Journal of Elementology ISSN 1644-2296

Król B., Słupczyńska M., Kinal S., Bodarski R., Tronina W., Mońka M. 2017. *Bioavailability of organic and inorganic sources of chromium in broiler chicken feeds*. J. Elem., 22(1): 283-294. DOI: 10.5601/jelem.2016.21.1.1119

ORIGINAL PAPER

BIOAVAILABILITY OF ORGANIC AND INORGANIC SOURCES OF CHROMIUM IN BROILER CHICKEN FEEDS*

Barbara Król[1], Maja Słupczyńska[1], Stefania Kinal[1], Rafał Bodarski[1], Wojciech Tronina[2], Martyna Mońka[1]

[1]Department of Animal Nutrition and Feed Quality
Wroclaw University of Environmental and Life Sciences
[2]Breeding and Innovating Company Tronina, Rakow near Wroclaw

Abstract

Chromium bioavailability in animals depends on their species, age and physiological state as well as fodder composition and Cr source. However, inorganic forms of chromium are poorly absorbed compared to organic compounds. One hundred and eighty Isa Vedetta chickens were assigned to 2 groups, with 3 replications of 30 birds each, to determine the effects of different Cr source on its bioavailability, growth performance and carcass characteristics of broiler chickens. All chickens were fed with commercial standard concentrate mixtures (starter, grower and finisher) depending on the birds' age. The dietary treatments consisted of a basal diet supplemented with chromium chloride (control group) or chromium-enriched yeast (experimental group). The treatments were supplemented with chromium so as to provide the same amount of pure chromium in both groups. Mortality, body weight and feed conversion rate were measured. On the 42nd day, 6 cockerels and 6 hens from each group were randomly selected, decapitated, blood samples were taken and carcass composition was determined. The bioavailability of Cr was evaluated by the level of that trace element in mentioned above soft and hard tissues. Furthermore, dry matter, crude protein and crude fat in muscles were determined and sensory analyses of quality muscles were carried out. Growth performance, feed conversion ratio and mortality were unaffected by treatments. There was no Cr source effect on outcomes of post-slaughter analyses. Cr enriched yeast effected the decrease ($P \leq 0.05$) in crude fat and dry matter content in breast and leg muscles compared to chromium chloride. Inclusion of chromium-enriched yeast to concentrate mixtures increased ($P \leq 0.01$) the level of Cr in analysed tissues, which might be evidence of its better bioavailability in chickens. It can be assumed that such animal origin products may be a good source of effectively absorbed Cr in human nutrition.

Keywords: chromium chloride, chromium enriched yeast, broiler chickens, growth performance, carcass characteristics.

dr hab. Rafał Bodarski, Assistant Professor, Department of Animal Nutrition and Feed Science, Wroclaw University of Environmental and Life Sciences, J. Chełmońskiego Street 38C, 51-630 Wrocław, Poland, phone: +48 71 3205 838, e-mail: rafal.bodarski@up.wroc.pl

* Publication supported by Wrocław Centre of Biotechnology, programme the Leading National Research Centre (KNOW) for years 2014-2018.

INTRODUCTION

Chromium bioavailability in animals depends on their species, age and physiological state as well as fodder composition and Cr source. Inorganic forms of chromium are poorly absorbed, for example 0.4-3% of inorganic Cr salts (>1%) can be absorbed, while the absorption of chromium bound with organic compounds (brewer's yeast, picolinate, nicotinate) is distinctly higher and ranges between 10 and 25% (Anderson et al. 1989, Bahrami et al. 2012). Also, the content of Cr and other elements in a diet as well as their mutual proportions are very important, for instance high levels of sugars, amino acids and ascorbic acids improve Cr absorption whereas antacids and phytate reduce Cr content in blood. However, the mechanism of absorption has not been completely elucidated yet. Chromium is probably transported with transferrin. Afterwards, Cr proceeds from the intestine to the liver and is probably built in GTF (Glucose Tolerance Factor). GTF is secreted into blood serum to enhance insulin activity. This issue is extremely complicated, which makes interpretation of Cr bioavailability difficult because the metabolism of minerals in animals is affected by numerous factors (Der-Nan et al. 2003).

Previous research indicated that chromium is one of the main trace elements participating in the metabolism of carbohydrates and lipids in both mammals and birds. Moreover, physiological stress or infections increase Cr demand as a result of 10- to 300-fold higher chromium loss with urine (Anderson et al. 1989). Therefore, some researchers (Kim et al. 1996, Lien et al. 1999) suggest that Cr supplementation in concentrate mixtures for chickens in poultry husbandry should become a standard practice. However, no standard for this element has been established yet. It has been demonstrated that Cr added to animal fodder shows antistress activity. Chromium prevents loss of some trace elements, such as Zn, Fe, Cu and Mg, improves immunity and survival rate of animals, and consequently enhances the efficiency of husbandry (Vincent 2000, Mohsen, Mehran 2014). The metabolic role of Cr still awaits complete recognition. A source of chromium often used in diets is dietary chromium picolinate $Cr(pic)_3$ – organic chromium in which this element is bound with picolinate acid and forms chelates. Vincent (2000) found a certain risk related to applying this chemical form of Cr in animal nutrition. Namely, Cr has to be previously reduced from the Cr^{+6} to Cr^{+3} state to make this element available in an animal's organism, which precipitates generation of free radicals.

The aim of this study was to estimate Cr bioavailability of chromium chloride and chromium-enriched yeast in broiler chickens as well as the effect of the bioavailability of chromium on chickens' growth performance and carcass characteristics.

MATERIAL AND METHODS

Broiler chickens housing and feeding

The research material consisted of 180 unsexed Isa Vedetta chickens, which were randomly allocated to 2 treatments with 3 replications per treatment (30 indiv. each). The chickens were kept in boxes (2,5 m^2) on dry sawdust. The poultry house was fitted with a mechanical ventilation system and the air exchange rate was adequate. Relative humidity during the experiment ranged from 67 to 77%.

The broilers were fed *ad libitum* with complete commercial diets: starter - from day 1 to 21, grower – from day 21 to 35, finisher – from day 35 to 42 of life, and had unlimited access to water. The factor differentiating all mixtures was a Cr source in the mineral-vitamin mixtures (premixes): chromium chloride (control) or chromium-enriched yeast (experimental group). The commercial mixtures were prepared in accordance with feeding standards (Poultry Nutrition Standards 1996).

Before commencing the experiment, all feed mixtures were chemically analysed to determine the content of basic nutrients and mineral components, i.e. calcium, sodium and phosphorus, by standard chemical methods (AOAC 2006), as well as chromium after wet mineralisation of the samples using a Zeiss AAS-3 spectrometer. The results of the analyses enabled us to assess the nutritive value of concentrate mixtures for chickens (Table 1).

Measurements of growth performance

On day 21 and 42 of the experiment, the chickens were weighed and the feed intake quantity as well as mortality were recorded. In this way, the birds' body weight and feed conversion rate were measured.

Blood and tissues samples collection

At the end of the experiment, on day 42 of rearing, 12 birds (6 cockerels and 6 hens) were randomly selected for blood sampling, slaughter and dissection. Afterwards, carcass yield, gutted carcass weight and the breast and leg meat yield and wings were measured. Samples of breast and leg muscles, livers and kidneys and femurs including the joint tissues prepared from the carcass were analysed. The qualitative parameters were expressed as a percentage of the total weight of each carcass.

Chemical analyses

The following parameters were determined in breast and leg muscles: dry matter, crude protein and crude fat according to standard chemical methods (AOAC 2006). After wet mineralisation of the samples with nitric acid using a plasma spectrometer with mass detection (Varian ICP-MS instrument), the Cr content was determined in the muscles, liver, kidneys and femur as well as in the blood serum of birds.

Table 1

Composition and nutritive value of all-mash mixtures

Ingredient	Starter	Grower	Finisher
Maize (%)	24.75	20.00	30.00
Wheat (%)	35.00	42.00	38.30
Soybean meal (46%)	32.00	29.30	23.50
Dicalcium phosphate (%)	1.700	1.500	1.200
NaCl (%)	0.250	0.250	0.250
Soybean oil (%)	4.000	4.800	5.000
Limestone %	1.300	1.150	0.750
Premix* (%)	1.000*	1.000*	1.000*
Nutritive value			
Metabolisable energy (MJ kg^{-1})	12.84	12.88	13.22
Crude protein (g kg^{-1})	220.0	197.5	184.5
Crude fibre (g kg^{-1})	25.00	25.00	25.00
Lysine (g kg^{-1})	12.00	11.70	10.50
Methionine (g kg^{-1})	5.400	5.200	4.800
Methionine + cysteine (g kg^{-1})	9.200	8.800	8.100
Tryptophan (g kg^{-1})	2.500	2.200	2.100
Treonine (g kg^{-1})	7.800	7.300	6.500
Total calcium (g kg^{-1})	8.700	8.200	7.000
Available phosphorus (g kg^{-1})	4.600	4.200	3.500
Total sodium (g kg^{-1})	1.600	1.500	1.600
Chromium (mg kg^{-1})	2.780	2.890	2.880

Sensory analysis

The breast and leg muscles were subjected to sensory analyses according to PN-ISO 6564 (1999), using the multiple comparison method and a 5-grade scale to evaluate colour, taste, smell, tenderness and juiciness. The sensory analyses were carried out by a team of 5 scientists from the Department of Animal Production Technology and Quality Management in Wroclaw University of Environmental and Life Sciences.

Statistical analyses

All data obtained in the experiment were statistically analysed by calculating arithmetic means, standard deviation (SD) and standard error of mean (SEM). Significant differences between the treatments were verified with Student's *t*-test using Statistica 9.2. software.

All procedures with animals were approved by the II Local Ethics Commission for Experiments on Animals.

RESULTS AND DISCUSSION

The Cr content in breast and leg muscles as well as in the liver, kidneys and femur of birds which were given chromium-enriched yeast in a diet was distinctly ($P \leq 0.01$) higher than in chickens which received chromium chloride (Table 2). This result implicates better bioavailability of the organic

Table 2

Chromium content in some soft tissues, femur (mg kg^{-1} fresh tissue) and in blood serum (μmol L^{-1}) of broilers

Item	Treatments		SEM
	I – chromium chloride	II - chromium enriched yeast	
Breast muscles			0.001
$\bar{x}$	0.042^{A}	0.082^{B}	
SD	0.005	0.007	
Leg muscles			0.001
$\bar{x}$	0.060^{A}	0.130^{B}	
SD	0.002	0.004	
Liver			0.001
$\bar{x}$	0.182^{A}	0.373^{B}	
SD	0.002	0.005	
Kidneys			0.002
$\bar{x}$	0.056^{A}	0.081^{B}	
SD	0.007	0.006	
Femur			0.002
$\bar{x}$	0.108^{A}	0.338^{B}	
SD	0.026	0.073	
Blood serum			0.000
$\bar{x}$	0.012^{A}	0.008^{B}	
SD	0.002	0.002	

A, *B* – values in rows with different letters differ highly significantly ($P \leq 0.01$), $\bar{x}$ – mean values, SEM – standard error of the mean

form of chromium. However, the content of this element in the blood serum of birds whose concentrate mixture was supplemented with chromium-enriched yeast decreased clearly ($P \leq 0.01$). The three-fold higher Cr content in the femurs of birds that received chromium-enriched yeast in diets than in those of chickens whose mixture was supplemented with chromium chloride might be indicative of better bioavailability of the organic source of chromium than the inorganic one (Table 2).

Research on animals has confirmed that Cr from organic complexes is absorbed more efficiently, about 25-30%, than from inorganic salts, about 1-3% (Toghyani et al. 2008). Better bioavailability of organic chromium is confirmed by findings obtained in the present study, where the chromium content in some soft tissues and femurs was analysed, and these are in accord with results reported by Anderson et al. (1989) from a study carried out on 33- week-old turkeys that received 25, 100, 200 ppb chromium picolinate, which increased the Cr content in breast and leg muscles, liver and kidneys. Saikat et al. (2008) showed that live weight gain, feed efficiency, energy and protein utilisation efficiency and efficiency of the conversion of feed protein to muscle protein increased with Cr^{3+} supplementation. The chromium content in tissues is directly proportional to the content this element in feed. Whereas Olsen et al. (1996) showed that an increase in dietary Cr content from 2.6 to 62.5 μg kg^{-1} DM in lambs' diet positively affected the chromium concentration in the liver, the Cr content in skeletal muscles remained on the same level. On the other hand Amatya et al. (2004) noted that chromium-enriched yeast added to concentrate mixtures for broilers decreased the Cr content in the liver compared to the liver of birds that received chromium as potassium chromate or chromium chloride. The knowledge on chromium absorption, retention and metabolism is rather limited. According to American standards, Cr absorption is low and ranges between 0.5% and 2.8% in humans and rats, but the mechanism of its absorption has not been completely elucidated yet. The Cr content in blood serum is not a reliable indicator of chromium bioavailability in animals and it is not correlated to the level of this trace element in tissues. This may underlie the lower chromium content in chickens' blood serum determined in the current experiment.

Better bioavailability of organic chromium affects the chemical composition of meat, especially crude fat. The lower ($P \leq 0.05$) dry matter content and slightly lower crude protein content in breast muscles were noted in broilers that received chromium-enriched yeast in mixtures. Chromium--enriched yeast added to a diet decreased ($P \leq 0.05$) the crude fat content in breast muscles. Inclusion of organic Cr to chickens' diets slightly reduced the dry matter content in leg muscles compared with control birds (Table 3). The crude protein content in leg muscles did not depend on the source of Cr in concentrate mixture for chickens, while the crude fat content in these muscles of the birds that received chromium-enriched yeast was lower ($P \leq 0.05$) than in birds from the control group (chromium chloride) – Table 3. Ward et al. (1993), and Kim et al. (1996) also reported that chromium-enriched yeast added to concentrate mixture for chickens reduced the fat content in breast muscles. Also Suksombat and Kanchanatawee (2005) in their experiment on broiler chickens showed that supplementation of organic chromium reduced ($P < 0.05$) the breast meat fat content but increased the breast meat protein content. On the other hand, Króliczewska et al. (2005), who tested supplementation of concentrate mixture for chickens with various levels of chromium-enriched yeast (300 and 500 μg Cr kg^{-1}), demonstrated that the dry matter and protein content in breast muscles did not depend on the amount of chromium administered in concentrate mixtures, while the fat

Table 3

Chemical composition of muscles (%)

Item	Treatments		SEM
	I – chromium chloride	II - chromium enriched yeast	
Breast muscles			0.020
Dry matter			
$\overline{x}$	28.16^a	26.15^b	
SD	1.170	0.500	
Crude protein			0.010
$\overline{x}$	22.01	21.86	
SD	0.240	0.580	
Crude fat			0.020
$\overline{x}$	3.260^a	2.390^b	
SD	1.590	0.150	
Leg muscles			0.010
Dry matter			
$\overline{x}$	27.13	26.47	
SD	0.320	0.320	
Crude protein			0.010
$\overline{x}$	17.60	17.46	
SD	0.370	0.200	
Crude fat			0.010
$\overline{x}$	8.050^a	6.890^b	
SD	0.720	0.470	

a, *b* – values in rows with different letters differ significantly ($P \leq 0.05$), $\overline{x}$ – mean values, SEM – standard error of the mean

content was reduced in birds that received organic chromium in an amount of 300 μg Cr kg^{-1}. In contrast, LIEN et al. (1999) performed an experiment on broiler chickens fed with concentrate mixtures including 0, 200, 400 and 800 ppb chromium picolinate and did not note any significant differences in meat composition. Likewise, the data obtained by HUANG et al. (2015) showed that Cr contained in concentrate mixture did not affect ($P > 0.45$) the live body weight or the percentage of breast muscle or thigh muscle, although it had some influence on dressing percentage and percentage of abdominal fat.

The decrease of crude fat content, found in our experiment, could be induced by the rise of insulin activity under the influence of chromium and suppressed lipogenesis in chickens' tissues (KIM et al. 1996, ANDERSON et al. 1989). Insulin enhances protein formation but the data obtained in our trials did not give any evidence for such a process (slightly decreased crude protein content both in breast and leg muscles was noted).

Table 4

Sensory evaluation of chicken meat (pts)

Item	Treatments		SEM
	I – chromium chloride	II – chromium enriched yeast	
Breast meat			
Colour			
$\bar{x}$	4.400	4.400	0.120
SD	0.390	0.660	
Taste			
$\bar{x}$	4.620	4.350	0.080
SD	0.360	0.530	
Flavour			
$\bar{x}$	4.290	4.350	0.100
SD	0.340	0.630	
Tenderness			
$\bar{x}$	4.530	4.640	0.070
SD	0.380	0.350	
Juiciness			
$\bar{x}$	4.420	4.400	0.140
SD	0.380	0.390	
Total note			
$\bar{x}$	4.490	4.430	0.140
SD	0.240	0.680	
Leg meat			
Colour			
$\bar{x}$	4.250	4.230	0.110
SD	0.590	0.370	
Taste			
$\bar{x}$	4.300	4.450	0.080
SD	0.330	0.370	
Flavour			
$\bar{x}$	4.390	4.440	0.080
SD	0.390	0.110	
Tenderness			
$\bar{x}$	4.510	4.680	0.040
SD	0.390	0.340	
Juiciness			
$\bar{x}$	4.500	4.530	0.080
SD	0.390	0.350	
Total note			
$\bar{x}$	4.360	4.500	0.030
SD	0.210	0.050	

$\bar{x}$ – mean values; SEM – standard error of the mean

Sensory evaluation of breast muscles (Table 4) indicated that applied in own researches Cr source did not effect on its quality. Slightly better taste and juiciness were assessed in the breast meat of birds that received Cr as chloride, while the inclusion of chromium-enriched yeast to mixture led to the meat having better flavour and tenderness. Leg meat of the birds that received the organic source of chromium, i.e. Cr-enriched yeast, was characterised by better flavour, tenderness, juiciness and a higher total score than meat of the control group chicken (chromium chloride). Similar dependence was demonstrated by Króliczewska et al. (2005), although the values they obtained were significantly lower than ours. Also, Amatya et al. (2004) demonstrated a positive effect of chromium-enriched yeast added to concentrate mixture for broilers on the sensory evaluation of chicken meat, whereas chromium picolinate in amounts of 200, 400 and 800 ppb did not affect the colour of meat.

No effect of better chromium bioavailability on chickens' performance was demonstrated in this study. On 21 and 42 day of the experiment, the body weight of chickens, regardless of their diet, was similar. The feed conversion ratio on day 21 was the same in both groups (1.33 kg), whereas on day 42 this ratio was lower in the birds that received chromium-enriched yeast in premix, yet the differences were not statistically confirmed. A 20% increase in mortality of broilers was noted in the group receiving chromium-enriched yeast compared to the group of birds fed mixtures supplemented with chromium chloride. The form of chromium applied in broilers' mixtures did not affect the broilers' body weight prior to slaughter, gutted carcass weight or carcass yield, which were similar in both treatments. Wing yield was slightly higher in birds that received chromium-enriched yeast in concentrate mixture although the differences were not statistically confirmed (Table 5).

Likewise, Moeini et al. (2011) and Amatya et al. (2004) did not note significant differences in body weight gains or feed conversion between broilers fed on a diet supplemented with Cr supplement and birds receiving a diet without Cr additive. Also, Króliczewska et al. (2005) stated that chromium-enriched yeast added to concentrate mixture for broiler chickens in amounts of 300 and 500 μg Cr kg^{-1} did not affect breast and leg meat yield, while the birds that received this trace element in an amount of 500 μg Cr kg^{-1} showed higher ($P \leq 0.05$) carcass yield. On the other hand, some authors (Toghyani et al. 2012, Huang et al. 2015) demonstrated experimentally that Cr addition to diet, regardless to its form, positively influenced broilers' growth performance and carcass traits. Amatya et al. (2004) administered chromium-enriched yeast in a dose of 0.2 μg kg^{-1} of concentrate mixture fed to broiler chickens and consequently found higher breast meat yield and higher ($P \leq 0.05$) carcass yield than in birds that received inorganic chromium as chromium chloride or potassium chromate.

Table 5

Broiler chickens' growth performance and carcass traits

Item	Treatments		SEM
	I – chromium chloride	II – chromium enriched yeast	
Growth performance			
Body weight (g)			
d 21st			1.090
$\overline{x}$	732.0	737.0	
SD	52.10	39.80	
d 42nd			12.50
$\overline{x}$	2538	2548	
SD	242.5	217.0	
Feed conversion (kg kg^{-1} b.w.)			0.010
d 1st to 21st			
$\overline{x}$	1.330	1.330	
SD	0.150	0.110	
d 22nd to 42nd			0.070
$\overline{x}$	2.020	1.970	
SD	0.230	0.260	
Mortality	4.440	5.560	
Carcass traits			
Body weight prior to killing (g)			14.98
$\overline{x}$	2570	2551	
SD	232.0	208.0	
Gutted carcass weight (g)			23.54
$\overline{x}$	1893	1909	
SD	309.0	320.0	
Carcass yield (%)			0.410
$\overline{x}$	73.29	74.51	
SD	6.270	8.820	
Meat yield (%)			
Breast			
$\overline{x}$	22.32	21.63	
SD	2.670	3.790	0.330
Legs			
$\overline{x}$	33.94	34.09	
SD	5.280	4.040	0.120
Wings yield (%)			
$\overline{x}$	10.21	10.62	
SD	0.570	0.480	0.040

$\overline{x}$ – mean values; SEM – standard error of the mean

CONCLUSIONS

Higher chromium content in breast and leg muscles, liver, kidneys and femur was determined in chickens that received chromium-enriched yeast in a feeding mixture. This is evidence of better bioavailability of the organic form of chromium in broilers' nutrition and the finding may lead to a possible increase in the chromium content increase in animal origin products, which can become good sources of chromium in human diet. In out experimental setup, supplementation of turkey broilers' diet with organic chromium did not enhance production performance of the birds not the carcass traits, but the tested diet might be implemented in order to produce lean meat, which is highly desirable in human nutrition.

REFERENCES

Amatya J.L., Haldar S., Ghosh T.K. 2004. *Effects of chromium supplementation from inorganic and organic sources on nutrient utilization, mineral metabolism and meat quality in broiler chickens exposed to natural heat stress.* Anim Sci., 79: 241-253.

Anderson R.A., Bryden N.A., Planski M.M., Richards M.P. 1989. *Chromium supplementation of turkeys: Effects on tissue chromium.* J Agr Food Chem., 37(1): 131-134. DOI: 10.1021/jf00085a031

AOAC 2006. *Official Methods of Analysis.*

Bahrami A., Moeini M.M., Ghazi S.H., Targhibi M.R. 2012. *The effect of different levels of organic and inorganic chromium supplementation on immune function of broiler chicken under heat-stress conditions.* J Appl Poultry Res, 21: 209-215.

Der-Nan L., Fu-Yu W., Yeong-Hsiang C., Rong-Shinn L., Po-Ching W. 2003. *Effects of dietary chromium picolinate supplementation on growth performance and immune responses of broilers.* Asian Austral J Anim., 16(2): 227-233.DOI: http://dx.doi.org/10.5713/ajas.2003.227

Huang Y., Yang J., Xiao F., Lloyd K., Lin X. 2015. *Effects of supplemental chromium source and concentration on growth performance, carcass traits, and meat quality of broilers under heat stress conditions.* Biol Trace Elem Res., 170(1): 216-223. DOI 10.1007/s12011-015--0443-z

Kim Y.H., Han I.K., Choi Y.J., Shin I.S., Chae B.J. Kang T.H. 1996. *Effects of dietary levels of chromium picolinate on growth performance carcass quality and serum traits in broiler chickens.* Asian Austral J Anim., 9(3): 341-347.DOI: http://dx.doi.org/10.5713/ajas.1996.341

Króliczewska B., Zawadzki W., Skiba T., Miśta D. 2005. *Effect of chromium suplementation on chicken broiler growth and carcass characteristics.* Acta Vet Brno, 74(4): 543-549. DOI: http://dx.doi.org/10.2754/avb200574040543

Lien T.F., Horng Y.M., Yang K.H. 1999. *Performance, serum characteristics, carcase traits and lipid metabolism of broilers as affected by supplement of chromium picolinate.* Brit Poultry Sci., 40: 357-363. DOI: 10.1080/00071669987458

Mohsen A., Mehran T. 2014. *Effects of dietary chromium picolinate and peppermint essential oil on growth performance and blood biochemical parameters of broiler chicks reared under heat stress conditions.* Int. J. Biometeorol., 58(6): 1383-1391. DOI: 10.1007/s00484-013--0740-1

Moeini M.M., Bahrami A., Ghazi S., Targhibi M.R. 2011. *The effect of different levels of organic and inorganic chromium supplementation on production performance, carcass traits and some blood parameters of broiler chicken under heat stress condition.* Biol Trace Elem Res., 144: 715-724. DOI: 10.1007/s12011-011-9116-8

Normy Żywienia Drobiu 1996. Zalecenia żywieniowe i wartość pokarmowa pasz.

OLSEN Q.R., RULE D.C., FIELD R.A., SNOWDER G.D., HU C.Y. 1996. *Dietary chromium picolinate does not influence growth or carcass composition in feedlot lambs*. Sheep Goat Res. J., 12: 22-24.

PN-ISO 6564. 1999. *Sensoric analyse – Methodology – Methods of flavorsomeness profiling.* (in Polish)

Poultry Nutrition Standards 1996. *Nutritional Recommendations and Nutritive Value of Feeds.* (in Polish)

SAIKAT S., SUDIPTO H., VIJAH B., TAPAN K.G. 2008. *Chromium picolinate can ameliorate the negative effects of heat stress and enhance performance, carcass and meat traits in broiler chickens by reducing the circulatory cortisol level*. J Sci Food Agr., 88(5): 787-796. DOI: 10.1002/jsfa.3146

SUKSOMBAT W., KANCHANATAWEE S. 2005. *Effects of various sources and levels of chromium on performance of broilers*. Asian Austral J Anim., 18(11): 1628-1633. DOI: http://dx.doi.org/10.5713/ajas.2005.1628

TOGHYANI M., KHODAMI A., GHEISARI A.A. 2008. *Effect of organic chromium supplementation on meat quality of heat stressed broiler chicken.* Am J Anim., 3: 62-67.

TOGHYANI M., TOGHYANI M., SHIVAZAD M., GHEISARI A., BAHADORAN R. 2012. *Chromium supplementation can alleviate the negative effects of heat stress on growth performance, carcass traits, and meat lipid oxidation of broiler chicks without any adverse impacts on blood constituents.* Biol Trace Elem Res., 146(2): 171-180. DOI: 10.1007/s12011-011-9234-3

VINCENT J.B. 2000. *The biochemistry of chromium*. J Nutr., 130(4), 715-718.

WARD T.L., SOUTHERN L.L., BOLEMAN S.L. 1993. *Effect of dietary chromium picolinate on growth, nitrogen balance and body composition of growing broiler chickens*. Poultry Sci., 72(1): 37.