Brazilian Journal of Poultry Science
Revista Brasileira de Ciência Avícola

ISSN 1516-635X Apr - Jun 2013 / v.15 / n.2 / 83-90

Effect of Dietary Fiber, Genetic Strain and Age on the Digestive Metabolism of Broiler Chickens

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Keywords

Age, fiber, metabolism, pair-fed, strain.

*Part of this article was published in the proceedings of Reunião Anual da Sociedade Brasileira de Zootecnia, 2010 and 2011.

Submitted: July/2011
Approved: March/2013

ABSTRACT

In this study, 360 male broilers, out of which 240 of a fast-growing strain (Cobb500), and 120 of a slow-growing strain (Label Rouge), were used to evaluate the effect of dietary fiber on digesta transit time and digestive metabolism during the period of 1 to 42 days of age. A completely randomized experimental design with a 3x2 factorial arrangement was applied, consisting of three groups of birds (slow-growing – SG; fast-growing fed *ad libitum* – FGAL; and fast-growing pair-fed with SG broilers – FGPF) and two iso-protein diets (a 3100 kcal ME/kg low-fiber diet –LFD- and a 2800 kcal ME/kg high-fiber diet –HFD- with 14% wheat bran and 4% oat hulls). HFD-fed birds presented lower ME retention ($p < 0.001$) and lower dry matter metabolizability (DMM) ($p < 0.001$), which is possibly related to the shorter digesta transit time observed in these birds ($p < 0.001$). DMM was reduced with age, whereas metabolizable energy remained almost constant ($p < 0.001$) independently of strain. This may be related to the increase in feed intake as birds age. The slow-growing strain did not present better utilization of the high-fiber diet as compared to the fast-growing strain in none of the analyzed ages, even though showing a significant better use of fiber and dietary energy from 31 days of age.

INTRODUCTION

Dietary fiber (DF) is poorly digested by poultry, and consequently contribution to the nutritional value of feeds is uncertain (Ferreira, 994). Otherwise, the use of alternative ingredients derived from biofuel production and that have with higher fiber content than corn and soybean meal would be more common in poultryuct fiber. Dietary fiber chemically includes non-starch polysaccharides such as cellulose, arabinoxylans, inulin, chitins, pectins, beta-glucans and phenolic polymer lignin that are present in the cell wall of plants (Bach Knudsen, 2001). Analytically, DF is usually considered as part of the dietary components that remain after the extraction with a neutral detergent solution, according to the method described by Van Soest & Wine (1967) it is known as neutral detergent fiber (NDF).

Several studies have shown that dietary metabolizable energy (ME) increases as birds age (Sell, 1996; Zelenka, 1968; Batal & Parsons, 2002). Shires *et al.* (1987) found lower feed passage rates in older birds, and suggested that the exposure of the diet for a longer period to microbial fermentation in the caeca may increase DF digestibility. On the other hand, Siregar & Farrel (1980) observed that ME values were not influenced by broiler age, whereas Bartov (1988) reported

ME decrease with age. It must be noted that the feed composition table of the NRC (1994) presents a single ME value for each feedstuff, and does not take into consideration digestibility changes in broilers of different ages.

Commercial broiler strains have been selected for high growth rate and high feed efficiency based on the use of high digestibility diets with no ME limitations. This selection promoted changes in digestive form shape and functions that may have reduced the utilization of low-digestibility diets (Shires *et al.*, 1987). On the other hand, low-performance genetic strains were not submitted to the same selection pressure; these birds are usually reared under alternative poultry production systems, and may be better adapted to lower quality diets.

This study aimed at comparing digesta transit time and diet metabolizability responses of a commercial fast-growing broiler strain to a slow-growing strain fed diets with increasing fiber levels, and determine the age or development phase when the utilization of dietary components is optimal, relating digestive transit time to nutrient metabolizability as influenced by dietary fiber.

MATERIAL AND METHODS

In this study, 360 male broilers were used, out of which 240 were of a fast-growing commercial strain (Cobb), and 120 of a slow-growing strain (Label Rouge). Birds were housed in 36 battery cages with 10 birds each, in a environmentally-controlled room with 24 h of light per day, from 1 to 42 days of age.

During the first four experimental days, all birds were fed a single pre-starter feed *ad libitum*. From day five, two iso-protein diets were fed: a low-fiber diet (LFD), based on corn and soybean meal, with 3100kcal ME/kg; or a high-fiber diet (HFD), based on the LFD, to which 14% wheat bran and 4% oat hulls were added, containin 2800 kcal ME/kg, which corresponded to an increase of 7.7% in neutral detergent fiber. The LFD and the pre-starter diet were formulated with nutritional levels similar to those recommended by Rostagno *et al.* (2005). A single experimental diet was fed during the entire period to each treatment group to allow comparing diet digestibility among different bird ages (Table 1).

Diets were fed to three different groups of 120 each: slow-growing Label Rouge birds fed *ad libitum* (SG), Cobb500 birds fed *ad libitum* (FGAL), and Cobb500 birds pair-fed with Label Rouge birds (FGPF). This last group was housed one day after the Label Rouge birds in order to receive the same amount of feed consumed by the Label group in the previous day to evaluate digestibility at the same feed intake. Pair-feeding was performed according to diet type, i.e., FGPF birds were fed once a day with the same amount of feed consumed by Label fed LFD or Label fed HFD during the previous day.

Table 1 - Nutritional composition of the experimental diets on fresh matter basis (FM).

Diets	Pre-starter	Low fiber	High fiber
Analyzed composition (% FM)			
Dry matter (%)	88.71	88.38	88.56
Neutral detergent fiber (%)	11.05	11.81	19.51
Acid detergent fiber (%)	2.55	3.63	7.37
Crude protein (%)	22.83	19.72	19.95
Ashes (%)	5.21	5.01	5.3
Calculated composition[1]			
Metabolizable energy (kcal/kg)	3050	3100	2800
Crude fiber (%)	-	3.12	5.19
Calcium (%)	1	0.93	0.93
Available phosphorus (%)	0.46	0.44	0.44
Sodium (%)	0.23	0.2	0.2
Digestible arginine (%)	1.19	1.14	1.15
Digestible lysine (%)	1.3	1.14	1.14
Digestible methionine (%)	0.62	0.54	0.54
Digestible Met + Cys (%)	0.94	0.83	0.83
Digestible tryptophan (%)	0.21	0.21	0.21
Digestible threonine (%)	0.86	0.74	0.74
Choline (mg/kg)	1500	1450	1450

[1] Levels calculated according to Rostagno *et al.* (2005).

A completely randomized experimental design in a 3x2 factorial arrangement, with 6 treatments and 6 replicates each, was applied. Treatments consisted of three groups of birds and two dietary fiber levels.

Digestive tract (DT) relative weight was evaluated 21 e and 42 days of age representative bird per replicate. The DT was removed, rinsed of digesta residues, and divided into two sections: the anterior section included the segment from the esophagus to the gizzard, whereas the posterior section included the segment from the duodenum to the vent. The relative weights of the total digestive tract (DTW), anterior section (DTWas), and posterior (DTWps) sections were calculated as a percentage of live weight.

Digesta transit time (DTT) was evaluated at 19 and 38 days of age, using 0.5% ferric oxide (Fe_2O_3) in the experimental diets (no fasting time was used), and the time in minutes elapsed between marker supply and its appearance in 60% of the excreta in the tray was recorded.

The following metabolizability and digestibility responses were evaluated: dry matter metabolizability (DMM), organic matter metabolizability (OMM), crude protein metabolizability (CPM), gross energy metabolizability (GEM); neutral detergent fiber digestibility (NDFD), acid detergent fiber digestibility (ADFD), and dietary metabolizable energy corrected for null nitrogen balance (AMEn). These responses were obtained by total excreta collection during four periods of digestibility assessment of three days each: 9-11, 19-21, 30-32, and 40-42 days of age, corresponding to intermediate days of 10, 20, 31, and 41, respectively.

Dry matter, ashes, organic matter, and crude protein of feeds and excreta were determined according to the methods of the AOAC (1995). NDF and ADF contents in feeds and excreta were determined according to Goering and Van Soest (1970). For the determination of NDF in the diets, 0.5 mL α-amylase per L of neutral detergent solution was used (Van Soest *et al.* 1991). Gross energy of feeds and excreta were determined using an isoperibolic calorimeter (IKA WERKE, model C2000).

Responses were submitted to analysis of variance using the statistical software package Statgraphics Plus 4.1 (Manugistics, 1997). Means were compared using the test of Student-Newman-Keuls (SNK) at 5% significance level. The effect of age on metabolizability and digestibility indexes was evaluated using the procedure of repeated measures between periods using the model Proc Mixed of SAS, and means were compared using the Least-Square-Difference test (LSD).

RESULTS AND DISCUSSION

Digestive tract weight and digesta transit time

There was no effect of interaction between the studied factors on the weight of the digestive tract and its segments, or on digesta transit time (Table 2). Dietary fiber content did not influence digestive tract weights, except for DTWas at 21 days of age, which was higher in birds fed the HFD ($p < 0.001$). This response is related to the higher activity of the gizzard, which resulted in its higher relative weight. According to Jorgensen *et al.* (1996), DTW, and particularly caeca weight, increases only when dietary fiber level was higher than that used in the present experiment. SG birds presented, in general, higher digestive tract weight as compared to the other groups. This response is partially explained by the lower final live weight of SG birds, which resulted in a higher DT weight relative to body weight. However, the higher DTWas at 21 days and DTWps at 38 days relative to FGPF birds indicates development differences, as their live weights were not considerably different.

Digesta transit time (DTT) at 19 days of age was not significantly influenced by dietary fiber level. However, at 38 days, DTT was lower in birds fed the HFD ($p < 0.001$), which is consistent with the findings of Shires *et al.* (1987). Warpechowski (1996) observed a significantly lower DTT when feeding adult cockerels with a diet containing 8.3% higher NDF levels as

Table 2 - Relative digestive tract weight (DTW) of 21- and 42-d-old and digesta transit time (DTT) of 19- and 38-old slow-growing and fast-growing broilers divided into three groups (SG, FGAL, FGPF) and fed diets with two fiber levels.

Age	21 d			19 d	42 d			38 d
	DTW	DTWas	DTWps	DTT	DTW	DTWas	DTWps	DTT
Diet	% LW			Minutes	% LW			Minutes
LFD	8.32	3.74	4.59	276	5.39	2.76	2.63	296
HFD	8.96	4.38	4.58	265	5.73	3.00	2.73	262
Group								
SG	9.34[a]	4.65[a]	4.69	341[a]	6.65[a]	3.21[a]	3.44[a]	322[a]
FGAL	8.20[b]	3.60[b]	4.60	282[b]	4.46[c]	2.29[b]	2.17[c]	319[a]
FGPF	8.38[b]	3.93[b]	4.45	189[c]	5.57[b]	3.14[a]	2.43[b]	195[b]
SEM	0.60	0.27	0.44	16.5	0.36	0.27	0.20	18.1
	Probability							
Diet	NS	***	NS	NS	NS	NS	NS	***
Bird group	*	***	NS	***	***	***	***	***
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

[a-c] Means followed by different letters in the same column are significantly different by the SNK test ($p<0.05$). DTWas=relative weight of the anterior section of the digestive tract – from the esophagus to the gizzard; DTWps=relative weight of the posterior section of the digestive tract – from the duodenum to the vent; LFD=low-fiber diet; HFD=high-fiber diet; SG=slow growing strain fed *ad libitum;* FGAL=fast growing strain fed *ad libitum*; FGPF=fast growing strain pair-fed with SG; SEM=standard error of the mean; *=p < 0.05; **=p < 0.01; ***=p < 0.001; NS=not significant.

compared to a basal diet. The transit time obtained in the present study was higher than that found by Cortés *et al.* (2009), d, using the same methodoogy and, found an average transit time of 228 minutes in 21-d-old broilers.

SG birds presented higher DTT as compared to FGAL at 19 days of age ($p < 0.001$). At 38 days, there were no significant differences between these groups. DTT was considerably lower in the FGPF group, both at 19 and 38 days ($p < 0.001$) relative to the other groups. Larbier & Leclerq (1992) found that transit time is lower in bird submit a long fasting times before feeding, which was the case of the FGPF birds. However, the observed DTT was not only due to fasting, but also to the fact that the virtually empty digestive tract allowed the rapid dilution of the marker in the liquid phase of the digesta. Perhaps a different methodology should be more appropriate in this case.

Digestibility

Digestibility responses, corresponding to the ages of 10, 20, 31, and 41 days, are presented in Tables 3 e 4. The significant interactions between the studied factors observed at 10 and 20 days of age did not contribute much to the discussion, as they were not consistent and did not present biological coherence. In all evaluated ages, birds fed the HFD presented lower DMM, OMM, GEM and NDFD and AMEn ($p < 0.001$). Crude protein metabolizability was not influenced by fiber level because the diets contained equal protein levels. HFD-fed birds also presented, in general, higher ADF digestibility ($p < 0.001$), which may be related to the low amount of ADF in the low-fiber diet.

The effect of fiber in the present experiment is consistent with the findings of Jorgensen *et al.* (1996) and Pinheiro *et al.* (2008), who showed a significant reduction in nutrient digestibility as fiber level increased in broiler diets.

As to bird group, at 10 days of age, the metabolizability of the diet and its fractions was higher in FGPF birds ($p < 0.001$). Several authors found better nutrient digestibility when there was moderate feed intake restriction (Teeter *et al.*, 1985; Yalda *et al.*, 1996; Bonnet *et al.,* 1997). At 20 days of age, SG and FGPF birds were similar to each other and significantly superior to FGAL birds as to DMM, OMM, GEM, and AMEn ($p < 0.001$). At 31 days of age, birds presented similar metabolism values, except for fiber digestibility, which was higher in SG birds as compared to FGPF ($p < 0.01$). At 41 days of age, DMM, OMM, and NDFD were not influenced by bird group, while SG birds presented significantly higher GEM ($p < 0.01$), AMEn ($p < 0.001$) and ADFD ($p < 0.001$) values.

The SG group presented higher ADFD and similar NDFD as compared to the other groups only during the last two periods, possibly indicating the higher development of the digestive tract of this strain, which allowed better fiber utilization.

Table 3 - Metabolizability and digestibility coefficients of 10- and 20-d-old slow-growing and fast-growing broilers divided into three groups (SG, FGAL, FGPF) and fed diets with two fiber levels.

Age	10 d							20 d						
	DMM	OMM	CPM	GEM	NDFD	ADFD	AMEn	DMM	OMM	CPM	GEM	NDFD	ADFD	AMEn
	%						kcal/kgDM	%						kcal/kgDM
Diets														
LFD	76.46	78.54	61.66	79.23	43.40	23.82	3498	74.59	76.88	62.78	77.99	31.55	12.71	3442
HFD	69.01	71.34	62.65	71.93	35.30	27.02	3110	67.09	69.36	61.08	70.36	26.40	19.17	3037
Bird group														
SG	71.25^b	73.43^b	57.14^c	74.58^b	34.77^b	24.97	3272^b	71.52^a	73.64^a	61.63^b	75.13^a	27.91^b	16.50	3284^a
FGAL	72.37^b	74.56^b	61.37^b	74.96^b	41.66^a	25.10	3277^b	68.90^b	71.18^b	59.52^c	72.26^b	26.75^b	14.53	3158^b
FGPF	74.57^a	76.83^a	67.96^a	77.21^a	41.63^a	26.20	3362^a	72.09^a	74.53^a	64.63^a	75.14^a	32.27^a	16.79	3276^a
SEM	1.17	1.13	2.21	1.05	2.67	3.04	44.1	1.02	0.95	1.81	0.96	2.66	2.66	39.8
	Probability													
Diet	***	***	NS	***	***	*	***	***	***	*	***	***	***	***
Group	***	***	***	***	***	NS	***	***	***	***	***	**	NS	***
Interaction	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	*	*	NS

[a-c] Means followed by different letters in the same column are significantly different by the SNK test ($p<0.05$). DMM=dry matter metabolizability; OMM=organic matter metabolizability; CPM=crude protein metabolizability; GEM=gross energy metabolizability; NDFD=neutral detergent fiber digestibility; ADFD=acid detergent fiber digestibility; AMEn=dietary apparent metabolizable energy level corrected for nitrogen; LFD=low-fiber diet; HFD: high-fiber diet; SG=slow growing strain fed *ad libitum;* FGAL=fast growing strain fed *ad libitum*; FGPF=fast growing strain pair-fed with SG; SEM: standard error of the mean; *=$p < 0.05$; **=$p < 0.01$; ***=$p < 0.001$; NS=not significant.

Table 4 - Metabolizability and digestibility coefficients of 31- and 41-d-old slow-growing and fast-growing broilers divided into three groups (SG, FGAL, FGPF) and fed diets with two fiber levels.

Age	---------- 31 d ----------							---------- 41 d ----------						
	DMM	OMM	CPM	GEM	NDFD	ADFD	AMEn	DMM	OMM	CPM	GEM	NDFD	ADFD	AMEn
	---------- % ----------						kcal/	---------- % ----------						kcal/
Diets							kgDM							kgDM
LFD	73.98	76.88	59.58	77.88	28.30	7.43	3432	74.73	77.70	56.28	78.06	29.18	10.02	3450
HFD	66.64	69.53	59.28	70.84	21.96	13.71	3122	66.16	69.07	54.88	70.39	23.74	15.08	3114
Bird group														
SG	70.64	73.20	57.22	75.10	28.01[a]	15.09[a]	3318[a]	70.65	73.53	50.30[b]	75.65[a]	28.90	18.84[a]	3365[a]
FGAL	70.22	73.00	58.41	74.43	25.62[ab]	9.63[b]	3283[ab]	69.35	72.42	51.50[b]	73.20[b]	26.55	11.98[b]	3247[b]
FGPF	70.08	73.40	62.67	73.54	21.75[b]	6.99[b]	3230[b]	71.33	74.20	64.94[a]	73.82[b]	23.94	6.82[b]	3236[b]
SEM	1.41	1.29	3.55	1.20	3.65	3.91	50.2	1.47	1.37	2.97	1.42	4.10	5.03	60.7
	---------- Probability ----------													
Diet	***	***	NS	***	**	**	***	***	***	NS	***	**	*	***
Group	NS	NS	NS	NS	*	**	*	NS	NS	***	**	NS	***	***
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a-c] Means followed by different letters in the same column are significantly different by the LSD test (p<0.05). DMM=dry matter metabolizability; OMM=organic matter metabolizability; CPM=crude protein metabolizability; GEM=gross energy metabolizability; NDFD=neutral detergent fiber digestibility; ADFD=acid detergent fiber digestibility; AMEn=dietary apparent metabolizable energy level corrected for nitrogen; LFD=low-fiber diet; HFD=high-fiber diet; SG=slow growing strain fed *ad libitum;* FGAL=fast growing strain fed ; FGPF=fast growing strain pair-fed with SG; SEM=standard error of the mean; *=p < 0.05; **=p < 0.01; ***=p < 0.001; NS=not significant.

The FGPF group showed higher DM, OM and GE metabolizability at 10 d, bendency trend was not followed at 20, 31 and 41 d of age. This may be related with the increase in feed restriction severity as a function of their genetic potential for growth. During the subsequent phases, these restricted-voracity were highly when at the time feed supplied, leading to lower transit time, and consequently, lower nutrient digestibility. It must be noted that these responses are not directly related to FCR, which was better in the final period in this group as compared to the others. However, the higher GEM and AMEn values of the SG groups at 41 days of age are consistent with their higher DTW at 42 days of age.

Comparison among periods

Using the analysis of repeated measures in time (Table 5), it was possible to conclude that all evaluated parameters presented significantly lower values during the periods after 10 days of age (p < 0.001), except for AMEn, which was lower only at 20 days as compared to the other periods (p < 0.01). The reduction in nutrient digestibility and AMEn stability as birds aged disagree with the findings of Zelenka (1968) and Batal & Parsons (2002), who showed that diet utilization improved with age. Carré *et al.* (1995) also observed higher carbohydrate digestibility in mature birds, which was attributed to their higher intestinal fermentation capacity and their higher efficiency of absorption of fermentation products.

The better digestibility on day 10 observed in the present study may be related to higher digesta retention in the digestive tract during the first weeks of life, and later with the increase in feed intake with age. According to Sell (1996), the gastrointestinal tract reaches higher proportion relative to body mass between 6 to 8 days after hatching. Therefore, during this period there is a higher fill effect in the gut, because the digestive tract grows faster than the rest of the body mass, promoting higher nutrient retention in the lumen of the digestive tract and consequent reduction in fecal excretion, thereby increasing digestibility. In the present study, relative DT weight at 21 days (8.6%) was higher as compared to 42 days (5.6%).

The interactions observed when the factor age was included in the analysis of repeated measures reflect the effects shown in Tables 3 and 4 by age, and therefore, do not add much to the previous discussion. Rather, they indicate the amplification of the significant effects when the number of observations is increased in the joint analysis of the four ages studied.

CONCLUSIONS

Digestive tract weight and digesta transit time were not influenced by broiler strain (slow-growing or fast-growing). The high-fiber diet increased the weight of the anterior section of the digestive tract and decreased digesta transit time. Independent of the genetic strain, dietary fiber reduced nutrient digestibility. The slow-growing Label Rouge broilers presented better fiber-diet digestibility than the fast-growing strain broilers after 31 days of age, possibly due to the higher development of the digestive tract in this phase, however, the utilization of high-fiber diet was similar along the experimental period, independently of genetic.

Table 5 - Effect of diet, bird group, and age, obtained by analysis of repeated measures of the evaluated periods, on metabolizability and digestibility coefficients of slow-growing and fast-growing broilers divided into three groups (SG, FGAL and FGPF) fed diets with two fiber levels.

	DMM	OMM	CPM	GEM	NDFD	ADFD	AMEn
Diets	----------------------------------			%	--------------------------		kcal/ kgDM
LFD	74.94	77.50	59.65	78.29	32.89	12.64	3455.39
HFD	67.23	69.82	59.90	70.88	26.85	18.75	3096.07
SEM	0.21	0.20	0.46	0.19	0.55	0.71	8.04
Group							
SG	71.02[b]	73.50[b]	56.57[b]	75.12[a]	29.90	19.14[a]	3309.91[a]
FGAL	70.21[c]	72.84[b]	57.70[b]	73.71[b]	30.15	15.31[b]	3241.51[c]
FGPF	72.02[a]	74.64[a]	65.05[a]	74.93[a]	29.56	12.63[c]	3275.76[b]
SEM	0.26	0.24	0.57	0.23	0.68	0.87	9.84
Age (d)							
10	72.73[a]	74.94[a]	62.16[a]	75.58[a]	39.35[a]	25.42[a]	3303.82[a]
20	70.84[b]	73.12[b]	61.93[a]	74.17[b]	28.98[b]	16.33[b]	3239.59[b]
31	70.31[b]	73.20[b]	59.43[b]	74.36[b]	24.68[c]	8.48[d]	3277.17[a]
41	70.45[b]	73.38[b]	55.58[c]	74.22[b]	26.46[c]	12.55[c]	3282.33[a]
SEM	0.30	0.28	0.65	0.27	0.78	1.01	11.4
	----------------------------------			Probability	------------------------------		
Diet (D)	***	***	NS	***	***	***	***
Group (G)	***	***	***	***	NS	***	***
Age (A)	***	***	***	***	***	***	**
D x G	NS	NS	NS	NS	NS	NS	NS
D x A	NS	NS	NS	NS	NS	NS	*
G x A	***	***	***	***	***	***	***
D x G x A	NS	*	NS	NS	**	**	NS

[a-d] Means followed by different letters in the same column are significantly different by the LSD test (P<0.05). DMM=dry matter metabolizability; OMM=organic matter metabolizability; CPM=crude protein metabolizability; GEM=gross energy metabolizability; NDFD=neutral detergent fiber digestibility; ADFD=acid detergent fiber digestibility; AMEn=dietary apparent metabolizable energy level corrected for nitrogen; LFD=low-fiber diet; HFD=high-fiber diet; SG=slow growing strain fed FGAL=fast growing strain fed ; FGPF=fast growing strain pair-fed with SG; SEM= standard error of the mean; *=p < 0.05; **=p < 0.01; ***=p < 0.001; NS=not significant.

ACKNOWLEDGEMENTS

The authors thank Coordenação de Aperfeiçoamento de Pessoal de nível Superior (CAPES), Ministério da Educação, Brazil, and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Ministério da Ciência e Tecnologia, Brazil for funding this study.

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