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EFFECT OF SUBSTITUTING SOYBEAN MEAL WITH RAPESEED MEAL ON BODY WEIGHT OF BROILER CHICKENS, CARCASS QUALITY AND APPARENT ILEAL AMINO ACID DIGESTIBILITY*

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Celem badań była ocena możliwości substytucji śruty sojowej poekstrakcyjnej śrutą rzepakową poekstrakcyjną w mieszankach paszowych dla kurcząt brojlerów. Doświadczenie wzrostowe wykonano na 640 1-dniowych seksowanych kurczętach odmiany Ross 308, w układzie Split-Plot, podzielonych na 4 grupy, każda w 16 powtórzeniach po 10 kurcząt. Kogutki i kurki utrzymywano w oddzielnych klatkach, po 8 powtórzeń dla każdej płci. Mieszanki paszowe w grupach żywieniowych zawierały 4 malejące poziomy śruty sojowej (starter/grower-finiszer) 36/30; 24,3/20,4; 21,2/17,7 i 17,1/11,2% oraz 4 rosnące poziomy śruty rzepakowej, odpowiednio: 0/0; 4/12,6 (poziom niski); 7/16,2 (poziom średni) i 11/20,7% (poziom wysoki). Diety zawierające śrutę rzepakową uzupełniono dodatkiem suszonego wywaru gorzelnianego (DDGS) i drożdży paszowych. Potrzeby aminokwasowe wszystkich grup zbilansowano dodatkiem L-lizyny i DL-metioniny. Substytucja śruty sojowej śrutą rzepakową obniżyła masę ciała kurcząt w porównaniu do grupy sojowej (kontrola) odpowiednio o 5,5; 5,4 i 9,8% (P≤0,01) oraz zwiększyła zużycie paszy na przyrost masy ciała odpowiednio o 4,8; 5,8 i 8,2%. Istotnie zwiększyła się śmiertelność kurcząt, a zmniejszeniu uległy masa i parametry kulinarne tuszek (P≤0,01). Poziom wysoki śruty rzepakowej w mieszankach paszowych (11 starter, 20,7% grower-finiszer) istotnie zwiększył śmiertelność kurcząt (P≤0,01). Nie stwierdzono różnic w pobraniu paszy, lecz nastąpiło istotne pogorszenie wskaźnika wykorzystania paszy. Ocenę pozornej jelitowej strawności białka ogólnego i aminokwasów wykonano na 320 kogutkach odmiany Ross 308, w wieku 2–4 tygodni, podzielonych na 4 grupy, każda w 8 powtórzeniach po 10 kurcząt. Badania prowadzono metodą wskaźnikową z użyciem trójtlenku chromowego. Kurczęta żywiono mieszankami typu grower-finiszer, o składzie i wartości pokarmowej jak w doświadczeniu wzrostowym. Substytucja śruty sojowej istotnie obniżyła pozorną strawność białka ogólnego w dietach doświadczalnych w porównaniu do kontrolnej z 85,5 do 76,7; 76,6 i 75,7%, lizyny z 88,2 do 81,8; 80,1 i 79,2% oraz metioniny z 93,9 do 86,9; 90,5 i 88,5%. Wyniki badań wykazały, że poekstrakcyjna śruta rzepakowa nie może zastąpić śruty sojowej w mieszankach paszowych dla kurcząt brojlerów, a jej poziom powyżej 4% dla kurcząt młodszych (starter) i 12–16% dla kurcząt starszych (grower-finiszer) przy zawartości około 9,5 glukozynolanów na gram poekstrakcyjnej śruty rzepakowej obniża produkcję, jakość tuszek i pozorną strawność jelitową białka oraz aminokwasów, a także istotnie zwiększa zużycie paszy na jednostkę produkcji.

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Słowa kluczowe: poekstrakcyjna śruta sojowa, poekstrakcyjna śruta rzepakowa, kurczęta brojlery, substytucja

The Act on Feeds of 22 July, 2006 (Dz. U. Nr 144, item 1045, with amendments) imposed a ban on the use of genetically modified (GM) feeds for feeding livestock in Poland (Brzóska, 2009 a). Amendments of The Act on Feeds adopted by the Sejm and the Senate (Parliament of Poland) three times postponed the date of the entering into force of the ban and it was finally set on 1 January, 2019. This law forced farmers to search for alternative protein-rich sources of dietary protein for feeding livestock. Currently a by-product of the extraction of soybean oil, i.e. soybean meal is the principal protein-rich feed for farm animals in the European Union, including Poland. There are two main categories of soybean meal containing 44% and 48% of total protein (Brzóska & Śliwa, 2016). The annual imports of soybean feeds, whole seeds and soybean meal from Argentine, Brasilia and the USA to the European Union are estimated at 34 million tons, including 2.05 million tons to Poland. Monitoring studies carried out in Poland demonstrated that 95% of soybean meal on the Polish market is genetically modified, resistant to glyphosate, an active substance of the herbicide Roundup Ready (Markowski & Korol, 2006). Approximately 59% of soybean meal is used for production of poultry feeds, including broiler chickens (Brzóska, 2009 a, b; Dzwonkowski et al., 2015). The remaining protein-rich dietary ingredients in our country include rapeseed feeds, meal and oilcake, sunflower meal, legume seeds, like pea, horse beans and lupine, fodder yeast and dried distillers grains with solubles (DDGS). Owning to soybean meal import, Poland is the largest producer and exporter of poultry meat in the European Union (Eurostat, 2016).

Studies of the 1980s indicated that rapeseed feeds were not a complete substitute for soybean meal in livestock feeding (Jamroz, 1984; Koreleski et al., 1986; Mazanowska et al., 1987) which means that soybean meal in animal diet cannot be fully replaced by other ingredients. It was confirmed by foreign studies, e.g. from Germany and Canada indicating that although rapeseed protein is valuable, it is not a substitute for the whole soybean protein (Lee et al., 1991; Dänicke et al., 1998; Jeroch et al., 2008). Rapeseed feeds contain anti-nutrients, like glucosinolates and a marked amount of crude fiber. Both these components significantly limit the use of rapeseed feeds in the diets of monogastric animals, including broiler chickens. Studies carried out in the 1990s on rapeseed meal identified recommended and permissible levels of these feeds in the diets of farm animals, including poultry (Pastuszewska et al., 1992; Jeroch et al., 2001). Since then 25 years of systematic selection works on new rapeseed varieties led to development of low-glucosinolate varieties which were licensed for cultivation. Glucosinolates fulfill a significant physiological role in cruciferous

plants (Fenwick et al., 1983; Słominski, 1986; Drozdowska, 1994; Mawson et al., 1994; Chen & Anderson, 2001; Tripathi & Mishra, 2007), but are undesirable in poultry diets. After crushing rapeseeds, glucosinolates are hydrolyzed by glucosinolate myrosinase to glucose and antinutritional substances promoting crop growth, like sulfides, thiocyanides, isothiocyanides and nitriles (Oleszek, 1995; Zduńczyk, 1995).

At present, domestic rapeseed varieties, mostly hybrids, contain less than 1.5% eriuc acid while glucosinolate content does not exceed 15–18 μM/g dry weight. In Poland, 31 spring rapeseed varieties and 111 winter varieties have been registered and licensed for cultivation (COBORU, 2015). In 2014 rapeseed cultivation area in Poland was 941,600 ha and harvested production was over 3.2 million tones. Production of rapeseed meal in Poland exceeds 2.2 million tones, of which 906,000 tones are used for production of feed mixes and 40% is exported mostly to Germany (Dzwonkowski et al., 2015). Rapeseed meal has a 22% share in production of feed mixes in Poland (Brzóska et al., 2009 a, b; Dzwonkowski et al., 2015).

It was assumed that considering systematic rapeseed selective breeding endeavors to obtain improved varieties and successful selection of low-glucosinolate varieties (AVG 15 μM/g DM), it will be possible to increase the level of rapeseed meal in broiler chicken diets. Data reported by Pastuszewska et al. (1992) provide general information on the recommended and permissible levels of rapeseed feeds in the diets for layer and broiler poultry making no distinction, however, between age and rearing phase of chickens. Soybean meal replacement by rapeseed meal in poultry diets requires supplementing the formulations also with other feeds rich in proteins and amino acids. In Poland, they may include legume seeds, mostly peas, horse bean and lupine, and dried distillers grains with solubles (DDGS) and fodder yeast. There are only scanty reports available on digestibility of broiler chicken diets containing increased contents of rapeseed meal with reduced amounts of soybean meal in mixes and diets, evaluated under rearing conditions of currently raised broiler chicken lines and hybrids.

The aim of the present studies was to determine the maximum proportion of rapeseed meal as a substitute for soybean meal in the diets of broiler chickens in two rearing phases. The studies focused on the estimation of body weight, feed intake and conversion, and mortality of chickens, and on examining the effect of soybean and soybean-rapeseed diets on carcass yield, percentage of commercial cuts in carcasses and on the chosen metabolic parameters based on plasma analysis. In addition, apparent ileal digestibility of protein and amino acids was investigated.

Material and methods

Design of growth performance experiment and experimental diets

Growth performance experiment was conducted in random block design on 640 sexed Ross 308 broiler chicks. Experimental variables included: substitution level of soybean meal in the diet and chicken sex (4 levels x 2 sexes x 8 replicates x 10 chicks per repetition). Broilers were divided into 4 groups, 2 subgroups, each in 8 repetitions of 10 chicks. Cockerels and hens were kept separately in 8 repetitions for each sex. Chickens were housed in metal pens with litter from deciduous wood shavings with free access to feed and water. Body weight of 1 day old chicks before experiment was 41.8±3.4 g. Chicks were weighted at 21 and 42 days of age and also at 43 days to determine slaughter weight. Chickens were fed loose feeds *ad libitum*. Feed mixes were not subjected to pressure application or thermal processing. For the first 6 days, feed was offered on small trays and from day 7 in vertical feeders. Water was available from a central system through drippers. There were two waterers per pen, which satisfied chicks' needs. Feeds were prepared in the Nationale Research Institute of Animal Production in Aleksandrowice according to delivered formulations. Production was supervised by a technical and engineering staff member. Starter diets were prepared for the first rearing phase (1 – 21 days) and grower-finisher diets for the second phase (22–42 days). The energy value of the diets was calculated using the computer program WINPasze (2017). Soybean meal and rapeseed meal contents in chicken diets for both periods are presented in Tab. 1.

Table 1. Level of soybean meal, rapeseed meal seed and glucosinolates in compound feeds

Compound feed		Level of high-protein ground grains (%)			
		control	low	medium	high
Starter	Soybean meal, %	33,0	24,3	21,2	17,1
	Rapeseed meal, %	0,0	4,0	7,0	11,0
	Glucosinolates, μM/g	0,0	0,38	0,67	1,05
Grower-finisher	Soybean meal, %	30,0	20,4	17,7	11,2
	Rapeseed meal, %	0,0	12,6	16,2	20,7
	Glucosinolates, μM/g	0,0	1,20	1,55	1,98

The levels of rapeseed meal in the diets were calculated based on glucosinolate level determination, and were classified as low, medium and high. The permissible level of glucosinolates in broiler chicken diets was assumed to be 0.5–1.0 μM/g of feed (Pastuszewska et al., 1992; Smulikowska & Rutkowski, 2005). Glucosinolate content in starter diets was 2–3 times lower than in grower-

finisher diets. The level of protein and amino acids in the diets containing rapeseed meal was balance by the addition of dried distillers grains with solubles, fodder yeast and crystalline amino acids L-lysine and DL-methionine. Feed ingredients and additives for formulation of feed mixes were commercially available. Compound feeds possessed a certificate conforming absence of mould toxins.

Experimental conditions

Stocking density of chicks in both, growth performance and digestibility experiments was 15 birds/m^2 in the first rearing phase which corresponded to 33 -35 kg of chicken body weight/m^2 of floor area in the final rearing phase. Disease control program involved the administration of an anti-diarrheal preparation in the form of 10% solution of the drug SCANOFLOX (1 ml l^{-1} water). On day 7 chickens were vaccinated against Gumbro disease using a vaccine dissolved in water and on day 14 against fowl plague (Newcastle disease) using the preparation BIO-VAC ND-IB. Chickens were also administered the vitamin preparation Vitazol dissolved in water. Three days before chick arrival, rooms were heated at a temperature of 34°C as required for raising chicks and was thereafter, maintained for 5 days according to applicable standards, then it was gradually decreased to 24°C. The rooms were constantly lit. In each pen, corresponding to one repetition within a group, feed intake was estimated everyday by weighing feed uneaten within the last 24 hours. To determine growth rate of chickens, all chicks were weighed at 21 and 42 days of the experiment. Before weighing, chicks were starved for 12 hours. Feed intake and conversion were calculated, and survivability of birds was also controlled.

Slaughter of chickens and dissection of carcasses, tissue and blood sample collection

On day 43 of the experiment, 10 chickens of both sexes (5 cockerels and 5 hens) were randomly selected, weighed, slaughtered after electrical stunning and exsanguinated during which blood samples were collected to obtain plasma for chemical analyses. After mechanical defeathering and decapitation, carcasses were eviscerated. Hot carcass weight, and weights of the gizzard, liver, omental fat and abdominal fat were determined. Both types of fat are termed depot fat.

Carcass yield was calculated based on slaughter weight and carcass weight before chilling with giblets and feet. Carcasses were chilled at a temperature of 5°C in a cold room for 24 h. Then, the right part of the carcass was dissected into commercial cuts, including breast muscles, leg muscles, liver, depot fat and skin, which were weighed. Percentage yield of carcass parts in relation to hot carcass weight (liver, depot fat) and to cold carcass weight (breast muscle, leg muscle, skin). Dissection was performed according to the procedure described by Zgłobica & Różycka (1972). Samples of breast muscles were collected for chmical analyses, ground and weighed at a temperature of –18°C. Analyses were carried out after a 30-day storage.

Design and procedure of digestibility experiment

The digestibility experiment was conducted in a random design on 320 cockerels (Ross 308) 2–4 days of age divided into 4 groups, each in 8 replicates of 10 chicks. Chicks were fed loose grower-finished diets available *ad libitum*. Chromium trioxide added to feed mixes at a concentration of 0.5%, was used as a digestibility indicator. Experiments lasted 21 days including 14 days of initial period and 7 days of test period. Before and after the experiment, samples of the diets were collected, combined, mixed and analytical samples were taken. After the end of the experiment, 10 chickens from each group were killed by Marbital (pentobarbital sodium) injection. After cutting the abdominal integuments, the digestive tract was taken out. The end fragment of the small intestine (*intestinum ileum*), from *Meckel's diverticulum* to the point 20 cm upstream of the junction of caecums with the large intestine, was excised, squeezing gently the intestinal contents to a plastic container. Intestinal content samples were frozen at a temperature of –18°C. After 20 days they were thawed, lyophilized and subjected to chemical analysis for total protein and amino acid contents, and digestibility was calculated. Broiler chicken feeding procedure and sample preparation for protein and amino acid analysis were in conformity with the methods described by Kadim and Moughan (1997). Housing conditions and experimental procedures were approved by a Local Ethics Commission for Experimental Animals in Kraków.

Laboratory analyses of feeds, tissues, blood and intestinal contents

The contents of dry matter, total protein, crude fat and crude fiber in feed ingredients, including soybean meal and rapeseed meal, and in chicken tissues were determined according to methods described in relevant analytical standards (AOAC, 2006). Glucosinolate content in rapeseed oilcake was estimated according to the standard PN-ISO 10633-1:2000P using high performance liquid chromatography on an HPLC Agilent system 1100 Series, on a column Zorbax ODS 5 µl 4,6 × 250 mm Agilent, with a UV-Vis detector, 229 nm. Injection volume of 50 µl (Agilent Autosampler) and reversed phase gradient elution A: H_2O, B: Acetonitrile: H_2O (20:80 v/v) were used. Flow rate was 1.0 ml/min and analysis time was 43 min. Uncertainty of determination was Nc=18.1%. Starch content was evalueted according to the standard PN-R-64785: 1994; calcium according to PN-EN ISO 6869:2000P, and phosphorus according to PN-ISO 6491-2002P. The contents of nutrients in chicken diets were calculated from their contents in dietary ingredients and their percent content in feed mixes using WINPasze software, based on equations listed in the European Tables of Energy Values for Poultry Feedstuffs (1989) and in article by Smulikowska & Rutkowski (2005).

Breast muscle samples were analyzed for dry matter, total protein, crude fat and crude ash contents. Analyses of feeds and chicken muscles were carried out by analytical methods in conformity with the European Commission Regulation 152/2009 of 27 January 2009 laying down the methods of sampling and analysis

for the official control of feed (Dz.U. L 54 of 26.2.2009, p. 1). Blood samples were collected to tubes with heparin during slaughter and exsanguination of chickens, and were centrifuged to obtain plasma. Fresh plasma was used for determination of glucose level and the rest was frozen for further analyses. Glucose level was determined using an enzymatic method with glucose oxidase. Plasma was thawed after 14 days. Plasma concentrations of total protein, triglycerides, total cholesterol and HDL cholesterol were determined with enzymatic and colorimetric methods using diagnostic kits (Cormay Diagnostyka Poland) according to procedures described by Kokot & Kokot (1996).

Intestinal contents after thawing were lyophilized and subjected to chemical analysis of chromium, total protein and amino acids. Chromium content in feed and intestinal contents was determined after wet mineralization in a mixture of nitric acid and perchloric acid $HNO_3/HclO_4$ (Saha i Gilberth, 1991). Before amino acid analysis in feeds and intestinal contents, all samples were subjected to hydrolysis in 6H HCl at 110°C for 22 h. Methionine and cysteine levels were determined after initial oxidation of samples in performic acid. Amino acid contents were estimated by HPLC after postcolumn derivatizetion in an analyzer Breckman 126 AA System Gold (AOAC, 2006). The contents of amino acids were corrected for incomplete recovery from hydrolysis.

Apparent ileal digestibility (AID) of protein and amino acids contained in the diets were calculated according to the following formula, using anhydrous chromium trioxide (Cr_2O_3) as an indicator (Kadim & Moughan, 1997):

$$AID\ (\%) = 100 - [(Cr_d \times AA_{tj}) / (Cr_{tj} \times AA_d)] \times 100$$

where:

Cr_d and Cr_{tj} – the content of the indicator (Cr) in the diet and intestinal content dry matter;

AA_{tj} and AA_d – the content of protein or amino acid in the digesta and diet dry matter, respectively.

Statistical analysis

Priori to calculation of significance of differences between chicken groups, mortality data were transformed according to the equation $x = log\ (x+2)$ for percent indicators and the transformed data were subjected to statistical analysis. The results of growth performance experiment were analyzed by 2-way analysis where the levels in soybean feed and rapeseed feed and chicken sex were factors, with evaluation also of an interaction between both factors. Significance of differences between the mean values for 4 groups was estimated by the Tukey's test at the 1% and 5% probability level. Calculations were performed using SAS 9.3.TS Level 1 MO software package. AID data were analyzed by one-way analysis of variance, statistically significant differences were identified using the Fisher test (NIR) at the 5% probability level.

Table 2. Components and nutrients content of feed mixtures for broiler chickens

Item	Soybean meal		Dietary inclusion level of high-protein feeds					
			low		medium		high	
	starter	grower-finisher	starter	grower-finisher	starter	grower-finisher	starter	grower-finisher
Maize, ground	55,8	48,2	50,1	42,0	49,7	41,2	48,9	40,7
Wheat, ground	-	10,0	-	10,0	-	10,0	-	10,0
Soybean meal	36,0	30,0	24,3	20,4	21,2	17,7	17,1	11,2
Rapeseed meal	-	-	4,0	12,6	7,0	16,2	11,0	20,7
Distillers dried grain with solubles	-	-	12,0	4,0	12,0	4,0	12,0	4,0
Fodder yeast	-	3,0	2,0	2,0	3,0	2,0	4,0	4,0
Rape oil	3,0	4,5	3,0	5,0	3,0	5,0	3,0	5,5
Ground limestone	2,0	1,2	1,7	1,3	1,2	1,2	1,1	1,2
Dicalcium phosphate	2,0	1,9	1,7	1,5	1,7	1,5	1,7	1,5
Fodder salt	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
DL-Methionine (99%)	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
L-Lysine (78%)	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Premix [1-2]	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Nutrients (g/kg)								
Dry matter	886,1	888,4	888,3	894,8	889,4	896,9	889,9	890,6
AME_n (MJ/kg)	12,52	12,20	12,54	12,17	12,56	12,18	12,50	12,18
Crude protein	221,6	209,8	221,3	210,3	222,0	210,3	221,3	209,2
Ether extract	31,7	60,1	48,4	74,6	45,4	82,1	54,2	72,9
Crude fibre	30,3	26,2	34,4	46,2	40,4	40,0	42,1	49,0
Starch	424,8	378,7	412,0	340,1	422,5	328,8	405,7	335,2
Ash	60,8	50,1	61,3	54,2	62,3	53,5	57,5	53,8
Calcium	8,5	8,4	8,7	8,5	8,5	8,4	8,6	8,4
Phosphorus	4,8	4,7	5,0	4,7	4,9	4,6	5,0	4,7
Lysine	13,8	12,6	13,7	12,5	13,8	12,7	13,7	12,6
Methionine	5,1	4,3	5,2	5,9	5,2	6,2	5,2	4,9
Cystine	3,8	3,2	3,8	3,2	3,8	3,1	3,7	3,2

[1/] Supplied to 1 kg of starter diet: vit. A – 13 500 IU; vit. D – 3 600 IU; vit. E – 45 mg; vit. B_1 – 3.25 mg; vit. B_2 – 7.5 mg; vit. B_6 – 5 mg; vit. B_{12} – 0.0325 mg; vit. K_3 – 3 mg; biotin – 0,15 mg; nicotinic acid – 45 mg; Ca-pantothenate – 15 mg; folic acid – 1.5 mg; choline chloride – 100 mg; Mn – 100 mg; Cu – 1,75 mg; Fe – 76,5 mg; Se – 0.275 mg; I – 1 mg; Zn – 75 mg; Co – 0.4 mg; Endox (antioxidant) – 125 mg; Sincox (coccidiostat) – 1 g and calcium – 0.679 g.

[2/] Supplied to 1 kg of grower diet: vit. A – 12 000 IU; vit. D – 3250 IU; vit. E – 40 mg; vit. B_1 – 2 mg; vit. B_2 – 7.25 mg; vit. B_6 – 4.25 mg; vit. B_{12} – 0,03 mg; vit. K_3 – 2.25 mg; biotin – 0,1 mg; nicotinic acid – 40 mg; Ca-pantothenate – 12 mg; folic acid – 1 mg; choline chloride – 450 mg; Mn – 100 mg; Cu – 1.75 mg; Fe – 76.5 mg; Se – 0.275 mg; I – 1 mg; Zn – 75 mg; Co – 0.4 mg; Endox (antioxidant) – 125 mg; Sincox (coccidiostat) – 1 g and calcium – 0,79 g.

Table 3. Body weight, mortality, feed consumption and conversion, and index of production

Item	Soybean meal	Dietary RSM inclusion level			SEM	Sex		P-value		
		low	medium	high		cockerels	hens	level	sex	inter-action
Body weight (g)										
21st day	703,7 Aa	701,4 Aa	700,7 Aa	656,8 Bb	4,3	725,2 Aa	656,2 Bb	< 0,001	< 0,001	0,588
42nd day	2537 Aa	2397 Bb	2399 Bb	2289 Cc	13,3	2510 Aa	2301 Bb	< 0,001	< 0,001	0,763
Mortality (%)	6 Bb	5 Bb	7 Aa Bb	9 Aa	3	8	6	< 0,001	0,690	0,858
Feed consumption (kg/42 days)	4,51	4,47	4,53	4,44	0,18	4,51	4,47	0,651	0,822	0,800
Feed conversion (kg/kg BW)	1,78 Bb	1,87 Aa	1,89 Aa	1,94 Aa	0,16	1,88	1,86	< 0,001	0,777	0,650
EPEI (pts)	319 Aa	290 Bb	281 Bb	256 Cc	12	292 Aa	277 Bb	< 0,001	< 0,001	0,790

A, B, C, D – values in the rows with the same letters are not different at P<0.01.
a, b, c, d – values in the rows with the same letters are not different at P<0.05.
EPEI, points – European Performance Efficiency Index.
SEM – standard error of mean.
BW – body weight.

Table 4. Chicken body weight, carcass yield and post-slaughter parameters of broiler chickens

Item	Soybean meal	Dietary RSM inclusion level			SEM	Sex		P-value		
		low	medium	high		cockerels	hens	level	sex	interaction
Slaughter weight (g)	2545 ^{Aa}	2450 ^{ABab}	2403 ^{Aab}	2247 ^{Cc}	39	2613 ^{Aa}	2209 ^{Bb}	< 0,001	< 0,001	0,592
Fresh carcass weight (g)	1903 ^{Aa}	1829 ^{Aa}	1783 ^{ABa}	1628 ^{Cc}	29	1920 ^{Aa}	1652 ^{Bb}	< 0,001	< 0,001	0,418
Cold carcass weight (g)	1843 ^{Aa}	1770 ^{Aa}	1727 ^{ABa}	1576 ^{Cc}	28	1858 ^{Aa}	1600 ^{Bb}	< 0,001	< 0,001	0,325
Carcass yield (%)	74,77 ^{Aa}	74,65 ^{Aa}	74,20 ^{Aa}	72,45 ^{Bb}	0,30	73,45 ^{Bb}	74,60 ^{Aa}	0,002	0,008	0,005
Parts of carcass (g)										
Breast muscles	520,8 ^{Aa}	487,4 ^{ABab}	471,2 ^{Bb}	415,4 ^{Cc}	8,0	499,2 ^{Aa}	448,2 ^{Bb}	< 0,001	< 0,001	0,247
Leg muscles	411,4 ^{Aa}	392,0 ^{ABab}	382,3 ^{Bb}	335,8 ^{Cc}	8,0	414,8 ^{Aa}	346,0 ^{Bb}	0,006	< 0,001	0,343
Liver	50,0	51,8	49,7	55,6	1,0	55,3 ^{Aa}	48,2 ^{Bb}	0,768	0,047	0,262
Carcass parts (%)										
Breast meat [1]	28,4 ^{a}	27,4 ^{ab}	27,3 ^{ab}	26,4 ^{b}	0,3	26,9 ^{b}	28,0 ^{a}	0,040	0,036	0,285
Leg meat [1]	22,3 ^{a}	22,1 ^{b}	22,1 ^{a}	21,3 ^{a}	0,2	22,3 ^{a}	21,6 ^{b}	0,024	0,002	0,343
Liver [2]	2,6 ^{Bb}	2,8 ^{Bb}	2,8 ^{Bb}	3,4 ^{Aa}	0,05	2,9	2,9	< 0,001	0,433	0,255

[1] In relation to cold carcass weight.

[2] In relation to fresh carcass weight.

A, B, C, D – values in the rows with the same letters are not different at P<0.01.

a, b, c, d – values in the rows with the same letters are not different at P<0.05.

Table 4. Chicken body weight, carcass yield and post-slaughter parameters of broiler chickens

Item	Soybean meal	Dietary RSM inclusion level			SEM	Sex		P-value		
		low	medium	high		cockerels	hens	level	sex	interaction
Slaughter weight (g)	2545 ^{Aa}	2450 ^{ABab}	2403 ^{Aab}	2247 ^{Cc}	39	2613 ^{Aa}	2209 ^{Bb}	< 0,001	< 0,001	0,592
Fresh carcass weight (g)	1903 ^{Aa}	1829 ^{Aa}	1783 ^{ABa}	1628 ^{Cc}	29	1920 ^{Aa}	1652 ^{Bb}	< 0,001	< 0,001	0,418
Cold carcass weight (g)	1843 ^{Aa}	1770 ^{Aa}	1727 ^{ABa}	1576 ^{Cc}	28	1858 ^{Aa}	1600 ^{Bb}	< 0,001	< 0,001	0,325
Carcass yield (%)	74,77 ^{Aa}	74,65 ^{Aa}	74,20 ^{Aa}	72,45 ^{Bb}	0,30	73,45 ^{Bb}	74,60 ^{Aa}	0,002	0,008	0,005
Parts of carcass (g)										
Breast muscles	520,8 ^{Aa}	487,4 ^{ABab}	471,2 ^{Bb}	415,4 ^{Cc}	8,0	499,2 ^{Aa}	448,2 ^{Bb}	< 0,001	< 0,001	0,247
Leg muscles	411,4 ^{Aa}	392,0 ^{ABab}	382,3 ^{Bb}	335,8 ^{Cc}	8,0	414,8 ^{Aa}	346,0 ^{Bb}	0,006	< 0,001	0,343
Liver	50,0	51,8	49,7	55,6	1,0	55,3 ^{Aa}	48,2 ^{Bb}	0,768	0,047	0,262
Carcass parts (%)										
Breast meat [1]	28,4 ^{a}	27,4 ^{ab}	27,3 ^{ab}	26,4 ^{b}	0,3	26,9 ^{b}	28,0 ^{a}	0,040	0,036	0,285
Leg meat [1]	22,3 ^{a}	22,1 ^{b}	22,1 ^{a}	21,3 ^{a}	0,2	22,3 ^{a}	21,6 ^{b}	0,024	0,002	0,343
Liver [2]	2,6 ^{Bb}	2,8 ^{Bb}	2,8 ^{Bb}	3,4 ^{Aa}	0,05	2,9	2,9	< 0,001	0,433	0,255

[1] In relation to cold carcass weight.

[2] In relation to fresh carcass weight.

A, B, C, D – values in the rows with the same letters are not different at P<0.01.

a, b, c, d – values in the rows with the same letters are not different at P<0.05.

Table 5. Meat chemical composition and blood plasma parameters

Item	Soybean meal	Dietary rapeseed meal inclusion level			SEM	Sex		P-value		
		low	medium	high		cockerels	hens	level	sex	interaction
Breast meat nutrients (% of DM)										
Dry matter (%)	25,96	25,96	25,85	25,90	0,08	25,91	5,91	0,771	0,698	0,671
Crude protein	23,72	23,78	23,67	23,66	0,06	23,71	23,70	0,893	0,907	0,536
Crude fat	1,07	0,99	1,00	1,07	0,03	1,03	1,03	0,613	0,958	0,147
Crude ash	1,17	1,19	1,18	1,17	0,00	1,19	1,18	0,357	0,299	0,819
Blood plasma indices										
Glucose (mmol/l)	15,6	15,3	15,0	15,4	4	15,3	15,3	0,546	0,885	0,741
Total protein (g/l)	36	34	37	38	2,6	37	36	0,561	0,859	0,153
Triglycerides (mmol/l)	0,79 ^{Bb}	0,70 ^{Bb}	0,70 ^{Bb}	1,04 ^{Aa}	1,0	0,79 ^{b}	0,83 ^{a}	0,008	0,046	0,748
Total cholesterol (mmol/l)	3,66	3,47	3,39	3,74	4,1	3,67 ^{a}	3,45 ^{b}	0,218	0,044	0,776
HDL (mmol/l)	2,37	2,24	2,26	2,30	2,3	2,44 ^{b}	2,14 ^{a}	0,498	0,022	0,549

A, B – values in the rows with the same letters are not different at $P<0.01$.
a, b, c, d – values in the rows with the same letters are not different at $P<0.05$.

Results

Composition of feed mixes tested in these experiments is presented in Fig. 2. Glucosinolate content in rapeseed meal utilized for formulation of these feed mixes was 9.57 μM/g of feed. Glucosinolate contents in feed mixes assumed lower values in accordance with the percent content of feed components in particular formulations. Elevation of the level of rapeseed meal and glucosinolates in chicken diets significantly reduced body weight of chickens in the first and the whole rearing period at all rapeseed meal substitution levels (Tab. 3; $P<0.05$). Body weight of cockerels was higher in both rearing phases ($P<0.05$), and interaction of rapeseed meal level and sex was not statistically significant. High levels of rapeseed meal in feed mixes and glucosinolates in the diets significantly increased mortaity of birds ($P<0.05$). This parametr was non-siginificaty higher in cockerels with no significant interaction between rapeseed meal level and sex. There was no significant impact of soybean meal substitution level on feed intake, and no significant interaction was noted between rapeseed meal level and sex in relation to both above parameters.

Carcass yield significantly decreased with increasing rapeseed meal levels in the diet ($P<0.05$) (Tab. 4). Raising dietary content of rapeseed meal significantly reduced carcass weight in absolute values, including breast muscles and leg muscles ($P<0.05$). These traits were significantly higher in cockerels ($P<0.05$). No significant differences in liver weight were observed at different rapeseed meal levels in chicken feed mixes and diets ($P>0.05$). Breast muscle and leg muscle percentages significantly dropped while liver percentage in carcasses increased in chickens from experimental groups, expressed in relative values ($P<0.05$). Breast and leg muscle weight was higher in cockerels than in hens whereas hens had more depot fat than cocks ($P<0.05$). No significant interaction between rapeseed meal level and sex was seen for any carcass trait.

Table 6. Apparent ileal crude protein and amino acids digestibility

Item	Soybean meal	Level of rapeseed meal			SEM	P-value
		low	medium	high		
Crude protein	85,5 ^{a}	76,7 ^{b}	76,6 ^{b}	75,7 ^{b}	1,1	<0,001
Essential amino acids						
Arginine	88,5 ^{a}	82,9 ^{b}	80,3 ^{b}	80,3 ^{b}	1,0	<0,001
Histidine	85,7 ^{a}	75,5 ^{b}	76,0 ^{b}	75,2 ^{b}	1,2	<0,001
Isoleucine	86,6 ^{a}	77,6 ^{b}	77,4 ^{b}	77,1 ^{b}	1,1	<0,001
Leucine	88,0 ^{a}	81,6 ^{b}	81,2 ^{b}	80,7 ^{b}	0,8	<0,001
Lysine	88,2 ^{a}	81,8 ^{b}	80,1 ^{b}	79,2 ^{b}	1,0	<0,001
Methionine	93,9 ^{a}	86,9 ^{c}	90,5 ^{b}	88,5 ^{b}	0,7	<0,001
Phenylalanine	87,7 ^{a}	81,62	80,8 ^{b}	81,6 ^{b}	0,8	<0,001
Threonine	81,5 ^{a}	70,5 ^{b}	70,3 ^{b}	69,4 ^{bc}	1,3	<0,001
Valine	85,0 ^{a}	76,4 ^{b}	76,0 ^{b}	76,0 ^{b}	1,1	<0,001

Non essential amino acids						
Alanine	86,2 [a]	78,5 [b]	78,1 [b]	77,2 [b]	1,0	<0,001
Aspartic acid	84,1 [a]	74,7 [b]	74,2 [b]	73,9 [b]	1,2	<0,001
Cystine	78,5 [a]	68,7 [c]	73,4 [b]	72,3 [b]	1,1	0,001
Glutamic acid	90,4 [a]	85,0 [b]	84,5 [b]	84,8 [b]	0,7	<0,001
Proline	87,1 [a]	80,7 [b]	80,4 [b]	80,5 [b]	0,8	<0,001
Serine	83,8 [a]	73,9 [b]	74,0 [b]	73,6 [b]	1,2	<0,001
Tyrosine	86,2 [a]	79,3 [b]	76,1 [b]	75,2 [b]	1,3	<0,001
Glycine	82,4 [a]	73,3 [b]	73,7 [b]	73,6 [b]	1,2	<0,001

a, b, c, d – values in the rows with the same letters are not different at $P < 0.05$.

No significant effect of rapeseed meal level in the diets on chemical composition of breast muscles and on plasma levels of glucose, total protein, total cholesterol and HDL cholesterol was noted (Tab. 5). High dietary contents of rapeseed meal coincided with a significant elevation of plasma triglyceride level ($P<0.05$). Plasma of cockerels was characterized by significantly lower triglyceride content and higher concentrations of total and high-density lipoprotein (HDL) cholesterol ($P<0.05$). No significant interaction was noted between rapeseed meal level and sex regarding breast muscle constituents and plasma parameters.

The studies demonstrated a significant reduction of digestibility of total protein and amino acids, including essential and non-essential amino acids, at all levels of rapeseed meal in broiler feed mixes (Tab. 6). Increasing the rapeseed meal substitution for soybean meal from low to medium and high level did not cause further reduction of digestibility of most amino acids, except for tyrosine. Histydine, isoleucine, threonine and valine, and also aspartic acid and serine showed the lowest digestibility while methionine and glutamic acid were characterized by the highest digestibility.

Discussion

Feed intake and conversion, chicken mortality

Results of studies on intake and conversion of the diets containing rapeseed meal were inconsistent. Studies of Ahmada et al. (2007) and Mushtaga et al. (2007) evidenced that diets containing 18% of rapeseed meal significantly reduced feed conversion. Other studies showed that diets containing 15% and 30% rapeseed meal significantly decreased feed intake, weight gain and feed conversion (Kermanshahi & Abbasi Pour, 2006). The studies presented in this paper did not indicate a significant reduction of feed intake but did show a significant drop in feed conversion. The decreased conversion of feeds

containing different levels of rapeseed meal could result from the reduced apparent digestibility of protein and amino acids. Diet supplementation with dried distillers grains with solubles (DDGS) at a constant relatively high level and increasing levels of fodder yeast could ameliorate the impact of rapeseed feeds on processes in the digestive tract of chickens. Scientific literature provides no information about mutual reaction of rapeseed meal to other protein-rich feeds used for preparation of feed mixes in this work. According to opinions of Zduńczyk (1995) and Lee & Hill (1983), since rapeseeds contain glucosinolates, saponins and tannins having bitter and pungent taste, intake of rapeseed feeds and amino acid digestibility are lower. In other studies, broilers fed the diet containing glucosinolates showed a reduced feed intake, limited growth rate and increased mortality (McNeill et al., 2004). The results obtained in this work did not confirm the adverse effect of rapeseed meal on feed intake, even though its content in the diet in group 4 was relatively high, reaching 11% in starter diet and 21% of feed mix in grower-finisher diet.

Earlier studies in Poland demonstrated that the increased level of glucosinolates in the diet due to soybean meal substitution with rapeseed meal did not affect feed conversion rati but increased thyroid gland size and suppressed growth of broiler chickens (Smulikowska et al., 1990). Denbowa (1994) suggested that feed intake by poultry was partially controlled by hepatic metabolism of such constituents as glucose, fats and amino acids. Woyengo et al. (2011) hypothesized that consumption of feed mixes containing rapeseeds could reduce microbiological intestinal degradation of glucosinolates and could increase hepatic metabolism. The significant increase in liver weight at high dietary rapeseed level confirms this opinion.

The reduced intake of feed mixes containing rapeseed oilcake was also attributed to the presence of sinapine, which was highlighted by Clandinin (1961). On the other hand, birds have poor sense of taste (Go, 2006) which can suggest that glucosinolates and sinapin only slightly affect feed intake. The results obtained in the present study indicate that the amounts of rapeseed meal exceeding its reference limit in feed mixes for broiler chickens did not reduce feed intake but there was a tendency towards the reduction of feed conversion.

Pastuszewska et al. (1992) estimated the permissible level of glucosinolates in feed mixes at 0.5–1.0 μM/g of feed. These values agree with the recommended levels of rapeseed feeds amounting to 10% of feed mix but markedly diverge from the permissible level of 15%. The contents of glucosinolates in feed mixes for breeder birds were estimated by Smulikowska & Rutkowski (2005) at 0.5 μM/g of starter diet and 1.0 μM/g of finisher diet. In the present study, glucosinolate level in experimental diets ranged from 0.38 to 1.05 μM/g of starter diet and from 1.20 to 1.98 μM/g of grower-finisher diet, which indicates that the recommended level for chicken rearing was exceeded at all levels of soybean meal substitution with rapeseed meal except for the low level in the starter diet.

The results obtained in this work indicate that soybean meal replacement by

rapeseed meal in broiler chicken diets supplemented with marked amounts of DDGS and fodder yeast, in which permissible level of glucosinolates was exceeded, increased chicken mortality already in the first experimental period. Although the causes of chicken deaths were not identified by autopsy, they could be attributed to the negative impact of glucosinolates on homeostasis of birds and their body functions, especially on hepatic metabolism (Denbow, 1994). The increased liver weight in the experiment was undoubtedly a symptom of detoxification processes induced in the body by dietary glucosinolates. Chicks, especially those with lower hatch weight did not show any signs of disease but died at night with no prior symptoms. Glucosinolate degradation products might be the toxic factor. It can suggest that toasting of rapeseeds during meal production process is not fully efficient or that current broiler chicken lines, selected for quick growth rate and feed efficiency, are very vulnerable to dietary glucosinolates. The above results suggest that in spite of a low content of glucosinolates in currently cultivated Polish rapeseed varieties, possibilities of increasing the level of rapeseed meal in broiler feed mixes are very limited. Exceedance of the recommended and permissible glucosinolate levels in diets produced negative effect on chick mortality.

Canadian studies linked the increased mortality of broilers fed diets containing rapeseed meal with deficit of the amino acid arginine. Arginine is a nitric oxide (NO) precursor producing vasodilator effect (Collier & Vallance, 1989). The lack of arginine was a pathogenetic factor of pulmonary hypertension in poultry (Shaul, 2002). This disease could be the cause of mortality in broiler chickens receiving diets supplemented with rapeseed products. In the light of these findings, Basoo et al. (2012) upgraded the requirement of 2- and 6-weeks-old chickens for Arginine to the level higher by 20% than NCR recommendations (1994).

The results of the present study demonstrated the lack of a significant interaction of rapeseed meal level in the diet with chick sex with regard to chicken mortality, which means that cockerels and hen responded in a similar way to variable amounts of rapeseed meal. It has a significant practical implication because large-scale broiler production flocks comprise ca. 50% of cockerels and 50% of hens.

Body weight and carcass quality

Apart from feed conversion rate and mortality, efficiency of broiler production depends on growth rate and body weight after 5 or 6 weeks of rearing, and also on carcass quality which is estimated by weight of different commercial cuts, including breast muscle and legs. Other important traits include: carcass yield, weight of giblets, in these the gizzard and liver, and meat composition and quality. Depot, i.e. omental and abdominal fat reduces carcass quality. Numerous studies of rapeseed feeds in broiler feeding brought diverse often divergent results. Jamroz (1984) reviewed results obtained in the 1970s and at the beginning of the 1980s and concluded that meal obtained from 00

rapeseed varieties could be added to broiler diets at the level above 15% without the risk of compromising the production efficiency. Fritz et al. (1984) surveyed studies conducted before 1983 and found that the discrepancies between efficiency of rapeseed feeds in broiler chicken feeding could be caused by differences in the contents of glucosinolate degradation products, including isothiocyanates (ITC) and 5 vinyl-2-oxazolidine-methionine (WOT), in rapeseed feeds and diets, and by different meal origin. Mazanowska et al. (1987) used 10% and 20% rapeseed meal from 00 Jantar variety for soybean meal replacement in broiler rearing till 56 days. Final chicken weight was 1800–1850 g. Feed conversion was reduced by 3.4% and 0.8%, respectively. Mortality of birds from soybean group was 4.2% and in rapeseed groups 2.9% and 6.5%, respectively. A significant increase in the liver and thyroid gland weight was observed. Carcass yield of chickens fed rapeseed supplemented diet was very low. The results obtained in the present study are in line with those cited above in spite of differences in experimental schedules and different broiler varieties then and now.

Studies carried out in the UK confirmed that rapeseed meal could be used for broiler feeding but at the limited level (Gordon et al., 2004). Namely, chickens were fed the diets containing increasing amounts of rapeseed meal from 0 to 16% with a 2% interval, and the highest rapeseed level was shown to reduce body weight of chicken but feed intake increased. The 6% rapeseed meal level in the diet was recommended as the optimal level for broilers. Van Kempen & Jansman (1994) and Lesson & Summers (1997) recommended similar dietary level of rapeseed meal as optimum. The results obtained in the present study are close to the British recommendations and indicate that the current guidelines for rapeseed meal level in the starter diet are too high. It cannot be excluded that currently used broiler chicken genotypes, adapted to high growth rate, are more vulnerable even to the reduced glucosinolate levels in the diet.

In further broiler feeding experiments, the diets containing 10% and 20% rapseed meal were used. Feed intake dropped by 10.5% and 9.5%, respectively, while 10% dietary level of rapeseed meal in the diet was recommended as optimal (McNeill et al., 2004). The above-descrived results did not provide specific recommendations for different phases but only for the whole rearing period of broiler chickens.

Retarded and diminished growth rate of chickens, receiving dietary rapeseed products was attributed to glucosinolates, assuming incomplete deactivation of the enzyme myrosinase during toasting of meal obtained after oil extraction. It was acknowledged that glucosinolate degradation products, especially progoitrin, impairs iodine uptake by the thyroid gland from blood. Iodine is indispensable for synthesis of the hormone triiodothyronine responsible for growth and development processes in birds (Schöne et al., 1997).

In the present studies, the reduced weight of chickens fed rapeseed meal resulted in the reduced carcass weight and proportionally smaller commercial cuts, especially breast and leg muscles. These traits are heavily genetically

determined in chicken and depend on body weight at slaughter and carcass yield (Scheuermann et al., 2003). The results obtained in this work indicated that exceedance of 7% rapeseed meal content in starter diets and 16% in grower-finisher diets led to reduction of final broiler body weight by 5.4% and to a significant increase in mortality of birds above 4% which is accepted as a standard level in large-scale broiler production. These results can suggest a lower profitability of broiler production when 7% and 16% rapeseed meal level is exceeded in starter and grower-finisher diets, respectively. These data demonstrated also significant sex-dependent differences in body weight and no interaction between rapeseed meal content in the diet and sex in affecting body weight and slaughter parameters of chickens. It indicates that both cockerels and hens equally reacted to the dietary level of rapeseed meal.

The studies evaluating carcass quality showed that the addition of rapeseed products to feed did not significantly affect dry matter, protein, fat and ash contents in chicken breast muscles. Breast muscle and leg muscle percentages were at a relatively high level. Earlier studies demonstrated 22–24% breast muscle percentage and 21–22% leg muscle percentage (Brake et al., 1993; Young et al., 2001; Brzóska et al., 2013) and similar levels were obtained in the present work.

Only a few studies have analyzed the effect of rapeseed feeds on basic metabolic indices of blood. Partially this issue was addressed in a review by Rutkowski & Dąbrowski (1984). The present studies did not show a significant impact of rapeseed meal addition to the diet at the levels exceeding recommended values on blood parameters, except for a significant increase in plasma triglyceride level at high rapeseed meal content in the diet.

No significant interaction was found between dietary rapeseed meal content or glucosinolate level with chick sex with regard to the above-described parameters of growth performance, caracass quality, breast muscles and plasma. It means that both cockerels and hens in a similar way responded to soybean meal substitution with rapeseed meal, except for a higher content of depot fat in hen carcasses compared with cock carcasses, but there were no differences in fat content in breast muscles.

Ileal digestibility of protein and amino acids

Ileal digestibility of amino acids in broiler chickens depends on many factors. Kim and Corzo (2012) demonstrated that true ileal amino acid digestibility depended on chicken line, age and sex. Huang et al. (2005) revealed that digestibility of amino acids from 8 feedstuffs increased with age which was attributed to the development of absorptive area of the small intestine in growing chickens. It was also shown that digestibility of amino acids in the digestive tract was influenced by intestinal passage rate of digesta. The intestinal passage in older birds is slower and their digestive tract is longer which augments digesta exposure to hydrolytic action of digestive enzymes while larger absorptive area increases ileal digestibility of amino acids (Shires et al., 1987). It is thought that

amino acid digestibility in poultry is reduced by anti-nutrients present in the diet, mostly crude fiber and tannins (Fan & Sauer, 1999). Available literature reports did not document an indirect dependence between dietary glucosinolate level and apparent or true digestibility of amino acids in the small intestine.

The present studies documented that grower-finisher diets for broilers containing all levels of rapeseed meal were characterized by reduced apparent ileal digestibility of protein and amino acids compared with diets containing soybean meal. It confirmed the results of earlier studies showing that the ileal digestibility of protein and amino acids from rapeseed feeds in poultry was lower than digestibility of soybean meal (Szczurek, 2009). Process of fat extraction from rapeseeds and soybeans, solvent for fats and temperature are similar, though because fat content in rapeseed meal is twice as high as in soybean meal, extraction of the former is much longer. The factors reducing protein and amino acid digestibility of rapeseed meal may include also solvent residue evaporation process and toasting of the extracted meal at a temperature of ca. 105°C for 30–45 min. A greater protection of soybean protein against thermal degradation can also result from higher starch content in soybeans in comparison with rapeseeds. Earlier studies showed that apparent ileal amino acid digestibility of feeds subjected to thermal processing, like toasting or drying is lower than amino acid digestibility of mechanically or thermally unprocessed cereal grains (Szczurek, 2008). It is commonly accepted that extraction and toasting of rapeseed meal deactivates anti-nutrients but may also reduce ileal digestibility of lysine and the remaining amino acids by overheating of rapeseed meal which was evidenced in the studies of Newkirk and Classen (2002).

Heating during solvent evaporation can damage feed proteins by inducing the Maillard reaction (Van Soest, 1994), which results in reduction of protein and amino acid digestibility. Earlier studies demonstrated that digestibility of lysine and cystine from rapeseed feeds is reduced in comparison with digestibility of these amino acids from soybean meal (Parsons et al., 1991; Newkirk & Classen, 1999; Newkirk et al., 2000) which suggested that thermal and pressure processing of rapeseed meal can cause stronger damage to proteins and amino acids and reduce their digestibility in chickens. Studies revealed that overheating of rapeseed meal diminished protein digestibility in *in vivo* studies and reduced chicken growth rate and amino acid digestibility in adult cocks (Anderson-Hafermann et al., 1993). Before toasting, post-extraction rapeseed meal was yellow in color while after completion of this process, it was brown which indicates that the Maillard reaction has occurred (Newkirk & Classen, 1999). Moisture-free evaporation of the solvent, i.e. hexane, gave a light-yellow product not turning brown (Newkirk & Classen, 2002). Pastuszewska et al. (2003) demonstrated that raising the heating temperature of rapeseed oilcake from 90 to 140°C for 45 min elevated protein degradation from ca. 0.36% to 0.55% DW. Classen et al. (2004) confirmed that the Maillard reaction in rapeseed meal occurred during solvent evaporation and toasting in the presence of moisture when temperature reached more than 105°C and the process lasted 30–45 min. Solvent

is removed from the meal by hot steam infusion which increases meal moisture to 15–18% and thus it requires drying (Spragg & Mailer, 2007).

It was also shown that soybean meal protein replacement by rapeseed meal protein in broiler diet reduced arginine level below the requirement for chickens which resulted in chicken body weight reduction (Izadinia et al., 2010). The diets containing rapeseed products showed particularly low arginine digestibility compared with soybean meal-based dietes (Khajali & Slominski, 2012). It was confirmed by the present studies where arginine digestibility in the diets with rapeseed meal addition was by 5–8 units lower than soybean meal digestibility. Toghyani et al. (2015) revealed that temperature of rapeseed processing affected lysine digestibility which suggested the occurrence of Maillard reaction. An apparent ileal digestibility (AID) of rapeseed meal from Canadian Canola varieties in the cited studies was observed for arginine, histidine, methionine and glutamic acid and lower for tyrosine, cystine and proline. The results of those studies were partially confirmed by the present experiments. Newkirk & Classen (2002) found that non-toasted Canola meal contained significantly more lysine, arginine, histidine, serine, valine, leucine, isoleucine, proline and phenylalanine.

Björck et al. (1984) demonstrated that high temperature modified cell wall matrix destroying bridges between polysaccharide chains, thus depolymerizing fiber particles to create water soluble fragments. The modification of fiber matrix increased its solubility leading to elevated viscosity and reduced digestibility of nutrients (Mateos et al., 2002; Garcia et al., 2008).

The tabulated data indicate that crude fiber content in rapeseed meal is twice as high as its content in soybean meal (Smulikowska & Rutkowski, 1994; Brzóska et al., 2015). A part of protein of both feeds is contained in crude fiber which could be the cause of reduced apparent ileal digestibility of both protein and amino acids for diets containing rapeseed meal used as a substitute for soybean meal in feeding broiler chickens in the present studies. Crude protein in broiler diets increases intestinal passage rate of digesta in the digestive tract while the passage rate decreases the time of exposure of protein and amino acids to digestive enzymes and thus digestibility and conversion of protein and amino acids. Toghyani et al. (2015) highlighted a significant negative correlation between the contents of neutral detergent fiber (NDF) and neutral detergent insoluble nitrogen (NDIN) in the diets containing rapeseed meal and the lysine digestibility. Those authors confirmed that younger chicks before 21 days of age are more vulnerable to soybean meal substitution with rapeseed meal which was fully confirmed by studies presented in this paper.

In summary, it can be concluded that soybean meal substitution with rapeseed meal in the diets balanced by dried distillers grains with insolubles (DDGS), fodder yeast and L-lysine and DL-methionine supplements in broiler chickens, independently of the substitution level in the range from 4% to 11% in starter diets and from 12.6% to 20.7% in grower-finisher diets, with exceeded the level of glucosinolates (0.38–1.05 μM/g in starter and 1.20–1.98 μM/g in grower-finisher diets) in feeds significantly reduced production efficiency of

broilers mostly due to reduction of apparent ileal digestibility of crude protein and amino acids, at all substitution levels, including lysine, methionine, arginine and threonine. The optimal level of rapeseed meal in diets should be defined as 4–6% in starter diet and 8–10% in grower-finisher diet if glucosinolate level in rapeseed meal does not exceed 9.5 μM/g. The exceedance of the contents, established by studies, can result in reduction of live weight and carcass quality of broilers at impaired feed conversion ratio.

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Effect of substituting soybean meal with rapeseed meal on body weight of broiler chickens, carcass quality and apparent ileal amino acid digestibility

SUMMARY

The aim of the study was to investigate the effect of substituting soybean meal (SBM) with rapeseed meal (RSM) in maize-wheat meal based diets, balanced with DDGS, fodder yeast, L-lysine and DL- methionine, on the growth performance, mortality, feed consumption and conversion, carcass traits and meat composition of broiler chickens and to determine ileal crude protein and amino acid apparent digestibility at 2–4 weeks of age. A total of 640 sexed chicks (Ross 308, 1 d old) were divided into 4 groups with 2 semi groups each (male and female), with 8 replications, 10 birds in each replication, and fed 4 mash diets. The diets were a complete corn-wheat meal with 4 decreasing SBM contents (starter/grower-finisher) in percent: 36/30; 24.3/20.4; 21.2/17.7 and 17.1/11.2, and 4 increasing RSM contents respectively: 0/0 (control); 4/12.6 (Low level); 7/16.2 (Medium level) and 11/20.7 (High level). Adequately to the RSM in the diets, the level of glucosinolates in the diets was, in μM/g, respectively: 0.0; 0.38; 0.67 and 1.05 (starter) and 0.0; 1.20; 1.55 and 1.98 (grower-finisher). The diets were formulated to have the same ME, CP, Ca, P and amino acids content using DDGS, yeast, L-Lys and DL-Met.

The dietary inclusion of RSM instead of SBM significantly decreased the body weight by 5.5%; 5.4% and 9.8% respectively compared to the control diet ($P \leq 0.01$). The feed conversion significantly increased by 4.8%; 5.8% and 8.2% respectively compared to the control diet ($P \leq 0.01$). The highest level of RSM in the diet, significantly decreased the broiler chicken mortality ($P \leq 0.01$). There was an increase in dietary level of RSM, a decrease of SBM, a decrease in the carcass, breast and leg muscles, but a significant increase of the liver weight at High level of RSM inclusion in the diet.

The effect of SBM substitution with RSM on ileal CP and AA apparent digestibility was also studied. A total of 320 cockerels (Ross 308), 2–4 weeks old were divided into 4 groups, with 8 replications,

10 birds in each replication, and fed 4 mash diets as in growing experiment (grower), with Cr_2O_3 as ileum digestibility marker. The diets were a complete corn-wheat meal with 4 decreasing SBM contents (starter/grower-finisher). RSM replaced dietary SBM, with DDGS and yeast significantly decreasing the CP and AA ileal digestibility at all levels of rapeseed meal in the experimental feed mixtures.

The results suggest that solvent rapeseed meal cannot replace soybean meal without adverse effects on performance, protein and apparent ileal amino acid digestibility of broiler chickens if used at more than 4–6% in starter and 8–10% in grower commercial feeds, if the concentration of glucosinolates in rapeseed meal does not exceed 9.5 μM/g.

Key words: soybean meal, rapeseed meal, broiler chicken, productivity, apparent digestibility of amino acids