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Gastrointestinal tract response and growth performance of growing turkeys as influenced by the whole wheat content of diets in two feeding programmes

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ABSTRACT. *The objective of this study was to determine the physiological responses and growth performance of turkeys fed 20% whole wheat (WW) in two feeding programmes, diets A and B, consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In diet B, in successive feeding periods (weeks 5–18), the soyabean meal content was increased by 2.89% to 5.13%, the wheat content was decreased by 5.29% to 8.18%, and the concentrations of L-lysine, DL-methionine and L-threonine were considerably increased. A total of 896 four-week-old Big-6 male turkeys with similar initial body weights were randomly assigned to four equal dietary treatment groups, with seven replicate pens per treatment. The birds had free access to water and pelleted diets that contained no WW or 20% WW. After 14 weeks of feeding, the body weight gains (BWG) of turkeys were similar in all dietary treatments. From week 13 to 18, WW contributed to a significant (P = 0.040) increase in the feed conversion ratio (FCR), whereas the increase in FCR noted over the entire experiment was nearly significant (P = 0.065). Dietary inclusion of WW had no effect on the weights of the gizzard, small intestine, or caecum, and it enhanced fermentation in the caecum, including increasing α-glucosidase activity and the concentrations of total short-chain fatty acids, and decreasing the pH of caecal digesta (all P = 0.001). No significant differences were noted in the parameters of gastrointestinal function and BWG between turkeys fed diets A and B. Diet B did, however, significantly (P = 0.045) improve FCR over the entire experiment.*

Introduction

Whole grain cereals, primarily wheat (WW), are fed to poultry to reduce the growth of pathogenic bacteria through better crop and gizzard development, which enhances intestinal morphology and function, thus improving the growth rate and feed conversion of birds (Biggs and Parsons, 2009; Svihus et al., 2010; Amerah et al., 2011). Feeding whole grains to poultry also increases economic efficiency by reducing the costs of production and transport of compound feeds (Svihus, 2010; Bennett et al., 2002). Another advantage of more natural' feeding systems is greater consumer acceptance (Gabriel et al., 2008).

In experiments on chickens, whole grains were included at 10%–20% (Amerah and Ravindran, 2008), or even 20%–40% of the daily diet (Gabriel

et al., 2008). An experiment on turkeys has demonstrated that turkeys can be successfully fed a diet containing 50% whole wheat or barley (Bennett et al., 2002). Dilution of a complete turkey diet with 30% WW reduced the final body weight and the weight of breast meat per bird by 15% and 20%, respectively (Bennett and Classen, 2003).

Our previous study (Jankowski et al., 2012a) showed that moderate dilution of complete turkey diets with wheat (18% on average from weeks 4 to 18) had no effect on the final body weights of birds or muscle yield, and improved feed efficiency. It was also found that supplementation of turkey diets with WW improved feed conversion as a result of better GIT function, lower pH of gizzard digesta, increased crypt depth in the jejunum, lower ammonia concentrations, lower pH in intestinal digesta, a higher proportion of *Eubacteria* and *Bifidobacterium* sp. and lower *Salmonella* sp. counts in intestinal microflora, and increased concentrations of butyric acid and total short-chain fatty acids (SCFAs) in the caecal digesta (Zdunczyk et al., 2013).

The results of another study, in which whole grain wheat was supplemented with appropriate protein, fat and mineral concentrate (Jankowski et al., 2013), showed that the lowest WW content of diets (up to 15% of the daily ration from week 4 to 12) had no effect on the growth performance and gastrointestinal function parameters of turkeys, while two-fold higher WW inclusion levels significantly increased gizzard weight, deteriorated feed conversion ratio (FCR), but did not decrease the body weight gain (BWG) of birds. A further increase in the inclusion rates of WW in turkey diets, in particular complete substitution of WW for ground and pelleted wheat, considerably affected the physicochemical and microbiological parameters of intestinal digesta, including an increase in *Escherichia coli* counts, and also significantly decreased the BWG of birds and deteriorated FCR.

According to Blair and Potter (1989) and Ferket and Sell (1990), the total protein content of turkey diets can be reduced even by 20% (relative to the NCR, 1994, recommendations) with no negative effect on the growth rate of birds, provided that the energy density of the diet is adequate. Further studies are needed to determine whether the above findings can be extrapolated to modern strains of heavy-type turkeys. It remains unknown if those birds respond to relatively small differences in protein content resulting from WW inclusion in the diet or different feeding strategies.

The aim of this study was to determine the physiological responses and growth performance of turkeys fed pelleted diets with different physical forms of wheat, i.e. exclusively ground wheat or 20% wheat as whole grain. The effects of the diet with WW were compared in two feeding programmes (diets A and B) consistent with NRC (1994) or B.U.T. (2012) recommendations.

Material and methods

Birds and housing

A total of 896 four-week-old heavy-type Big-6 male turkeys (Hatchery Grelavi Co., Kętrzyn, Poland) were randomly assigned to four dietary treatments, with seven replicate pens per treatment and 32 birds per pen. The birds had free access to pelleted diets and water. All diets were fed throughout four experimental periods, i.e. weeks 5–8, 9–12, 13–16 and 17–18.

The experiment was carried out at the Research Laboratory of the Department of Poultry Science, University of Warmia and Mazury, Olsztyn (Poland). The protocol for this study was approved by the Local Ethics Committee, and the study was carried out in accordance with EU Directive 2010/63/EU for animal experiments.

Experimental design and diets

A 2 × 2 factorial arrangement of four dietary treatments was used to evaluate the effects of isoenergetic diets that contained no WW or 20% WW on the growth performance, carcass traits and gastrointestinal tract response of growing turkeys (5–18 wk). Diets diluted with different physical forms of wheat were administered in two feeding programmes: diet A, consistent with the NRC recommendations (1994) and diet B, consistent with the B.U.T. recommendations (2012). The diameters of pellets in diets with and without WW, administered during weeks 5–8 and 9–18, were 3 mm and 4 mm, respectively.

Wheat grain from the same batch was used in all dietary treatments, and its chemical composition was estimated based on crude protein content (12%) and Polish Feedstuff Analysis Tables (Smulikowska and Rutkowski, 2005). The nutritional value of wheat grain used in the study (Table 1) was used to calculate the nutrient composition of experimental diets. WW accounted for 20% of the ration, irrespective of the total wheat content. A preliminary trial showed that the maximum inclusion rate of WW in turkey diets is 20%, as it has no adverse effects on the pelletizing process and pellet cohesion.

Table 1. *Dietary ingredients and the nutrient content (g · kg^{-1} as-fed basis) of diets fed to turkeys from 5 to 18 weeks of age*

Indices	5–8 wk		9–12 wk		13–16 wk		17–18 wk	
	A[1] (NRC)	B[1] (BUT)	A (NRC)	B (BUT)	A (NRC)	B (BUT)	A (NRC)	B (BUT)
Ingredients								
ground wheat	438.5	385.6	556.0	474.2	642.2	570.5	706.4	627.1
soyabean meal (46% CP)	396.1	425.0	265.0	316.3	177.9	220.5	104.3	149.1
sunflower meal	30	30	40	40	40	40	40	40
rape seed (20.7% CP)	60	60	70	70	70	70	80	80
soyabean oil	27.2	36.5	15.5	29.3	19.9	32.5	14.4	28.3
lard	10	10	20	20	20	20	30	30
limestone	13.6	15.9	12.1	15.2	10.9	14.1	10	13.9
monocalcium phosphate	14.1	23.4	10.6	21.7	8.9	19.9	6.2	19.2
choline chloride	1	1	1	1	1	1	1	1
Na_2SO_4	1	1	1	1	1	1	1	1
NaCl	2.2	2.2	1.8	1.8	1.8	1.8	1.9	1.9
DL-Methionine (99)	1.3	3.1	0.7	2.7	0.6	2.5	–	2.3
L-Lysine HCL(78)	2.3	3.1	3.4	3.1	2.2	3.1	1.8	3.3
L-Threonine (98.5)	0.2	0.7	0.4	1.2	1.1	0.6	0.5	0.4
vitamin-mineral premix[2]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Calculated analysis[3]								
metabolizable energy, kcal · kg^{-1}	2900	2900	3000	3000	3100	3100	3200	3200
crude protein	260	268.5	220	235	190	201.9	165	177.8
lysine	15.0	16.2	13.0	13.8	10.0	11.6	8.0	10.1
methionine	5.0	6.9	4.0	6.1	3.5	5.5	2.7	5.0
methionine + cysteine	9.5	11.4	8.0	10.3	7.1	9.3	6.0	8.5
threonine	9.5	10.3	8.0	9.4	7.5	7.5	6.0	6.4
tryptophan	3.4	3.5	2.8	3.0	2.4	2.6	2.1	2.2
arginine	16.9	17.5	13.8	15.0	11.6	12.5	9.7	10.7
Ca	10.0	12.6	8.5	11.8	7.5	10.8	6.5	10.4
available P	5.0	7.0	4.2	6.6	3.8	6.2	3.2	6.0

[1] diets A and B consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In the diets A_{ww} and B_{ww} 200 g ground wheat was substituted by whole wheat; [2] provided the following per kilogram of diet in the successive (5–12 and 13–18 weeks) feeding periods, mg: retinol 3.38 and 2.88, cholecalciferol 0.12 and 0.10, α-tocopheryl acetate 94 and 80, vit. K_3 5.6 and 4.8, thiamine 4.7 and 4.0, riboflavin 7.5 and 6.4, pyridoxine 5.6 and 4.8, cobalamin 0.028 and 0.024, biotin 0.28 and 0.24, pantothenic acid 24 and 20, nicotinic acid 75 and 64, folic acid 2.8 and 2.4, Fe 56 and 48, Mn 112 and 96, Zn 103 and 88, Cu 19 and 16, I 2.8 and 2.4, Se 0.28 and 0.24, choline chloride 376 and 320, respectively; [3] calculated from the analysis of feed ingredients provided by the manufacturer

Growth trial

Before the experiment, from 1 to 4 weeks of age, all turkeys were fed identical commercial diets formulated to meet their nutrient requirements. Next, birds with similar initial body weights were assigned to four equal dietary treatment groups. A four-phase feeding programme (week 5–8, 9–12, 13–16 and 17–18) was used during the study. At 8, 12 and 18 wk, the turkeys were weighed and feed intake was recorded. The body weight gain of birds and feed conversion ratio were calculated for each feeding period. Mortality rates were recorded daily, and the body weights of dead birds were used to adjust for average daily gain, average daily feed intake, and FCR. At 56 and 126 days of age, fresh excreta samples from four birds per replicate pen were collected and pooled to determine excreta dry matter (DM) content. The experiment lasted for 126 days.

At the termination of the experiment, footpad dermatitis (FPD) scores for all birds were determined according to the method described by Krautwald-Junghanns et al. (2011), on a five-point scale (0–4 points) where 0 – the skin of the footpad feels soft to the touch and no swelling or necrosis is evident, 4 – more than half of the footpad is covered by necrotic cells. With regard to performance parameters, each replicate pen (n = 7) was considered an experimental unit for the statistical analysis.

Carcass traits

At 18 weeks of age, six birds representing the average weight of each treatment were selected and slaughtered in the Department's processing plant eight hours after feed withdrawal. The birds were electrically stunned (400 mA; 350 Hz), hung on a shackle line and exsanguinated by a unilateral

neck cut severing the right carotid artery and jugular vein. After a three-minute bleeding period, the birds were scalded at 61°C for 60 s, defeathered in a rotary drum picker for 25 s, and manually eviscerated (non-edible viscera: intestines, proventriculus, gall bladder, spleen, oesophagus and full crop). Head, neck, legs, edible viscera (heart, liver and gizzard), and fat (perivisceral, perineal and abdominal) were removed. Following evisceration, whole carcasses were air pre-chilled at 12°C for 30 min, air chilled and stored at 4°C, and hand-deboned on a cone 24 h post mortem. The carcass, abdominal fat, breast meat (including *pectoralis major* and *pectoralis minor* muscles), and leg meat (including thigh and drumstick) were weighed. The percentage of eviscerated carcass was calculated as the ratio between the eviscerated carcass and live body weight after fasting. The weights of the liver, gizzard, breast meat, leg meat and abdominal fat were also calculated relative to live body weight.

Sample collection

Segments of the digestive tract (small intestine, caecum, colon) were removed. Digesta samples were collected, caeca were flushed with water, blotted on filter paper and weighed. The ileum was defined as the segment from Meckel's diverticulum to the ileo-caecal junction. As soon as possible after euthanasia (about 20 min), pH was measured in digesta from each segment using a microelectrode and a pH-ion meter (model 301, Hanna Instruments, Vila do Conde, Portugal). Fresh samples of the ileal (middle 1/3 section of ileum) and caecal contents were used for the analysis of DM, ammonia, and short-chain fatty acids. The remaining portion of the caecal digesta was transferred to test tubes and stored at –70°C until needed.

Chemical analysis

The DM content of excreta and caecal digesta was determined at 105°C. Ammonia was determined by microdiffusion analysis in Conway's dishes (Hofirek and Haas, 2001) and SCFAs were analysed using a gas chromatograph (Shimadzu GC-2010, Kyoto, Japan) equipped with a capillary column (SGE BP21, 30 m × 0.53 mm, SGE Europe Ltd., Kiln Farm Milton Keynes, UK) as described earlier (Juskiewicz et al., 2011). The activity of bacterial enzymes (α- and β-glucosidase, α- and β-galactosidase, β-glucuronidase, α-arabinopyranosidase, β-xylosidase) released into the caecal environment was measured by the rate of *p*- or *o*-nitrophenol release from their nitrophenylglucosides. The reaction mixture contained 0.3 ml of a substrate solution (5 mM) and 0.2 ml of a 1:10 (v/v) dilution of the caecal sample in 100 mM phosphate buffer (pH 7.0) after centrifugation at 7211 *g* for 15 min. Incubation was carried out at 39°C and *r*-nitrophenol was quantified at 400 nm and at 420 nm (*o*-nitrophenol concentration) after the addition of 2.5 ml of 0.25 M-cold sodium carbonate. The enzymatic activity was expressed as μmol product formed per hour per gram of digesta. The above procedure concerns the extracellular activities of bacterial enzymes released from bacterial cells into the gastrointestinal environment (Juskiewicz et al., 2011). To determine the total enzymatic activity of selected bacterial enzymes in the caecal sample, which includes extracellular and intracellular activities of bacterial enzymes, the caecal sample diluted in phosphate buffer (as described above) was mechanically disrupted by vortexing with glass beads (212–300 μm diameter; four periods of 1 min with intervals of 1 min on ice). After that the resulting mixture was centrifuged at 7211 *g* for 15 min at 4°C. The supernatant was used for the enzyme assay. By comparison of the entire enzyme activity with the activity of bacterial enzyme released into the environment, the intracellular activity was calculated, and also expressed as μmol product (*p*- or *o*-nitrophenol) formed per hour per gram of digesta.

Statistical analysis

For growth performance analysis scores, seven pens per treatment and 32 birds per pen were used and each pen was considered an experimental unit. Other results were analysed with each bird as a replicate (n = 6). The model assumptions of normality and homogeneity of variance were examined by the Shapiro-Wilk and Levene tests, respectively. The statistical analysis was performed according to the GLM procedure for Statistica 10.0 software. The data were subjected to two-way ANOVA, to examine: a. the main effect of wheat grain (0 and 200 g · kg^{-1}), b. the main effect of diet (diets A and B), and c. the interaction between the diet and wheat content. Growth performance data were performed by two-way ANOVA with initial body weight as the dependent variable (covariate). When the ANOVA indicated significant treatment effects, means were separated using the Newman-Keuls test (Snedecor and Cochran, 1989). The effects were considered to be significant at $P \leq 0.05$, and were expressed as mean values with pooled standard errors.

Results

The present experiment aimed to determine the effects of two factors: the physical form of wheat in pelleted diets (100% ground wheat and 80% ground wheat + 20% WW) and feeding programmes consistent with the NRC (1994) or B.U.T. (2012) recommendations on the physiological responses and growth performance of turkeys. The difference in protein content between diet A and diet B was initially small (0.85% at 5–8 wk), and in successive feeding periods it increased to 1.5%, 1.19% and 1.28%, respectively (Table 1). In diet B, higher levels of protein and amino acids were achieved by increasing the concentrations of L-lysine, DL-methionine and L-threonine, and soyabean meal content (by 2.89% to 5.1%), and decreasing wheat content by 5.29%–8.18% in successive feeding periods.

The applied dietary treatments had no effect on feed intake, BWG in successive feeding periods, or the final body weights of turkeys (Table 2). In the second and third phase (weeks 9–12 and 13–18), dietary inclusion of WW at 20% progressively deteriorated FCR ($P = 0.064$ and 0.040, respectively), compared with ground wheat. The increase in FCR noted over the entire experiment was nearly significant ($P = 0.065$). No differences were found in BWG in successive feeding periods or in the final body weights of turkeys fed diets A and B. However, diet B significantly ($P = 0.045$) improved FCR over the entire experiment. The interaction between the experimental factors (wheat form × feeding programme) had no significant effect on BWG and FCR.

Carcass dressing percentage, relative size of valuable cuts (breast, thigh and drumstick muscles) as a percentage of liveweight, and carcass fat content were not significantly affected by diet composition (Table 3).

Gizzard weight was similar in all groups regardless of dietary treatment. Among the analysed pa-

Table 2. Growth performance and feed conversion ratio of turkeys from 5 to 18 weeks of age[1]

Effect	DFI, g per bird				BWG, kg				Final	FCR, kg · kg^{-1}			
	5–8 wk	9–12 wk	13–18 wk	5–18 wk	5–8 wk	9–12 wk	13–18 wk	5–18 wk	BW, kg	5–8 wk	9–12 wk	13–18 wk	5–18 wk
Treatment[2]													
A	231.6	448.5	605.2	447.1	3.77	5.60	8.69	18.06	19.40	1.79	2.25	2.96	2.49
A_{ww}	233.9	460.6	601.7	450.6	3.86	5.49	8.52	17.87	19,21	1.78	2.32	3.02	2.53
B	225.9	450.4	590.4	440.9	3.78	5.64	8.68	18.10	19.44	1.76	2.20	2.88	2.44
B_{ww}	228.4	450.6	594.2	441.3	3.78	5.55	8.42	17.75	19.09	1.76	2.24	3.00	2.49
Pooled SEM	1.366	2.674	5.992	2.926	0.026	0.034	0.087	0.107	0.108	0.008	0.015	0.023	0.012
Whole wheat													
WW_0	228.5	449.5	597.3	443.8	3.77	5.62	8.68	18.08	19.42	1.77	2.22	2.92^{b}	2.46
WW_{200}	231.2	455.6	597.9	446.0	3.82	5.52	8.47	17.81	19.15	1.77	2.28	3.01^{a}	2.51
Diet													
A (NRC)	232.8^{a}	455.0	603.3	449.0	3.81	5.54	8.60	17.96	19.29	1.78	2.29^{a}	3.00	2.51^{a}
B (B.U.T.)	227.2^{b}	450.5	592.3	441.1	3.78	5.59	8.55	17.93	19.27	1.76	2.22^{b}	2.94	2.46^{b}
P													
wheat (W)	0.369	0.256	0.993	0.751	0.401	0.154	0.239	0.235	0.236	0.677	0.064	0.040	0.065
diet (D)	0.045	0.455	0.381	0.211	0.581	0.496	0.762	0.869	0.871	0.159	0.024	0.221	0.045
W × D interaction	0.965	0.277	0.776	0.806	0.385	0.903	0.814	0.720	0.723	0.846	0.596	0.479	0.859

[1] data represent mean values of 7 replications per treatment. DFI – daily feed intake, BWG – body weight gain, FCR – feed conversion ratio, SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 28); [2] diets A and B consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In the diets A_{WW} and B_{WW} 200 g ground wheat was substituted by whole wheat; [a,b] means with different superscripts within columns for each main effect are significantly different at $P < 0.05$. All interactions are insignificant

Table 3. Main effects of dietary treatments on slaughter yields of meat portions and tissues of turkeys (body weight = 100%) at 18 weeks of age[1]

Effect	Carcass dressing	Breast	Thigh	Drumstick	Liver	Abdominal fat
Whole wheat						
WW_0	83.40	23.55	10.82	7.89	0.86	1.25
WW_{200}	83.65	24.05	11.02	7.80	0.83	1.21
Diet						
A (NRC)	83.76	23.88	10.88	7.95	0.86	1.24
B (BUT)	83.29	23.71	10.96	7.75	0.83	1.22
Pooled SEM	0.178	0.258	0.109	0.090	0.020	0.081
P						
wheat (W)	0.498	0.363	0.413	0.628	0.514	0.789
diet (D)	0.206	0.763	0.749	0.287	0.432	0.902
W × D	0.798	0.861	0.746	0.418	0.847	0.592

[1] data represent mean values of 6 replications per treatment. SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 24). All differences and interactions insignificant

Table 4. Indices of intestinal development and function in turkeys[1]

Effect	Gizzard, g · kg^{-1} BW	Small intestine weight[2]	Caecal tissue g · kg BW	Caecal digesta			
				g · kg^{-1} BW	DM, %	ammonia, mg · g^{-1}	pH
Treatment[3]							
A	5.1	11.6	1.93	0.917	19.4	0.788	6.37
A_{ww}	5.5	12.3	1.90	0.888	19.1	0.754	5.85
B	5.3	11.4	2.06	0.942	19.0	0.824	6.45
B_{ww}	5.3	11.7	2.10	0.971	19.2	0.790	5.78
Pooled SEM	0.012	0.316	0.046	0.050	0.320	0.033	0.084
Whole wheat							
WW_0	5.2	11.5	1.99	0.929	19.2	0.806	6.41^{A}
WW_{200}	5.4	12.0	2.00	0.929	19.1	0.772	5.82^{B}
Diet							
A (NRC)	5.3	12.0	1.91	0.902	19.3	0.771	6.11
B (BUT)	5.3	11.5	2.08	0.957	19.3	0.807	6.12

[1] data represent mean values of 6 replications per treatment. SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 24). All interactions insignificant; [2] total weight with contents, g · kg^{-1} BW; [3] diets A and B consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In the diets A_{WW} and B_{WW} 200 g ground wheat was substituted by whole wheat; [A,B] means with different superscripts within columns for each main effect are significantly different at $P < 0.01$

Table 5. Extracellular and intracellular activity of bacterial enzymes in the caeca of turkeys[1]

Effect	α-glucosidase		β-glucosidase		α-galactosidase		β-galactosidase		β-glucuronidase		α-arabino-pyranosidase		β-xylosidase	
	extra[2]	intra[3]	extra[2]	intra[3]	extra[2]	intra[3]	extra[2]	intra[3]	extra[2]	intra[3]	extra[2]	intra[3]	extra[2]	intra[3]
Treatment[4]														
A	50.4	8.41	25.0	12.1	42.5	49.1	52.0	47.2	41.3	28.8	3.29	3.48	12.3	13.8
A_{ww}	65.1	11.5	22.4	13.2	45.7	41.1	64.1	41.9	52.0	24.5	3.61	3.51	14.6	12.8
B	40.5	7.86	19.9	12.1	46.6	42.3	54.2	47.5	40.0	34.2	1.76	3.66	11.0	13.4
B_{ww}	66.1	11.6	24.6	13.1	49.6	41.1	65.6	38.9	46.6	40.8	3.23	3.98	12.6	14.2
Pooled SEM	3.241	0.902	1.664	0.796	2.563	2.755	5.338	5.131	3.349	2.591	0.295	0.314	0.961	0.825
Whole wheat														
WW_0	45.4^{B}	8.14	22.4	12.1	44.5	45.7	53.1	47.4	40.6	31.5	2.52	3.57	11.6	13.6
WW_{200}	65.6^{A}	11.6	23.5	13.1	47.6	41.1	64.9	40.4	49.3	32.6	3.42	3.74	13.6	13.5
Diet														
A (NRC)	53.3	9.72	22.3	12.6	48.1	41.7	59.9	43.2	43.3	37.5^{a}	2.49	3.82	11.8	13.8
B (BUT)	57.7	9.97	23.7	12.6	44.1	45.1	58.1	44.6	46.6	36.4^{b}	3.45	3.50	13.4	13.3

[1] data represent mean values of 6 replications per treatment. SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 24); [2] extracellular activity, μmol · h · g^{-1}; [3] intracellular activity, μmol · h · g^{-1}; [4] diets A and B consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In the diets A_{WW} and B_{WW} 200 g ground wheat was substituted by whole wheat; [a,b,A,B] means with different superscripts within columns for each main effect are significantly different at $P < 0.05$ and $P < 0.01$, respectively. All interactions insignificant

Table 6. Short chain fatty acid (SCFA) concentrations (μmol · g^{-1} digesta) and SCFA profile (% of total SCFAs) in the caecal digesta of turkeys[1]

Effect	SCFA concentrations, μmol · g^{-1} fresh digesta							Profile, % of total SCFAs		
	C2	C3	C4i	C4	C5i	C5	Total	C2	C3	C4
Treatment[2]										
A	101	32.0	2.87	25.1	3.95	4.47	170	59.7	18.9	14.8
A_{ww}	125	45.6	1.6	40.1	3.21	3.98	218	57.2	21.1	18.3
B	84.2	28.2	2.08	21.9	3.29	4.63	144	58.3	19.5	15.2
B_{ww}	123	45.9	1.61	43.1	3.60	4.31	222	56.0	20.6	19.1
SEM	4.439	2.042	0.214	2.474	0.264	0.265	8.330	0.639	0.437	0.635
Whole wheat										
WW_0	92.8^{B}	30.1^{B}	2.47^{A}	23.5^{B}	3.62	4.55	157^{B}	59.0	19.2	15.0^{B}
WW_{200}	124^{A}	45.8^{A}	1.34^{B}	41.6^{A}	2.95	4.15	220^{A}	56.6	20.8	18.7^{A}
Diet										
A (NRC)	104	37.0	1.85	32.5	3.44	4.47	183	57.2	20.1	17.1
B (BUT)	113	38.8	1.97	32.6	3.13	4.23	194	58.5	20.0	16.5

[1] data represent mean values of 6 replications per treatment. SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 24); 2 diets A and B consistent with the NRC (1994) and B.U.T. (2012) recommendations, respectively. In the diets A_{WW} and B_{WW} 200 g ground wheat was substituted by whole wheat; [A,B] means with different superscripts within columns for each main effect are significantly different at $P < 0.01$. All interactions insignificant

Table 7. Main effects of dietary treatments on excreta DM content and FPD symptoms at 18 weeks of age[1] and mortality of turkeys[1]

Effect	DM, %	FPD, points	Mortality, % 1 – 18 wk
Whole wheat			
WW_0	21.6	1.42	3.86
WW_{200}	21.0	1.58	3.13
Diet			
A (NRC)	21.3	1.58	3.85
B (BUT)	21.2	1.44	3.14
Pooled SEM	0.217	0.078	–

[1] data represent mean values of 7 replications per treatment; SEM – standard error of the mean (SD divided by the square root of the number of replications, n = 28). All differences and interactions insignificant

rameters of intestinal development and function, significant differences were noted only with respect to the pH of caecal digesta (Table 4), which was lower ($P = 0.001$) in turkeys fed 20% WW.

Differences in diet composition, including WW content, had a minor effect on microbial enzyme activity in the caecum (Table 5). The 20% WW inclusion rate contributed to a significant increase in the activity levels of extracellular and intracellular α-glucosidase, determined in the native caecal digesta ($P = 0.001$) and in the caecal digesta that was homogenized to release enzymes from bacterial cells ($P = 0.068$), respectively. No differences were observed in the activities of the other analysed enzymes in the caecal microflora.

The caecal digesta of turkeys fed 20% WW was characterized by significantly higher concentrations of acetate, propionate, butyrate and total SCFAs (all $P = 0.001$), and lower ($P = 0.004$) isobutyrate levels (Table 6). The proportion of acetate decreased ($P = 0.062$) and the percentages of propionate and butyrate ($P = 0.006$ and $P = 0.002$, respectively) increased in the total SCFA pool determined in the caecal digesta of turkeys fed 20% WW. No significant differences were found in SCFA concentrations in the caecal digesta of turkeys fed diets A and B.

The applied dietary treatments had no effect on excreta DM, FPD scores at the end of the experiment, or mortality rates of birds over the entire experiment (Table 7).

Discussion

Numerous experiments performed on chickens have shown that whole grains stimulate development of the gastrointestinal tract (including an increase in the weights of the proventiculus and gizzard), thus improving feed efficiency and/or increasing BWG (Bennet at al., 2002; Gabriel et al., 2008; Biggs and Parsons, 2009; Svihus et al., 2010). Studies investigating the effect of whole grains in turkeys remain scarce, and their results are inconclusive. Bennett et al. (2002) demonstrated that the BWG of turkey was unaffected by feeding increasing levels of whole barley (5%, 20% and 50% on days 19–33, 34–40 and 41–96) when the diets were supplemented with a protein-mineral-vitamin concentrate. In our earlier study (Jankowski et al., 2013), when the diets were supplemented with a protein-mineral concentrate, a substantial decrease in body weight was noted at a higher (about 40%) inclusion rate of WW. In the present study, WW added to pelleted diets at 20% had no influence on the BWG or final body weights of turkeys, which corroborates the above findings.

The results of previous studies on turkeys do not explain the effect of the content of whole grain in the diet on feed conversion. Bennett et al. (2002) noted similar FCR values for diets containing whole and ground barley, whereas Bennett and Classen (2003) reported a worse FCR in turkeys fed a commercial diet diluted with wheat grain. In our earlier study (Jankowski et al., 2013), a low substitution level of ground wheat by whole wheat (12.5% and 15% whole grain wheat content of the daily ration in weeks 4–8 and 9–12, respectively) did not negatively affect the feed conversion ratio, but two-fold higher whole grain inclusion levels deteriorated FCR. At the first stage of the present experiment (weeks 5–8), the applied dietary treatments had no effect on FCR. In the second and third phase (weeks 9–12 and 13–18), dietary inclusion of WW at 20% progressively deteriorated FCR ($P = 0.064$ and 0.040, respectively), compared with ground wheat. Our findings indicate that the negative effect of WW on feed efficiency was not determined by the bird's age but by increased consumption of feed containing WW.

In the current study, the proportions of major muscle groups (including breast muscles) in turkey carcasses were not affected by the physical form of wheat. The experimental factor had no effect on the final body weights of birds, either. In an experiment by Bennett and Classen (2003), a high level of diet dilution with wheat (from 21% to 29%) significantly reduced the final body weights of turkeys and the weight of breast meat per bird, by 15% and 20%, respectively. We did not note a decrease in carcass fat content in response to feeding wheat-diluted diets, which was reported in an experiment involving broiler chickens (Amerah and Ravindran, 2008).

No increase in the weight of the gizzard or small intestine was observed in our study. According to many authors (Bennett et al., 2002; Amerah and

Ravindran, 2008; Biggs and Parsons, 2009; Jankowski et al., 2013; Zdunczyk et al., 2013), relative gizzard weight can be increased by feeding whole grains to chickens and turkeys. An increase in gizzard size was reported by Wu et al. (2004) at post-pelleting inclusion of 20% WW, whereas no such effect was observed at pre-pelleting inclusion of WW. The findings of Wu et al. (2004) and our results may suggest that the pelletizing process changes the physicochemical properties of cereal grain and accelerates the passage rate of pelleted feed, compared with whole grain fed with a pelleted diet.

Previous experiments (Biggs and Parsons, 2009) have demonstrated that the wheat content of chicken diets had no effect on SCFA concentrations in the caecal digesta. According to Gabriel et al. (2008), wheat grain improves gizzard function and nutrient digestibility, thus reducing the amount of substrate available for the proliferation of intestinal microbiota. Different results were obtained in a previous experiment on turkeys where wheat grain increased SCFA concentrations in the caecal digesta and the weight of the caecal wall (Zdunczyk et al., 2013). In the current study, the inclusion of WW in turkey diets enhanced the activity of microbial α-glucosidase. The increase in the glycolytic activity of gut microflora was followed by an increase in the SCFA concentrations and a decrease in pH. The above suggest that pre-pelleting inclusion of wheat increases the amounts of carbohydrates in the caecal digesta, which are degraded to SCFAs. However, the energy provided by carbohydrates fermented in the caecum contributes approximately 3.5% of metabolizable energy in poultry (Jamroz et al., 2002). This explains reduced utilization of WW-based diets, despite a significant increase in the production of SCFAs in the caecum.

In our previous studies (Jankowski et al., 2012a, 2013; Zdunczyk et al., 2013), the severity of FPD varied among young turkeys, but at the end of fattening (at the highest level of diet dilution with wheat) no significant differences were found between groups in this respect. In the present study, the experimental factors had no significant effect on excreta DM. It is known that high excreta moisture increases the risk of FPD in poultry (Jankowski et al., 2012b).

Different feeding regimes had an insignificant effect on the parameters of gastrointestinal function, including SCFA concentrations in the caecal digesta. Changes in the carbohydrate composition of diets, caused by different inclusion levels of soyabean meal and wheat, were small, particularly in the first phase of feeding. In our previous studies (Jankowski et al., 2009), enhanced caecal fermentation in young turkeys could have resulted from high concentrations of raffinose family oligosaccharides rather than from the crude fibre content of diets (Zdunczyk et al., 2010).

In this study, feed efficiency was higher in turkeys fed diet B formulated as recommended by B.U.T. (2012). The above could be due to the fact that from 9 weeks of age the content of amino acids and total protein was reduced to a lesser extent in diet B than in diet A formulated as recommended by the NRC (1994). As a result, nutrient density per unit of metabolizable energy was higher in diet B. In the last phase of feeding, the wheat-to-soyabean meal ratio in diets A and B reached 7:1 and 4:1, respectively. It seems that nutrients provided by soyabean meal are more efficiently utilized than those supplied by wheat. Other authors (Waldroup et al., 1997; Applegate et al., 2008) demonstrated that the amino acid levels suggested by NRC (1994) were adequate to support maximum performance in turkeys. In a study by Applegate et al. (2008), diets formulated with supplemental amino acids to 100% or 110% of NRC (1994) amino acid recommendations had no effect on the body weights of turkeys and breast meat yield.

Conclusions

The results of our study indicate that in both feeding programmes, 20% inclusion of whle wheat (WW) in pelleted diets may deteriorate the feed conversion ratio (FCR), without significantly decreasing the body weight gain of turkeys. Increased production of short-chain fatty acids in the caeca of turkeys fed WW did not compensate the deterioration in FCR. Compared with the diet based on NRC (1994) recommendations, the diet consistent with the B.U.T. (2012) recommendations significantly improved the FCR in turkeys.

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