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Chromium yeast affects growth performance but not whole carcass composition of growing-finishing pigs

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Abstract — An experiment with 40 pigs (24.5 kg initial and 105.5 kg final live weight) was conducted to investigate the effects of supplemented trivalent chromium (Cr) from chromium yeast on growth performance, carcass composition, fatty acid profile of the carcass fat, and blood parameters both after a 24-h fasting period and 2 h after feeding. Ten pigs per treatment were fed a barley-wheat-soybean meal diet supplemented with either 0 (C), 200 (C200), 400 (C400) or 800 ppb Cr (C800) at a restricted feeding scale. Pigs receiving the C200 treatment showed both improved average daily gains and feed conversion ratios compared to those receiving treatment C for the total experiment ($P < 0.06$), especially in the finishing period. While carcass measurements and composition, as well as the fatty acid profile, were not significantly affected by the Cr supply, concentrations of plasma insulin, triglycerides, non-esterified fatty acid (NEFA), urea N and ketone bodies gave evidence that supplemented Cr affected carbohydrate and fat metabolisms. The failure of plasma metabolite changes to be reflected in the whole body composition may have been dependent on the genotype (lean in this experiment) and the manner of feeding (restricted feeding scale in this experiment vs. ad libitum in other reported experiments). (© Elsevier / Inra)

chromium / pig / carcass / hormones

Résumé — La levure enrichie en chrome affecte les performances de croissance mais pas la composition des carcasses de porcs en fin d'engraissement. Un essai avec 40 porcs (d'un poids vif moyen et final de 24,5 et 105,5 kg respectivement) a été conduit pour étudier les effets d'une supplémentation en chrome trivalent (Cr) sous forme de levure de chrome sur les performances de croissance, la composition de la carcasse, le profil des acides gras des lipides de la carcasse et les paramètres sanguins après une période de jeûne de 24 h et 2 h après le repas. Les animaux (dix par traitement)

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ont reçu une alimentation rationnée à base d'orge, de blé et de soja, additionnée soit de 0 (C), 200 (C200), 400 (C400) ou 800 ppb (C800) de chrome. Les porcs du traitement C200 ont présenté un gain de poids quotidien moyen et un indice de consommation meilleurs que ceux du traitement C sur la totalité de la période expérimentale ($p < 0,06$) et plus particulièrement en fin de période d'engraissement. La supplémentation en chrome n'a influencé significativement ni la composition et les mesures de carcasse ni le profil des acides gras ; au contraire des concentrations plasmatique d'insuline, de triglycérides de NEFA, d'azote uréique, et de corps cétoniques qui ont clairement démontré son effet sur le métabolisme glucidique et lipidique. La lignée génétique utilisée dans cet essai (animaux de type maigre) et le mode d'alimentation (restrictif et non ad libitum comme dans d'autres essais) sont peut-être la cause du non-recouvrement des changements observés dans les métabolites plasmatiques et dans la composition de la carcasse. (© Elsevier / Inra)

chrome / porc / carcasse / hormones

1. INTRODUCTION

Trivalent chromium (Cr) is thought to interact with functions of the thyroid hormones, to affect nucleic acid metabolism and to be involved in carbohydrate metabolism by altering insulin action [17]. Since these metabolic pathways influence growth, it is not surprising that dietary Cr supplementation has been found to affect feed intake, daily gain and feed efficiency in growing-finishing pigs [3, 14, 25]. Special interest has been focused on Cr research in pig nutrition since dietary Cr was reported to increase lean body mass and decrease the percentage of body fat content [20, 21, 25].

The content of total Cr in food is low and often below 100 ppb [13], especially with respect to cereals [22]. Moreover, only a small proportion of total Cr is bioavailable and hence can be utilised by humans or animals, implying that Cr supplementation is necessary [22]. However, several known (and probably also unknown) individual and environmental factors interact with dietary Cr, resulting in apparently inconsistent responses of various parameters due to Cr [3, 14, 19, 25, 30].

Therefore, an experiment with growing-finishing pigs was performed under Swiss conditions (i.e. use of lean pig breed and feeding diets based on wheat-barley-soybean meal at restricted feeding levels, which are in contrast to most published data) to examine the response of increasing levels of Cr supplemented as Cr yeast on performance. Special interest was directed to carcass composition and fatty acid profile of the carcass lipids. Analysis of plasma metabolites and hormones were also performed to elucidate the effects of Cr on carbohydrate, fat and protein metabolism.

2. MATERIAL AND METHODS

2.1. Animals and diets

Forty castrated male Swiss Large White pigs with average live weights (LW) of 24.5 kg (initial) and 105.5 kg (final) were randomly allocated to experimental blocks based on LW into four dietary treatments at two dates (interval of 7 weeks/20 pigs per date/a total of ten pigs per treatment). The barrows were housed in individual pens with concrete floors (with litter) in environmentally controlled buildings under normal husbandry conditions. One pig of the first allocation block was replaced because of illness (diarrhoea).

The basal diet for the growing (25–57 kg LW) and finishing periods (57–105 kg LW) consisted of barley, wheat, wheat starch, middling, soybean meal, sunflower meal and bone fat (*table I*). The level of nutrients was calculated to meet the requirement for 20–60 kg growing and 60–100 kg finishing pigs [4]. The basal growing and finishing diets were split into four treatments with either 0 (C), 200 (C200), 400 (C400), or 800 ppb

Table I. Ingredient composition of the experimental diets ($g \cdot kg^{-1}$).

Ingredients	Grower	Finisher
Barley	359.5	455.0
Wheat	290.0	290.0
Soybean meal 44 %	145.5	55.0
Wheat starch	50.0	50.0
Middling	50.0	50.0
Sunflower meal	50.0	50.0
Bone fat	20.0	20.0
Calcium carbonate	15.5	13.5
Monocalcium phosphate	5.0	2.0
Lysine-HCl	4.0	4.0
DL-methionine	0.6	0.3
L-threonine 98 %	0.9	0.8
Salt	4.2	4.2
Premix[a]	5.0	5.0

[a] Supplied per kilogram of diet: 10 000 IU of vitamin A, 1 000 IU of vitamin D_3, 40 IU of vitamin E, 4 mg of vitamin B_2, 4 mg of vitamin B_6, 0.015 mg of vitamin B_{12}, 1 mg of vitamin K_3, 15 mg of pantothenic acid, 20 mg of niacin, 0.2 mg of folic acid, 60 mg Fe as $FeSO_4$, 1 mg I as $Ca(IO_3)_2$, 0.3 mg Se as Na_2Se, 15 mg Cu as $CuSO_4$, 100 mg Zn as ZnO_2, 40 mg Mn as MnO_2.

(C800) of supplemented chromium. Cr was provided as a chromium yeast extract (20 000 ppm Cr, Alltech Biotechnology Center, Nicholasville, Kentucky, USA). The diets were offered as pellets. The animals were fed once a day according to a weight-based feeding scale, whereas water was available ad libitum. The daily feed rations were adapted weekly after weighing the animals.

2.2. Blood samples

Two blood samples were collected from each pig on experimental day 88 (87.4 kg LW). After a fasting period of 24 h, blood samples were obtained by vena puncture from the vena cava. Thereafter, the pigs were allowed to consume their daily ration and were bled again exactly 2 h after the initiation of the feeding. The blood samples were kept on ice until centrifugation at 1 500 *g* for 15 min at 4 °C. The collected plasma was frozen immediately and stored (–25 °C) until analysis.

2.3. Carcass data

When pigs exceeded a weight of 97 kg they were slaughtered in the following week. After a fasting period of 24 h, the pigs were slaughtered by electric stunning followed by exsanguination at the abattoir of the 'Swiss Pig Performance Testing Station (MLP) Sempach, Switzerland'. Slaughter and dissection procedures were carried out according to MLP methods [26].

The saw method according to Bee [2] was applied to evaluate the chemical carcass composition. After chilling at 0 °C for 24 h, the right halves of the carcasses without their heads were frozen at –30 °C. Each frozen carcass side was sawn to approximately 40 slices by means of an electrical saw and 2.1 to 2.8 kg of sawdust was collected from each carcass side. Prior to analyses, samples of the sawdust were freeze-dried and minced under liquid nitrogen. It was assumed that the right side of the carcass had the same composition as the left side.

2.4. Chemical analysis

Dry matter (DM), ash, crude fibre (CF), crude protein (CP = N × 6.25) and fat (SF) analysis by the soxhlet extraction method of feed were carried out according to the methods of the VDLUFA [23]. The content of Kjeldahl-nitrogen was analysed using an automated Büchi 323 distillation unit (Büchi Laboratory-Techniques Ltd., Flawil, Switzerland), 665 Dosimat, and 678 Processor (Metrohm Ltd., Herisau, Switzerland). SF was analysed as a petroleum ether extract and gross energy was determined using an anisothermic bomb calorimeter (System C 700 T, IKA Analysentechnik GmbH, Heitersheim, Germany). The diets were analysed for Cr by graphite furnace atomic absorption spectrometry (AS PE/5100 PC/ZL) at the laboratory of the Swiss Federal Research Station for Animal Production (Posieux, Switzerland).

Analyses of the carcass sawdust (DM, ash, CP, SF) were carried out as with feed analyses. Total DM was computed by both moisture loss during freeze-drying and drying at 104 °C. SF was determined without prior HCl-hydrolysis.

Fatty acid profiles of the carcass lipids were determined by gas chromatography of the methyl esters (FAME). The lipids were extracted by a modified method of Hara and Radin [11]: prior to cold extraction with hexane:isopropanol (3:2),

triundecanine (C 11:0) was added as an internal standard. Subsequently, the extract was filtered through folded paper filters (Schleicher & Schuell 5951/2 Faltenfilter, Ø 150 mm). The FAMEs were prepared by transesterification by sodium hydroxide and boron trifluoride both in methanol according to the method of Metcalfe and Smith [18]. FAMEs were determined using a gas chromatograph (HP 5860 A GC) equipped with a flame ionisation detector. The FAMEs were separated on a 30 m * 0.32 mm Supelcowax TM 10 fused-silica capillary column (Supelco Inc., PA, USA). The oven temperature was as follows: the initial temperature was 160 °C for 1 min, raised to 190 °C at a rate of 20 °C/min; raised to 230 °C at a rate of 4 °C/min; held at 230 °C for 16 min; raised to 250 °C at a rate of 20 °C/min; held at 250 °C for 8 min. The detection temperature was 270 °C and split at 250 °C. FAMEs were quantified using C11:0 as the internal standard and calculated as triglycerides.

Insulin (Pharmacia Insulin RIA 100 Pharmacia AB, Uppsala, Sweden) and glucagon (Double Antibody DPC, Los Angeles, CA, USA) as well as T_3 and T_4 (Coat-A-Count DPC, Los Angeles, CA, USA) were measured using standard RIA methods, whereas glucose, total protein, urea N, cholesterol, high density lipoprotein (HDL) cholesterol, triglycerides (Roche Basel, Switzerland), non-esterified fatty acid (NEFA) (Wako, Germany), and β-hydroxy-butyrate (BHB) (Sigma Diagnostics, USA) were analysed by means of a Cobas Mira Analyser (Hoffmann-La Roche Ltd., Basel, Switzerland) using standard enzymatic methods.

2.5. Statistical analysis

Data were submitted to an analysis of variance (GLM procedures of SAS [27]). Linear and quadratic contrasts were used to evaluate dose-dependent effects of chromium. The dietary levels of Cr were not equally spaced; therefore, the coefficients used to calculate the sums of squares for the polynomial contrasts were calculated by the PROC IML method [27]. The basal diet was included as the 0 ppb level of added Cr. In addition, non-orthogonal single degree of freedom comparisons between C and C200 as well as C and C400 were performed. The model included terms for the allocation date and blocked initial LW. Individual pig values served as the experimental unit for all response parameters. Results of the chemical composition of the carcasses were adjusted for hot carcass weight by covariance. Values of the fatty acid profile were analysed using lipid contents of the DM of the carcasses as covariates. In *tables III* to *VII*, least-square means and the standard error of the mean, calculated as root MSE/$\sqrt{n}$, are shown. *P*-values greater than 0.10 were considered not significant.

3. RESULTS

3.1. Diet

The basal diets were formulated to meet nutrient requirements for growing and finishing pigs according to Boltshauser et al. [4]. The results of the analysis verified that all requirements were met, although the values of the CP:digestible energy (DE) ratio were slightly higher than the requirements (*table II*). The analysed Cr contents clearly demonstrated an increasing chromium level from the C diet to the 800 ppb treatment. The total Cr concentrations of the grower and finisher C diets were 415 and 376 ppb, respectively. The Cr concentrations in all of the diets containing added Cr were close to the calculated levels.

3.2. Growth performance

In the finishing period, there was a quadratic effect of Cr observed for the average daily weight gain ($P < 0.10$) where pigs fed the C200 diet showed the highest daily gain (*table III*). For the overall experimental period, the daily gain of the C200 pigs was 5.9 % higher compared to the pigs of treatment C ($P < 0.06$), whereas daily gain of the pigs fed higher amounts of Cr was similar to treatment C. There was a quadratic response in daily feed intake ($P < 0.10$) in the growing period. In the finishing period, the feed conversion ratio (FCR) was 7.4 % ($P < 0.06$) and in the overall experimental period it was 6.1 % ($P < 0.05$) lower due to supplementation of 200 ppb Cr compared to treatment C. The FCR was, however, impaired with further incremental Cr supplementation.

Table II. Analysed nutrients (g·kg^{-1} dry matter [DM]), energy ([MJ]·kg^{-1} DM) and chromium contents (ppb in DM) of the experimental diets.

	Grower				Finisher			
	C	C200	C400	C800	C	C200	C400	C800
Dry matter	876	876	877	877	875	874	875	875
Ash	65	66	64	63	57	56	56	55
Crude protein	191	198	195	196	163	163	162	161
Crude fat	36	36	37	37	38	37	38	38
Crude fibre	65	58	59	60	59	58	61	63
Nitrogen-free extracts	644	643	644	644	684	687	683	684
Gross energy	18.55	18.54	18.37	18.55	18.42	18.48	18.51	18.58
Digestible energy[a]	14.13	14.39	14.40	14.37	14.48	14.51	14.38	14.35
Ratio CP:DE[b]	13.52	13.76	13.54	13.64	11.26	11.23	11.27	11.22
Chromium (ppb)	415	678	772	1010	376	515	672	1 000

[a] Digestible energy (DE) calculated from the analysed nutrient content according to the formula: DE (MJ·kg^{-1} DM) = 18.974*crude protein (g·g^{-1} DM) + 33.472*crude fat (g·g^{-1} DM) – 21.216*crude fibre (g·g^{-1} DM) + 16.611*nitrogen-free extracts (g·g^{-1} DM).
[b] Ratio crude protein:digestible energy.

Table III. Effect of chromium from chromium yeast on growth performance of growing- finishing pigs[a].

	Treatment[b]				
Item	C	C200	C400	C800	SEM
Daily gain (g)					
Grower	688	695	661	679	14.8
Finisher[cd]	783	855	807	786	21.5
Total trial[e]	741	785	742	736	15.8
Daily feed intake (kg)					
Grower[c]	1.55	1.53	1.53	1.54	0.012
Finisher	2.40	2.43	2.41	2.43	0.023
Total trial	2.03	2.04	2.02	2.03	0.013
Feed conversion ratio (kg·kg^{-1})					
Grower	2.26	2.19	2.31	2.27	0.051
Finisher[e]	3.11	2.88	3.01	3.11	0.081
Total trial[f]	2.78	2.61	2.73	2.75	0.058

[a] Mean body weight at the initiation of the trial, at the initiation of the finisher phase, and at the trial termination was 24.5, 57.4 and 105.4 kg, respectively.
[b] Data are least-square means of 10 pigs, standard error of the mean (SEM) = root MSE/$\sqrt{n}$.
[c] Quadratic, $P < 0.10$.
[d] Single degree of freedom contrast of treatment C vs. C200, $P < 0.03$.
[e] Single degree of freedom contrast of treatment C vs. C200, $P < 0.06$.
[f] Single degree of freedom contrast of treatment C vs. C200, $P < 0.05$.

3.3. Carcass measurements

Compared to treatment C, the dressing percentage of the C200 group was impaired ($P < 0.09$), but a higher dietary Cr supplementation had no further effects (*table IV*). In addition, there was a linear increase in palmitoleic acid in the carcass lipids ($P < 0.04$) (*table V*). Dietary Cr did not affect dissection parameters, chemical composition nor fatty acid profiles.

3.4. Plasma metabolites and hormones

Increasing amounts of added Cr reduced triglyceride concentrations ($P < 0.03$) linearly in plasma after 24 h of fasting (t0), whereas the NEFA concentrations increased linearly ($P < 0.08$) (*table VI*). In addition, there was a numerical increase in urea N concentration at t0 with incremental amounts of dietary Cr.

Two hours post-feeding (t2), the Cr effect on BHB was quadratic ($P < 0.04$), with the C400 group showing the highest value. In addition, the change in the BHB concentration from t0 to t2 was linear ($P < 0.09$) and negative in pigs with treatment C (–11.4 mmol·L^{-1}) and positive in pigs with treatment C800 (+7.2 mmol·L^{-1}). Pigs with treatment C200 (–0.8 mmol·L^{-1}) and C400 (+0.7 mmol·L^{-1}) showed intermediate values. Plasma triglycerides of the C200 and C800 pigs were reduced at t2 compared with group C ($P < 0.06$), but the triglyceride concentrations of the C400 pigs did not differ from treatment C. The added chromium did not significantly affect hormone concentrations but the insulin values and insulin to glucagon ratios, as well as the insulin to glucose ratios, seemed to be lower when Cr was supplemented (*table VII*).

Table IV. Effect of chromium from chromium yeast on carcass measurements and chemical composition of pig carcasses.

	Treatment[a]				
Item[b]	C	C200	C400	C800	SEM
Dissection parameters (% of carcass)					
Hot carcass weight (kg)	83.0	83.7	83.9	83.1	0.58
Dressing percentage[c]	79.28	78.05	79.42	79.75	0.491
Lean cuts	54.59	55.08	54.16	53.58	0.738
Fat cuts	13.87	13.88	13.96	14.41	0.477
Abdominal fat	1.63	1.49	1.51	1.70	0.135
Fat thickness (mm)	17.9	18.8	17.7	18.6	0.48
Chemical composition (% of DM)[d]					
Dry matter (%)	41.30	41.21	40.89	41.39	0.820
Ash	7.55	7.54	7.64	7.22	0.233
Protein	41.69	41.51	42.15	39.29	1.459
Fat	49.67	50.28	49.49	52.48	1.528

[a] Data are least square means of ten pigs, standard error of the mean (SEM) = root MSE/$\sqrt{n}$.
[b] Lean cuts: shoulder, back, and ham without fat layers; Fat cuts: fat layers above shoulder, back, and ham; Fat thickness: thinnest part in the middle of the back between two whirls.
[c] Single degree of freedom contrast of treatment C vs. C200, $P < 0.09$.
[d] Hot carcass weight was used as a covariate.

Table V. Effect of chromium from chromium yeast on the fatty acid profile of the extracted fat of pig carcasses[a].

	Treatment[b]				
Item[c]	C	C200	C400	C800	SEM
SFA	41.89	41.64	41.17	41.26	0.499
C 16:0	23.78	23.82	23.62	23.84	0.203
C 18:0	15.88	15.61	15.35	15.15	0.357
MUFA	46.76	47.06	47.42	47.56	0.484
C 16:1[d]	2.45	2.53	2.53	2.68	0.070
C 18:1	42.85	43.13	43.44	43.51	0.435
PUFA	11.36	11.30	11.42	11.18	0.142
C 18:2	9.68	9.67	9.73	9.70	0.127
C 18:3	0.75	0.76	0.75	0.73	0.017

[a] In % of the extracted fat of the carcass; fat content of the dry matter (DM) of the carcass was used as a covariate.
[b] Data are least-square means of ten pigs, standard error of the mean (SEM) = root MSE/$\sqrt{n}$.
[c] SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.
[d] Linear, $P < 0.04$.

4. DISCUSSION

4.1. Diets

The CP:DE ratios in the diets were slightly higher than the recommendations (12.6 to 11.3 g CP[MJ] DE^{-1} for growing and 11.3 to 9.9 g CP[MJ] DE^{-1} for finishing pigs) (*table II*) [4, 24]. Thus, we can assume that the pigs were provided with adequate levels of protein. The chromium contents of the pelleted diets, analysed by means of atomic absorption spectrometry, were higher than expected. Besides the feedstuff Cr concentration, contamination with inorganic complexed Cr during feed processing (milling, mixing and pelleting) probably influenced the amount of total chromium [13]. Wenk et al. [30] reported an increased Cr content of 35 % due to pelleting processes. The authors concluded that the increase did not affect the amount of bioavailable Cr. The content of bioavailable Cr is, however, far lower than the total Cr content of the feedstuff [22].

4.2. Growth performance

Cr requirements depend on many individual and environmental factors and therefore, comparisons of the results from different Cr studies have to be used carefully. For example, Lindemann et al. [14] and Ward et al. [29] observed interactions between dietary Cr and dietary lysine levels. Boleman et al. [3] and Mooney and Cromwell [21] reported an influence of duration of Cr supply on Cr effects.

Daily feed intake was similar in all treatments since the slight Cr effect in the growing period could be ignored because differences between treatments were only 10 to 20 $g \cdot d^{-1}$. The effects on daily gain were inversely mirrored by the feed conversion ratios. We have no explanation to this phenomenon since it tended to follow a quadratic response. To our knowledge, no dose response study has reported such an effect on daily gain and feed conversion ratio. Mooney and Cromwell [21] reported higher daily gain when growing pigs

Table VI. Effect of chromium from chromium yeast on plasma metabolites of pigs both after 24-h fasting and 2-h postprandial on experimental day 88 (87.4 kg LW).

	Treatment[a]				
Item[b]	C	C200	C400	C800	SEM
After 24-h fasting (t0)					
Total protein ($g \cdot L^{-1}$)	71.2	71.0	71.6	69.3	1.22
Urea N ($mmol \cdot L^{-1}$)	3.27	3.50	3.51	3.74	0.215
Triglycerides ($mmol \cdot L^{-1}$)[c]	0.571	0.554	0.490	0.480	0.0310
NEFA ($mmol \cdot L^{-1}$)[d]	0.148	0.187	0.184	0.243	0.0359
β-hydroxy-butyrate ($\mu mol \cdot L^{-1}$)	62.9	55.0	67.0	42.7	7.22
Cholesterol ($mmol \cdot L^{-1}$)	2.81	2.91	2.61	2.80	0.099
HDL-cholesterol ($mmol \cdot L^{-1}$)	1.22	1.30	1.15	1.23	0.048
Glucose ($mmol \cdot L^{-1}$)	5.19	5.27	5.13	5.12	0.152
2-h post-feeding (t2)					
Total protein ($g \cdot L^{-1}$)	71.8	70.7	72.4	71.1	1.26
Urea N ($mmol \cdot L^{-1}$)	4.44	4.63	4.65	4.92	0.259
Triglycerides ($mmol \cdot L^{-1}$)	0.522	0.422	0.483	0.421	0.0358
NEFA ($mmol \cdot L^{-1}$)[e]	0.038	0.036	0.050	0.040	0.0051
β-hydroxy-butyrate ($\mu mol \cdot L^{-1}$)[fg]	51.5	55.8	66.3	49.9	5.31
Cholesterol ($mmol \cdot L^{-1}$)	2.79	2.78	2.61	2.79	0.085
HDL-cholesterol ($mmol \cdot L^{-1}$)	1.22	1.25	1.18	1.26	0.051
Glucose ($mmol \cdot L^{-1}$)	5.35	5.28	5.23	5.07	0.184

[a] Data are least-square means of ten pigs, standard error of the mean (SEM) = root MSE/$\sqrt{n}$.
[b] NEFA: non-esterified fatty acids; HDL: high density lipoproteins.
[c] Linear, $P < 0.03$.
[d] Linear, $P < 0.08$.
[e] Single degree of freedom contrast of treatment C vs. C400, $P < 0.10$.
[f] Quadratic, $P < 0.04$.
[g] Single degree of freedom contrast of treatment C vs. C400, $P < 0.06$.

received 200 ppb Cr as Cr picolinate (CrP) compared to pigs fed 0 or 400 ppb CrP but they found in addition an increased daily feed intake which abolished the benefit of growth rate. Min et al. [19] observed lower daily feed intakes but no effect on daily gain in finishing pigs supplied 200 ppb CrP compared to those provided with 0, 100 and 400 ppb. In contrast, Page et al. [25] reported a linear decline in both daily gain and feed intake with an increasing dietary CrP level (0, 100, 200, 400, 800 ppb CrP). Lindemann et al. [14] and Grela et al. [9] did not determine any dose-dependent response on performance due to Cr. Nevertheless, in the present study an improved daily gain of 5.9 % and feed conversion ratio of 6.1 % in treatment C200 compared to treatment C indicated that 200 ppb dietary Cr provided the best effects under our experimental conditions, particularly in the finishing period. However, studies carried out with only one level of Cr supplementation (nearly all with 200 ppb Cr) also demonstrated variable results in daily gain, feed intake and feed conversion rate which were also partly dependent on other nutritional and non-nutritional factors [3, 14, 20, 29]. It should be noted that with the exception of one study [3], the published data refer to ad libitum

Table VII. Effect of chromium from chromium yeast on plasma hormones of pigs both after 24-h fasting and 2-h postprandial on experimental day 88 (87.4 kg LW).

	Treatment[a]				
Item[b]	C	C200	C400	C800	SEM
After 24-h fasting (t0)					
Insulin ($\mu U \cdot mL^{-1}$)	8.45	8.95	7.20	9.90	1.109
Glucagon ($pg \cdot mL^{-1}$)	76.3	90.5	72.1	92.6	4.71
Ratio insulin: glucagon	5.11	5.01	4.64	4.98	0.819
Ratio insulin: glucose	1.17	1.21	1.02	1.37	0.148
T_3 ($nmol \cdot L^{-1}$)	0.93	1.04	0.94	1.06	0.083
T_4 ($nmol \cdot L^{-1}$)	52.0	56.8	53.7	52.8	2.26
2-h post-feeding (t2)					
Insulin ($\mu U \cdot mL^{-1}$)	35.50	30.00	30.40	28.45	5.899
Glucagon ($pg \cdot mL^{-1}$)	115.9	123.4	103.2	128.0	7.33
Ratio insulin: glucagon	16.62	11.10	13.17	10.22	2.81
Ratio insulin: glucose	4.70	4.46	4.32	3.98	0.953
T_3 ($nmol \cdot L^{-1}$)	1.21	1.32	1.36	1.37	0.084
T_4 ($nmol \cdot L^{-1}$)	60.5	63.2	64.3	62.9	3.39

[a] Data are least-square means of ten pigs, standard error of the mean (SEM) = root $MSE/\sqrt{n}$.
[b] Ratio insulin: glucagon ($pg \cdot mL^{-1}$:$pg \cdot mL^{-1}$), insulin $pg \cdot mL^{-1} = \mu U \cdot mL^{-1} * 45\ pg \cdot \mu U^{-1}$; ratio insulin:glucose (($mol \cdot L^{-1}$: $mol \cdot L^{-1}$) * 10^{-8}), insulin $pmol \cdot L^{-1} = \mu U \cdot mL^{-1} * 7.175\ pmol \cdot \mu U^{-1}$.

trials leading to Cr effects on feed intake which may have been prevented by the restricted feeding level applied in this present study. We assume that Cr effects on growth performance among other dietary factors such as lysine [14, 29] might also be affected by feeding regime.

4.3. Carcass measurements

Although pigs were slaughtered in a similar manner 7 days after they exceeded 97 kg live weight, differences in final body weight occurred. Since hot carcass weights were similar, the final weights were inversely mirrored by dressing percentages (*table IV*). The weights of the viscera (data not shown) did not differ and thus we suggest that different residual fillings of the gastrointestinal tract may have caused the differences in dressing percentages.

Although several experiments that were performed with varying levels of dietary Cr demonstrated a decrease in back fat thickness and fat accretion rate [9, 14, 19, 25] and increase in lean or muscle percentage [14, 25], no clear dose-response relationship could be established between Cr dosage and nutrient deposition, which is in good agreement with the present results. In contrast to previous studies, we observed elevated fat contents and proportion of fat cuts in treatment C800 compared to those of treatment C, which implies an increasing rather than decreasing effect on fat (*table IV*). The weak effect on nutrient deposition could most likely be attributed to the lean pig breed used, and/or to the restricted feeding scale since it is well known that carcasses of pigs fed ad libitum compared to those of pigs fed on a restricted feeding scale usually have higher fat and reduced protein contents as well as lower percentages of

lean cuts [2, 31]. In addition, a proper protein to energy ratio in the diet probably also prevented excessive fat deposition. In most of the cited studies, back fat thickness of the control groups was higher than 25 mm compared to a mean of 18.3 mm in this study, suggesting that high fat deposition is a prerequisite for a fat-reducing effect of Cr supplementation.

In contrast to the present data which demonstrated no effect of Cr supplementation on fatty acid profiles except for palmitoleic acid (*table V*), Grela et al. [9] reported decreased contents of saturated fatty acids (SFA) and enhanced contents of polyunsaturated fatty acids (PUFA) in back fat due to Cr (0, 200, 500 ppb Cr as Cr yeast). This was, however, an indirect Cr effect because fat deposition on the back was also reduced by Cr, and PUFA in the back fat of the control pigs were probably diluted by SFA deriving from de novo fatty acid synthesis [2, 31].

4.4. Plasma metabolites and hormones

Plasma profiles of metabolites and hormones of a single blood collection, as in the present study, merely reflect the physiological state of the animals at the time of bleeding and the results should therefore be interpreted carefully. Present plasma data may however give evidence of alterations due to dietary Cr (*tables VI* and *VII*).

Several studies with pigs have demonstrated the involvement of Cr in insulin metabolism [1, 7, 8, 10, 15]. Moreover, a recent investigation has demonstrated the probable mechanism in which Cr is involved in improving insulin action [6]. The slightly, but not significant, lower insulin concentrations in plasma of Cr treated pigs at t2 may be explained by the postulated hypothesis by McCarty [16] that an improved effectiveness of insulin by dietary Cr must result in a compensatory down-regulation of insulin secretion. On the other hand, glucagon secretion should increase due to Cr treatment [16]; however, the plasma glucagon levels at t2, and the insulin:glucagon ratios, indicating the net effect of both hormones [28], did not confirm this hypothesis since glucagon concentrations in plasma of pigs fed diet C400 were lower than those in pigs fed treatment C. Plasma insulin and glucagon levels after 24 h of fasting also showed no relationship to Cr dosage.

However, the linear decline in plasma triglycerides as well as the linear increase in NEFA suggest an elevated catabolic state during fasting with incremental Cr supplementation [12]. The numerical but non-significant elevated plasma urea N concentrations with increasing Cr levels at t0 and t2 are consistent with this hypothesis. Moreover, the changes in plasma BHB level from t0 to t2, which as was normally expected [5] negative in pigs fed diet C, but were unchanged in pigs fed diets C200 and C400, and positive in pigs of treatment C800 further support the hypothesis of an altered metabolism. Since ketogenesis is usually associated with gluconeogenesis [5], we assume an enhanced gluconeogenesis rate due to increasing Cr supplementation.

5. CONCLUSION

The present data suggest that supplementation with 200 ppb Cr fed as Cr yeast had a favourable impact on growth performance and feed conversion rate, but we have no explanation for the finding that supplementations of 400 and 800 ppb Cr did not affect performance. Carcass evaluation did not support the results of other studies which reported enhanced protein or decreased fat deposition by Cr. On the contrary, our data implicate rather an elevated fat accretion due to Cr supplementation. We assume that a high fat deposition is a prerequisite for dietary Cr to lower fat accretion since pigs used in other studies had comparatively high fat depositions. Low effects on plasma hormones and metabolites suggest an altered physiology due to Cr.

While the direction of many observed responses were as hypothesised, the responses of Cr supplementation, especially on carcass characteristics and plasma traits, were rather weak and further research is needed to study the impact of Cr supplementation on the physiology and performances of the animals. Therefore, further experiments are planned to investigate possible interactions between Cr supplementation and other nutritional factors.

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