

EFFECTS OF DIETARY CELLULOSE LEVEL ON NUTRIENT UTILIZATION IN CHICKENS

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Summary

The effects of 5%, 10%, 15% and 20% dietary cellulose levels on the nutrient utilization in chickens were investigated. Four experimental diets were alternatively given to 8 colostomized White Leghorn cockerels to make a 4 × 4 Latin-square design. The diets of 70 g/day were force-fed once a day, and water was given freely. The digestibilities of DM and energy increased linearly with the increase in dietary cellulose level. The digestibilities of ether extract and nitrogen-free extract were not so much influenced by the dietary cellulose level. The digestibility of acid detergent fiber was very low and not influenced by the dietary cellulose level. The digestibility of neutral detergent fiber was not different among the diets containing 5%-15% cellulose, but that of the 20% cellulose diet was diminished. This might be due to the reduction of hemicellulose digestibility. True digestibility and biological value of protein were also not influenced by the dietary cellulose level from 5% to 20%. In conclusion, no ill-effect was found even when the chicken was fed a diet containing 20% of cellulose.

(Key Words : Digestibility, Dietary Cellulose Level, Chicken)

Introduction

Cellulose is one of the major polysaccharides in the plant cell wall which has no nutritional value, however, it has been considered to be essential in the diet because of its physiological and nutritional functions. Delorme and Wojcik (1982) reported that increased dietary cellulose level diminished the digestibility of nutrients in rats, however, Hoover and Haitmann (1972) did not find any difference in protein digestibility in rabbits when they were given diets containing 15% and 30% of acid detergent fiber. If the digestibility of nutrients was reduced by the supplementation of cellulose to the diet, feed efficiency and retention rates of nutrients might become worse when the dietary cellulose level was increased. Siri et al. (1992b) reported, however, that feed intake, body weight gain and retentions of dry matter, energy and nitrogen were increased with the increase in dietary cellulose level from 5% to 20%, when the diets were iso-

caloric and iso-nitrogenous. In order to verify this result, effects of dietary cellulose level on the digestibility of nutrients and biological value of protein were determined in the present experiment.

Materials and Methods

Seven-month-old White Leghorn cockerels were colostomized by the method of Okumura (1976), 8 of which were selected based on the health condition and used as experimental animals. They were divided into 4 groups of 2 birds each, and force-fed 70 g/day of the experimental diets for 7 days. Four experimental diets were formulated so as to contain 5, 10, 15 and 20% of cellulose powder MN 100 (Macherey-Nagel GmbH & Co. KG). By adjusting the corn starch and corn oil contents, these diets were iso-nitrogenous and iso-caloric (in metabolizable energy). Ingredient and chemical compositions are given in table 1. As seen in the table, contents of dry matter (DM), ash and crude protein (CP) were almost similar in all the diets, but the contents of ether extract (EE) and gross energy (GE) were increased with the increase in cellulose level. The diets to be fed were altered every week to make a 4 × 4

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TABLE 1. INGREDIENT AND CHEMICAL COMPOSITIONS OF EXPERIMENTAL DIETS

Diet (cellulose level, %)	5.0	10.0	15.0	20.0
Ingredient composition (g/kg)				
Soybean protein	214.0	214.0	214.0	214.0
Corn starch	666.0	580.5	495.5	410.0
Corn oil	10.0	45.5	80.5	116.0
Cellulose powder	50.0	100.0	150.0	200.0
DL-methionine	1.5	1.5	1.5	1.5
Choline chloride	1.5	1.5	1.5	1.5
Vitamin mixture ¹	0.7	0.7	0.7	0.7
Mineral mixture ¹	56.3	56.3	56.3	56.3
Chemical composition (%)				
Dry matter (DM)	88.0	88.9	89.5	89.9
Ash	5.6	5.5	5.8	5.6
Crude protein (CP)	18.4	18.7	18.7	17.3
Ether extract (EE)	1.9	5.2	8.5	11.9
Nitrogen-free extract (NFE) ²	56.0	48.4	40.5	35.7
Neutral detergent fiber (NDF)	6.1	11.1	16.0	19.4
Acid detergent fiber (ADF)	4.2	8.7	13.2	17.3
Hemicellulose ³	1.9	2.4	2.8	2.1
Gross energy (kJ/g)	15.4	16.5	17.3	18.3

¹ Siri et al. (1992b).

² NFE = DM - (Ash + CP + EE + NDF).

³ Hemicellulose = NDF - ADF.

Latin-square design. During the experimental periods the birds were kept in individual metabolism cages which were placed in a room maintained at $21 \pm 2^\circ\text{C}$ with continuous lighting for 24 hours. Feces and urine were separately collected every morning during the last 3 days of each period. Pooled feces thus collected were dried using a forced air oven at 55°C for 72 hours and ground for chemical analysis. Pooled urine was stored in a deep freezer till analysis.

DM, EE and ash of the diets and feces, and nitrogen of the diets, feces and urine were determined by AOAC (1984) method. GE of the diets and feces was determined using an automatic bomb calorimeter (Shimadzu, model CA-3). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) in the diets and feces were determined by the methods of Van Soest (1963) and Van Soest and Wine (1967), respectively. Nitrogen-free extract (NFE) was calculated by reducing the sum of ash, CP, EE and NDF from DM, and hemicellulose content was estimated as a difference between NDF and ADF.

True digestibility and biological value of protein were calculated using the values of metabolic fecal nitrogen (MFN) and endogenous urinary nitrogen (EUN) which were obtained by Terapuntuwat and Tasaki (1984). ME values of the diets were calculated by subtracting urinary energy from the digestible energy, where urinary energy was estimated by multiplying urinary nitrogen with 7 kcal (Tasaki and Sakurai, 1969). The obtained data were statistically analyzed and the treatment means were compared by Duncan's new multiple range test (Steel and Torrie, 1980).

Results and Discussion

Fecal excretion and digestibility of DM, EE, NFE, NDF, ADF, hemicellulose and energy are shown in table 2. The amounts of DM and energy excreted into feces increased with the increase in cellulose level ($r = 0.98$), and this result was in agreement with the reports of Delorme and Wojcik (1982) in rats, of Kies et al. (1984)

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TABLE 2. FECAL EXCRETION AND DIGESTIBILITY OF DM, EE, NFE, NDF, ADF, HEMICELLULOSE AND ENERGY

Dietary cellulose level (%)	5.0	10.0	15.0	20.0	SEM
Fecal excretion (g/3 days)					
DM	22.6 ^a	30.8 ^b	41.6 ^c	51.8 ^d	1.2
EE	0.3 ^a	0.4 ^{ab}	0.5 ^b	0.6 ^b	0.1
NFE	3.2	3.4	3.8	3.2	0.3
NDF	9.2 ^a	18.1 ^b	26.5 ^c	37.1 ^d	1.1
ADF	8.3 ^a	16.6 ^b	24.5 ^c	34.5 ^d	1.1
Hemicellulose (NDF-ADF)	0.9 ^a	1.5 ^b	2.0 ^b	2.6 ^c	0.1
Energy (kJ/3 days)	307 ^a	463 ^b	643 ^c	811 ^d	17
Digestibility (%)					
DM	87.8 ^d	83.5 ^c	77.9 ^b	72.6 ^a	0.7
EE	91.8 ^a	96.5 ^b	97.5 ^b	97.6 ^b	0.4
NFE	97.3 ^c	96.7 ^{bc}	95.4 ^a	95.8 ^{ab}	0.3
NDF	28.0 ^b	22.1 ^b	21.0 ^b	9.1 ^a	3.1
ADF	6.3	9.6	11.6	5.1	3.6
Hemicellulose	77.2 ^c	68.5 ^{bc}	66.9 ^b	41.7 ^a	2.8
Energy	90.5 ^d	86.7 ^c	82.3 ^b	78.9 ^a	0.5
Digestible energy (kJ/g)	13.9 ^a	14.3 ^b	14.2 ^{ab}	14.4 ^b	0.1
Metabolizable energy (kJ/g)	13.8	14.1	14.1	14.2	0.1

Means not sharing a common superscript are significantly different ($p < 0.05$).

in humans and of Okumura et al. (1982) in chickens. Reflecting these, the digestibilities of DM and energy were highly related with the cellulose level; the regression equations being $Y = 93.54 - 1.06X$ and $Y = 94.74 - 0.82X$, respectively, where Y represented digestibility of DM in the former equation and that of energy in the latter equation, and X was cellulose level. Delorme et al. (1981), Delorme and Wojcik (1982), Kelsay et al. (1978) and Farrell et al. (1978) also reported that the digestibility of DM or energy decreased with the increase in dietary fiber level in various animals. Siri et al. (1992a) previously reported that DM and energy digestibilities of the 10% cellulose diet were 84.9% and 87.5%, respectively, and these values were agreeable with those in the present experiment. The digestible and metabolizable energy values of the diets were calculated and indicated in table 2. It was found that these values were not so much different among the diets as expected when the diets were formulated.

Fecal excretion of EE was very low but tended to increase with the increase in cellulose level.

The EE excretion might be due to the corn oil level but not to the cellulose level, and the EE digestibility was mainly affected by the dietary oil level. The EE digestibility of the 5% cellulose diet was significantly lower than those of the other diets among which no difference in digestibility was found. Saito et al. (1959) reported that the addition of 26.5% cellulose powder to the basal diet lowered EE digestibility in chicks, but Farrell et al. (1978) did not observe any differences in EE digestibility in humans even when the fiber level in the diets was increased. Fecal excretion of NFE was not different among the diets, and subsequently not so much difference was found in NFE digestibility.

Fecal excretion of NDF, ADF and hemicellulose were all significantly increased with the increase in cellulose level, where the correlation coefficients between the NDF, ADF and hemicellulose excretion and the dietary cellulose level were very high, being 0.973, 0.968 and 0.818, respectively. There was not a significant difference in the slopes of the regression equations between the cellulose level and the amounts of fecal

excretion of NDF and ADF, being $b = 1.882$ and $b = 1.773$, respectively, but both of them were significantly higher than that for hemicellulose, being $b = 0.108$. It might be explained by the fact that the amount of excreted hemicellulose was not so much changed when the dietary cellulose level was increased. Siri et al. (1992a) reported that fecal excretion of NDF and ADF of birds fed the 10% cellulose diet was 18.24 and 16.41 g/3 days, respectively, and these figures are almost the same to those in the present experiment.

The digestibility of ADF was not different among the diets used here, and this is in agreement with the report of Farrell et al. (1978). The NDF digestibility was not significantly different among the diets having 5%, 10% and 15% cellulose, but that of the 20% cellulose diet was very low. This might be a reflection of the hemicellulose digestibility, being high in the 5%, 10% and 15% cellulose diets and low in the 20% cellulose diet. According to Siri et al. (1992a), most part of ADF may be cellulose and the part of NDF other than ADF is mainly hemicellulose component. Therefore, the digestible NDF is considered to be hemicellulose. This result would support the report of Keys et al. (1969) who suggested that hemicellulose was more digestible than cellulose in rats. Siri et al. (1992a) reported in the previous paper that the digestibility of ADF was 11.5% which was similar to the value obtained in the present experiment, however, the digestibility of NDF was very low, being 8.3%, compared with the present value. This might be due to the purity of the cellulose powder used; indeed, the ADF/NDF ratio was 93% in the previous experiment and 78% in the present experiment. The high digestibility of NDF and hemicellulose in the lower cellulose diets might

be due to the long transit time of digesta in the intestine which would permit time for microbial degradation of polysaccharide polymers in hemicellulose as discussed by Farrell et al. (1978) and Keys et al. (1970). Slavin et al. (1981) also reported that the digestibility of NDF and cellulose was higher in the low cellulose diet than in the high cellulose diet.

Digestibility and biological value of protein are presented in table 3. Fecal and urinary nitrogen excretion was not significantly different among the diets used in this experiment. Consequently, true digestibility of protein was not different among the diets, being 96-97%, and this value was similar to that obtained in the previous experiment (Siri et al., 1992a). Slavin and Marlett (1980) reported that there was no significant effect on the nitrogen excretion and apparent digestibility among the diets having from 9.5% to 23.5% NDF in humans. On the other hand, Garrison et al. (1978) reported that the digestibility of crude protein differed between the 0% and 5% ADF diets, and both of them were higher than those of the 10% and 15% ADF diets, both of which were not different from each other. Hove and King (1979) and Delorme et al. (1981) also reported that the nitrogen digestibility would be diminished with an increase in dietary cellulose level in rats.

The biological value of protein was not influenced by the dietary cellulose level from 5% to 20%. This is in agreement with the result of Hove and King (1979) with rats. Siri et al. (1992a) reported that the biological value of protein in birds fed the 10% cellulose diet was very high, being 90.0%. The reason why such a big difference between the previous and present experiments occurred is not clear, but some errors might be included during the previous experiment, because the amount of urinary nitrogen excretion

TABLE 3. DIGESTIBILITY AND BIOLOGICAL VALUE OF PROTEIN

Dietary cellulose level (%)	5.0	10.0	15.0	20.0	SEM
N intake (g/3 days)	6.18	6.27	6.30	5.82	—
N excretion, fecal (g/3 days)	0.48	0.36	0.45	0.45	0.03
N excretion, urinary (g/3 days)	3.96	4.26	4.02	5.13	0.72
True digestibility (%)	95.5	97.3	95.7	95.8	0.4
Biological value (%)	54.8	54.3	56.9	52.2	8.2

Values of metabolic fecal nitrogen and endogenous urinary nitrogen were referred to Terapuntuwat and Tasaki (1984), being 91.5 mg/100 g DM consumed and 14 mg/100 g body weight, respectively.

was too small in the previous experiment when compared with that of the present experiment. The amounts of metabolic fecal and endogenous urinary nitrogen were not determined in the present experiment, and the values reported by Terapuntuwat and Tasaki (1984) were used for calculation of true digestibility and biological value of protein. According to Shah et al. (1982), excretion of metabolic fecal nitrogen increased with the increase in dietary cellulose level. Okumura et al. (1982) reported that the excretion of metabolic fecal nitrogen was influenced by the dietary cellulose level when it was indicated as per metabolic body size of the chicken but not when it was indicated as per feed intake. They also suggested that the endogenous urinary nitrogen excretion per metabolic body size was not influenced by the dietary cellulose level. Therefore, fixed values of metabolic fecal nitrogen and endogenous urinary nitrogen can be used for the calculation.

Literature Cited

- AOAC. 1984. Official Methods of Analysis. 14th ed., AOAC Inc. Arlington.
- Delorme, C. B. and J. Wojcik. 1982. Interaction of dietary protein with cellulose in the adaptation to caloric dilution by weanling rats. *J. Nutr.* 112:21-28.
- Delorme, C. B., J. Wojcik and C. Goldon. 1981. Method of addition of cellulose to experimental diets and its effect on rat growth and protein utilization. *J. Nutr.* 111:1522-1527.
- Farrel, D. J., L. Girdle and J. Arthur. 1978. Effects of dietary fiber on the apparent digestibility of major food components and on blood lipids in men. *Austr. J. Exp. Biol. Med. Sci.* 56:469-479.
- Garrison, M. V., R. L. Reid, P. Fawley and C. P. Breidentein. 1978. Comparative digestibility of acid detergent fiber by laboratory albino and wild Polynesian rats. *J. Nutr.* 108:191-195.
- Hove, E. L. and S. King. 1979. Effects of pectin and cellulose on growth, feed efficiency and protein utilization and their contribution to energy requirement and cecal VFA in rats. *J. Nutr.* 109:1274-1278.
- Hoover, W. H. and R. N. Heitmann. 1972. Effects of dietary fiber levels on weight gain, cecal volume and volatile fatty acid production in rabbits. *J. Nutr.* 102:375-380.
- Kelsay, J. L., K. M. Behall and E. S. Prather. 1978. Effect of fiber from fruits and vegetables on metabolic responses of human subjects. I. Bowel transit time, number of defecations, fecal weight, urinary excretions of energy and nitrogen and apparent digestibilities of energy, nitrogen and fat. *Am. J. Clin. Nutr.* 31:1149-1153.
- Keys, Jr. J. E., P. J. Van Soest and E. P. Young. 1969. Comparative study of the digestibility of forage cellulose and hemicellulose in ruminants and nonruminants. *J. Anim. Sci.* 29:11-15.
- Keys, Jr. J. E., P. J. Van Soest and E. P. Young. 1970. Effect of increasing dietary cell wall content on the digestibility of hemicellulose and cellulose in swine and rats. *J. Anim. Sci.* 31:1172-1177.
- Kies, C., V. E. Sanchez and H. M. Fox. 1984. Cellulose supplementation of a nutritionally complete, liquid formula diet: Effect on gastrointestinal tract function of humans and fecal fiber recovery. *J. Food Sci.* 49:815-817.
- Okumura, J. 1976. Method of colostomy and cannulation in the chickens. *Br. Poult. Sci.* 17:547-551.
- Okumura, J., Y. Isshiki and Y. Nakahiro. 1982. Influence of dietary cellulose and indigestible dry matter on metabolic and endogenous nitrogen excretion in chickens. *Jpn. Poult. Sci.* 19:300-303.
- Saito, M., I. Tasaki, K. Kibe, H. Yamada and T. Igarashi. 1959. Effect of various cellulose levels in the diet on the chick growth. *Poult. Sci.* 38:373-376.
- Shah, N., M. T. Atallah, R. R. Mahoney and P. L. Pellett. 1982. Effect of dietary fiber components on fecal nitrogen excretion and protein utilization in growing rats. *J. Nutr.* 112:658-666.
- Siri, S., H. Tobioka and I. Tasaki. 1992a. Effect of dietary fiber on utilization of energy and protein in chickens. *Jpn. Poult. Sci.* 29:23-29.
- Siri, S., H. Tobioka and I. Tasaki. 1992b. Effects of dietary cellulose level on growth performance, development of internal organs, energy and nitrogen utilization and lipid contents of growing chicks. *Asian-Austr. J. Anim. Sci.* 5:369-374.
- Slavin, J. L. and J. A. Marlett. 1980. Effect of refined cellulose on apparent energy, fat and nitrogen digestibilities. *J. Nutr.* 110:2020-2026.
- Slavin, J. L., P. M. Brauer and J. A. Marlett. 1981. Neutral detergent fiber, hemicellulose and cellulose digestibility in human subjects. *J. Nutr.* 111:287-297.
- Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach. 2nd ed. McGraw-Hill Book Co. Inc., N. Y., pp. 137-188, pp. 239-284.
- Tasaki, I. and H. Sakurai. 1969. Studies on energy metabolism in the fowl. II. Metabolism in fasting condition. *Jpn. J. Zootech. Sci.* 35:18-25.
- Terapuntuwat, S. and I. Tasaki. 1984. Protein and amino acid digestibility, biological value of protein and energy metabolizability of some leaf protein concentrates in chickens. *Jpn. Poult. Sci.*

- 21:64-73.
- Van Soest, P. J. 1963. The use of detergents in the analysis of fibrous feed. II. A rapid method for the determination of fiber and lignin. J. AOAC, 46:829-835.
- Van Soest, P. J. and R. H. Wine. 1967. Use of detergent in the analysis of fibrous feed. IV. Determination of plant cell wall constituents. J. AOAC 50: 50-55.