Indian J. Anim. Res., 53(11) 2019: 1480-1484
Print ISSN:0367-6722 / Online ISSN:0976-0555

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
www.arccjournals.com

Effect of whole wheat levels in diet on production performance, egg quality and Nutrient digestibility of laying hens

K. Saikhlai[1], T. Poeikhampha[1], C. Bunchasak[1], N. Krutthai[2], B. Chomtee[3] and C. Rakangthong*[1]

Department of Animal Science, Faculty of Agriculture,
Kasetsart University, Bangkok, Thailand.
Received: 23-07-2017 Accepted: 31-10-2017 DOI: 10.18805/ijar.B-803

ABSTRACT

The experiments were conducted to evaluate the effects of whole wheat on the production performance, egg quality, and nutrient digestibility when supplemented primarily at the expense of corn in ground corn-soybean meal control diets. The experiments utilized Lohmann Brown Classic laying hens from 45 to 53 wk of age. The results were shown that feeding 5, 10, 15, 20, or 25% whole wheat in diet had no effect on the production performance and egg quality, whereas 15, 20, and 25% whole wheat in diet decreased the yolk color (based on the Roche color fan score) when compared with layers fed the control diet.Whole wheat level in diet had no effect on dry matter,organic matter digestibility, and apparent metabolizable energy when compared with laying hens fed the control diet. Therefore, whole wheat can be used at levels of up to 25% in laying hen diets without negatively affecting the production performance, but levels over 15% whole wheat decreased the yolk color.

Key words: Egg Quality, Egg production, Layer, Nutrient digestibility, Yolk color.

INTRODUCTION

The major challenge before the nutritionist is to minimize the feed cost without compromising on the quality or to maintain the feed cost and improve the quality of the feed to exploit the genetic potential of the bird to the maximum (Bhrathidhasan *et al.*, 2009). Feed is the single largest cost item in poultry production, accounting for 65-70% of total expenditure. Cereal grains are the major constituents of poultry diets and are generally ground and mixed into a single homogenized feed. Grinding of whole grains is the second largest energy cost after pelleting in poultry production (Reece *et al.*, 1986) and is probably the highest energy component in layer hen production wherefeeds are not pelleted (Deaton *et al.*, 1989)

Corn, most often, constitutes the highest proportion of ingredients in the formation of any poultry ration due to high energy value and bulkiness (Adesola *et al.*, 2013). Other alternative ingredients to corn are sorghum, millet, barley and wheat. Wheat is the cereal grain of choice for whole grain feeding, despite the fact that globally corn is the most common cereal grain because of availability. However, as corn markets tighten and corn supplies go to nonagricultural uses such as ethanol production, there appears to be a need for alternative grain sources for pullet and layer hen rations. (Singh *et al.*, 2014). The primary aim of whole grain feeding is to lower feed costs by eliminating the grinding step. Furthermore, this also meets consumer demands for a natural feeding system and improved animal welfare (Gabriel *et al.*, 2008). Whole wheat makes an excellent replacement for corn in poultry feeds, but it has high levels of non-starch polysaccharide as a structural carbohydrate in the aleurone and endosperm walls. The majority of the carbohydrate fraction is derived from arabinoxylan. After ingestion, arabinoxylans become soluble, resulting in increased digesta viscosity (Teitge *et al.*, 1991). The viscous nature of intestinal digesta seems to be responsible for negative effects exhibited by wheat pentosans. Increased intestinal viscosity reduces the passage rate of digesta (Antoniou and Marquardt, 1983). As the viscosity increases, the rate of nutrient absorption decreases (Fengler and Marquardt, 1988). High viscosity digesta also lead to an increased incidence of sticky droppings(Classen and Bedford, 1991).

However, birds are able to utilize whole wheat because they can generate high grinding pressure in their gizzards (Sturkie, 1965) and this is also a beneficial application in that it reduces feed milling and transportation costs (Hetland *et al.*, 2005; Rose, 1996). Although whole wheat feeding is becoming a useful practice, particularly in broiler production, this application has not yet been established in layer hen feeding because of insufficient studies using layers as a model.Therefore, the present study attempts to investigate the effects of the whole wheat level

*Corresponding author's e-mail:fagrcwr@ku.ac.th
[1]Department of Animal Science, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.
[2]Department of Agricultural Technology and Development, Faculty of Agricultural Technology, Chiang Mai Rajabhat University, Chang Mai, Thailand.
[3]Department of Statistics, Faculty of Science, Kasetsart University, Bangkok, Thailand.

in diets of laying hens on the production performance, egg qualityand nutrient digestibility of laying hens.

MATERIALS AND METHODS

This study was conducted in line with the animal ethics guidelines of the Research Policy of Kasetsart University, Thailand.

In total, 576 forty-five-week-old Lohmann Brown Classic laying hens(layers) were supplied from the experimental farm of the Department of Animal Science, Kasetsart University, Thailand and randomly allocated to battery-type wire cages. Four layers were placed in each of four consecutive cages with 6 replicates and assigned to receive one of the 6 dietary treatments. Battery cages were equipped with nipple drinkers. Each set of 4 consecutive cages formed an experimental unit in which 16 birds were housed. Laying hens were maintained in an environmentally controlled experimental house with air ventilationand windows and received additional artificial light to provide 16 h light and 8 h dark daily. Feed was offered 2 times daily (8 am and 4 pm) and all experimental diets were fed *ad libitum* to the laying hens and water was available all the time throughout the experimental period.

The six dietary treatments were: 1) control diet (corn-soy base diet), 2) 5% whole wheat diet, 3) 10% whole wheat diet, 4). 15% whole wheat diet, 5) 20% whole wheat diet, and 6) 25% whole wheat diet (Table 1). The feed ingredients were obtained from thelocal feed market andmixed using a horizontal mixer (200kg capacity) in the feedmixing unit.Experimental diets were formulatedto be isocaloric and isonitrogenous and contained 16.32% Crude protein and 2,725 kcal/kg Apparent Metabolizable Energy (AME). The whole wheat diet was prepared by replacing the ground corn with whole grain wheat,according to the recommendation for Lohmann Brown Classic hens (Lohmann, 2012). Other feed ingredients were prepared using a commercial feed mill in mash form.

The birds were weighed at the start (45 wk of age) and end (53 wk of age) of the trial. The feed intake was recorded weekly and the egg production daily. The total egg weight was measured daily by weighing all the eggs collected from the experimental groups. The feed intake was calculated per replicate and period on the basis of the total feed provided minus the total feed leftover. Egg mass was calculated from collecting data ofegg production and egg weight via: Egg mass=(Egg production x Egg weight)/100. Feed conversion

Table 1: Nutrients and feed composition of experimental diets.

Ingredient (kg)	Control	Whole wheat (%)				
		5	10	15	20	25
Corn	59.327	54.720	50.114	45.509	40.902	36.294
Whole wheat	0.000	5.000	10.000	15.000	20.000	25.000
Lard	1.655	1.649	1.644	1.638	1.632	1.627
Rice bransolvent	5.000	5.000	5.000	5.000	5.000	5.000
Soybean meal 48% CP	22.198	21.812	21.426	21.040	20.654	20.269
DL-Methionine	0.162	0.160	0.157	0.154	0.151	0.149
Monodicalciumphophate	1.493	1.495	1.497	1.499	1.502	1.504
Calcium carbonate	9.663	9.662	9.661	9.660	9.659	9.658
Salt	0.175	0.175	0.174	0.173	0.173	0.172
Vitamin and mineral premix[1]	0.250	0.250	0.250	0.250	0.250	0.250
Choline chloride 60%	0.077	0.077	0.077	0.077	0.077	0.077
Total	100.00	100.00	100.000	100.000	100.000	100.000
Cost (USD/kg)	0.381	0.381	0.381	0.380	0.380	0.380
Nutrient by calculate						
Metabolizable energy (Kcal/kg)	2,725.00	2,725.00	2,725.00	2,725.00	2,725.00	2,725.00
Crude protein (%)	16.320	16.320	16.320	16.320	16.320	16.320
Fat (%)	3.980	3.889	3.798	3.707	3.616	3.525
Crude fiber (%)	3.393	3.670	3.947	4.223	4.500	4.777
Calcium (%)	4.000	4.000	4.000	4.000	4.000	4.000
Total phosphorus (%)	0.690	0.694	0.697	0.699	0.701	0.703
Available phosphorus (%)	0.370	0.370	0.370	0.370	0.370	0.370
Salt (%)	0.250	0.250	0.250	0.250	0.250	0.250
Lysine (%)	0.820	0.816	0.810	0.805	0.799	0.794
Methionine + Cystine (%)	0.700	0.700	0.700	0.700	0.700	0.700
Methionine (%)	0.430	0.423	0.420	0.416	0.413	0.409
Threonine (%)	0.600	0.595	0.593	0.591	0.589	0.588
Choline (mg/kg)	400.000	400.000	400.000	400.000	400.000	400.000

Lutavit mix CNK004 consisting of vitamin A 5.0 MIU; D_3 1.2 MIU; E 4,000 IU; K_3 0.6 g; B_1 0.8 g; B_2 2.0 g; B_6 1.2 g; B_{12} 0.0025 g; Nicotinic acid 5.00 g; Pentothenic acid 3.76 g; Folic acid 0.2 g; Biotin 0.036 g; Mn 24.00 g; Zn 20.00 g; Fe 16.00 g; Cu 4.00 g; Iodine 0.8 g; Co 0.08 g; Se 0.04 g; Feed preservative substance 0.4 g, and carrier added to 1.00 kg premix.

ratio(g of feed/g of egg) was calculated via: Feed conversionratio = Feed intake (g of feed/hen)/Egg mass (g of egg/hen) (Olgun *et al.*, 2015). The feed cost (per 1 kg egg) was calculated by multiplying the feed cost (THB/kg feed) by the FCR of egg.

At the end of the trial, all eggs from each replication were weighed and four eggs from each replication having a weight close to the replication's mean were chosen for the analysis of egg qualities and internal egg quality consisting of the: eggshell breaking strength (using an Eggshell Force Gauge Model II, Robotmation Co., Ltd., Tokyo, Japan), eggshell thickness (using an electronic digital micrometer), percentage of eggshell, percentage of albumen, percentage of yolk, albumen height (using a tripod micrometer) and yolk color (using the Roche yolk color fan). The Haugh unit (HU) was calculated using the formula from Eisen *et al.* (1962): $HU = 100\log[H-1.7W^{0.37}+7.57]$ where W is the egg weight (g) and H is the albumen height (mm).

One hundred and forty-four laying hens from performance study were randomly allocated to 36 cages, 4 birds per cage. Six test diets were prepared and randomly allocated to birds, 6 cages (24 hens) per diet. All test diets were fed to birds ad libitum. Amount of the remaining test diet in each feeder was recorded. All wet excreta from each cage were collected, weighed, and kept in -20°C refrigerator await for analysis. The test diet and dried excreta samples were collected and analyzed in duplicate by drying at 100°C for 6 h (AOAC, 2000), organic matter by heating to 600°C for 1 h in a muffle furnace (AOAC, 2000) and gross energy (GE) in duplicate using an adiabatic bomb calorimeter. The AME and nutrients digestibility of the experimental diets were calculated by equations below.

AME (Kcal/kg) = [(GE in feed x g feed intake) - (GE excreta x g feces)]/(g feed intake)

Digestibility (g/kg) = [(Nutrient in feed - Nutrient in feces)/ Nutrient in feed] × 1000

All data were analyzed using analysis of variance (ANOVA). Statements of statistical significance were tested at the level $P< 0.05$. The differences between the means of groups were separated using Duncan's new multiple range test.

RESULTSAND DISCUSSION

There were no significant differences among the treatments in terms of the eggproduction (hen day production),egg weight, egg mass, daily feed intake, FCR egg (feed to egg mass ratio) and feed cost/kg egg. (Table 2). The effects of the whole wheat level in the diets on egg quality and egg internal egg quality are shown in Tables 3 and 4. Feeding a diet with whole wheat to laying hens had no effect on the egg shell breaking strength, egg shell thickness, albumene weight,albumen height and yolk weight.However, the yolk color was significantly decreased with an increase in the whole wheat in the diet ($P< 0.05$). The dry matter and organic matter digestibility and AME were not affected by the dietary treatment (Table 5).

The whole wheat level in the diets did not affect the egg production, egg weight, egg mass, feed intake, FCR, feed cost/kg egg, and mortality. Similarly, Ciftci *et al.* (2003)

Table 2: Effect of whole wheat levels in diet on production performance of laying hens (Means±SD).

Whole wheat (%)	Egg production[1] (%)	Egg weight (g)	Egg mass (g/hen)	Feed intake (g/hen/d)	FCR	FCG	Mortality (%)
0	70.00 ±5.33	65.91 ±0.75	46.32 ±3.69	114.23 ±2.64	2.48 ±0.20	31.48 ±2.48	0.52 ±1.28
5	69.32 ±7.89	65.62 ±1.55	45.47 ±4.96	116.69 ±1.80	2.59 ±0.25	32.88 ±3.17	2.12 ±2.62
10	71.39 ±4.37	66.62 ±1.44	47.54 ±2.78	115.30 ±2.30	2.43 ±0.12	30.86 ±1.47	0.63 ±1.40
15	72.33 ±6.93	66.22 ±1.01	47.89 ±4.52	115.63 ±2.69	2.43 ±0.21	30.85 ±2.62	0.00 ±0.00
20	68.11 ±3.78	66.86 ±1.18	45.39 ±3.16	114.63 ±1.73	2.53 ±0.17	32.12 ±2.21	0.00 ±0.00
25	69.02 ±4.21	65.28 ±1.12	45.25 ±2.32	111.87 ±4.49	2.48 ±0.11	31.49 ±1.40	1.04 ±1.61
SEm±[1]	1.02	0.21	0.67	0.51	0.03	0.42	0.26
P-value	0.87	0.21	0.80	0.10	0.70	0.71	0.16

[1]SEm± =Standard error of the mean.

Table 3: Effect of whole wheat levels in diet on egg quality of laying hens (Means±SD).

Whole wheat (%)	Egg shape	Shell breaking strength(kg)	Shell thickness (mm)	Shell weight (g)	Albumen weight	Albumen (g)	Haugh unit height (mm)
0	76.47 ±1.37	3.54 ±0.16	0.39 ±0.01	6.49 ±0.21	44.42 ±1.60	7.90 ±0.49	86.70 ±2.54
5	75.06 ±1.91	3.40 ±0.22	0.40 ±0.01	6.35 ±0.12	42.47 ±1.45	7.84 ±0.59	86.74 ±3.08
10	75.73 ±2.03	3.30 ±0.31	0.40 ±0.00	6.42 ±0.09	43.70 ±0.99	8.07 ±0.49	87.88 ±2.72
15	76.65 ±1.16	3.56 ±0.19	0.40 ±0.02	6.37 ±0.10	44.12 ±0.86	7.96 ±0.64	87.08 ±3.71
20	77.56 ±0.92	3.44 ±0.33	0.40 ±0.01	6.43 ±0.21	44.21 ±1.32	7.73 ±0.27	85.55 ±1.53
25	77.24 ±2.18	3.57 ±0.17	0.39 ±0.01	6.37 ±0.11	41.99 ±0.67	8.17 ±0.55	88.91 ±3.24
SEm±[1]	0.42	0.56	0.00	0.04	0.30	0.13	0.70
P-value	0.63	0.34	0.89	0.78	0.11	0.85	0.83

[1]SEm± =Standard error of the mean.

Table 4: Effect of whole wheat levels in diet on internal egg quality of laying hens (Means±SD).

Whole wheat(%)	Yolk weight (g)	Yolk color	Albumen : Yolk ratio	Yolk percentage	Shell percentage	Albumen percentage
0	16.32 ±0.52	5.83 ±0.28^{A}	2.72 ±0.18	24.31 ±1.02	9.68 ±0.43	66.01 ±1.41
5	16.67 ±0.17	5.79 ±0.20^{A}	2.55 ±0.08	25.45 ±0.56	9.70 ±0.19	64.84 ±0.69
10	16.56 ±0.20	5.69 ±0.19^{AB}	2.64 ±0.07	24.84 ±0.47	9.63 ±0.17	65.53 ±0.59
15	16.29 ±0.58	5.38 ±0.30^{BC}	2.71 ±0.13	24.41 ±0.90	9.54 ±0.09	66.05 ±0.89
20	16.73 ±0.29	5.29 ±0.58^{C}	2.64 ±0.11	24.85 ±0.69	9.55 ±0.32	65.60 ±0.80
25	16.47 ±0.79	4.79 ±0.19^{D}	2.56 ±0.12	25.40 ±0.91	9.82 ±0.13	64.78 ±0.90
SEm±[1]	0.09	0.07	0.02	0.16	0.06	0.17
P-value	0.41	0.01	0.66	0.74	0.15	0.50

[1]SEm± =Standard error of the mean.

[ABCD]Values with different, lowercase superscripts differ statistically at P≤0.05.

Table 5: Effect of whole wheat levels in diet on nutrient utilization of laying hens (Means±SD).

Whole wheat (%)	Dry matter digestibility (g/kg)	Organic matter digestibility (g/kg)	AME (kcal/kg)
0	84.72 ±1.75	67.57 ±2.38	2721.16 ±71.72
5	84.30 ±1.79	65.72 ±2.01	2725.05 ±68.72
10	84.93 ±1.88	66.91 ±1.82	2711.75 ±53.01
15	84.93 ±1.88	67.89 ±2.10	2784.66 ±103.38
20	85.52 ±1.41	64.50 ±2.63	2697.02 ±86.61
25	83.32 ±3.31	65.64 ±1.87	2687.01 ±68.69
SEm±[1]	0.41	0.39	13.24
P-value	0.38	0.09	0.34

[1]SEm± =Standard error of the mean.

did not observe any effect on laying-hen performance when 30% corn was substituted by wheat in SCWL hens from 27 to 43 wk of age. In contrast, Lazaro *et al.* (2003) and Safaa *et al*. (2009) reported no differences in productive performance when 50% corn was substituted by soft wheat in the diets for SCWL Hy-Line W-77 and Lohman brown hens from 20 to 44 wk of age, respectively. However, Kim *et al.* (1976) reported that SCWL hens fed a corn diet from 21 to 43 wk of age had higher feed intake and produced heavier eggs than hens fed a wheat diet but that the body weight and egg production were not affected. In contrast Mirzaie *et al.* (2012) reported that the egg weight and egg mass decreased with an increasing level of whole wheat. The reasons for the inconsistencies among studies are not known but might be related to the type of wheat used and the strain of bird employed in the study as well as the characteristics of the experimental diets.However, the trial observation has shown that the hens selectively eating whole wheat because leftover feed as mash form with a little bit of whole wheat. The feed cost/kg egg was not different in all of treatment due to the same feed cost and FCR was not affected by the treatment diet as well. However, the feed cost/kg egg would have changed if the price of wheat and corn had changed.

In the current study, from 45 to 53 wk of age, the addition of whole wheat in the diet did not affect the egg shell breaking strength, egg shell thickness, albumen height, yolk weight, shell weight, % albumen, % yolk, % shell, albumen:yolk ratio, and Haugh unit but decreased the yolk color. Pérez-Bonilla *et al.* (2011) reported a similar reduction in the yolk color when corn was substituted by 15, 20, and 25% whole wheat in diets. Ciftci *et al.* (2003) reported that the Roche fan yolk color number was higher in control diets than whole wheat diets. A lower Roche fan,egg yolk color number can be attributed to a lack of carotenoids in whole wheat.

The AME, dry matter and organic matter digestibility were not affected by diet. In contrast, Choct *et al.* (1996) reported that the ileal digestibility of starch, protein, and lipids was significantly depressed in broilers when wheat by-products, rich insoluble NSP, were included in the diet. Lipids must be emulsified before digestion and absorption, a process that is hindered by viscous digesta. (Mirzaie *et al.*, 2012). However, the trial observation has shown that transit time and moisture of feces was not different in all treatment.

CONCLUSION

The results of the current experiment show that up to 25% whole wheat can be included in layer diets without affecting the production performance, egg quality and nutrient digestibility. But, an increase in whole wheat to 25% resulted in a reduced Roche fanegg yolk color number.

ACKNOWLEDGEMENT

This research was supported in part by a Graduate Program Scholarship from the Graduate School, Kasetsart University, Bangkok, Thailand.

REFERENCES

Adesola, A., Ng'ambi, J., Norris, D. (2013). Effect of ascorbic acid supplementation to the diets of indigenous Venda hens on productivity of their progenies aged 8 to 13 weeks. *Indian Journal of Animal Research*. **47**: 97-104.

Antoniou, T.C. and Marquardt, R.R .(1983). The utilization of rye by growing chicks as influenced by autoclave treatment, water extraction and water soaking. *Poultry Science.* **62**: 91-102.

AOAC (2000). *Official Methods of Analysis*. Association of Official Analytical Chemists, Washington, DC, USA.

Bharathidhasan, A., Chandrasekaran, D., Natarajan, A., Ravi, R., Ezhilvalavan, S. (2009). Effect of enzyme supplementation on digestibility and metabolizability of broilers to nutrient reduced diet. *Indian Journal of Animal Research*. **43**: 79-83.

Choct, M., Hughes, R., Wang, J., Bedford, M., Morgan, A. and Annison, G. (1996). Increased small intestinal fermentation is partly responsible for the anti-nutritive activity of non starch polysaccharides in chickens. *British Poultry Science*. **37**: 609-621.

Ciftci, I., Yenice, E. and Eleroglu H. (2003). Use of triticale alone and in combination with wheat or maize: effects of diet type and enzyme supplementation on hen performance, egg quality, organ weights, intestinal viscosity and digestive system characteristics. *Animal Feed Scienceand Technology*. **105**: 149-161.

Classen, H. and Bedford, M. (1991). *Recent Advances in Animal Nutrition*.Butterworth-Heinemann Ltd., Oxford, U.K.

Deaton, J., Lott, B., Simmons, J.(1989). Hammer mill versus roller mill grinding of corn for commercial egg layers. *Poultry Science*. **68**: 1342-1344.

Eisen, E., Bohren, B., Mckean, H. (1962). The Haugh unit as a measure of egg albumen quality. *Poultry Science*. **41**: 1461-1468.

Fengler, A.I. and Marquardt, R.R. (1988). Water-soluble pentosans from rye: I. Isolation, partial purification, and characterization. *Cereal Chemistry*. **65**: 291-297.

Gabriel, I., Mallet, S., Leconte, M., Travel, A., Lalles, J.P. (2008). Effects of whole wheat feeding on the development of the digestive tract of broiler chickens. *Animal Feed Science and Technology*. **142**: 144-162.

Hetland, H., Svihus, B., Choct, M. (2005). Role of insoluble fiber on gizzard activity in layers. *Journal of Applied Poultry Research*. **14**: 38-46.

Kim, S., Patel, M., Reddy, S., Mcginnis, J. (1976). Effects of different cereal grains in diets for laying hens on production parameters and liver fat content. *Poultry Science*. **55**: 520-530.

Lazaro, R., Garcia, M., Aranibar, M.J., Mateos, G.G. (2003). Effect of enzyme addition to wheat-, barley- and rye-based diets on nutrient digestibility and performance of laying hens. *British Poultry Science*. **44**: 256-265.

Lohmann (2012). *Management Guide for Laying Hens: Lohmann Brown-Classic*. Lohmann Tierzucht GmbH, Cuxhaven, Germany.

Mirzaie, S., Zaghari, M., Aminzadeh, S., Shivazad, M., Mateos, G.G. (2012). Effects of wheat inclusion and xylanase supplementation of the diet on productive performance, nutrient retention, and endogenous intestinal enzyme activity of laying hens. *Poultry Science*. **91**: 413-425.

Olgun, O., Yildiz, A. Ö., Cufadar, Y. (2015). The effects of eggshell and oyster shell supplemental as calcium sources on performance, eggshell quality and mineral excretion in laying hens. *Indian Journal of Animal Research*. **49**: 205-209.

Pérez-Bonilla, A., Frikha, M., Mirzaie, S., García, J., Mateos, G. (2011). Effects of the main cereal and type of fat of the diet on productive performance and egg quality of brown-egg laying hens from 22 to 54 weeks of age. *Poultry Science*. **90**: 2801-2810.

Reece, F., Lott, B., Deaton, J. (1986). The effects of hammer mill screen size on ground corn particle size, pellet durability, and broiler performance. *Poultry Science*. **65**: 1257-1261.

Rose, S. (1996). The use of whole wheat in poultry diets. *World's Poultry Science*. **52**: 59-60.

Safaa, H.M., Jimenez-Moreno, E., Valencia, D.G., Frikha, M., Serrano, M.P., Mateos, G.G. (2009). Effect of main cereal of the diet and particle size of the cereal on productive performance and egg quality of brown egg-laying hens in early phase of production. *Poultry Science*,**88**: 608-614.

Singh, Y., Amerah, A.M., Ravindran, V. (2014). Whole grain feeding: Methodologies and effects on performance, digestive tract development and nutrient utilisation of poultry. *Animal Feed Science and Technology*. **190**: 1-18.

Sturkie, P.D. (1965). *Avian Physiology*. Tindall and Cassell, London, UK.

Teitge, D., Campbell, G., Classen, H., Thacker, P. (1991). Heat pretreatment as a means of improving the response to dietary pentosanase in chicks fed rye. *Canadian Journal of Animal Science*. **71**: 507-513.