American Journal of Agricultural and Biological Sciences 2 (4): 267-275, 2007
ISSN 1557-4989

Effect of Dietary Yeasts Enriched with Cu, Fe and Mn on Digestibility of Main Nutrients and Absorption of Minerals by Growing Pigs

[1]Daniel Korniewicz, [1]Zbigniew Dobrzanski, [2]Katarzyna Chojnacka,
[1]Adolf Korniewicz and [1]Roman Kolacz
[1]The Department of Animal Hygiene and Environment, Wroclaw University of Environmental and Life Sciences, Chelmonski st. 38C, 51-630 Wroclaw
[2]Institute of Inorganic Technology and Mineral Fertilizers; Wroclaw University of Technology, Smoluchowski st. 25, 50-372 Wroclaw, Poland

Abstract: Yeasts *Saccharomyces cerevisiae* containing in 1 kg of dry product, separately 32.0 g Fe (Y-Fe), 23.0 g Cu (Y-Cu), 35.4 g Mn (Y-Mn), were used as the source of these microelements in complete diet for growing pigs. If considering livestock requirements, feed supplementation with this organic form of microelements, covered animals' requirements in: Fe-27%, Cu-75%, Mn-30%. ZnO was the source of zinc. The experiments were carried out on 25 barrows. Digestibility of the main nutrients, the apparent absorption and balance for Fe, Cu, Mn as well as Zn, Ca, P, Mg, were carried out. The supplemented microelements did not have the adverse effect on digestibility of the main nutrients and the apparent absorption of Ca, P and Mg. Barrows fed with feed containing Y-Fe excreted more iron with urine than the control, which statistically significantly ($P<0.05$) influenced decrease of retention from 67.4 to 58.0 %. Absorption was similar in both groups. The supplementation of Y-Cu had the influence on increase of retention of Cu up to 25.6 % and absorption up to 28.1 % when compared with the control group (21.3 and 23.7 %), respectively. Supplementation of Y-Mn also significantly ($P<0.05$) increased Mn retention up to 20.1 % and absorption up to 21.4 % when compared with the control group (12.8 and 13.8 %, respectively). Joint supplementation of Y-Fe, Y-Cu and Y-Mn did not improve retention and absorption of all the microelements. In the group Y-Cu, significant ($P<0.05$) decrease of retention and absorption of Zn was observed when compared with the remaining groups. It was found that in pigs feeding, yeasts enriched with copper and manganese may find application in practice. However, yeasts enriched with iron, were found to be less efficient than inorganic form of this bioelement.

Key words: Barrows, yeasts, minerals, trace elements, retention, apparent absorption

INTRODUCTION

Biological value of minerals in livestock diet depends mainly on degree of absorption from the digestive tract. Monovalent ionic forms are absorbed the mostly easily. Nutrients which are not absorbed easily, require employment of activating factors, e.g. carrier proteins, enzymes, etc. [1,2]. Also, chemical form of minerals in feed plays a significant role in bioavailability of nutrients[3-5].

Conventionally used source of microelements in livestock feeding are mineral salts: sulfates, carbonates, oxides and chlorides. Due to relatively low retention of microelements from inorganic forms, they are excreted with feces [6,7]. Microelements, supplemented in the form of organic compounds do not form disadvantageous compounds with phytates or fiber [5,8]. However, bioplexes are absorbed by mucous membrane of intestine in an unchanged form. The mechanism is typical as for dipeptides or amino acids[4,9]. This enables to avoid competition between microelements for the same site of absorption. There are observed interactions between elements: either synergistic or antagonistic. Elements may compete or support in their activity and absorption from gastrointestinal tract and may be stored in organs. In a specific concentration range, a given element can be synergistic to another and in the case of higher or lower concentration, can become antagonist[10,11].

Corresponding Author: Z. Dobrzanski, Department of Animal Hygiene and Environment, Wroclaw University of Environmental and Live Sciences, Wroclaw, Poland, fax/tel. +48713205866

In feeding of pigs, a particular attention is paid to microelements, such as iron, copper, zinc, manganese, selenium, iodine, chromium and cobalt[5,11,12], which may have effect on health condition, absorption of nutrients from feed and production yields.

The aim of the present work was to investigate the effect of organic forms of microelements (enriched yeasts *Saccharomyces cerevisiae*) on digestibility of the main nutrients, nitrogen balance as well as on apparent absorption and the balance of iron, copper, manganese, zinc, calcium, phosphorus and magnesium in barrows during the first period of fattening.

MATERIALS AND METHODS

Experimental diets and design: Yeasts *Saccharomyces cerevisiae* enriched separately with iron (Y-Fe), copper (Y-Cu) and manganese (Y-Mn) were produced according to the original technology elaborated by Dolinska et al. [13] for research purposes, as the source of microelements in an organic form. Chemical analyses showed that dry biomass of yeasts contained the following levels of microelements in 1 kg of dry product:

- iron yeasts – 32.0 g Fe
- copper yeasts – 23.0 g Cu
- manganese yeasts – 35.4 g Mn

The yeasts were investigated as the source of iron, copper and manganese and were added to vitamin-mineral supplements which were introduced to complete diet type of grower (CDG). The supplemented premix type Global Max (PGM) were produced according to a recipe of LNB Poland Ltd. Company in Kiszkowo. The mixture differed in the form of iron, copper and manganese. PGM was supplemented in the quantity 3 % to the complete diet (CDG). Five different complete diets CDG were obtained from the same feeding materials, but differed in the form of iron, copper and manganese, present in PGM. In all the mixtures, the source of zinc was zinc oxide. The system of the studied groups was as follows:

– Group I – control; the source of Fe was ferric sulfate, Cu – copper sulfate, Mn – manganese oxide
– Group II – the source of Fe were yeasts *Saccharomyces cerevisiae* (Y-Fe), Cu – copper sulfate, Mn – manganese oxide
– Group III – the source of Cu were yeasts *Saccharomyces cerevisiae* (Y-Cu), Fe – ferric sulfate, Mn – manganese oxide
– Group IV – the source of Mn were yeasts *Saccharomyces cerevisiae* (Y-Mn), Fe – ferric sulfate, Cu – copper sulfate
– Group V – the source of iron, copper and manganese were yeasts *Saccharomyces cerevisiae* (Y-Fe, Y-Cu, Y-Mn).

The contribution of yeasts in supplementary mixtures (PGM) was diversified and depended on the content of the three microelements and recommended levels of Cu, Fe and Mn in dosages for barrows[15].

Microelement	Content in 1 kg diets (mg/kg)	Supplementation in PGM (mg)	Relative participation in CDG* (%)
Fe	178	48 (Y-Fe)	27
Cu	20	15 (Y-Cu)	75
Mn	50	15 (Y-Mn)	30
Zn	172	120 (ZnO)	70

*PGM/CDG x100

Feeding materials used in the production of CDG (wheat, barley, pszenzyto meal, extracted soya meal) underwent chemical analyses with the use of currently valid AOAC methods[14]. On the basis of these analyses, the content of the main nutrients and minerals in fodders was determined. The energetic value was calculated on the basis of own analyses of constituents and digestibility coefficients as well as procedures of Polish Feeding Standards for Pigs[15] and CVB[16].

CDG produced in the powder form, containing iron, copper and manganese in organic form (yeasts) underwent biological assessment on growing pigs. Nutrients digestibility, nitrogen retention, balance and absorption of the chosen microelements, as well as the main macroelements was investigated.

Animals and sample collection: The experiment was carried out in (Experimental Station of Animal Feeding) in Gorzyn (AU Poznan) on 25 barrows originating from sows (Polish Landrace x Polish Large White) mated to a Hampshire x Pietrain boar. The initial body weight of barrows was 29.0 ± 2.6 kg. Barrows were divided into 5 feeding groups. All the animals were kept separately in coops equipped with feeding automats and nipple drinkers.

The period of 21 days of individual feeding was considered as preliminary that was carried out to prepare to digestibility-balance studies. After 3 weeks of barrows feeding with a given feeds, individual control of body weight was carried out. Barrows were placed in special stainless steel metabolism pens. Barrows were continued to be fed with the same mixtures. The quantity of a given mixture was similar for all the animals, which was ca. 2 kg/day. Every day in the morning, the mass of not consumed residues of the feed were recorded. The period of the first 3 days was treated as preliminary. This was the preparation after changing breeding conditions. The further 4 days were considered as the specific period. During these 4 days, the quantity of consumed feed and the quantity of excrements, which were feces and urine was recorded. Every subsequent day (4 days) at the same time, excreted feces and urine was weighed. 10 % of feces and urine collected daily was sampled and placed in tightly closed jars (urine) and plastic bags (feces). The collected samples were stored in refrigerator at 3-4 ^oC. Feces and urine collected during 4 days were grinded thoroughly. Samples of feces (1 kg) and urine (1 l) were taken for the analyses. The average prepared samples from 4 days collection underwent chemical analyses.

Analyses: In the samples of wet feces, the content of dry mass and nitrogen was determined and in the samples of dry feces, raw fat, raw fiber, raw ash and Ca, P, Mg, Fe, Cu, Mn and Zn were analyzed. In urine samples, the content of N, Ca, P, Mg, Fe, Cu and Zn was determined. Chemical analyses were carried out with the use of conventional methods[14] in analytical laboratory of Department of Animal Nutrition and Feed Science, Wroclaw University of Environmental and Life Sciences.

On the basis of the obtained results, it was possible to calculate digestibility of the main nutrients as well as the apparent absorption. Also, balance of mineral components was carried out according to standardized methods[17].

The results were elaborated statistically with the use of single factor analysis of variance and the difference between the mean values between the groups was assessed by multiple range Duncan test, with the use of Statgraphics software ver. 5.0. Differences were considered significant when $p<0.05$.

RESULTS AND DISCUSSION

Elaboration of diets: Complete diets for all the groups contained 12.9 MJ/kg of metabolic energy, 15.9 % total protein, 2.91 % raw protein, 1.3 % raw fat, 4.81 % raw ash. The contribution of total lysine was 1.02 %, methionine with cystine 0.65 %. The remaining balanced amino acids, such as threonine, tryptophan and isoleucine were in the same quantities.

The content of macroelements (Ca, P, Mg, Na) and microelements (Zn, Fe, Cu, Mn) was the same in all the diets. Chemical and dietetical content of the diets was in conformance with Polish feeding standards for pigs[15].

When considering the total content of the analyzed microelements, the supplementation by supplementary feeding mixture (PGM) contributed from 27 % (Fe) to 75 % (Cu). According to Polish feeding standards for pigs[15], the required level of microelements for growing pigs was: Fe- 90-100, Mn -30-40, Zn -70-150 mg/kg dry mass of feed. The assigned level for copper was 20 mg/kg, however since 16th week of life it was evaluated as 165 mg/kg feed. Since January, 26th, 2004 (Commission Regulation (EC) No 1334/2003 of 25 July 2003), the maximum levels of microelements in complete diets for pigs are obligatory. The recommended levels are as follows (in 1 kg feed): Fe - 750, Mn- 150, Zn – 150 mg. For piglets and growing pigs (younger than 16th week), the limit for Cu was evaluated as 160 mg/kg and in the later period 25 mg Cu/kg feed. These levels were not exceeded in the experimental diets for pigs

Digestibility of the main nutrients and nitrogen balance (tab.1): The results of digestibility studies of the main nutrients and nitrogen balance in the applied diets showed that microelements supplemented in the organic form of yeasts did not influence the increase of digestibility of protein, fat, fiber, nitrogen-free extracts or dry organic mass. The observed differences between the groups were not statistically significant. Barrows fed with mixtures supplemented with Y-Cu and Y-Mn (groups III and IV) although excreted with urine significantly ($p<0.05$) less nitrogen, this did not cause changes in the retention of nitrogen when considering N that was consumed (46.7 - 49.3 %) or digested N (57.8 – 60.3 %).

Digestibility of the studied nutrients present in the diets, in particular dry organic mass, protein and nitrogen-free extractable compounds was determined in all the studied groups as high. Similar values of digestibility coefficients of these nutrients were reported by many authors as typical for pigs in this phase of fattening.

In the previous studies of Korniewicz *et al*.[7], in 1 kg of diet for fatteners, 80 mg of Zn was supplemented in the form of yeasts *Saccharomyces cerevisiae*. This significantly influenced nitrogen metabolism, due to 10 % increase of nitrogen retention. In the studies of Li *et al*.[18], few percent increase of nitrogen occurred, after supplementation of phytase, citric acid and vitamin D to the diet. However, the mechanism of their positive interaction has not been understood well, yet.

Apparent absorption and calcium, phosphorus and magnesium balance (tab. 2): The quantity of calcium consumed by fatteners in each group was from 11.08 to

13.12 g/day/head. This macroelement was not used very efficiently, because a. 68 % of calcium was excreted by fatteners with feces. For this reason, evaluated retention of Ca, as related to the absorbed quantity was from 29.5 to 32.4 % and the apparent absorption from 30.2 to 33.4 %. The highest degree of retention and absorption of calcium was observed in the group IV (Y-Mn), but the differences in the relation to the remaining groups were not significant (p>0.05).

Similar retention coefficients were obtained in the studies of Eeckhout and Paepe[19]. However, in digestibility-balance experiment carried out by Orda *et al*.[20], it was found that in fatteners, significantly higher retention of Ca (38 %) was found. According to other authors[21] in early weanling fatteners, reduction in calcium excretion with feces 12 and 28 % was obtained, after the application of microbiological phytase (Natuphos) or acetic acid, respectively.

The quantity of phosphorus consumed by fatteners in each group was from 8.32 to 9.88 g/day/head. The differences between the groups resulted from the quantity of consumed diet. The digestibility of this macroelement was also not very high – ca. 58 % was excreted with feces. For this reason P retention when compared to the consumed quantity was only from 40.1 to 43.9 % and the apparent absorption from 41.8 to 45.5 %. Similarly as in the case of calcium, the highest values of retention and absorption were reported in the group Y-Mn. but the differences n the relation to the remaining groups were not significant (p>0.05). Iron and copper, supplemented in feed did not influence phosphorus absorption.

Diets for barrows contained 0.54 % total phosphorus and their source in 63 % was phosphorus from grain, and thus in phytin form. The obtained retention of P when compared with the consumed quantity of P was considered as good. The increase in the absorption of phosphorus from grain could be achieved only by supplementation of phytase of microbiological origin, which was shown in various studies[18,22,23]. The studies of Revy *et al*.[24] showed that phosphorus absorption in weanling pigs was improved by the supplementation of zinc, independently on the chemical form.

Magnesium was consumed by barrows in the quantity 1.76 – 2.09 g/day/head. This macroelement was not digested well, because ca. 70 % of the quantity absorbed by fatteners was excreted with feces. Retention of Mg in the relation to the quantity absorbed was 24.4-30.1 % and the apparent absorption 27.8-33.5 %. The best (p<0.05) absorption of magnesium was observed also in the group in which manganese (IV) was supplemented. For this reason we could assume the existence of synergism between Mn and Mg.

The only source of magnesium in diets was feed of plant origin. For this reason, this macroelement was not used very efficiently by barrows, from both control and experimental groups supplemented with yeasts. In digestibility-balance studies, carried out on piglets by Frankiewicz and Potkanski[25], it was found that retention of magnesium was low (29.4 %). Even lower retention in this group of pigs was reported by Revy *et al*. [24], although it is possible, that can increase significantly, similarly as apparent absorption, after supplementation with microbiological phytase together with zinc. However, phytase with copper significantly increased the concentration of this element in bones of growing pigs[26].

As it was found in the present study, microelements supplemented in organic form, generally did not influence the absorption of calcium, phosphorus and magnesium present in mixtures, although there were observed tendencies of advantageous effect of Y-Mn on retention and absorption of magnesium and calcium.

Apparent absorption and balance of iron, copper, manganese and zinc: The results of digestibility-balance studies concerning Fe, Cu, Mn and Zn are presented in Table 3 and 4.

Iron absorption: From 1 kg of the complete diet, barrows consumed 178 mg Fe, from which 27 % was supplemented in the form of sulfate or by yeasts *Saccharomyces cerevisiae*. Iron excreted with feces by barrows from all the groups constituted averagely 25 % as related to the consumed quantity. However, significant differences (p<0.05) were found between the groups in the quantity of iron excreted with urine.

Barrows from the control group excreted with urine ca. 6 % Fe and fatteners from the group II, the diet of which was supplemented in the form of yeasts (Y-Fe) excreted with urine as much as 17 % Fe as related to the consumed quantity. Finally, Fe retention as related to the consumed quantity, was only 58 % lower (p<0.05) when comparing with the control group. Fatteners from this group, excreted less Fe in feces than from the control group, but more than in the remaining groups and for this reason, calculated apparent absorption was similar in all the studied groups (73.0-76.9 %). On the basis of these data, we concluded that iron present in yeasts was not absorbed in higher extent than from inorganic forms.

Iron from yeasts *Saccharomyces cerevisiae* was readily soluble and for this reason, fatteners excreted more iron with urine than barrows from the control group, the diet of which was supplemented in the form of sulfate. Increase, almost three-time higher excretion of iron in urine could result from its higher level in feed. According to Preis and Kinal[27], at higher supply of microelements, their excretion is more intense with feces and urine. Other sources[28] report that iron from organic forms (Availa-Fe®) was significantly better absorbed in growing pigs than from inorganic forms (sulfate) which is of particular significance during increased requirements for this bioelement (physiological anemia). It is worth to mention that absorption of iron could decrease if increased quantities of zinc are supplemented[10,23].

Copper absorption: From 1 kg of complete diet, barrows absorbed 20 mg Cu, from which 75 % in the form of copper sulfate or in the form of yeasts *Saccharomyces cerevisiae*. Barrows from the control groups fed with the diet supplemented with copper sulfate excreted 79 % Cu and for this reason Cu retention was 21.3 % and the apparent absorption was 23.7 %. However, in the case of barrows from the group III, fed with the mixture containing copper yeasts, better digestion was observed. The effect of this was lower excretion with feces (below 28.1 %, P<0.05).

The lowest values concerning retention and absorption of Cu were detected in the group IV, in which the source of manganese was manganese yeasts these data may show antagonism between Cu and Mn. The obtained results showed that Cu present in yeasts *Saccharomyces cerevisiae* was absorbed with higher efficiency than from copper sulfate. In digestibility-balance experiment carried out by Orda *et al.*[20] on piglets with body weight ca. 45 kg, the effect of phytase, sodium phosphate and calcium phosphate supplementation on degree of absorption, digestibility and retention of phosphorus, calcium, zinc, copper and nitrogen was investigated. Barrows consumed in feed 19.5 mg Cu/day/head. The calculated Cu retention constituted from 9.3 to 15.8 % and the apparent absorption 15.2-24.9 %. In our studies, barrows absorbed more Cu (32-38 mg) but also Cu retention when compared with the consumed quantity was higher 25.6 %. From these comparisons we concluded that Cu present in yeasts is utilized better than from mineral form – copper sulfate. Valencia and Chavez[21] reported that increase in apparent digestibility of copper (and also iron) in weanling pigs could be reached by supplementation with phytase and acetic acid. However, supplementation of phytase together with copper decreased absorption of zinc[26].

Table 1: Digestibility coefficients, daily balance and nitrogen retention

Item	Group				
	I Control	II Y-Fe	III Y-Cu	IV Y-Mn	V Fe + Cu + Mn (Y)
	Digestibility coefficients (%)				
Dry matter	81.1	80.6	81.1	81.4	81.1
	± 0.61	± 2.05	± 2.47	± 2.56	± 1.36
Dry matter organic	83.5	82.5	83.0	83.3	83.0
	± 0.81	± 1.99	± 2.18	± 2.18	± 1.29
Crude protein	83.4	82.4	82.0	80.7	81.9
	± 2.70	± 1.28	± 2.84	± 3.75	± 1.17
Crude fat	38.7	38.7	41.3	39.5	36.5
	± 3.67	± 6.34	± 8.61	± 9.26	± 6.03
Crude fibre	20.2	18.8	21.7	19.7	22.9
	± 4.51	± 5.95	± 7.48	± 4.88	± 6.19
Crude ash	50.5	48.9	48.9	47.5	47.4
	± 3.36	± 6.49	± 8.42	± 7.71	± 3.39
N-free extractives	88.3	87.1	87.5	87.3	87.2
	± 1.01	± 2.13	± 1.68	± 1.61	± 1.63
	Daily balance and nitrogen retention (g)				
N intake (g)	48.3	45.8	40.7	40.7	43.2
	± 3.72	± 7.01	± 5.72	± 5.72	± 7.01
N excreted (g) in:					
feces	7.9	8.0	7.4	8.0	8.0
	± 1.35	± 1.30	± 1.87	± 2.67	± 1.63
urine	17.0^{a}	15.0	13.3^{b}	13.8^{b}	14.8
	± 4.00	± 1.77	± 2.35	± 2.28	± 2.66
Retention N (g)	23.4	22.7	20.0	18.9	20.4
	± 4.36	± 5.27	± 2.51	± 2.65	± 3.73
in N received (%)	48.4	49.3	49.3	46.7	47.2
	± 4.38	± 5.27	± 4.43	± 5.32	± 4.58
in N digested (%)	58.0	59.7	60.3	57.8	58.1
	± 5.60	± 5.65	± 3.72	± 4.44	± 5.16

a- b, c-d – P<0.05

Table 2: Balance and apparent absorption of calcium, phosphorus and magnesium

Item	Group				
	I Control	II Y-Fe	III Y-Cu	IV Y-Mn	V Fe + Cu + Mn(Y)
Calcium balance					
Ca intake (g)	13.12 ± 1.52	12.44 ± 1.86	11.08 ± 1.52	11.08 ± 1.52	11.32 ± 1.42
Ca excreted (g) in:					
faeces	9.04 ± 1.12	8.54 ± 0.93	7.48 ± 0.99	7.38 ± 1.02	7.90 ± 1.17
urine	0.14 ± 0.05	0.11 ± 0.06	0.10 ± 0.07	0.10 ± 0.03	0.08 ± 0.01
Ca retention (g)	3.94 ± 0.79	3.79 ± 1.33	3.49 ± 0.94	3.59 ± 0.89	3.34 ± 0.74
Ca retention (%)	30.0 ± 4.3	30.5 ± 7.0	31.5 ± 6.5	32.4 ± 5.7	29.5 ± 5.8
Absorption %	31.0 ± 4.2	31.3 ± 7.0	32.4 ± 6.2	33.4 ± 5.4	30.2 ± 5.8
Phosphorus balance					
P intake (g)	9.88 ± 1.16	9.36 ± 1.42	8.32 ± 1.16	8.32 ± 1.16	8.52 ± 1.08
P excreted (g) in:					
faeces	5.67 ± 0.84	5.46 ± 1.05	4.84 ± 0.82	4.53 ± 1.04	4.77 ± 0.98
urine	0.13 ± 0.05	0.15 ± 0.07	0.10 ± 0.07	0.14 ± 0.08	0.09 ± 0.01
P retention (g)	4.08 ± 0.36	3.75 ± 0.50	3.38 ± 0.41	3.65 ± 0.58	3.66 ± 0.13
P retention (%)	41.5 ± 2.9	40.1 ± 3.8	40.6 ± 2.8	43.9 ± 5.4	42.9 ± 3.7
Absorption %	42.8 ± 2.7	41.7 ± 3.9	41.8 ± 3.2	45.5 ± 5.4	44.0 ± 3.8
Magnesium balance					
Mg intake (g)	2.09 ± 0.25	1.98 ± 0.30	1.76 ± 0.25	1.76 ± 0.25	1.80 ± 0.23
Mg excreted (g) in:					
feces	1.48 ± 0.19	1.40 ± 0.22	1.27 ± 0.25	1.17 ± 0.20	1.24 ± 0.14
urine	0.09 ± 0.04	0.07 ± 0.03	0.06 ± 0.03	0.07 ± 0.02	0.08 ± 0.01
Mg retention (g)	0.52 ± 0.06	0.52 ± 0.09	0.43 ± 0.09	0.53 ± 0.05	0.48 ± 0.10
Mg retention (%)	25.0 ± 2.7	26.3 ± 2.9	24.4^{a} ± 6.0	30.1^{b} ± 3.0	26.7 ± 3.8
Absorption %	29.3 ± 2.7	29.3 ± 3.3	27.8^{a} ± 6.7	33.5^{b} ± 2.3	31.1 ± 3.2

a- b, c-d – $p< 0.05$

Table 3: Balance and apparent absorption of iron and copper

Item	Group				
	I Control	II Y-Fe	III Y-Cu	IV Y-Mn	V Fe + Cu + Mn (Y)
Iron balance					
Fe intake (mg)	338.0 ± 39.8	320.0 ± 48.7	285.0 ± 39.8	285.0 ± 39.8	285.0 ± 39.8
Fe excreted (mg) in:					
feces	91.3^{a} ± 14.6	80.3 ± 10.2	65.8^{b} ± 19.9	69.4^{b} ± 6.6	74.1 ± 19.5
urine	18.9^{a} ± 6.3	54.0^{b} ± 12.2	38.9 ± 17.5	25.6^{a} ± 18.6	24.1^{a} ± 4.4
Fe retention (mg)	227.8 ± 31.5	185.7 ± 51.5	180.3 ± 35.7	190.0 ± 15.9	186.8 ± 21.1
Fe retention (%)	67.4^{b} ± 3.5	58.0^{a} ± 8.4	63.3 ± 5.8	66.7 ± 3.6	65.5 ± 4.4
Absorption %	73.0 ± 4.0	74.9 ± 3.0	76.9 ± 4.4	75.6 ± 1.5	74.0 ± 3.5
Copper balance					
Cu intake (mg)	38.00 ± 4.47	36.00 ± 5.48	32.00 ± 4.47	32.00 ± 4.47	32.80 ± 4.15
Cu excreted (mg) in:					
faeces	30.07^{a} ± 1.00	28.10 ± 5.40	23.00^{b} ± 1.19	25.51 ± 4.52	25.77 ± 3.84
urine	0.82 ± 0.15	0.61 ± 0.27	0.80 ± 0.30	1.05 ± 0.46	1.03 ± 0.17
Cu retention (mg)	8.09^{a} ± 0.90	7.29 ± 0.70	8.20^{a} ± 1.05	5.44^{b} ± 0.70	5.99^{b} ± 0.58
Cu retention (%)	21.3^{c} ± 2.9	20.3 ± 3.7	25.6^{ad} ± 3.0	17.2^{b} ± 3.2	18.3^{b} ± 1.8
Absorption %	23.7^{c} ± 2.8	21.9 ± 4.0	28.1^{ad} ± 3.1	20.3^{b} ± 6.7	21.4 ± 2.3

a- b, c-d – $p<0.05$

Table 4: Balance and apparent absorption of manganese and zinc

Item	Group				
	I Control	II Fe	III Cu	IV Mn	V Fe + Cu + Mn
Manganese balance					
Mn intake (mg)	95.00 ± 11.2	90.00 ± 13.7	80.00 ± 11.2	80.00 ± 11.2	82.00 ± 10.4
Mn excreted (mg) in:					
feces	82.06^{a} ± 11.5	75.00 ± 12.0	66.27 ± 10.8	62.89^{b} ± 12.4	63.70^{b} ± 13.5
urine	0.72 ± 0.18	1.01 ± 0.50	1.17 ± 0.45	0.92 ± 0.43	1.00 ± 0.14
Mn retention (mg)	12.21 ± 3.05	13.03 ±3.65	12.56 ± 2.09	16.07 ± 3.85	17.30 ± 3.51
Mn retention (%)	12.8^{a} ± 3.6	14.5^{c} ± 2.7	15.7 ± 2.8	20.1^{b} ± 5.9	21.1^{b,d} ± 5.8
Absorption %	13.8^{a} ± 3.5	15.6 ± 3.4	17.2 ± 2.9	21.4^{b} ± 5.5	22.3^{b} ± 6.1
Zinc balance					
Zn intake (mg)	326.8 ± 38.4	310.0 ± 47.1	275.0 ± 38.5	275.0 ± 38.5	282.0 ± 35.7
Zn excreted (mg) in:					
feces	262.0 ± 38.2	249.4 ± 44.8	236.5 ± 26.9	222.8 ± 36.8	228.3 ± 40.9
urine	4.1 ± 1.3	3.6 ± 1.3	4.7 ± 2.1	3.8 ± 1.6	5.4 ± 1.6
Zn retention (mg)	60.7^{a,c} ± 15.0	56,5^{a} ± 12.2	33.8^{b} ± 12.1	48.4^{a,d} ± 6.1	48.3^{a,d} ± 7.5
Zn retention (%)	18.6^{a} ± 4.7	18.2^{a} ± 4.2	12.2^{b} ± 2.3	17.6^{a} ± 2.7	17.1^{a} ± 3.6
Absorption %	19.8^{a} ± 4.6	19.5^{a} ± 4.0	14.0^{b} ± 2.2	19.0^{a} ± 2.4	19.0^{a} ± 4.1

a- b, c-d – $p<0.05$

Manganese absorption: From 1 kg of complete diets, barrows consumed 50 mg Mn, from which 30 % was in the form of manganese oxide or yeasts *Saccharomyces cerevisiae*. Barrows from the control group fed with diet containing manganese oxide excreted with feces 82 % of consumed Mn and retention of this microelements constituted only 12.8 %. However, manganese from yeasts used in feeding of barrows in the group IV and V was absorbed better. In this case Mn retention when considered the consumed quantity increased up to 20.1 and 21.1 % which was statistically significant ($p<0.05$) when compared with the group I and II. Similarly, in the case of the apparent absorption, it was significantly higher in the groups IV and V when compared with the control.

Manganese from yeasts, was generally better utilized by barrows than from manganese oxide. Similar results were obtained by Nowotny *et al*. [5] who reported in growing pigs averagely 9.04 % lower concentration of Mn in feces if pigs that were fed with diet containing 1 % bioplex (Aminovitan®) containing 400 mg/kg of this elements when compared with the group which consumed Mn in inorganic form. No differences in the content of Mn in urine of pigs between the groups were denoted. Gralak[10] reported the occurrence of synergisms between manganese and calcium, phosphorus and magnesium.

Zinc absorption: From 1 kg of complete diets, barrows consumed 172 mg Zn from which 70 % in the form of zinc oxide. Barrows from the groups I, II, IV and V excreted in feces 80 % of consumed zinc and in urine 1.5 %. Zn retention when compared with the consumed quantity was ca. 18 % and apparent absorption 19 %. However, in feces of barrows from the group III (Y-Cu), excreted zinc constituted ca. 86 % which influenced decrease of Zn retention to 12.2 % and apparent absorption up to 14 % which statistically differs ($p<0.05$) from the values obtained in the remaining groups. This result is probably the effect of antagonism between Zn and Cu.

The main source of zinc (70 %) in the complete diets was zinc oxide, Antagonism between zinc supplemented in such form and copper supplemented in the organic form was observed. In the previous studies, Korniewicz *et al*.[6] reported that Zn absorption from similar doses of nutrients (259 mg Zn/day/head) was 18.5 %. This absorption increased up to 28.6 % if organic form (as *Saccharomyces cerevisiae*) was supplemented instead of inorganic form. Also, in laying hens zinc is absorbed better from yeasts[29] and in ruminants zinc is better absorbed from chelates when compared with zinc oxide[30].

Studies of Revy *et al*.[24] on weanling pigs showed that Zn from organic forms (Zn-methionine) did not improve Zn retention in organism if compared with zinc sulfate. However, the addition of microbiological phytase increased bioavailability of zinc and also modified retention of Ca, P, Mg, Fe and Cu which confirms complexity of retention and absorption of bioelements by these animals.

CONCLUSIONS

The obtained results showed that supplemented microelements did not influence digestibility of the main nutrients and the apparent absorption of Ca, P and Mg. Barrows with the diet containing iron yeasts, excreted with urine more iron than from the control group which influenced decrease of retention from 67.4 to 58.0 %. Absorption was similar in both groups. Supplementation of copper yeasts increased retention of Cu from 21.3 to 25.6 % and absorption from 23.7 to 28.1 %. The supplementation of manganese yeasts increased Mn retention from 12.8 to 20.1 % and absorption from 13.8 to 21.4 %. Associative supplementation of Fe, Cu and Mn yeasts did not improve retention or absorption of microelements. Antagonism between Cu and Mn as well as between Cu and Zn was observed, that was manifested by decreased retention and apparent absorption of these microelements. In the group, the diet of which was supplemented with Cu, decrease of retention of Zn from 18.6 to 12.2 % and absorption from 19.8 to 14.0 % occurred.

When considering the obtained results of digestibility-balance studies, we concluded that copper and manganese yeasts may find an application in pigs feeding. However, iron yeasts were found to be low efficient when compared with inorganic form of this bioelement.

ACKNOWLEDGMENTS

This research was financially supported by the Ministry of Science and Higher Education of Poland (grant nr 3T09 B 09328).

REFERENCES

1. Cheng, J., E.T. Kornegay and T. Schell, 1998. Influence of dietary lysine on the utilization of zinc from zinc sulfate and zinc-lysine complex by young pigs. J. Anim. Sci. 76: 1064-1074.
2. Pallauf, J. and G. Rimbach, 1997. Nutritional significance of phytic acid and phytase. Arch. Anim. Nutr., 50: 301-319.
3. Kinal, S., A. Korniewicz, R. Zieminski, D. Jamroz, B. Paleczek, A. Tomaszewski and M. Slupczynska, 2002. The influence of organic forms of trace elements on milk composition and quality. Chem. Agric., 3: 290-296.
4. Novotný, J., H. Seidel, G. Kovác and R. Babcek, 2005. Bioavailability of trace elements proteinates in pigs. Medycyna Wet., 61(1): 38-41.
5. Männer, K., O. Simon and T. Schlegel, 2006. Effects of different iron, manganese, zinc and copper (sulfates, chelates, glycinates) on their bioavailability in early weaned piglets. 9 Tagung Schweine und Geflügelernähnung, Universität Halle-Wittenberg, Germany, 28-30 Nov. 2006, pp. 25-27.
6. Jondreville, C., P.S. Reavy and J.Y. Dourmad, 2003. Dietary means to better control the environmental impact of copper and zinc by pigs from weaning to slaughter. Livest. Prod. Sci., 84: 147-156.
7. Korniewicz, A., Z. Dobrzanski, R. Kolacz and D. Korniewicz, 2003. Bioavailibity of zinc, selenium and chromium absorption from yeast *Saccharomyces cerevisiae* for swine. Chem. Agric., 4:171 – 181.
8. Richter, G., R. Kirmse and W.I. Ochrimenko, 2006. Organisch gebundene Spurenelemente in der Legehennenfüterung. 9 Tagung Schweine und Geflügelernähnung, Universität Halle-Wittenberg, Germany, 28-30 Nov. 2006, pp. 163-166.
9. Close, W.H., 1998. New developments in the use of trace minerals proteinates to improve pig performance and reduce environmental impact, European Lecture Tour, Alltech, pp. 51-58.
10. Gralak, M., 1999. Znaczenie niektórych mikroelementów w zywieniu zwierzat gospodarskich. Mat. Konf. Nauk. „Ekologiczne kierunki produkcji zywnosci - zywienie zwierzat, a zdrowie czlowieka" SGGW. Warszawa, pp. 52-66.
11. Jongbloed A.W., Kemme P.A., De Groote G., Lippens M., Meschy F., 2002. Bioavailability of major and trace minerals. International Association of the European (EU) Manufacturers of Major, Trace and Specific Feed Mineral Materials, EMFEMA Brussels.
12. Grela, E.R., T. Studzinski, A. Rabos, A. Winiarska and J. Dziduch, 1997. Effect of chromium yeast supplement in growing-finishing pig diets on performance, carcas traits and fatty acid composition of adipose tissue. J. Anim. Feed Sci., 6: 87-100.
13. Dolinska, B., F. Ryszka and Z. Dobrzanski, 2006. Optimization of the procesess of incubation yeast *Saccharomyces cerevisiae* enriched with microelements. Chem. Agric. 6: 175-180.
14. AOAC, 1990. Official Methods of Analysis of the Association of Official Analytical Chemists. 15th edition, Arlington, Virginia, USA.

15. Normy Zywienia Swin. Wartosc pokarmowa pasz, 1993. Wyd. IFiZZ PAN Jablonna, Ed. Omnitech Press, Warszawa.
16. CVB, 2004. Veevoedertabel 2004. Centraal Veevoederbureau, Lelystad, The Netherlands.
17. Jamroz, D., (red.), 2001. Zywienie zwierzat i paszoznawstwo. Wyd. Nauk. PWN, Warszawa.
18. Li, D., X. Che, Y. Wang, C. Hong and P.A. Thacker, 1998. Effect of microbial phytase, vitamin D_3, and citric acid on growth performance and phosphorus, nitrogen and calcium digestibility in growing swine. Anim. Feed Sci. Technol., 73: 173-186.
19. Eeckhout, W. and H. Paepe, 1992. The digestibility of three calcium phosphates for pigs as measured by difference and by slope-ratio assay. J. Anim. Physiol. Anim. Nutr., 77: 53-60.
20. Orda, J., B. Fuchs, A. Wiliczkiewicz and J. Pres J, 1998. Wplyw dodatku fosforanu sodu, wapnia i fitazy mikrobiologicznej na stopien wykorzystania wybranych skladników mineralnych w dawkach pokarmowych tuczników. Prace Nauk. AE Wroclaw, 792: 376-385.
21. Valencia, Z. and E.R. Chavez, 2002. Phytase and acetic acid supplementation in the diet of early weaned piglets: effect on performance and apparent nutrient digestibility. Nutr. Res., 22: 623-632.
22. Grela, E.R., 2001. Mozliwosci zwiekszenia biodostepnosci fosforu z pasz roslinnych w zywieniu loch. Annales of Warsaw Agric. Univ., ser. Animal Science (Special number), 179-185.
23. Roberson, K.D., 1999. Estimation of the phosphorus requirement of weanling pigs fed supplemental phytase. Anim. Feed Sci. Technol., 80: pp.91-100.
24. Revy, P.S., C. Jondreville, J.Y. Dourmad and Y. Nys, 2004. Effect of zinc supplemented as either an organic or an inorganic source and of microbial phytase on zinc and other minerals utilisation by weanling pigs. Anim. Feed Sci. Technol., 116: 93-112.
25. Frankiewicz, A. and A. Potkanski, 1997. Wplyw dodatków fitazy do pasz na retencje azotu, magnezu, zelaza, cynku oraz miedzi u mlodych swin. Mat. Konf. „Zywieniowe metody ograniczania wydalania do srodowiska azotu, fosforu i innych pierwiastków przez zwierzeta gospodarskie”. Inst. Zoot., Kraków, pp.155-160.
26. Zacharias, B., H. Ott and W. Drochner, 2003. The influence of dietary microbial phytase and copper on copper status in growing pigs. Anim. Feed Sci. Technol.,106: 139-148.
27. Pres, J. and S. Kinal, 1996. Aktualne spojrzenie na sprawe zaopatrzenia zwierzat w mikroelementy. Zesz. Probl. Post. Nauk Rol., 434: 1043-1061
28. Yu, B., W-J. Huang and P. W-S. Chiou, 2000. Bioavailability of iron from amino acid complex in weanling pigs. Anim. Feed Sci. Technol., 86: 39-52.
29. Dobrzanski, Z., D. Jamroz, H. Górecka and S. Opalinski, 2003. Bioavailability of selenium and zinc supplied to the feed for laying hens in organic and inorganic form. EJPAU, ser. Animal Husbandry, vol. 6, issue 2.
30. Korniewicz, A., S. Kinal, B. Paleczek and M. Slupczynska, 2002. The application of zinc in oxide and chelate form in sheep nutrition. Chem. Agric., 3: 274-281.