COMPARISON OF UTILIZATION OF CELLULOSE AND CORN DIETARY FIBER AS AN ENERGY SOURCE IN CHICKS

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Summary

An experiment was conducted to investigate effects of fiber source on growth performance, N and neutral detergent fiber (NDF) digestibility, and utilization of energy in chicks fed an isocaloric low-energy diet from 7 to 21 days of age. Two fiber sources, cellulose and corn dietary fiber (CDF), were included in a diet at 10, 20 and 30% at the expense of kaolin, an inert diluent. The CDF contained 76.5% NDF consisting mainly of hemicellulose. The results showed that growth performance, N and NDF digestibility, dietary DE and ME values, energy deposition, and NE for production in birds fed CDF were inferior to those in birds fed cellulose. It can be concluded, from the present study, that chicks can utilize cellulose more efficiently than CDF up to a level of 30%.
(Key Words : Cellulose, Corn Dietary Fiber, Digestibility, DE, Energy Utilization, Chicks)

Introduction

Hegde et al. (1982) found that chickens could obtain some energy, though to a small extent, from dietary fiber through bacterial actions in the gut. Because the transit of gut content in chickens is fast compared with that in mammalian species, the efficacy of fiber digestion and metabolism as an energy source in chickens would be different from those reported in mammalian species. For example, the addition of guar gum as low as 2.5% to a diet resulted in growth depression of birds (Verma and McNab, 1985), whereas in rats dietary supplemented guar gum could be efficiently utilized up to 15% (Tulung et al., 1987).

The type of fiber included in a diet is an important determinant of fiber utilization. Hemicellulose, for instance, was found to be more digestible and thereby better source of energy than cellulose in rats (Keys et al., 1969), pigs (Keys et al., 1970), and chimpanzees (Milton and Demment, 1988). In this sense, the capacity of chickens to utilize dietary fiber would also depend on fiber sources, although chickens are a poor utilizer of dietary fibers. The present study was

done, therefore, to investigate whether the efficiency of dietary fibers as an energy source is different between two dietary fibers, cellulose and corn dietary fiber (CDF), in chickens when fed an isonitrogenous, isocaloric low-energy diet.

Materials and Methods

Day-old Single comb White Leghorn male chicks were raised in electrically-heated brooders until 7 days of age, and 49 birds were selected out of 200 birds. They were distributed in 7 groups of 7 so that mean body weights throughout the treatment groups were as uniform as possible. The birds were reared individually in wire-mesh metabolism cages during the experimental period from 7 to 21 days of age. Experimental diets and water were provided for *ad libitum* consumption for the entire experimental period. Ambient temperature was thermostatically maintained at $30 \pm 2°C$, and light was provided continuously for 24 h per day.

The composition of the isonitrogenous, isocaloric low-energy diets is given in table 1. The control diet contained 30% kaolin as an inert diluent. Cellulose was added at 10, 20 and 30% as dietary fiber at the expense of kaolin. CDF (Nisshoku Cellufer®, Nisshoku Kako Co. Ltd., Tokyo, Japan), which contained 76.5% NDF consisting mainly of hemicellulose, and had 5.4% crude protein and 2.3 kJ/g ME, was added at

TABLE 1. COMPOSITION OF THE EXPERIMENTAL DIETS

Diet	Control	Cellulose			Corn dietary fiber		
		10%	20%	30%	10%	20%	30%
Cellulose	0.00	10.00	20.00	30.00	0.00	0.00	0.00
Corn dietary fiber[1]	0.00	0.00	0.00	0.00	13.07	26.14	39.22
Kaolin	30.00	20.00	10.00	0.00	20.00	10.00	0.00
Isolated soybean protein[2]	22.60	22.60	22.60	22.60	21.76	20.92	20.08
Cornstarch	35.04	35.04	35.04	35.04	32.06	29.09	26.11
Corn oil	3.00	3.00	3.00	3.00	3.75	4.49	5.23
Sucrose				1.59			
Vitamin mixture[3]				0.20			
Mineral mixture[4]				6.49			
Choline. Cl				0.15			
Myoinositol				0.10			
Glycine				0.42			
L-Methionine				0.29			
L-Threonine				0.12			
Calculated value : Crude protein (%)				19.81			
Metabolizable energy (kJ/g)				10.24			

[1] Nisshoku Cellufer® (Nisshoku Kako Co. Ltd, Tokyo, Japan) containing 76.5% neutral detergent fiber mainly consisting of hemicellulose, and having 5.4% of crude protein and 2.3 kJ/g metabolizable energy.

[2] Fujipro-R (Fuji Oil Co. Ltd., Osaka, Japan).

[3] Muramatsu et al. (1987).

[4] Nesheim et al. (1962), except for selenium which was included at twice the published value.

13.1, 26.1 and 39.2% to supply 10, 20 and 30% NDF respectively, at the expense primarily of kaolin and of isolated soybean protein, cornstarch and corn oil to adjust dietary crude protein and ME. The values for crude protein and ME of the experimental diets were set at 19.81% and 10.24 kJ/g, respectively.

From 18 to 21 days of age, droppings were collected into 100 ml of 0.06 M hydrochloric acid in a deep, stainless steel tray located beneath each metabolism cage. The acid prevented further microbial action in the droppings and loss of ammonia. The droppings were dried in a forced-air oven at 55℃ for 48 h and were ground for chemical analyses.

At 21 days of age birds were killed by cervical dislocation. The whole carcass including feathers was frozen by plunging into liquid N_2, and was stored at −20℃ until analysis. The frozen carcass was minced with a meat grinder, which was previously cooled with solid carbon dioxide, and was frozen again with liquid N_2. This mincing procedure was repeated three times to get homo-genous samples of the whole carcass. The minced carcasses were dried at 55℃ for 48 h and ground before analysis of body composition.

Total N in the droppings and the diets was analyzed by a Kjeldahl method. The combustion energy of the diets, cellulose and of droppings was determined with an automated bomb calorimeter (Shimadzu CA-3, Shimadzu Co., Kyoto, Japan). NDF was determined according to the method of Van Soest and Wine (1967). Dietary ME value was calculated after the correction for retained N (Hill and Anderson, 1958).

For obtaining DE value of the diet, Li_2CO_3 extraction of excreta was used to obtain urinary N compounds, and subsequently to calculate urinary energy and fecal energy values as described previously (Muramatsu et al., 1991). Approximately 2 g of the ground droppings was weighed and placed in a 200 ml flask to which about 80 ml of saturated Li_2CO_3 was added and homogenized. The flask was sealed and incubated overnight at 37℃, and the Li_2CO_3 extract was then filtered and made to 100 ml with saturated

Li_2CO_3.

Total N, protein and uric acid in the Li_2CO_3 extract were determined by the Kjeldahl method, the method of Lowry et al. (1951) using a bovine serum albumin as a standard, and that of Pudelkiewicz et al. (1968), respectively. A Conway's microdiffusion method was used for the determination of ammonia and urea in the extract. Total creatinine in the extract was determined by a Jaffe reaction as described previously (Muramatsu and Okumura, 1979). The losses of N during the entire procedure including collection, drying and overnight incubation with saturated Li_2CO_3 were corrected for each compound from the respective recoveries measured. Urinary N contents were defined as total nonprotein N calculated from the difference between total N and protein N in the Li_2CO_3 extract. As a result, fecal N was obtained by subtracting the urinary N, i.e. total nonprotein N in the extract, from total N in the droppings. Urinary energy was estimated by the sum of each N compound multiplied by a factor (Tasaki and Sakurai, 1963) as follows: uric acid, 34.3 kJ/g N; ammonia, 30.6 kJ/g N; urea, 22.6 kJ/g N; total creatinine, 52.0 kJ/g N. Because there was a small, but significant amount of unidentified N detected in the extract, its energetic value was tentatively estimated as 34.9 kJ/g N by taking the average value of combustion energy for overall extracted compounds.

Carcass N was determined by a Kjeldahl method, and carcass crude protein was defined as $N \times 6.25$. Carcass fat was determined by overnight extraction with diethyl ether using a Soxhlet apparatus, and determined gravimetrically. In order to determine the deposition of body protein and fat, a group of 5 chicks having body weights similar to those in the experimental groups was killed by cervical dislocation at 7 days of age, and the initial body protein and fat contents were obtained. These values were subtracted from figures obtained for the experimental groups slaughtered at 21 days of age. Retained energy was calculated as follows:

$$RE = 23.7 \times RP + 39.1 \times RF$$

where RE, RP and RF stand for retained energy (kJ/14 days), retained protein (g/14 days) and retained fat (g/14 days), respectively. Heat production was calculated as the difference between ME intake and energy deposition over the 14 day-experimental period.

The data without the control values were treated statistically by a 2×3 factorial analysis of variance, and the significance of difference between means was assessed by a protected LSD method (Snedecor and Cochran, 1980) using the GLM procedure of Statistical Analysis System (1985). Each treatment mean was compared only when a significant interaction was detected.

Results

Table 2 gives the values for body weight gain, feed intake and feed efficiency. On average, cellulose gave significantly better body weight gain ($p < 0.05$) and feed efficiency ($p < 0.01$) than did the CDF, whereas no significant difference was detected between the two fiber sources in feed intake. In these measurements, there was no significant effect of increasing the fiber content in the diet.

The values for N and NDF digestibility, and dietary ME and DE with the ratio of ME/DE are given in table 3. Both N and NDF digestibility were significantly higher in birds given cellulose than the CDF. In the case of NDF digestibility, a significant increase ($p < 0.05$) was found by increasing dietary cellulose levels, whereas the value was considerably decreased by increasing dietary CDF levels from 20 to 30 %. On average, both DE and ME values were higher in birds given cellulose than the CDF, but the differences in the overall means was ascribable solely to the difference at 30% level as indicated by the significant interaction for these measurements. There was no significant change in ME/DE ratios among treatments.

The values for protein, fat and energy deposition, heat production and net energy (NE) for production are shown in table 4. There were no significant changes in either protein deposition or fat deposition between the two dietary fibers. However, energy deposition, which was calculated as the sum of retained energy of protein and fat, was significantly higher in cellulose than in the CDF ($p < 0.05$) with no effect of increasing fiber levels. Heat production was not significantly different between the two fiber sources. On average, NE for production was significantly higher ($p < 0.05$) in cellulose than in the CDF.

Figure 1 shows the change in dietary DE values by increasing dietary fiber contents, indi-

TABLE 2. GROWTH PERFORMANCE OF CHICKS FED AN ISOCALORIC, LOW-ENERGY DIET CONTAINING GRADED LEVELS OF CELLULOSE OR CORN DIETARY FIBER (CDF)[1]

Fiber source	Level (%)	Body wt gain (g/14 d)	Feed intake (g/14 d)	Feed efficiency (g gain/g intake)
Cellulose	10	82	236	0.35
	20	74	205	0.36
	30	84	227	0.37
	Group Mean	80	223	0.36
CDF	10	71	215	0.33
	20	60	211	0.28
	30	68	231	0.29
	Group Mean[2]	66*	219ns	0.30**
Pooled SE		4.3	8.4	0.01
Error Mean Square (36 df)		393.8	1492.1	0.00253
			Analysis of variance	
Source	df		Significance level[2]	
Fiber (F)	1	*	ns	**
Level (L)	2	ns	ns	ns
F × L	2	ns	ns	ns

[1] The number of birds used was 7 per treatment.

ns, not significant; *$p < 0.05$, **$p < 0.01$.

TABLE 3. DIGESTIBILITY OF N AND NEUTRAL DETERGENT FIBER (NDF), AND DIETARY DE AND ME VALUES IN CHICKS FED AN ISOCALORIC, LOW-ENERGY DIET CONTAINING GRADED LEVELS OF CELLULOSE OR CORN DIETARY FIBER (CDF)[1]

Fiber source	Level (%)	N digestibility (%)	NDF digestibility (%)	DE (kJ/g)	ME (kJ/g)	ME/DE (%)
Cellulose	10	74.9	18.8	10.1	9.2	91.3
	20	75.8	25.1	10.7	9.8	91.9
	30	82.2	20.5	11.0	10.1	92.0
	Group Mean	77.6	21.5	10.6	9.7	91.7
CDF	10	69.7	12.4	9.8	9.0	92.2
	20	72.0	20.1	10.5	9.7	92.6
	30	67.4	6.7	9.1[2]	8.3[2]	91.2
	Group Mean[3]	69.7**	13.1**	9.8**	9.0**	92.0
Pooled SE		1.6	2.1	0.2	0.1	0.7
Error Mean Square (36 df)		54.9	90.7	0.63	0.28	10.5
			Analysis of variance			
Source	df		Significance level[3]			
Fiber (F)	1	**	**	**	**	ns
Level (L)	2	ns	*	ns	**	ns
F × L	2	ns	ns	*	**	ns

[1] The number of birds used was 7 per treatment.

[2] Significantly different from the corresponding cellulose value with the same fiber level at $p < 0.01$.

ns, not significant; *$p < 0.05$, **$p < 0.01$.

TABLE 4. DEPOSITION OF CARCASS PROTEIN, FAT AND ENERGY, HEAT PRODUCTION AND NE FOR PRODUCTION IN CHICKS FED AN ISOCALORIC, LOW-ENERGY DIET CONTAINING GRADED LEVELS OF CELLULOSE OR CORN DIETARY FIBER (CDF)[1]

Fiber source	Level (%)	Protein deposition (g/d)	Fat deposition (g/d)	Energy deposition (kJ/d)	Heat production (kJ/d)	NE for production (kJ/g)
Cellulose	10	0.98	0.36	37.2	118	1.58
	20	1.15	0.01	27.4	116	1.42
	30	1.35	0.06	34.1	130	1.57
	Group Mean	1.16	0.14	32.9	121	1.52
CDF	10	1.14	0.03	28.0	112	1.51
	20	1.05	−0.05	22.9	123	1.14
	30	1.11	0.02	27.1	111	1.14
	Group Mean[2]	1.10ns	0.00ns	26.0*	115ns	1.26*
Pooled SE		0.08	0.06	2.3	4.5	0.09
Error Mean Square (36 df)		0.14	0.07	110.9	432.5	0.158
			Analysis of variance			
Source	df		Significance level[2]			
Fiber (F)	1	ns	ns	*	ns	*
Level (L)	2	ns	ns	ns	ns	ns
F × L	2	ns	ns	ns	ns	ns

[1] The number of birds used was 7 per treatment.
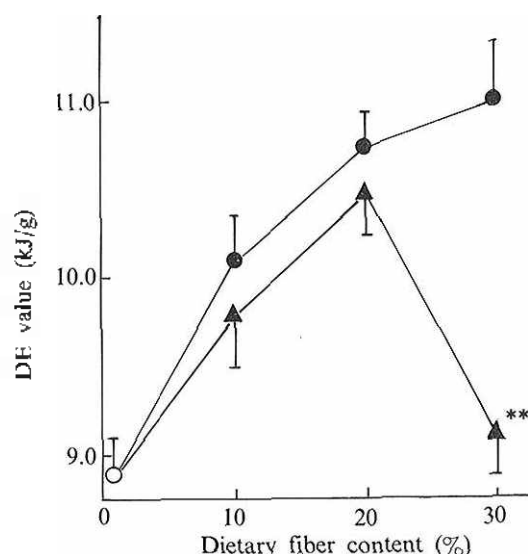
[2] ns, not significant; * $p < 0.05$.

Figure 1. The comparison between cellulose (●) and corn dietary fiber (CDF, ▲) in increasing dietary DE value (kJ/g). Vertical bars stand for SEM of 7 birds. **Significantly different from cellulose at the same dietary fiber content at $p < 0.01$.

cating that biopotency of CDF for increasing dietary DE value was lower, though not significantly up to 20% and clearly at 30%, than cellulose.

Discussion

In the present study, an isonitrogenous, isocaloric low-energy diet was used to facilitate the detection of differences, if any, between the two fiber sources. The diet was limiting in energy because it has been frequently observed in the authors' laboratory that a similar purified diet in which only the dietary fiber of the experimental diets was replaced by corn starch have supported growth 1.5 to 2 times as fast as those in the present study. The overall poor growth with the low-energy diet might be brought about in part by decreased density of the diet, because there is a limited capacity of the bird which could eat daily maximum volume of feed. However, the differences between the two fiber sources in the present study should reflect the differences in the course of digestion and subsequent metabolism of the digested and absorbed products, provided

that density of the two fibers was not very different.

In the present study, not only ME values but also DE values were determined. The reason is that nutritional impacts of differences in the two dietary fibers, if any, would be expected to occur primarily at the digestion step. Similar ME/DE values among treatments (table 3) may support the hypothesis that the difference is at digestion step. In chickens, however, DE value of a diet cannot be measured easily because urine and feces are excreted together in the droppings. For measuring DE values, therefore, the chemical extraction of urinary N and energy from droppings was attempted as described previously (Muramatsu et al., 1991). The chemical fractionation method was a simple and convenient technique for measuring DE values in young chicks with which surgical separation of feces and urine is difficult and laborious.

The results of growth performance, N and NDF digestibility, dietary DE and ME values, energy deposition, and NE values for production showed that the CDF was inferior to cellulose. This was unexpected in the light of the findings in mammals. Compared with cellulose, hemicellulose, which is a more soluble fiber than cellulose, was reported to be digested more easily and utilized more efficiently in rats (Keys et al., 1969), pigs (Keys et al., 1970), and chimpanzees (Milton and Demment, 1988). If this also applies to the chicken, CDF which consists mainly of hemicellulose should be a better energy source than cellulose, although fiber utilization in chickens is not so efficient as in mammalian species due to the fast transit of gut contents.

The reason for poorer performance of birds fed CDF was unknown, but it may be that the CDF contains plenty of hemicellulose, which is degraded to release pentoses such as arabinose and xylan. There appears to be limited ability in chickens to absorb these pentoses. Wagh and Waibel (1966) reported, for example, that the addition of pentose to a diet more than 10% would result in growth retardation, diarrhea, and lack of appetite. When fiber was included at 20, 40 and 60% in a chicken diet, feed efficiency was less by feeding xylose than glucose, and increased xylose levels resulted in further poorer performance (Baker, 1977). The inefficient pentose absorption might probably the case for the poor

utilization of CDF especially at 30% where ME and DE values were significantly lower in comparison with cellulose at the same 30% concentration.

In the present study, the ME value of the low-energy diets was set at 10.24 kJ/g, but the observed ME values were lower, ranging from 8.3 to 10.1 kJ/g. During the early stage of chicken growth as in the present study, ME value of a diet would be less than the one measured later (Zelenka, 1968), partly due to low digestibility of dietary fat. However, the expected decrease in ME value due to age would be by 4 to 5% under the conditions in the present study (Zelenka, 1968), suggesting that another 16% reduction was unexplained. The reason for this discrepancy remained to be studied in the context of high fiber inclusion in a diet.

Acknowledgements

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