

The effect of incremental inclusion of whole grain wheat in the diet of growing turkeys on growth performance, feed conversion ratio, cecal health, and digesta characteristics

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1 **The effect of incremental inclusion of whole grain wheat in the diet of growing turkeys**
2 **on growth performance, feed conversion ratio, cecal health, and digesta characteristics**

3

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10

11

12 **ABSTRACT**

13 This study was conducted to determine the effects of adding incremental amounts of whole
14 grain wheat (0, 100, and 200 g per kilogram of feed) to the diet of growing turkey poults on
15 growth performance, feed efficiency, digesta pH, and the incidence of cecal distension.
16 Seventy two, 6-wk-old commercial line turkeys were blocked by live weight and randomly
17 allocated to 1 of 3 dietary treatment (n = 4 pens/treatment). Turkeys were offered their
18 respective treatments for the duration of the study. Feed offered and refused and body
19 weights were determined weekly. At 63 d of age 12 turkeys from each treatment were
20 euthanized and crop contents were collected and weighed, pH of gizzard and cecal digesta
21 measured, and ceca and cecal contents visually scored. At 84 d of age, all remaining turkeys
22 were euthanized and the same sampling procedure repeated. Feed conversion ratio was
23 poorer in those turkeys offered diets containing whole grain wheat ($P < 0.05$), declining
24 quadratically ($P < 0.005$) as the proportion of whole grain wheat (**WGW**) in the diet
25 increased. The proportion of WGW found in the crop post-mortem reflected whole wheat
26 inclusion rates of the diets. The pH of gizzard contents at 63 d was lower in turkeys receiving
27 diets supplemented with WGW, declining quadratically ($P = 0.005$) as the proportion of
28 WGW in the diet increased. However, this difference in gizzard pH was not apparent at 84 d
29 of age. Cecal content pH, cecal visual appearance scores, and cecal content visual
30 appearance scores were not affected by the inclusion of WGW to the diet. The inclusion of
31 WGW to the diets of growing turkeys reduces growth performance and feed efficiency
32 suggesting that the addition of whole wheat may have reduced the nutritional quality of the
33 diet as a whole.

34 *Keywords*

35 *Turkey, Wheat, Gizzard, Ceca, Digesta*

36 **1. Introduction**

37 The feeding of whole grains to poultry has been shown as a means of improving poultry
38 gut health whilst reducing feed processing costs (Forbes and Covasa, 1995, Singh et al.,
39 2014). As a consequence there has been renewed attention by the commercial poultry
40 industry to the feeding of whole grains, not only as a way of reducing feeding costs, but as a
41 means of improving gut health and subsequent litter quality, which could impact negatively
42 on performance, welfare, and carcass quality (Amerah and Ravindran, 2008).

43 The feeding of whole grains to poultry has been associated with a number of effects on
44 performance, although responses seem to be variable and to some extent dependent upon the
45 species of bird and the way in which whole grains were offered. Munt et al. (1995) reported
46 reduced growth rates in broilers offered free choice diets, whereas Erener et al. (2006)
47 reported improved rates of gain in turkeys using a free choice system. Both Husveth et al.
48 (2015) and Singh and Ravindran (2015) reported improved feed conversion ratio (**FCR**) in
49 broilers fed wholegrains that had been incorporated into the pellet, whereas Taylor and Jones
50 (2001) reported no improvement. Jankowski et al. (2014) reported no improvement in turkey
51 performance when whole grains were incorporated into the pellet, but did report an
52 improvement in FCR when whole grains were added to the diet post-pelleting (Jankowski et
53 al., 2012).

54 During the past 50 years poultry nutrition, structure of the diet and nutrient requirements
55 have changed noticeably due to improvements in nutritional knowledge and advances in
56 poultry genetics (Havenstein et al., 2003). There is considerable research showing that
57 physical structure of feed (type and form) can affect the development of the digestive tract
58 (Amerah et al., 2007b, Engberg et al., 2002, Svihus et al., 2004), which in turn has been
59 shown to influence subsequent nutrient digestibility (Amerah et al., 2007a, Gabriel et al.,

60 2008, Hetland et al., 2002, Svihus et al., 2010), and digesta characteristics (e.g., pH)
61 (Zdunczyk et al., 2013). Changes in the composition of digesta arriving at the cecum may
62 result in changes in excreta consistency that may in turn impact litter quality (Zdunczyk et al.,
63 2013); both Engberg et al. (2004) and Taylor and Jones (2004) have reported increased
64 digesta viscosity in turkeys fed diets containing whole wheat.

65 A previous study conducted by this research group investigating the effects that whole
66 grain wheat (**WGW**) had on turkey gut health had noted that consumption of WGW, when
67 offered through a free choice feeding system, was highly variable and that a number of
68 turkeys consumed very little, if any, WGW when given free choice. The aim of this study
69 was to determine whether the feeding of pelleted diets that had been mixed with the graded
70 addition of WGW resulted in selective feeding, and to determine the effects that wheat
71 inclusion, and subsequent nutrient dilution had on turkey growth performance, aspects of gut
72 health, and digesta pH.

73 74 **2. Materials and methods**

75 The study was subject to local review and conducted in accordance with the University
76 of Reading's current animal research policy and conformed to the United Kingdom's Animal
77 (Scientific Procedures) Act 1986.

78 A total of seventy two 6-wk-old commercial line turkeys were used in this study. Wing
79 tagged turkey poults were provided by Aviagen (Aviagen Turkeys Ltd, Tattenhall, Cheshire,
80 UK), and were all of the same age, breed, and sourced from a single unit. After arrival
81 turkeys were individually, weighed, blocked by live weight and then randomly allocated to 1
82 of 3 dietary treatments. Treatments included an unsupplemented control that comprised a
83 pelleted diet that contained no supplementary WGW, a group that received the pelleted diet
84 supplemented with 100g WGW per kilogram of feed and a group that received the pelleted

85 diet supplemented with 200g WGW per kilogram of feed. The pelleted diet comprised of a
86 commercial grower diet (ingredient composition of pelleted diets not disclosed); Grower 1
87 (F66503, GLW-Feeds Leicestershire, UK) was offered from 42 days of age to 63 d of age,
88 and Grower 2 (F66504, GLW-Feeds) from 63 d to 84 d of age. The change from Grower 1 to
89 Grower 2 was abrupt and occurred in all pens at the same time. The whole grain wheat was
90 mixed with pelleted feed using a mechanical mixer.

91 The study was conducted in an open pole barn between January and March 2015. The
92 building provided natural ventilation and natural lighting. There were 4 pen replicates per
93 treatment with 6 turkeys in each pen. Each pen provided approximately 0.5 m²/turkey, was
94 bedded with white wood shavings and equipped with a single bell type drinker, a single
95 suspended feed hopper, and a suspended halogen heat lamp that remained on for the duration
96 of the study.

97 Turkeys received their experimental diets throughout the entire study period. All feed
98 offered and refused were weighed and recorded weekly on a per pen basis throughout the
99 study. Turkeys were weighed weekly on an individual basis and weights recorded.

100 Laboratory analysis of Grower1 and Grower 2 pelleted diets and whole wheat used in the
101 study are shown in Table 1.

102 At 63 d of age, three turkeys were randomly selected from each pen and euthanized by
103 captive bolt followed by abrupt exsanguination. The crop was removed intact after which the
104 contents were emptied and sorted to determine the proportion of WGW within the crop. The
105 viscera were exposed and the ceca scored in-situ in terms of appearance using a numerical
106 system adapted from (Raman et al., 2011; Table 2). Cecal contents were emptied from the
107 cecal sac into an Eppendorf tube, scored for their appearance using a system proposed by Saif
108 (2011; Table 2), and cecal digesta pH measured. The gizzard was removed, the contents

109 emptied into a container, and gizzard digesta pH measured. At 84 d of age, all remaining
110 turkeys were euthanized by captive bolt followed by abrupt exsanguination. The viscera
111 were exposed and the ceca scored in-situ in terms of appearance using a numerical system
112 adapted from (Raman et al., 2011; Table 2). Cecal contents were emptied from the cecal sac
113 into an Eppendorf tube, scored for their appearance using a system proposed by Saif (2011;
114 Table 2), and cecal digesta pH measured. The gizzard was removed, the contents emptied
115 into a container, and gizzard digesta pH measured.

116 Digesta pH (both gizzard and cecal contents) were determined immediately post-sample
117 harvesting. 50 mL of distilled water was added to 5 g of digesta material, mixed thoroughly,
118 and pH measured using a calibrated digital pH probe (Hannah Instruments, HI 110,
119 Bedfordshire, UK). The probe was cleaned with distilled water and calibration checked
120 between samples.

121 Data pertaining to turkey performance includes feed intake (calculated average feed
122 intake per turkey based on group pen intake), live weight gain (calculated within pen
123 individual daily live weight gain), and feed conversion ratio (calculated from total pen feed
124 intake and total weight gained within pen with respect to age). Growth data, and digesta pH
125 (gizzard and ceca), were analysed by analysis of variance (ANOVA) using a general linear
126 model (GLM) using the Genstat 17th edition statistical software package (VSN International
127 Ltd, Hemel Hempstead, UK). Sources of variation included wheat inclusion rate (2 df).
128 Results are presented as least square means with the standard error of the mean with
129 orthogonal polynomials. Data pertaining to cecal external visual appearance scores and cecal
130 content visual scores were analysed by Pearson Chi-Square. Data are presented graphically
131 with the Chi Square value, degrees of freedom, and *P*-value.

132

133 3. Results

134 3.1 Growth performance

135 There were no effects of WGW inclusion on rates of feed intake at 63 d of age, although
136 there were effects on growth rate and feed conversion ratio (Table 3). Growth rates were
137 greatest in those turkeys receiving the 0 g WGW per kilogram of feed diet ($P = 0.036$) and
138 decreased quadratically ($P = 0.028$) as the proportion of whole wheat inclusion increased.
139 Feed conversion ratios were better in those turkeys receiving the 0 g WGW per kilogram of
140 feed diet ($P = 0.009$) with feed efficiency declining quadratically ($P = 0.004$) as the
141 proportion of whole wheat included in the diet increased. The effects of wheat inclusion on
142 feed conversion ratio seen at 63 d of age was still apparent at 84 d with turkeys receiving the
143 0 g WGW per kilogram of feed diet having better feed conversion ratios ($P = 0.004$) than
144 those supplemented with WGW with feed efficiency declining quadratically ($P = 0.002$) as
145 the proportion of whole wheat in the diet increased.

146

147 3.2 Proportion of wheat in the crop

148 As anticipated there was an effect of dietary treatment ($P < 0.001$) on the proportion of
149 wheat found in the crop post-mortem; the proportion of wheat found in the crop mirrored that
150 of the study structure (Table 4), indicating that inclusion and increasing the proportion of
151 wheat in the diet did not appear to result in selective feeding. However, proportions of wheat
152 found in the crop ranged markedly within treatment; 70 to 223 g/kg in turkeys receiving the
153 100 g per kilogram of feed diet and 104 to 683 g/kg in those receiving the 200 g per kilogram
154 of feed. This would suggest that there was a degree of selection between individual turkeys.

155

156 3.3 Gizzard and ceca digesta pH

157 At 63 d of age, the pH of gizzard digesta from turkeys receiving whole grain wheat was
158 lower than when compared to those receiving the 0 g WGW per kilogram of feed diet ($P =$
159 0.006), with pH declining quadratically ($P = 0.005$) as the proportion of WGW in the diet
160 increased (Table 4). However, this difference was not evident at 84 d of age. There were no
161 effects of treatment on cecal content pH.

162

163 3.4 Cecal appearance and content scores

164 There were no effects of treatment on cecal appearance scores (Figure 1; Pearson Chi
165 square = 4.878, $P = 0.570$) or cecal content scores (Figure 2; Pearson Chi square = 5.764; $P =$
166 0.450).

167

168 4. Discussion

169 The dilution of poultry feed by the use of WGW has been practiced for a number of
170 years using a number of different feeding strategies and inclusion rates of WGW into the base
171 diet. Feeding strategies that have been used include pre-pelleting (pelleted mixture of WGW
172 and other dietary components), post-pelleting inclusion resulting in nutrient dilution, post-
173 pelleting inclusion with dietary adjustment (use of protein concentrate to compensate for
174 nutrient dilution), and free choice feeding (WGW offered in separate feeders to standard diet)
175 (Jankowski et al., 2016). The current study used post-pelleting inclusion that when compared
176 to the 0 g WGW per kilogram of feed diet, resulted in a calculated graded dilution of crude
177 protein content (≈ 15 and 30 g/kg for 100 and 200 g WGW per kilogram of feed,
178 respectively), sugar content (≈ 5 and 10 g/kg for 100 and 200 g WGW per kilogram of feed,
179 respectively) and an increase in starch content (≈ 25 and 55 g/kg for 100 and 200 g WGW per

180 kilogram of feed, respectively). However, the inclusion of WGW did not appreciably affect
181 the calculated energy density of the diets.

182 Studies investigating the effects of whole grain inclusion and its subsequent effects on
183 turkey performance are limited, although there are a number of studies conducted on broilers.
184 The findings of the current study are similar to those of (Bennett and Classen, 2003); the
185 current study found that although there were no effects of treatment on intake behaviour there
186 were effects with respect to rates of weight gain and subsequent feed conversion efficiency,
187 with rates of gain and efficiency of feed use being poorer in turkeys offered diets containing
188 WGW. Bennett and Classen (2003) reported that the inclusion of WGW reduced both
189 weight gain and feed conversion efficiency as WGW inclusion increased (150-350 g/kg). In
190 contrast, (Jankowski et al., 2012) reported that the feeding of WGW up to 225 g per kilogram
191 did not adversely affect feed intake or body weight gain but improved feed conversion ratio
192 (FCR) when compared to comparable inclusions of ground wheat. The changes in turkey
193 growth performance seen in the current study and that of Bennett and Classen (2003) may be
194 a consequence of the dilution of crude protein; in the current study crude protein contents of
195 the diets, when compared to the control, were reduced by 15 to 30 g/kg with a metabolisable
196 energy (ME) content across diets of 13.5 MJ/kg, and that of Bennett and Classen (2003) were
197 reduced by 15 to 25 g/kg with an ME content across diets of 12.6 MJ/kg. However, the
198 study of Jankowski et al. (2012) had similar levels of crude protein dilution as seen in the
199 current study but in contrast had reported improvements in feed conversion efficiency with
200 the addition of WGW to the diet. These differences in responses between studies are difficult
201 to reconcile and may reflect differences in turkey management and/or environmental
202 conditions (stocking rate, temperature, etc.).

203 There are a number of studies reporting on improvements in gizzard development and
204 associated digestive health in poultry fed whole grains; increases in gizzard weights in both

205 turkeys (Jankowski et al., 2014, Zdunczyk et al., 2013) and broilers (Bennett et al., 2002a,
206 Gabriel et al., 2003, Preston et al., 2000, Williams et al., 2008) have been reported when fed
207 diets containing whole grains. The current study did not assess gizzard weight but instead
208 determined the pH of digesta within the gizzard. The reduction in pH of gizzard contents has
209 been reported in both turkeys (Bennett et al., 2002b, Zdunczyk et al., 2013), and broilers
210 (Engberg et al., 2004, Gabriel et al., 2003). Svihus (2011) proposed that this reduction in pH
211 was most likely due to increased gizzard volume leading to increased digesta retention time
212 resulting in a stimulatory effect on gizzard activity and hydrochloric acid secretion. Benefits
213 of this acidic environment may include reduced pathogenic bacteria (Engberg et al., 2004),
214 and improved gastric digestion (Gabriel et al., 2003, Zdunczyk et al., 2013).

215 The inclusion of WGW did reduce gizzard digesta pH at 63 d of age in the current study
216 but responses followed a quadratic ($P = 0.005$) rather than linear ($P = 0.116$) response. It
217 could be hypothesised that as the proportion of WGW increased linearly in the diet there
218 would be a commensurate increases in retention time resulting in reductions in gizzard
219 digesta pH. However, this was not the case and reflects the findings of Zdunczyk et al.
220 (2013) who showed that there was no dose dependent change in gizzard digesta pH when the
221 level of whole wheat inclusion in the diet of turkeys was increased. However, it should also
222 be noted that in the current study fibrous bedding material (wood shavings) was found in both
223 the crop and gizzards of all birds sampled. This accumulation of fibrous material may well
224 have increased digesta retention time within the gizzard and as such may have influenced
225 subsequent gizzard digesta pH. A similar observation was made at 84 d of age, whereby
226 bedding material was present in gizzard digesta, irrespective of treatment. This too may have
227 influenced retention time and subsequent digesta pH values thus masking any effect of whole
228 wheat inclusion on gizzard digesta pH resulting in what appeared to be a time dependent
229 response in gizzard digesta pH. Unfortunately only the quantity of feed pellets and whole

230 wheat found in the crop were quantified whereas the presence of bedding material was only
231 noted but not measured. As a consequence it is not possible to confirm this hypothesis in the
232 current study.

233 Zdunczyk et al. (2013) reported that cecal content pH was lower in turkeys fed diets
234 containing high levels of whole wheat (225 g per kilogram of feed) and this was associated
235 with increases in the concentrations of acetic and butyric acids found in cecal digesta. The
236 findings of the current study were unable to establish any effects of treatment on cecal pH.
237 However, the associated reductions in cecal pH reported by Zdunczyk et al. (2013) were quite
238 small and it could be that any small pH difference seen between treatments in the current
239 study may have been masked by individual bird variation. Short chain fatty acids (**SCFA**)
240 were not determined in the current study but it would have been interesting to note whether
241 SCFA concentrations were influenced by the ingestion of whole wheat; the findings of
242 Zdunczyk et al. (2013) indicated that SCFA concentrations in cecal digesta were altered in
243 both low and high whole wheat fed birds, although cecal digesta pH was only lower in those
244 receiving the highest quantity of whole wheat in their diet. Furthermore Zdunczyk et al.
245 (2013) reported that butyrate concentrations were greater in the digesta of birds receiving
246 whole wheat; butyrate is the preferred energy source for enterocytes and has been shown to
247 positively affect cellular differentiation and proliferation resulting in an increase in epithelial
248 surface area and absorptive capacity (Guilloteau et al., 2010).

249 Turkeys remained healthy throughout the current study, although there was evidence of
250 mildly distended ceca (cecal scores 2 and above). These were not treatment related
251 suggesting that the provision of whole wheat to the diet did little to reduce the incidence of
252 cecal distention. Similarly, cecal content scores indicated that the majority of ceca contained
253 foamy/liquid content, but this too was not related to treatment, although the foaming was
254 most probably indicative of some form of fermentation activity.

255

256 **5. Conclusion**

257 The inclusion of whole wheat in the diets of growing turkeys resulted in lower growth
258 rates in the earlier part of the study and poorer rates of feed conversion throughout the entire
259 study period, suggesting that the addition of whole wheat may have reduced the nutritional
260 quality of the diet as a whole. Lower gizzard pH has been related to improved gizzard
261 function and improved digestion, and the findings of this study would suggest that as the
262 consumption of whole wheat increases there is a commensurate reduction in gizzard pH,
263 although the consumption of fibrous bedding material may affect this response. Whole wheat
264 inclusion in the current study did not appear to affect visual cecal health. Although the
265 current study did not evaluate the economic benefit of feeding whole wheat there is a need to
266 evaluate whether improvements in digestive health, and any subsequent improvements in
267 litter and carcass quality, outweigh the associated reductions in turkey growth and feed
268 efficiency.

269

270 **Conflict of interest statement**

271 The authors declare that they have no conflict of interest.

272

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278

279 **References**

- 280 Abdollahi, M., Ravindran, V., Amerah, A., 2016. Influence of partial replacement of ground
281 wheat with whole wheat and exogenous enzyme supplementation on growth
282 performance, nutrient digestibility and energy utilization in young broilers. *J. Anim.*
283 *Physiol. Anim. Nutr.* 100, 929-937.
- 284 Amerah, A., Ravindran, V., Lentle, R., Thomas, D., 2007a. Feed particle size: Implications
285 on the digestion and performance of poultry. *World Poult. Sci. J.* 63, 439-455.
- 286 Amerah, A., Ravindran, V., Lentle, R., Thomas, D., 2007b. Performance and digestive tract
287 characteristics of broilers as influenced by particle size and feed form. *Proc. Aust.*
288 *Poultry Science. Symp., WPSA, Sydney, NSW, February 2007.* 85-88.
- 289 Amerah, A., Ravindran, V., 2008. Influence of method of whole-wheat feeding on the
290 performance, digestive tract development and carcass traits of broiler chickens. *Anim.*
291 *Feed Sci. Technol.* 147, 326-339.
- 292 Bennett, C., Classen, H., Riddell, C., 2002. Feeding broiler chickens wheat and barley diets
293 containing whole, ground and pelleted grain. *Poult. Sci.* 81, 995-1003.
- 294 Bennett, C., Classen, H., 2003. Effect of whole wheat dilution on performance and carcass
295 characteristics of male turkeys. *J. Appl. Poult. Res.* 12, 468-475.
- 296 Engberg, R. M., Hedemann, M. S., Jensen, B., B. 2002. The influence of grinding and
297 pelleting of feed on the microbial composition and activity in the digestive tract of
298 broiler chickens. *Br. Poult. Sci.* 43, 569-579.
- 299 Engberg, R. M., Hedemann, M. S., Steinfeldt, S., Jensen, B. B., 2004. Influence of whole
300 wheat and xylanase on broiler performance and microbial composition and activity in the
301 digestive tract. *Poult. Sci.* 83, 925-938.

302 Erener, G., Ocak, N., Garipoglu, A.V., Sahin, A., Ozturk, E., 2006. Feeding turkey poults
303 with starter feed and whole wheat or maize in free choice feeding system: its effects on
304 their performances. *Asian-Australas. J. Anim. Sci.* 19:1, 86-90.

305 Forbes, J., Covasa, M., 1995. Application of diet selection by poultry with particular
306 reference to whole cereals. *World Poult. Sci. J.* 51, 149-165.

307 Gabriel, I., Mallet, S., Leconte, M., 2003. Differences in the digestive tract characteristics of
308 broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted
309 protein concentrate. *Br. Poult. Sci.* 44, 283-290.

310 Gabriel, I., Mallet, S., Leconte, M., Travel, A., Lalles, J., 2008. Effects of whole wheat
311 feeding on the development of the digestive tract of broiler chickens. *Anim. Feed Sci.*
312 *Technol.* 142, 144-162.

313 Gracia, M. I., Sanchez, J., Millan, C., Casabuena, O., Vesseur, P., Martin, A., Garcia-Pena, F.
314 J., Medel, P., 2016. Effect of feed form and whole grain feeding on gastrointestinal
315 weight and the prevalence of campylobacter jejuni in broilers orally infected. *PLoS One*,
316 11, 1-16.

317 Havenstein, G., Ferket, P., Qureshi, M., 2003. Growth, livability, and feed conversion of
318 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poult.*
319 *Sci.* 82, 1500-1508.

320 Guiloteau P., Martin L., Eeckhaut V., Ducatelle R., Zableski R., Van Immerseel F., 2010.
321 From the gut to the peripheral tissue: the multiple effects of butyrate. *Nutr. Res. Rev.* 23,
322 366-384.

323 Hetland, H., Svihus, B., Olaisen, V., 2002. Effect of feeding whole cereals on performance,
324 starch digestibility and duodenal particle size distribution in broiler chickens. *Br. Poult.*
325 *Sci.* 43, 416-423.

326 Husveth, F., Pal, L., Galamb, E., Acs, K.C., Bustyahazai, L., Wagner, L., Dublicz, F.,
327 Dublicz, K., 2015. Effects of whole wheat incorporated into pelleted diets on the growth
328 performance and intestinal function of broiler chickens. *Anim. Feed Sci. Technol.* 210,
329 144-151.

330 Jankowski, J., Mikulski, D., Zdunczyk, Z., Mikulska, M., Juskiewicz, J., 2012. The effect of
331 diluting diets with ground and pelleted or with whole wheat on the performance of
332 growing turkeys. *J. Anim. Feed Sci.* 21, 735-747.

333 Jankowski, J., Zdunczyk, Z., Mikulski, D., Przybylska-Gornowicz, B., Sosnowska, E.,
334 Juskiewicz, J., 2013. Effect of whole wheat feeding on gastrointestinal tract development
335 and performance of growing turkeys. *Anim. Feed Sci. Technol.* 185, 150-159.

336 Jankowski, J., Mikulski, D., Zdunczyk, Z., Juskiewicz, J., Lichtorowicz, K., 2014.
337 Gastrointestinal tract response and growth performance of growing turkeys as influenced
338 by the whole wheat content of diets in two feeding programmes. *J. Anim. Feed Sci.* 23,
339 253-261.

340 Jankowski, J., Zdunczyk, Z., Juskiewicz, J., 2016. Whole grain in turkey nutrition. Part 2:
341 Production results in different feeding systems. *World Poult. Sci. J.* 72, 563-572.

342 Lv, M., Yan, L., Wang, Z., An, S., Wu, M., LV, Z., 2015. Effects of feed form and feed
343 particle size on growth performance, carcass characteristics and digestive tract
344 development of broilers. *Anim. Nutr.* 1, 252-255.

345 McDonald, P., Edwards, R., Greenhalgh, J., Morgan, C., 2002. *Animal Nutrition*. Sixth ed.
346 Pearson Education Ltd, London, UK.

347 Munt, R.H.C., Dingle, J.G., Sumpa, M.G. 1995., Growth, carcass composition and
348 profitability of meat chickens given pellets, mash or free-choice diet. *Br. Poult. Sci.*
349 36:2, 277-284.

350 Preston, C., Mccracken, K., Mcallister, A., 2000. Effect of diet form and enzyme
351 supplementation on growth, efficiency and energy utilisation of wheat-based diets for
352 broilers. *Br. Poult. Sci.* 41, 324-331.

353 Raman, M., Banu, S. S., Gomathinayagam, S., Raj, G. D., 2011. Lesion scoring technique for
354 assessing the virulence and pathogenicity of Indian field isolates of avian *Eimeria*
355 species. *Veterinarski Arh.* 81, 259-271.

356 Ravindran, V., Wu, Y., Thomas, D., Morel, P., 2006. Influence of whole wheat feeding on
357 the development of gastrointestinal tract and performance of broiler chickens. *Crop*
358 *Pasture Sci.* 57, 21-26.

359 Saif, Y. M., 2008. *Diseases of Poultry*. Twelfth ed. Wiley-Blackwell Publishing, Hoboken,
360 NJ, USA.

361 Singh, Y., Amerah, A., Ravindran, V., 2014. Whole grain feeding: Methodologies and effects
362 on performance, digestive tract development and nutrient utilisation of poultry. *Anim.*
363 *Feed Sci. Technol*, 190, 1-18.

364 Singh, Y., Ravindran, V., 2015. Influence of method wheat inclusion and pellet diameter on
365 performance, nutrient utilisation, digestive tract measurements and carcass
366 characteristics of broilers. *Anim. Prod. Sci.* 55, 474-483.

367 Svihus, B., Juvik, E., Hetland, H., Krogdahl, Å., 2004. Causes for improvement in nutritive
368 value of broiler chicken diets with whole wheat instead of ground wheat. *Br. Poult. Sci.*
369 45, 55-60.

370 Svihus, B., Sacranie, A., Denstadli, V., Choct, M. 2010., Nutrient utilization and functionality
371 of the anterior digestive tract caused by intermittent feeding and inclusion of whole
372 wheat in diets for broiler chickens. *Poult. Sci.* 89, 2617-2625.

373 Svihus, B., 2011. The gizzard: function, influence of diet structure and effects on nutrient
374 availability. *World Poult. Sci. J.* 67, 207-224.

375 Taylor, R.D., Jones, G.P.D., 2001. The effect of whole wheat, ground wheat and dietary
376 enzymes on performance and gastro-intestinal morphology of broilers. Proc. Aust. Poult.
377 Sci. Symp., WPSA, Sydney, NSW, 2001. 187-190.

378 Taylor, R.D., Jones, G.P.D., 2004. The incorporation of whole grain into pelleted broiler
379 chicken diets. II. Gastrointestinal and digesta characteristics. Br. Poult. Sci. 45, 237-246.

380 Williams, J., Mallet, S., Leconte, M., Lessire, M., Gabriel, I., 2008. The effects of fructo-
381 oligosaccharides or whole wheat on the performance and digestive tract of broiler
382 chickens. Br. Poult. Sci. 49, 329-339.

383 Xu, Y., Stark, C., Ferket, P., Williams, C., Pacheco, W., Brake, J., 2015. Effect of dietary
384 coarsely ground corn on broiler live performance, gastrointestinal tract development,
385 apparent ileal digestibility of energy and nitrogen, and digesta particle size distribution
386 and retention timornowicze. Poult. Sci. 94, 53-60.

387 Zaefarian, F., Abdollahi, M., Ravindran, V., 2016. Particle size and feed form in broiler diets:
388 impact on gastrointestinal tract development and gut health. World Poult. Sci. J. 72, 277-
389 290.

390 Zdunczyk, Z., Jankowski, J., Mikulski, D., Przybylska-G, B., Sosnowska, E., Juskiewicz, J.,
391 2013. Gastrointestinal morphology and function in turkeys fed diets diluted with whole
392 grain wheat. Poult. Sci. 92, 1799-1811.

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397 **Fig 1.** Effect of whole grain wheat (WGW) inclusion (g/kg of feed) on cecal external
398 appearance score (adapted from Raman et al., 2011) (Pearson Chi-Square = 4.878, df = 6, P =
399 0.570)

400

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402

403 **Fig 2.** Effect of whole grain wheat (WGW) inclusion (g/kg of feed) on cecal content score
404 (adapted by Saif, 2011) (Pearson Chi-Square = 5.764, df = 6, P = 0.450)

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406

407 **Table 1**408 Laboratory analysis of Grower 1, Grower 2 pelleted diets and whole wheat (g/kg DM¹ unless
409 otherwise stated)

Calculated analysis	Grower 1	Grower 2	Whole wheat
Crude protein	257	237	124
Starch	343	286	607
Sugar (sucrose)	67	42	21
Ether extract	85	90	19
Ca	15	9.9	0.7
Mg	2.2	2.1	1.1
P	8.8	6.6	3.2
Metabolisable energy (MJ/kg DM ¹)	13.5	13.7	13.4

410 ¹DM = Dry matter

411

412 **Table 2**

413 Scoring systems used for the assessment of cecal appearance and content.

414

Score	Description
Appearance	
0	No pathological changes
1	Mild distension with no colour change
2	Moderate distension with pale colour change
3	Complete distension with blood present in the wall
4	Complete distension with severe cell necrosis
Content	
0	No pathological changes - light brown, smooth consistency
1	Thick and viscous, brown/dark brown in colour
2	Foamy/liquid content, pale yellow in colour
3	Foamy/liquid content, pale yellow in colour with blood present
4	Thick coagulated blood present

415 (Adapted from Saif, 2011, and Raman et al., 2011)

416 **Table 3**

417 Effect of whole grain wheat inclusion on turkey growth performance.

Item	Whole wheat (g/kg of pelleted diet)			SEM	Treatment	P-values	
	0	100	200			Linear	Quadratic
63 d of age							
Feed intake (g/d)	360	346	365	9.0	0.352	0.668	0.181
Growth rate (g/d)	140	124	131	3.2	0.036	0.101	0.028
FCR (g/g) ¹	2.68	2.91	2.76	0.04	0.009	0.180	0.004
84 d of age							
Feed intake (g/d)	473	468	484	13.8	0.705	0.590	0.542
Growth rate (g/d)	200	183	199	6.6	0.186	0.958	0.078
FCR (g/g) ¹	2.37	2.57	2.46	0.03	0.004	0.053	0.002

418 ¹Feed conversion ratio

419

420 **Table 4** Effect of whole grain wheat inclusion on crop content and digesta pH

421

Item	Whole wheat (g/kg of pelleted diet)			SEM	<i>P</i> -Values		
	0	100	200		Treatment	Linear	Quadratic
63 d of age							
Crop whole wheat content (g/kg DM)	0	120	239	35	< 0.001	< 0.001	0.927
Gizzard pH	3.45	2.60	3.05	0.18	0.006	0.116	0.005
Cecal pH	5.78	5.78	5.49	0.21	0.535	0.332	0.583
84 d of age							
Gizzard pH	3.23	3.47	3.08	0.13	0.130	0.452	0.061
Cecal pH	5.77	5.54	5.79	0.14	0.397	0.938	0.178