Effect of Dietary Fiber on Utilization of Energy and Protein in Chickens

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Cellulose powder, pectin, alginic acid and finely ground rice straw were used as the dietary fiber source. Experimental diets were composed of soybean protein, corn starch, corn oil and some minor ingredients with 10% of above mentioned dietary fibers. A total of 8 colostomized White Leghorn male chickens were forced-fed 70 g/day of the experimental diets for 7 days alternatively so as to make a 4×4 Latin-square design. The amount of fresh feces was significantly higher in the pectin and alginic acid diets, however, water content in the feces was also higher in these diets. Consequently, the dry matter excreted were not different between the treatments, which resulted in no difference of dry matter and energy digestibilities among the diets. Protein digestibility was higher in the cellulose diet and lower in the pectin diet due to the significant difference in fecal nitrogen excretion. Urinary nitrogen was very low in the cellulose diet, and reflecting its biological value of protein was higher in the cellulose diet. Acid detergent fiber was digested by chickens to a small extent, but hemicelluloses seemed to be not digested, because the digestibility of neutral detergent fiber was the same to that of acid detergent fiber.

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Key words : dietary fiber, energy utilization, protein utilization, chicken

Introduction

Dietary fiber is defined as the plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzymes of man¹⁾. It has been reported that the dietary fiber reduces utilization of nutrients including protein in humans and rats²⁻⁴⁾. According to DELORME and GORDON⁵⁾, pectin lowered the digestibility of energy and protein in rats. KIBE *et al.*⁶⁾ reported that dietary cellulose slightly increased biological value and true digestibility of protein in chickens. The present experiment was carried out to compare the effects of some dietary fibers on utilization of energy and protein in chickens, since this kind of study was scanty.

Materials and Methods

Cellulose powder, pectin, alginic acid and finely ground rice straw were used as the dietary fiber source. The composition of experimental diets was as follows (in %) : soybean protein (90% protein) 21.4, corn starch 61.6, corn oil 1.0, DL-methionine 0.15, choline chloride 0.15, vitamin mixture 0.07, mineral mixture 5.63, and either cellulose powder, pectin, alginic acid or finely ground rice straw 10.0. Where, vitamin mixture contained (mg/0.7 g) thiamin HCl 100, niacin 100, riboflavin 16, inositol 100, biotin

0.6, Ca-pantothenate 20, vitamin B₁₂ 0.02, pyridoxine HCl 6, folic acid 4, p-amino-benzoic acid 2, menadione 5, ascorbic acid 250, vitamin A acetate (1,000,000 IU/g) 10, vitamin D₃ 0.015, vitamin E 0.0005, BHT 0.0156 and made up to 0.7 g with corn starch. Mineral mixture contained (g/56.3 g) CaHPO₄ 20.7, CaCO₃ 14.8, KH₂PO₄ 10.0, KCl 1.0, NaCl 6.0, FeSO₄ · H₂O 0.333, MgSO₄ 3.0, MnSO₄ · H₂O 0.333, CuSO₄ · 5 H₂O 0.0167, KI 0.0026, ZnO 0.062, CoCl · 6 H₂O 0.0017, Na₂MoO₄ · 2 H₂O 0.0083, Na₂SeO₃ 0.0001 and made up to 56.3 g with corn starch.

Twelve-month-old White Leghorn male chickens were colostomized by the method of OKUMURA⁷⁾, and 8 of which were taken as experimental animals based on the health condition. They were divided into 4 groups of 2 birds each and were forced-fed 70 g/day of the experimental diets for 7 days, of which last 3 days were employed for collection of feces and urine. The diets provided were changed every week to make a 4 × 4 Latin-square design. During the experimental period the birds were kept in individual metabolism cages which were placed in a room maintained at 21 ± 2°C, and lighting was provided for 24 hours continuously. Feces and urine were separately collected every day from artificial and original ana, respectively. Pooled feces thus collected were dried up 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.

Dry matter (DM) of the diets and feces was determined by the method of AOAC⁸⁾. Nitrogen of the diets, feces and urine was determined by Kjeldahl method, and energy by means of a bomb calorimeter (Shimadzu Co. CA-3). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) in the diets and feces were determined by the methods of VAN SOEST⁹⁾, and VAN SOEST and WINE¹⁰⁾, respectively. True digestibility and biological value of protein were calculated using values of metabolic fecal nitrogen and endogenous urinary nitrogen which were obtained by TERAPUNTUWAT and TASAKI¹¹⁾, since they were not determined in this experiment. The data were subjected for statistical analysis, and the comparison of the treatment means was made by DUNCAN's New Multiple Range Test¹²⁾.

Results and Discussion

Intake and fecal excretion of DM and energy are shown in Table 1. The amounts of fresh feces varied remarkably ; i.e., significantly higher in the pectin and alginic acid diets than in the cellulose and rice straw diets, however, the DM contents were also quite different, higher in the cellulose and rice straw diets. Consequently, the amounts of DM excreted into feces were not different between dietary treatments. As a result, DM digestibility was not different between the diets used here. The chickens fed the pectin or alginic acid diet excreted more water in the feces due to high water holding capacity of pectin and alginic acid. TSAI *et al.*¹³⁾ reported that the rats fed a diet containing pectin showed mild diarrhea, but appeared normal and healthy. WAGNER and THOMAS¹⁴⁾ reported that the chicks fed a pectin diet excreted sticky feces.

The fecal energy excretion was not different between dietary treatments, and consequently energy digestibility was not different between them, being about 88%. This result was supported by AKIBA and MATSUMOTO¹⁵⁾, who reported that the

Table 1. Fecal excretion and digestibility of DM and energy

Diet			Cellulose	Pectin	Alginic acid	Rice straw	SEM
Intake	DM	(g/day)	62.2	62.0	61.7	61.9	
	Energy	(kcal/day)	277.5	274.7	269.6	280.5	
Feces	Fresh	(g/day)	46.1 ^a	96.2 ^b	84.3 ^b	54.0 ^a	4.5
	DM	(%)	20.5 ^b	9.1 ^a	11.2 ^a	17.1 ^b	1.1
	DM	(g/day)	9.4	8.6	9.9	9.0	0.7
	Energy	(kcal/day)	34.7	31.8	31.1	33.1	2.6
Digestibility (%)	DM		84.9	86.1	84.0	85.0	1.1
	Energy		87.5	88.4	88.5	88.2	0.9

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

Table 2. Digestibility and biological value of protein

Diet		Cellulose	Pectin	Alginic acid	Rice straw	SEM
Nitrogen intake	(g/day)	2.13	2.16	2.16	2.23	
Fecal nitrogen	(g/day)	0.13 ^a	0.38 ^c	0.23 ^b	0.20 ^b	0.02
Urinary nitrogen	(g/day)	0.57 ^a	1.04 ^b	1.14 ^b	1.09 ^b	0.07
True digestibility	(%)	96.8 ^c	85.6 ^a	92.1 ^b	93.8 ^b	0.75
Biological value	(%)	90.0 ^b	63.2 ^a	60.7 ^a	64.1 ^a	3.61

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

addition of cellulose, rice hull, rice hull NDF, alfalfa meal, peanut hull NDF and polyamide at a level of 4% did not change energy retention of forced-fed chicks. On the contrary, VIOLA *et al.*¹⁶⁾ reported that the dietary fiber, particularly pectin, reduced the digestibility of energy.

Digestibility and biological value of protein are indicated in Table 2. Fecal nitrogen excretion was highest in the pectin diet followed by the alginic acid and rice straw diets, and lowest in the cellulose diet ($P < 0.05$). Urinary nitrogen excretion was not different between the pectin, alginic acid and rice straw diets, but that for the cellulose diet was significantly lower than that for the other diets. This result is in agreement with the reports by NOMANI *et al.*¹⁷⁾ and SHAH *et al.*⁴⁾

True digestibility of protein was consistently higher in the cellulose diet and lower in the pectin diet, but the difference between the highest and the lowest was not so large. VIOLA *et al.*¹⁶⁾ and FLEMING and LEE²⁰⁾ also reported that the lowest protein digestibility was obtained in a pectin diet with rats. As discussed by FORMAN and SCHNEEMAN¹⁸⁾, pectin might coat the absorptive lining of the gut, thereby interfering with the absorption of the products of digestion. SHAH *et al.*²¹⁾ reported that pectin reduced the pepsin and trypsin activities, because pectin is water soluble fiber that gives rise to highly viscous solution or even gels when dissolved, thereby slowing transport phenomena such as diffusion and mixing, and increasing the size of the unstirred layer, and also pectin contains ionizable carboxylic acid groups that can act

as the ion-exchangers. The above mechanisms can serve to explain why pectin reduces protein digestibility. As stated before dietary pectin increased fecal nitrogen excretion. Such an increased fecal nitrogen loss may partially be due to the increased secretion of digestive enzymes as discussed by FORMAN and SCHNEEMAN¹⁸⁾. SHEARD and SCHNEEMAN¹⁹⁾ suggested the possibility that pectin might increase the sloughing of cells of intestinal mucosa. If so, metabolic fecal nitrogen would be more than estimated, and the digestibility of protein of the pectin diet might be higher than that shown in Table 2.

The biological value of protein was higher in the cellulose diet than in the other diets, and the difference was almost 30%. This figure is very similar to the result of NOMANI *et al.*¹⁷⁾. The high biological value of the cellulose diet was due to the low excretion of urinary nitrogen, however, the reason why dietary cellulose reduced urinary nitrogen excretion was not clarified yet.

NDF and ADF contents of the ingredients of diets are indicated in Table 3. Corn starch and soybean protein did not contain NDF and ADF. Cellulose powder contained 95% of NDF, of which 93% was ADF, and rice straw contained 70% of NDF, of which 70% was ADF. According to the definition of dietary fiber, pectin and alginic acid might not contain NDF and ADF. In fact, NDF was not detected in both alginic acid and pectin, but by the usual method for ADF determination a quite big ADF value was obtained particularly in alginic acid, because alginic acid is acid-precipitable.

Intake and fecal excretion of NDF and ADF in the experimental birds fed the cellulose and rice straw diets are shown in Table 4 together with the digestibility of these substances. NDF intake was a little higher than ADF intake because the diets

Table 3. Contents of ADF and NDF in ingredients of the diet (%)

	NDF	ADF
Soybean protein	0	0
Corn starch	0	0
Cellulose powder	94.71	88.25
Rice straw	69.74	49.08

Table 4. Digestibility of ADF and NDF (mean $\pm$ SE)

		NDF	ADF
Intake (g/day)	Cellulose diet	6.63	6.18
	Rice straw diet	4.88	3.44
Fecal excretion (g/day)	Cellulose diet	6.08 $\pm$ 0.15	5.47 $\pm$ 0.13
	Rice straw diet	3.50 $\pm$ 0.33	2.47 $\pm$ 0.23
Digestibility (%)	Cellulose diet	8.26 $\pm$ 2.26	11.47 $\pm$ 2.13
	Rice straw diet	28.30 $\pm$ 6.82*	28.02 $\pm$ 6.67*

* Significantly different ($P < 0.05$) between diets.

contained higher NDF than ADF as shown in Table 3. Fecal excretion also followed this tendency, and the digestibility of NDF was not statistically different from that of ADF both in the cellulose and rice straw diets. Most part of ADF is recognized to be cellulose, and the part of NDF other than ADF is mainly hemicelluloses. The statistical data also showed that the digestibility of ADF and NDF were significant. It means that the birds can digest cellulose even if a very small amount, but can not digest hemicelluloses, however, the amount of hemicellulose intake was very small, and more precise experiment will be needed to verify whether hemicellulose can not be digested. The fiber digestibility of the rice straw diet was almost 3 folds that of the cellulose diet, and the difference was quite significant. It seems that the fiber of rice straw is more easily digested by the chicken than the cellulose powder used in this experiment.

In conclusion, cellulose powder, pectin, alginic acid or rice straw do not affect the digestibility of dry matter or energy of the diets, but the dietary pectin reduces protein digestibility of the diet. Biological value of protein is remarkably improved by the addition of cellulose. Possibility is shown that a part of cellulose can be digested by the chicken.

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鶏におけるエネルギーおよび蛋白質の利用性に 対する食物繊維の影響

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本実験においては、市販の大豆蛋白を蛋白質源とし、食物繊維としてセルロース末、ペクチン、アルギン酸または細粉稲ワラを各10%含む半精製飼料を人工肛門設着鶏に定量給与し、糞および尿を採取して上記食物繊維が飼料のエネルギーおよび蛋白質の利用性に及ぼす影響を中心に検討した。

各飼料を同量給与したにもかかわらずペクチンおよびアルギン酸給与鶏では排糞量が特に多かったが、これはペクチンおよびアルギン酸の保水性が高く、そのために糞中水分含量が多くなったためであり、乾物排泄量では各飼料間に有意差がみられなかった。すなわち乾物消化率に対する食物繊維の影響はなかった。またエネルギーの消化率についても飼料間差はなかった。

糞中窒素排泄量はペクチン給与で有意に多く、セルロース給与で有意に少なかった。これを反映して蛋白質の消化率はセルロース給与で有意に高く、ペクチン給与で有意に低かった。なお蛋白質の生物価はセルロース給与により他よりも高い値を示したが、これはセルロース給与時の尿中排泄窒素量が特に少なかったことに起因している。しかしこのような現象の生じた理由については明

らかにできなかった。

本実験に用いたセルロース末は約95%のNDFを含み、このうち88%がADFで、稲ワラはNDFが70%、ADFが50%であった。NDFのうちADF以外の部分はヘミセルロースと考えられるが、この含有割合はセルロース末では非常に少なく、稲ワラでは20%にも達していた。NDFとADFの摂取量と排泄量からそれらの消化率を計算すると、いずれも稲ワラのほうがセルロース末よりも有意に高く、また両者とも有意な消化率を示した。すなわち通常の飼育条件では、僅かではあるが鶏はセルロースを消化でき、さらに稲ワラのセルロースは、ここに用いた純セルロース末よりも消化性が高いと考えられる。しかし前述したようにエネルギーの消化性に差がみられないことから、見掛け上の消化性が高まっても、真に利用性が向上したとは考えにくい。なおADFとNDFの消化率に差がないことは、ヘミセルロースの消化性がないことを意味している。

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