Journal of Applied Animal Research
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/taar20

Improved performance and small intestinal development of broiler chickens by dietary L-glutamine supplementation

Hassan Nassiri Moghaddam [a] & Amir Hossein Alizadeh-Ghamsari [a]
[a] Centre of Excellence in Department of Animal Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran
Version of record first published: 23 Jan 2013.

To cite this article: Hassan Nassiri Moghaddam & Amir Hossein Alizadeh-Ghamsari (2013): Improved performance and small intestinal development of broiler chickens by dietary L-glutamine supplementation, Journal of Applied Animal Research, DOI:10.1080/09712119.2012.738214

To link to this article: http://dx.doi.org/10.1080/09712119.2012.738214

Journal of Applied Animal Research, 2013
http://dx.doi.org/10.1080/09712119.2012.738214

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

Improved performance and small intestinal development of broiler chickens by dietary L-glutamine supplementation

Hassan Nassiri Moghaddam and Amir Hossein Alizadeh-Ghamsari*

Centre of Excellence in Department of Animal Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

(*Received 19 November 2011; final version received 15 May 2012*)

An experiment was conducted to evaluate the effect of L-glutamine (Gln) supplementation on performance and intestinal morphology of broiler chickens. A total of 192 day-old male broilers (Ross 308) were used in a completely randomised design with four treatments and four replicates of 12 birds each. Four experimental diets were formulated to be isonitrogenous and isocaloric with different levels of Gln supplementation (0, 0.5, 1.0 and 1.5%) in control and treatment groups, respectively and were fed for the first 3 weeks of life. On days 21 and 42, one bird from each replicate was slaughtered and morphometric indices of the small intestine were evaluated. Results obtained on days 21 and 42 showed increased ADWG in the birds that consumed 1% Gln supplemented diet compared to the control birds fed a standard corn-SBM diet ($P \leq 0.05$). On day 21, birds fed diets supplemented with 1 or 1.5% Gln had a significantly heavier duodenum and jejunum relative weight compared to the control birds ($P \leq 0.05$). Morphological assays showed that villus height and villus surface area of the duodenum and jejunum were significantly increased at both 21 and 42 days of age, as 1 or 1.5% Gln was supplemented in broiler diets ($P \leq 0.05$). The results of this study indicated that addition of 1% Gln to the diet for 21 days improved growth performance and small intestinal development of broiler chickens at the end of the starter (day 21) and grower (day 42) period.

Keywords: broiler; L-glutamine; performance; intestinal development

1. Introduction

Functional development of the intestine is necessary for optimised poultry production. Some nutrients are essential for intestinal development and homeostasis. It has been indicated that the lack of Glutamine (Gln) and polyamines inhibit cell proliferation and migration in the intestinal epithelium (Ruemmele et al. 1999).

Gln is the most common amino acid in the bloodstream, accounting for 30–35% of amino acid N in the plasma and free amino acid pool in the body (Newsholme et al. 1985). It is also the main energetic substrate for rapidly proliferating cells such as intestinal enterocytes and activated lymphocytes (Calder and Yaqoob 1999), and is considered a conditionally essential amino acid in some species under inflammatory conditions such as infection and injury (Newsholme 2001). Gln is an important precursor for the synthesis of amino acids, nucleotides, nucleic acids, amino sugars, proteins, and many other biologically important molecules (Souba 1993).

Many benefits have been observed due to Gln supplementation in the diet of humans and rats; however, little research has been carried out with swine and poultry. Yi et al. (2001) reported that supplementing the diet with 1% Gln improved weight gain and feed efficiency ratio (FCR) of turkey poults during the first week post-hatch as compared with poults fed a standard corn–soya bean meal (SBM) diet. Kitt et al. (2002) reported that the addition of 1% Gln to the diet improved the feed efficiency in weanling pigs. Glutamine supplementation increased intestinal villi height in poults (Yi et al. 2001) and weanling pigs (Kitt et al. 2002). Glutamine supplementation has been reported to stimulate gut mucosal proliferation in rats (Inoue et al. 1993). It has also been observed that supplementing with 1.5% Gln in total parenteral nutrition diets maintains gut integrity (Naka 1996), which is important in preventing bacterial infections. According to Yi et al. (2005), early access to 1% glutamine supplemented diet could greatly improve the growth performance and decrease the mortality of broiler chickens. In a more recent study, Bartell and Batal (2007) indicated that broiler chicks fed diets with 1% Gln had improved growth performance, heavier intestinal relative weights and longer intestinal villi as compared with the chicks fed the corn–SBM diet.

To date little research has been conducted on the use of Gln supplementation in poultry diets. Therefore, an experiment was conducted to determine the

*Corresponding author. Email: amir3279@gmail.com

effects of Gln supplementation on growth performance and intestinal morphology of broiler chicks.

2. Material and methods

2.1. Bird management

Ross 308 day-old boiler chicks were feather sexed, and male birds were selected. Chicks were then transported to the Poultry Research Facility of Ferdowsi University and placed in floor pens. Fresh and dried wood shavings were used as litter at a depth of approximately 5 cm in all pens. One hanging feeder and one water cup was provided for each pen. Birds had free access to feed and water at all times and were exposed to 24 h lighting photoperiod throughout the experiment. Initial room temperature was maintained at 32°C and was gradually decreased (2.5°C every week) to reach a constant temperature at 42 days of age. The experimental protocols were reviewed and approved by the Animal Care Committee of the Ferdowsi University of Mashhad, Iran.

2.2. Dietary treatments

A total of 192 Ross 308 day-old male broilers (with average initial BW of 44 g) were allocated to four dietary treatments in a completely randomised design with four replicates of 12 birds each. Four experimental diets were fed for the first 3 weeks posthatch and formulated to be isocaloric and isonitrogenous with different levels of Gln, as follows (Table 1): corn–SBM basal diet without Gln supplementation (control), and corn–SBM diets supplemented with 0.5, 1.0 and 1.5% Gln (Crystalline L-Glutamine, Evonik Company, Essen, Germany), respectively. Diets were fed in mash form and formulated to meet or exceed the requirements of broiler chicks during the starter (days 0–21) and grower (days 21–42) period according to National Research Council (1994). Corn and SBM were analysed for CP (Association of Official Analytical Chemist 2006) and their amino acid contents (%) were estimated (by NIRS [Near Infrared spectroscopy] at Evonik Co., Essen, Germany) prior to formulation.

Table 1. Feed ingredients and chemical composition of the starter (day 0–21) and grower (day 21–42) diets (g/kg as fed).

	Starter diets (day 0–21)				
	Dietary glutamine supplementation (%)				
Ingredients	0	0.5	1.0	1.5	Grower diet (day 21–42)
Corn	545.0	556.0	565.8	577.8	612.9
Soya bean meal	355.0	343.2	330.5	319.0	303.8
Soya bean oil	42.0	42.0	42.0	42.0	45.0
Common salt	3.0	3.0	3.0	3.0	2.7
Dicalcium phosphate	17.3	17.4	18.9	18.2	16.3
Limestone	13.4	13.4	14.0	13.7	10.6
Bicarbonate sodium	1.0	1.0	1.0	1.0	1.0
DL-Methionine	3.0	3.1	3.2	3.3	2.4
L-Lysine	0.5	1.0	1.3	1.7	0.2
L-Threonine	–	–	0.2	0.3	–
Vit + Min premix[a]	5.0	5.0	5.0	5.0	5.0
Sand	15	10	5	–	–
L-Glutamine	–	5	10	15	–
Calculated nutrients					
ME (kcal /kg)	3050	3050	3050	3050	3157
Crude Protein (%)	21.85	21.85	21.85	21.85	19.73
Calcium (%)	0.99	0.99	1.04	1.01	0.85
Available P (%)	0.45	0.45	0.47	0.46	0.42
Sodium (%)	0.16	0.16	0.16	0.16	0.15
Lysine (%)	1.20	1.20	1.20	1.20	1.05
Met + Cys (%)	0.95	0.95	0.95	0.95	0.85
Threonine (%)	0.82	0.80	0.80	0.80	0.75
Glutamine (%)	3.21	3.63	4.04	4.47	2.91

[a]To provide vitamins and minerals per kilogram of diet: vitamin A, 11000 IU; vitamin D_3,1800 IU; vitamin E, 36 mg; vitamin K_3, 5 mg; vitamin B_{12}, 1.6 mg; thiamine, 1.53 mg; riboflavin, 7.5 mg; niacin, 30 mg; pyridoxine, 1.53 mg; biotin, 0.03 mg; folic acid, 1 mg; pantothenic acid, 12.24 mg; Etoxycoin, 0.125 mg; Fe, 250 mg; Zn-sulfate, 84 mg; Mn-sulfate, 160 mg; iodine, 1.6 mg; Cu-sulfate, 20 mg; selenium, 0.2 mg; and cobalt, 0.4 mg.

2.3. Measurements

Body weight and feed consumption were recorded on a pen basis at weekly intervals. On days 21 and 42, one chicken from each replicate with average pen weight was starved for approximately 12 hours, then sacrificed by decapitation, plucked and eviscerated. Different parts of the small intestine including duodenum (from gizzard to pancreo-biliary ducts), jejunum (from pancreo-biliary ducts to Meckel's diverticulum) and ileum (from Meckel's diverticulum to ileo-cecal junction) were sectioned, and the relative weight of each was calculated, as follows:

$$\text{relative weight} = (\text{organ weight}/\text{live body weight}) \times 100.$$

2.4. Tissue sampling and staining

Segments of the duodenum and jejunum measuring 1 cm in length were taken from the midpoint, flushed with 0.9% saline to remove the contents, and fixed in 10% neutral-buffered formalin solution for tissue study. Samples were transferred from formaldehyde, after dehydration by passing tissue through a series of alcohol solutions; they were then cleared in xylene and embedded in paraffin. Longitudinal sections measuring 5 μm were cut using Leica Rotary Microtome (RM 2145, Leica Microsystems, Wetzlar, Germany), placed on glass slides, prepared and processed for staining with haematoxylin-eosin according to Uni et al. (1995). Micrographs were taken with Olympus light microscope BX41 (Olympus Corp., Tokyo, Japan) using Epix XCAP (Epix Inc., Buffalo Grove, IL, USA) to calculate the morphometric variables.

2.5. Morphometric evaluation

Nine intact and vertically oriented villi were chosen from each sample and used for morphometric measurements. The parameters measured were: villus height (measured from the tip of the villus to the villus-crypt junction), villus width (measured at the midvillus height), crypt depth (measured from the crypt-villus junction to the base of the crypt), muscular layer thickness (measured form the submucosa to the serosal layer of intestine). Villi surface area was calculated as follows:

$$2\pi \times (\text{VW}/2) \times \text{VH}, \text{ where } \pi = 3.14,$$

VW = villus width and VH = villus height (Sakamoto et al. 2000). Villus density was calculated as the number of each per unit of surface area (mm^2).

2.6. Statistical analysis

Data were analysed using GLM procedures of SAS software (SAS Institute 2002) in a completely randomised design. The pen of chicks served as the experimental unit. Percentage data were first arcsin transformed. Means were compared using Duncan's multiple range test (Duncan 1955). Orthogonal contrasts were used to determine linear and quadratic relationships among treatments. Statements of statistical significance were based upon $P \leq 0.05$.

3. Results

3.1. Performance

The effect of dietary Gln supplementation on average daily weight gain (ADWG), average daily feed intake (ADFI) and feed conversion ratio (FCR) is presented in Table 2. During the starter (days 0–21) and the whole experimental period (days 0–42), ADWG quadratically increased in the birds receiving up to 1% dietary Gln supplementation ($P \leq 0.05$). In comparison with the control, chickens fed 0.5 and 1.5%

Table 2. Effect of dietary glutamine supplementation on performance of broiler chickens.

	Average daily weight gain (g/bird)			Average daily feed intake (g/bird)			Feed conversion ratio (g/g)		
	Period (day)			Period (day)			Period (day)		
Dietary Gln inclusion (%)	0–21	21–42	0–42	0–21	21–42	0–42	0–21	21–42	0–42
0	27.26[b]	72.73	50.00[b]	48.39	144.01	96.20	1.79	2.00	1.93
0.5	28.20[b]	73.60	50.90[ab]	52.16	144.54	98.36	1.85	1.98	1.94
1.0	31.94[a]	78.71	55.32[a]	54.23	147.15	100.69	1.71	1.87	1.82
1.5	25.54[b]	71.80	48.67[b]	47.65	142.02	94.83	1.87	1.98	1.95
±SEM	1.148	3.157	1.607	1.817	1.923	1.415	0.091	0.086	0.059
P-value	0.013	0.445	0.050	0.075	0.348	0.058	0.589	0.700	0.412
Contrasts									
Linear	0.7832	0.8722	0.9522	0.9856	0.7017	0.7852	0.8070	0.6494	0.8464
Quadratic	0.0077	0.2423	0.0369	0.0146	0.1663	0.0151	0.5689	0.4660	0.3414

[a,b]Values in the same columns and variable with no common superscript differ significantly ($P \leq 0.05$)

Table 3. Effect of dietary glutamine supplementation on relative weight of each small intestinal section to live body weight (%) in broiler chickens.

	Duodenum	Jejunum	Ileum
Dietary Gln inclusion (%)		(%)	
Day 21			
0	1.067[b]	2.080[b]	2.076
0.5	1.205[ab]	2.366[ab]	2.162
1.0	1.416[a]	2.924[a]	2.856
1.5	1.465[a]	3.107[a]	2.603
±SEM	0.096	0.244	0.274
P-value	0.042	0.039	0.198
Contrasts			
Linear	0.007	0.006	0.087
Quadratic	0.653	0.837	0.548
Day 42			
0	0.607	1.133	0.994
0.5	0.615	1.345	1.242
1.0	0.667	1.369	1.076
1.5	0.732	1.400	1.186
±SEM	0.066	0.089	0.0802
P-value	0.541	0.193	0.183
Contrasts			
Linear	0.176	0.061	0.277
Quadratic	0.680	0.329	0.407

[a,b]Values in the same columns and variable with no common superscript differ significantly ($P \leq 0.05$).

Gln supplemented diets showed higher and lower ADWG respectively, although none of these results were statistically significant. During days 0–42, the highest ADWG were observed in the birds that received 1% Gln supplement, followed by the birds fed 0.5% Gln supplemented diets. The lowest ADWG were observed in the birds that consumed 1.5% Gln supplement, followed by the control birds.

Dietary Gln inclusion up to 1% quadratically increased ADFI of broiler chickens compared with the control. Average daily feed intake declined in the birds fed diets supplemented with 1.5% Gln. There was no significant effect on FCR due to the addition of Gln.

3.2. *Intestinal development and morphology*

The effect of Gln supplementation on small intestinal development of broiler chickens has been shown in Table 3. During the starter period (day 0–21), dietary Gln supplementation linearly increased the relative weight of duodenum and jejunum (as percentage of live body weight) compared to the control ($P \leq 0.05$). Gln inclusion did not have any significant effect on the relative weight of intestinal segments at the end of the experiment (day 42).

The effect of Gln supplementation on intestinal morphometric indices has been presented in Tables 4 and 5. At the end of the starter period (day 21), the addition of Gln supplement in the feed linearly increased VH, VW and villus surface area of the duodenum and jejunum compared to the control ($P \leq 0.05$).

Table 4. Effect of dietary glutamine supplementation on small intestinal morphology of broiler chickens at 21 days of age.

Dietary Gln inclusion (%)	Villus height	Villus width	Crypt depth	Muscular layer thickness	Villus height to crypt depth ratio	Average villus density	Villus surface area
	(μm)				(μm/μm)	(villi/mm^2)	($\times 10^{-3}$, μm^2)
Duodenum							
0	824.22[b]	101.36[b]	218.35	202.41	3.772	5.5	261.14[b]
0.5	1076.50[ab]	102.19[b]	205.59	234.78	5.317	7	345.42[b]
1.0	1187.15[a]	132.82[a]	192.46	295.72	6.164	7	495.87[a]
1.5	1285.98[a]	147.87[a]	211.39	212.61	6.298	8	597.09[a]
±SEM	88.597	4.083	21.835	29.517	0.8064	0.75	33.316
P-value	0.049	0.003	0.856	0.255	0.246	0.272	0.0061
Contrasts							
Linear	0.019	0.0007	0.745	0.526	0.079	0.089	0.001
Quadratic	0.435	0.156	0.508	0.122	0.043	0.755	0.811
Jejunum							
0	848.05[b]	92.84[b]	236.35	202.27	3.650	7	247.43[b]
0.5	890.19[b]	89.61[b]	191.96	209.51	4.647	7	251.17[b]
1.0	1123.77[a]	132.26[a]	209.27	247.30	5.432	7.5	465.13[a]
1.5	1234.58[a]	143.81[a]	208.41	289.81	5.930	8.5	559.24[a]
±SEM	51.821	7.017	20.479	39.343	0.4834	0.7906	35.917
P-value	0.016	0.011	0.552	0.463	0.098	0.555	0.0079
Contrasts							
Linear	0.003	0.003	0.507	0.163	0.024	0.230	0.002
Quadratic	0.543	0.351	0.347	0.677	0.633	0.561	0.276

Note: All measurements were done by 5x objective lens.
[a,b]Values in the same columns and variable with no common superscript differ significantly ($P \leq 0.05$).

At the end of the grower period (day 42), dietary Gln supplementation for the first 3 weeks of life linearly increased VH, muscular layer thickness and villus surface area of the duodenum and jejunum compared to the control ($P \leq 0.05$). Average villus density, VW and VCR were not significantly affected by Gln inclusion; however, they numerically increased when diets were supplemented with Gln.

On both days 21 and 42, the birds fed with diets containing 1.5% supplemental Gln had the longest villi and the greatest villus surface area of duodenum and jejunum, while there was no significant difference between them and the birds were fed with 1% Gln supplemented diet in this regard.

4. Discussion

Significant improvements in BW (data not shown) and ADWG were observed by 1% Gln supplementation in the feed for 21 days, as compared with the birds fed the control corn–SBM diet. These findings are in agreement with those obtained by Yi et al. (2005) who recorded better BW of broilers received 1% Gln supplementation. Bartell and Batal (2007) similarly reported that 1% Gln supplementation in broiler diets significantly increased body weight gain comparing to the control birds. In contrast, improvement in weight gain had not been reported in swine (Kitt et al. 2002) due to dietary Gln inclusion. Yi et al. (2001) indicated an increase in BW gain in turkey poults given a diet supplemented with 1% Gln, but it was only mentioned for the first week of age. There may be several factors contributing to the improved growth performance when feeding Gln. Those factors may include the supply of enteral Gln as an energy substrate for rapidly proliferating cells such as enterocytes and a nitrogen source for nucleotide synthesis (Calder and Yaqoob 1999), and the importance of Gln in maintaining mucosal structure, especially in the maintenance of the tight junction and permeability of intestinal mucosa (Panigrahi et al. 1997). Glutamine may also act as a signal or regulator of metabolic demands, increasing protein synthesis and decreasing protein degradation in skeletal muscle (Haussinger et al. 1994) for young broilers. The numerical performance depression in chicks fed 1.5% Gln supplement may indicate toxic effects of dietary Gln inclusion at levels $>1\%$, as Soltan (2009) and Bartell and Batal (2007) have previously reported depressive effects of 2 and 4% dietary Gln inclusion on growth performance, respectively.

It has been proposed that feed nutrients utilisation is strongly related to the intestinal structure and villus health, and the small intestine is known as a major digestion and absorption site of dietary nutrients (Pluske et al. 1996). It is clear that longer villi lead to increased villus surface area in the small intestine. The greater absorptive area may increase capacity for

Table 5. Effect of dietary glutamine supplementation on small intestinal morphology of broiler chickens at 42 days of age.

Dietary Gln inclusion (%)	Villus height	Villus width	Crypt depth	Muscular layer thickness	Villus height to crypt depth ratio	Average villus density	Villus surface area
	(μm)				(μm/μm)	(villi/mm^2)	($\times 10^{-3}$, μm^2)
Duodenum							
0	1354.16^{b}	145.33	253.58	262.34^{c}	5.34	5.5	609.63^{c}
0.5	1437.19^{b}	146.80	246.57	325.32^{ab}	5.97	5.5	660.98^{bc}
1.0	1754.35^{a}	166.48	202.36	310.83^{b}	8.78	6	916.71^{ab}
1.5	1797.97^{a}	189.28	220.44	351.64^{a}	8.17	5.5	1069.33^{a}
±SEM	46.913	19.546	25.355	8.870	0.7158	0.4330	70.008
P-value	0.006	0.443	0.525	0.009	0.068	0.803	0.026
Contrasts							
Linear	0.001	0.158	0.274	0.003	0.024	0.481	0.006
Quadratic	0.696	0.614	0.646	0.279	0.434	0.594	0.509
Jejunum							
0	929.90^{b}	124.21	241.60	219.04^{b}	3.941	6.5	361.82^{b}
0.5	1098.80^{ab}	143.51	241.23	297.38^{a}	4.553	7	496.60^{ab}
1.0	1238.48^{a}	157.77	202.32	237.54^{b}	6.121	7	614.44^{a}
1.5	1267.66^{a}	165.01	212.77	306.63^{a}	5.993	7.5	657.25^{a}
±SEM	53.648	8.161	16.566	12.543	0.4639	0.6123	45.306
P-value	0.034	0.080	0.351	0.018	0.068	0.734	0.0325
Contrasts							
Linear	0.008	0.020	0.165	0.022	0.020	0.335	0.007
Quadratic	0.262	0.500	0.760	0.731	0.469	1.000	0.367

Note: All measurements were done by 5x objective lens.
[a,b,c]Values in the same columns and variable with no common superscript differ significantly ($P \leq 0.05$).

absorption of available nutrients, which results in improved performance especially in early stages of chick life (Caspary 1992). Zijlstra et al. (1996) reported that increased body weight was associated with an increase of mucosal layer thickness with long and healthy villi in piglets. In the present study, the addition of 1 or 1.5% Gln to the diet for 21 days resulted in an improvement of small intestinal development, as reflected in the significant increases of VH, VW, villus surface area and relative weights of the duodenum and jejunum when compared to the control. These results have been supported by previous studies, which showed the stimulant effects of dietary Gln inclusion on small intestinal development (Bartell and Batal 2007; Fischer da Silva et al. 2007; Murakami et al. 2007). It has also been estimated that all of the dietary glutamine and most of the glutamate and aspartate are catabolised by the small intestinal mucosa (Wu 1998). In the present study, villus density and VCR showed a numerical but not necessarily significant increase, as Gln supplement was included in the diet. Enhanced villi height has been suggested to increase performance by improving nutrient absorption (Coates et al. 1954; Izat et al. 1989). The increase in villi height observed here might indicate that the birds fed diets supplemented with 1% Gln might have had more nutrient absorption and utilisation, as an increase in villi height results in greater surface area. The increase in surface area might also explain the heavier relative weights of duodenum and jejunum and improved weight gain when feeding Gln supplement. Although the birds fed diets supplemented with 1.5% Gln had numerically longer villi in comparison with the 1% Gln treatment, they had significantly lower growth performance. This may indicate the toxic effects of supplemental Gln when included in diet at levels $>1\%$.

5. Conclusions

Under the conditions of this study, it was concluded that a 1% dietary Gln supplementation for the first 3 weeks posthatch improved growth performance of broiler chicks. This effect might be achieved through the significant improvement in the small intestinal development of the chicks received dietary supplemental Gln. Further studies are needed in order to investigate the effect of glutamine on the expression of intestinal–morphological related genes such as Mucin2 in broiler chicks.

Acknowledgements

This study was financially supported by Centre of Excellence in the Department of Animal Science, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran. The authors would like to thank Evonik for generously providing L-glutamine. We also express our gratitude to the histology laboratory staff at the Veterinary College in Ferdowsi University of Mashhad for their technical support.

References

Association of Official Analytical Chemist (AOAC). 2006. Official methods of analysis. 18th ed. Washington (DC): Association of Official Analytical Chemist.

Bartell SM, Batal AB. 2007. The effect of supplemental glutamine on growth performance, development of the gastrointestinal tract, and humoral immune response of broilers. Poultry Science 86:1940–1947.

Calder PC, Yaqoob P. 1999. Glutamine and the immune system. Amino Acids 17:227–241.

Caspary WF. 1992. Physiology and pathophysiology of intestinal absorption. The American Journal of Clinical Nutrition 55:299–308.

Coates ME, Davies MK, Kon SK. 1954. The effect of antibiotics on the intestine of the chick. British Journal of Nutrition 9:110–119.

Duncan DB. 1955. Multiple range and multiple F tests. Biometrics 11:1–42.

Fischer da Silva AV, Maiorka A, Borges SA, Santin E, Boleli IC, Macari M. 2007. Surface area of the tip of the enterocyte in small intestine mucosa of broilers submitted to early feed restriction and supplemented with glutamine. International Journal of Poultry Science 6:31–35.

Haussinger D, Lang F, Gerok W. 1994. Regulation of cell function by cellular hydration state. American Journal of Physiology – Endocrinology and Metabolism 267:343–355.

Inoue Y, Grant JP, Snyder PJ. 1993. Effect of glutamine-supplemented intravenous nutrition on survival after *Escherichia coli*-induced peritonitis. Journal of Parenteral and Enteral Nutrition 17:41–46.

Izat AL, Thomas RA, Adams MH. 1989. Effects of dietary antibiotic treatment on yield of commercial broilers. Poultry Science 68:651–655.

Kitt SJ, Miller PS, Lewis AJ, Fischer RL. 2002. Effects of glutamine on growth performance and small intestine villus height in weanling pigs. Lincoln (NE): University of Nebraska Swine Reports. p. 29–32.

Murakami AE, Sakamoto MI, Natali MRM, Souza LMG, Franco JRG. 2007. Supplementation of glutamine and vitamin E on the morphometry of the intestinal mucosa in broiler chickens. Poultry Science 86:488–495.

Naka S. 1996. Alanyl-glutamine-supplemented total parenteral nutrition improves survival and protein metabolism in rat protracted bacterial peritonitis model. Journal of Parenteral and Enteral Nutrition 20:417–423.

National Research Council (NRC). 1994. Nutrient requirements of poultry. Washington (DC): National Academy Press.

Newsholme P. 2001. Why is L-glutamine metabolism important to cells of the immune system in health post-immune, surgery, or infection? The Journal of Nutrition 131:2515–2522.

Newsholme EA, Crabtree B, Ardawi MS. 1985. Glutamine metabolism in lymphocytes: its biochemical, physiological and clinical importance. Quarterly Journal of Experimental Physiology 70:473–489.

Panigrahi P, Gewolb IH, Bamford P, Horvath K. 1997. Role of glutamine in bacterial transcytosis and epithelial cell injury. Journal of Parenteral and Enteral Nutrition 21:75–80.

Pluske JR, Thompson MJ, Atwood CS, Bird PH, Williams IH, Hartmann PE. 1996. Maintenance of villus height and crypt depth, and enhancement of disaccharide digestion and monosaccharide absorption, in piglets fed on cows' whole milk after weaning. British Journal of Nutrition 76:409–422.

Ruemmele FM, Ruemmele C, Levy E, Seidman E. 1999. Les me′canismes mole′culaires de la re′gulation du renouvellement de cellules e′pithe′liales intestinales par des nutriments [The molecular mechanisms regulating the renewal of intestinal epithelial cells by nutrients]. Gastroentérologie Clinique et Biologique 23:47–55.

Sakamoto K, Hirose H, Onizuka A. 2000. Quantitative study of changes in intestinal morphology and mucus gel on total parenteral nutrition in rats. Journal of Surgical Research 94:99–106.

SAS Institute. 2002. SAS users guide: statistics. Cary (NC): SAS Institute Inc.

Soltan MA. 2009. Influence of dietary glutamine supplementation on growth performance, small intestinal morphology, immune response and some blood parameters of broiler chickens. International Journal of Poultry Science 8:60–68.

Souba WW. 1993. Glutamine and cancer. Annals of Surgery 218:715–728.

Uni Z, Noy Y, Sklan D. 1995. Posthatch changes in morphology and function of the small intestine in heavy- and light-strain chicks. Poultry Science 74:1622–1629.

Wu G. 1998. Intestinal mucosal amino acid catabolism. The Journal of Nutrition 128:1249–1252.

Yi FG, Allee GL, Knight CD, Dibner JJ. 2005. Impact of glutamine and oasis hatchling supplement on growth performance, small intestinal morphology, and immune response of broilers vaccinated and challenged with *Eimeria maxima*. Poultry Science 84:283–293.

Yi FG, Allee GL, Spencer JD, Frank JW, Gaines AM. 2001. Impact of glutamine, menhaden fish meal and spray-dried plasma on the growth performance and intestinal morphology of turkey poults [Abstract]. Poultry Science 80(Suppl.1):201.

Zijlstra RT, Whang KY, Easter RA, Odle J. 1996. Effect of feeding a milk replacer to early weaned pigs on growth, body composition, and small intestinal morphology, compared with suckled littermates. Journal of Animal Science 74:2948–2959.