; Vitamin E, 30 mg; Niacin, 10 mg; Ca-D-Pantothenate, 5 mg; Riboflavin, 2 mg; Vitamin B12 (Cyanocobalamin), 5 mg.

Table 2 Effect of nCrPic on growth performance, feed intake and feed efficiency in finisher gilts during summer

	Control	nCrPic	sed ^a	P- value
Day 0 to 14				
ADFI ^b , kg/d	2.31	2.37	0.076	0.43
ADG ^b , kg/d	0.88	0.95	0.047	0.12
FCR (Feed: gain)	2.72	2.55	0.127	0.20
Day 14 to 28				
ADFI ^b , kg/d	2.53	2.75	0.085	0.02
ADG ^b , kg/d	0.99	1.02	0.048	0.59
FCR (Feed: gain)	2.63	2.77	0.136	0.32
Day 0 to 28				
ADFI ^b , kg/d	2.42	2.56	0.070	0.05
ADG ^b , kg/d	0.94	0.99	0.030	0.09
FCR (Feed: gain)	2.61	2.62	0.080	0.96

^a Standard error of the difference

^b – initial weight used as covariate

Table 3 Effect of nCrPic on carcass characteristics in finisher gilts during summer

	Control	nCrPic	sed ^a	P- value
Final weight ^b , kg	94.0	95.4	0.83	0.09
HCWT ^b , kg	70.2	71.1	0.69	0.14
Dressing %	74.4	74.4	0.44	0.71
P2 fat depth ^c , mm	8.0	8.0	0.19	0.94
Leg fat depth ^c , mm	9.0	9.1	0.20	0.45

^a Standard error of the difference; ^b Initial weight used as covariate;

^c Initial P2 and HCWT used as covariate

Table 4 Effect of nCrPic on plasma glucose, insulin, NEFA, HOMA and QUICKI in finisher gilts during summer period

	Control	nCrPic	sed ^a	P- value
Cortisol nmol/L ^b	1.25 (17.8)	1.12 (13.2)	0.067	0.06
Glucose, mmol/L	3.91	3.98	0.09	0.48
Insulin, mU/L	11.0	11.0	0.74	0.96
NEFA, μ M	307	309	6.45	0.69
HOMA	1.91	1.93	0.174	0.91
QUICKI	0.62	0.62	0.017	0.98

^a Standard error of the difference

^b Data were log-transformed before analyses due to heterogeneity of variances. Values in parentheses are the geometric mean.