Longitudinal investigations of anatomical and morphological development of the gastrointestinal tract in goats from colostrum to postweaning

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ABSTRACT

The digestive tract development in goat kids around weaning is vital to the establishment of digestion and absorption function, growth, and health of adults. The objective was to explore the effects of age and solid feed on the anatomical and morphological development of the gastrointestinal tract of Laiwu Black goat kids. Forty-eight female Laiwu Black goats at 8 ages (1, 7, 14, 28, 42, 56, 70, and 84 d; 6 goats per group) were selected and killed for anatomical and morphological analysis. The goats experienced the following 4 diet phases: maternal colostrum (MC; d 1, d 7), maternal milk (MM; d 14, d 28), maternal milk plus solid diet (MMSD; d 42, d 56) and only solid diet (OSD; d 70, d 84). The body and carcass weights were not significantly changed during MC and MM phases but changed during the MMSD phase. The absolute growth of body and carcass weights were higher in the MMSD phase than in MM phase. In addition, the dressing percentage was the highest in the MMSD phase. The body size indices evolved progressively and increased over time. The percentage of internal and external organs to body weight decreased over time, whereas the percentage to complex stomach percentage increased. The rumen and omasum weight experienced synchronous absolute growth over time, especially in the OSD phase. In contrast, the absolute growth of the reticulum and abomasum was the highest in MMSD and MC phases, respectively. After weaning, the goats showed the highest papillae height, lamina propria, muscle layer thickness, and epithelial thickness. The OSD phase showed the highest colonic mucosa thickness, ileal villus height, and ileal muscle layer thickness. The crypt depth was higher in the MMSD phase than in the MM phase. Moreover, the crypt depth and muscle layer thickness of jejunum increased over time. Furthermore, duode-

nal crypt depth, muscle layer thickness, and epithelial thickness increased in the OSD phase compared with other stages. In conclusion, the histological investigation supports the improvement of the morphological development of the digestive tract and the growth performance in the solid feed phase. It is recommended to add solid food as early as 4 wk old.

Key words: anatomic development, gut morphology, gastrointestinal tract, solid feed, weaning

INTRODUCTION

Goats (*Capra hircus*) are a global livestock species because they provide essential products, such as milk, meat, and skin (Wang et al., 2021). The number of goats in China at the end of 2020 was 133.45 million (National Bureau of Statistics of China, 2020). The rapid economic growth increased the demand for improving the quality and productivity of goats. After birth, the digestive tract exhibits morphological, biochemical, and ultrastructural changes that contribute to its maturation (Lopez-Pedrosa et al., 1998). The digestive tract development in goat kids has a long-term effect on the establishment of digestion and absorption function, production performance, and health status (Jiao et al., 2016; Diao et al., 2019). Therefore, it is vital to master the rules of anatomical and morphological development of the gastrointestinal tract to tap the growth potential of goats and promote industrial development (Jin et al., 2018). The knowledge about the longitudinal effects of gastrointestinal physiology, especially in the transition weaning stage, could be helpful to increase our understanding of the anatomical and morphological development of the digestive tract to control stress after weaning, to avoid challenges in livestock production.

The small intestine is the main site for digestion of liquid feed, such as maternal colostrum (MC), maternal milk (MM), or milk replacer (MR; Górká et al., 2011). The results of Blättler et al. (2001) showed the improvement of small intestine development in neonatal

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calves fed colostrum. The digestion of goat kids shifts from the intestine to the rumen during the transition of diets from milk to solid feed (Li et al., 2019a). Adequate nutrition, meanwhile, guarantees gastrointestinal development, immunity, and metabolite changes (Liu et al., 2017; Saro et al., 2018; Yang et al., 2018). Several studies show that the solid diet in early life substantially affects the early development of the rumen epithelium (Lv et al., 2019) and reduces nutritional deficiency and weight loss after weaning (Khan et al., 2011). Furthermore, rumen development and VFA production stimulated by solid feed intake promotes the nutrient availability in the intestine and its morphology development (Baldwin, 1999). Therefore, further studies are needed to explore the effects of nutrition on the digestive tract development of young goats. Age is also an essential factor to be considered because it can change the physiology and function of the gut (Merchant et al., 2016). In goats, the effects of age from birth to d 70 and feeding system (supplemental feeding vs. grazing) have been reported in rumen development (Jiao et al., 2015b) and the small intestine (Li et al., 2016). They show an improvement of gastrointestinal morphology over time, irrespective of the feeding system (Jiao et al., 2015b; Li et al., 2016). However, this development was strong during the weaning and the diet-change periods (Jiao et al., 2015b; Li et al., 2016), suggesting that the age effects are still confounded by the dietary changes. The study of Jiao et al. (2016) showed that the gut bacteria of grazing goat kids undergo stage-associated changes from the preruminant to ruminant stages.

The Laiwu Black goat is an excellent local breed in China. In the early Qing Dynasty, a distribution center for goat breeding and trading was formed in the Laiwu area. With continuous selection, the Laiwu Black goat formed the characteristics of high fecundity, resistance to rough feeding, strong disease resistance, and delicious meat (Liu et al., 2012). By the late Qing Dynasty, the food culture of eating meat and drinking soup made by Laiwu Black goat had spread and became the most famous food in the hotel at that time. Finally, the Laiwu Black goat was recognized as an excellent local breed by China in 1999, and was listed as a protected breed of livestock genetic resource by the state in 2013 (Liu et al., 2012). However, to the best of our knowledge, there has been no data published about the anatomic and morphological development of the digestive tract of the Laiwu Black goat during transition weaning and the influence of solid feed on this process. Further studies are needed to clarify the development rules of the digestive tract with changes in diet and age. It is hypothesized that the staged development of rumen morphology of the Laiwu Black goat is associated with the longitudinal change of diets from liquid to solid, and to the

phased development of the small and large intestines as well as the liver, kidney, and other organs. Therefore, the purpose of this study was to explore the anatomical and morphological development of the gastrointestinal tract and the growth performance of Laiwu Black goat kids by studying the colostrum, milk, milk and starter, and starter stages at 8 time points from birth to 84 d of age.

MATERIALS AND METHODS

Animals, Diets, and Housing

The experiment was approved by the Animal Ethics Committee of the Chinese Academy of Agricultural Sciences (with protocol AEC-CAAS-20191105; approval date: November 3, 2019). The experiment was conducted at Xiang Feng black goat farm, Laiwu district, Jinan city, Shandong, China (latitude, 36°02' N; longitude 117°19' E).

A total of 48 healthy female goats of different ages (1, 7, 14, 28, 42, 56, 70, and 84 d old) were randomly selected from the goat farm. One goat at d 1 with abnormal conditions was excluded from the experiment, so the total number of goats was 47. All the experimental goats were pure Laiwu Black goats with the same genetic background and raised at the same environment. The young goats' feeding regimens were as follows (Figure 1): MC was fed after birth, and MM was followed from d 8. After d 28, the solid diet was introduced with the MM (MMSD). Then, the goats were weaned at 60 d of age and offered only solid diet (OSD). This feeding management system was designed to elicit the stress of weaning.

The goats were under daily farm veterinary care throughout the experiment. After birth, goats were housed in well-ventilated pens with dams (14 m × 6 m: 20 animals per pen). At d 60, the goats were separated from their dams and transferred into individual pens with a slatted floor (4 m × 4 m: 10 goats per pen) until the end of the trial (d 84). During the experimental period, goats had free access to water and were offered a commercial starter diet *ad libitum* (Kangmeihua feed Company, China; Supplemental Table S1, <https://doi.org/10.6084/m9.figshare.17111312.v1>), which was formulated according to NRC (2007). The chemical analysis of solid diet samples was performed at the end of the experiment in the Laboratory of Ruminant Physiology and Nutrition, Feed Research Institute of Chinese Academy of Agricultural Sciences (Supplemental Table S1). Samples were analyzed for DM (AOAC International, 2003; method 934.01), CP (AOAC International, 2003; method 954.01), ash (AOAC International, 2003; method 942.05), ether extract (AOAC International,

2003; method 920.39), calcium (AOAC International, 2006; method 968.08), phosphorus (AOAC International, 2006; method 985.01), and NDF and ADF using the method described by Van Soest et al. (1991). Total energy and NFC were calculated according to NRC (2001) using the following equations:

$$\text{NFC, \%} = 100 - (\text{NDF} + \text{CP} + \text{ether extract} + \text{ash});$$

$$\begin{aligned} \text{Total energy, Mcal/kg} = & \\ & (\text{NFC}/100) \times 4.2 + (\text{NDF}/100) \times 4.2 + (\text{CP}/100) \\ & \times 5.6 + (\text{ether extract}/100) \times 9.4. \end{aligned}$$

Growth Performance and Carcass Measurements

All the goat kids were taken to an on-farm experimental abattoir for slaughter. The live BW was recorded, and the body size indices (oblique body length, height, cannon bone circumference, chest circumference, and chest depth) were measured using tape with an accuracy of 0.1 cm immediately before the slaughter of goats. Then, the goats were anesthetized using sodium pentobarbitone, killed by exsanguination from the jugular vein, skinned, and eviscerated according to the method described by Chai et al. (2018). The internal organs (heart, liver, spleen, lungs, and kidneys) and external organs (head, hoof, and skin) were weighed. The hot carcass weight (**HCW**) and the dressing percentage were determined. The empty weight of rumen, reticulum, omasum, and abomasum were recorded. The rumen volume was recorded by filling the rumen with water. Furthermore, the forestomach parts were expressed as a percentage of live BW or complex stomach weight. The absolute growth of BW, HCW, internal and external organs, stomach chambers, and rumen volume were calculated according to the following equation:

$$\text{Absolute growth rate} = (W_2 - W_1)/(T_2 - T_1),$$

where W_1 is the initial value at time T_1 , and W_2 is the final value at time T_2 . The absolute growth rate

was used to distinguish the growth intensity of different feeding stages.

Histomorphological Examination

Rumen, small intestine (duodenum, jejunum, and ileum), and large intestine (colon) tissue samples were collected. Tissue samples (about 1 cm²) were separated with a sharp scalpel from the nonsqueezed parts of the organ, washed with prechilled phosphate buffer solution (pH = 7.1), placed in an embedding box, and immersed in a 10% formalin solution immediately. After fixation, samples were dehydrated by a TSJ-II fully automatic closed tissue dehydrator (Zhongwei Electronic Instrument Co., Ltd.). The samples were trimmed and embedded in paraffin blocks using a BMJ-III type embedding machine (Zhongwei Electronic Instrument Factory). The formed blocks were cut on a rotary microtome (Leica-2016) and stained with hematoxylin and eosin (Chengdu Lilai Biological Technology Co., Ltd.). The histomorphological examination was done using a BA400 digital trinocular micro-camera (McAudio Industrial Group Co., Ltd.) and Image-Pro-Plus 6.0 software (American Media Cybernetics). Six pictures were taken for each sample, including 2 objective lenses of 4× and 40×. Ten sets of data were measured for each slice number. The small intestine indicators included villus height, crypt depth, and muscle layer thickness by lens 4×, as well as the epithelial thickness by lens 40×. Colonic mucosal thickness and muscle layer thickness were measured by lens 4×, and the colonic epithelial thickness was measured by lens 40×. The rumen indicators included rumen papillae height, rumen papillae width, lamina propria thickness, muscle layer thickness (4× lens), epithelial thickness, and stratum corneum thickness (40× lens).

Statistical Analysis

The data were tested for normality before the statistical analysis. The data analysis was performed by one-way ANOVA using IBM SPSS Statistics 22 (IBM Corp.). The statistical model was as follows:

Figure 1. The experimental feeding management system from birth to 84 d of age in goats ($n = 47$).

$$Y_i = \mu + T_i + \varepsilon_i,$$

where Y_i is the dependent variable, μ is the overall mean, T_i is the fixed effect of group (8 time points), and ε_i is the error term. Orthogonal polynomials were used to test polynomial trends (linear, quadratic, and cubic effects). Statistical differences between the means of groups were tested using Duncan's multiple range test. In addition, the differences were considered significant at the level of $P < 0.05$.

RESULTS

Growth Performance

The BW and HCW increased linearly ($P < 0.01$) over time, reaching 10.3 ± 0.41 and 4.97 ± 0.21 kg at d 84, respectively ($\pm$ SE; Table 1). The goats were heavier ($P < 0.01$) at d 84 than d 42, at d 42 than d 28, and at d 28 than d 1. The dressing percentage showed a quadratic increase ($P < 0.01$) over time and reached $52.7 \pm 0.55\%$ in the MMSD phase. The absolute growth of BW was higher ($P < 0.05$) in the MMSD phase (114 ± 10.1 kg) than in the MM phase (65.1 ± 7.31 kg; Figure 2). In addition, the absolute growth of HCW was higher ($P < 0.05$) in the MMSD phase than in both OSD and MM phases (63.6 ± 9.4 , 25.6 ± 10.4 , and 37.5 ± 3.25 kg, respectively). Moreover, the oblique body length and body height experienced a synchronous linear increase ($P < 0.01$) over time and reached 49.5 and 44.5 cm at d 84, respectively (Table 1). The goats showed higher values at d 42 than d 14 and d 84 than d 42. Moreover, the chest circumference was higher ($P < 0.01$) at d 14 than d 7, d 42 than d 28, and d 70 than d 42. In addition, the cannon bone circumference and chest depth showed a slow increase ($P < 0.01$) over time; the d 42 values were higher than d 1 values (7.17 vs. 6.10 cm for cannon bone circumference; 18.0 vs. 8.80 cm for chest depth).

Organ Development

The internal and external organs increased ($P < 0.01$) over time, as shown in Table 2. The heart was heavier at d 42 than d 1 (40.1 vs. 25.2 g) and d 56 than d 28 (47.8 vs. 32.4 g). In addition, the liver was heavier at d 42 than d 1 (142 vs. 92.6 g) and d 70 than d 42 (197 vs. 142 g). In addition, the spleen was heavier at d 42 than d 7 (15.2 vs. 7.40 g) and d 56 than d 28 (20.4 vs. 13.9 g). The lungs were heavier at d 42 than d 7 (85.2 vs. 53.6 g) and d 70 than d 42 (117 vs. 85.2 g). The kidney weight was higher at d 70 and d 56 than d 1 (38.3, 38.7, and 25.1 g, respectively). Moreover, head and hoof were heavier at d 28 than d 1 (339 vs. 253 g

Table 1. Body and carcass weight and body size indices from colostrum to postweaning in goats (n = 47)

Item ¹	Diet ¹									
	MC			MM			MMSD			P-value ²
	d 1	d 7	d 14	d 28	d 42	d 56	d 70	d 84	Cub	
BW, kg	2.91 ^e	3.43 ^{de}	4.36 ^{de}	4.80 ^d	6.66 ^c	8.00 ^{bc}	8.89 ^{ab}	10.3 ^a	0.41	
Carcass weight, kg	1.40 ^d	1.68 ^c	2.23 ^{cd}	2.47 ^c	3.59 ^b	4.25 ^{ab}	4.36 ^{ab}	4.97 ^a	0.21	
Dressing percentage, %	47.5 ^b	49.2 ^{ab}	50.8 ^{ab}	51.5 ^{ab}	52.7 ^a	52.7 ^a	49.1 ^{ab}	48.0 ^{ab}	0.55	
Body oblique length, cm	28.7 ^d	29.9 ^d	33.6 ^{cd}	37.6 ^c	43.1 ^b	44.7 ^{ab}	45.7 ^{ab}	49.5 ^a	1.20	
Body height, cm	31.4 ^d	31.7 ^d	33.8 ^d	35.3 ^{cd}	38.7 ^{bc}	41.4 ^{ab}	42.2 ^{ab}	44.5 ^a	0.83	
Cannon circumference, cm	6.10 ^c	6.50 ^{bc}	6.83 ^{abc}	6.92 ^{abc}	7.17 ^{ab}	7.58 ^a	7.17 ^{ab}	7.58 ^a	0.11	
Chest girth, cm	33.4 ^e	34.7 ^e	38.9 ^d	39.6 ^d	44.9 ^c	48.0 ^{bc}	50.8 ^{ab}	53.0 ^a	1.07	
Chest depth, cm	8.80 ^d	8.08 ^d	10.2 ^d	15.8 ^c	18.0 ^{bc}	20.6 ^{ab}	18.9 ^{abc}	22.1 ^a	0.86	

^{a-e}Means within the same rows with different letters are significantly different ($P < 0.05$).

¹Diets: maternal colostrum (MC), maternal milk (MM), maternal milk plus solid diet (MMSD), and only solid diet (OSD).

²Lin = linear effect of age; Qua = quadratic effect of age; Cub = cubic effect of age.

Figure 2. The absolute growth of BW, carcass weight, internal and external organs, complex stomach chamber weight, and rumen volume in goats ($n = 47$) fed different diets from colostrum to 84 d of age. Different letters (a–c) represent a significant difference between the different feeding stages ($P < 0.01$). Error bars represent SEM.

for the head; 135 vs. 90.8 g for hoof). In addition, the skin was heavier at d 84 than d 42 and d 42 than d 7 (1,033, 809, and 533 g, respectively).

In contrast, the organ indices expressed as a percentage of BW decreased over time ($P < 0.05$; Table 2). Heart index was lower at d 70 than d 28, and d 28 than d 14 (0.54, 0.67, and 0.79%, respectively). In addition, the liver and hoof indices were lower at d 42 than d 28 (2.14 vs. 2.79% for the liver; 2.08 vs. 2.84% for hoof). The spleen index was lower at d 84 than d 28 (0.18 vs. 0.30%). Moreover, the lungs index was lower at d 42 than d 1 (1.29 vs. 1.65%). Furthermore, the kidney and head indices were lower at d 56 than d 14 and d 14 than d 1 (0.49, 0.67, and 0.88%, respectively, for kidney; 6.24, 7.35, and 8.81%, respectively, for head). In addition, the skin index was lower at d 28 than d 14 (12.3 vs. 15.3%) and d 84 than d 28 (10.0 vs. 12.3%). The absolute growth of the organ was not significantly affected over the different feeding stages (Figure 2).

Anatomic Development of Digestive Tract

The rumen volume increased quadratically ($P < 0.05$) over time, as shown in Table 3; it was higher at

d 70 than d 56 (750 vs. 483 mL), d 56 than d 28 (483 vs. 190 mL), and d 42 than d 14 (376 vs. 54.2 mL). In addition, the rumen was heavier ($P < 0.01$) at d 80 than d 70 (189 vs. 138 g), d 70 than d 56 (138 vs. 82.5 g), and d 42 than d 28 (67.4 vs. 30.4 g). Moreover, the reticulum was heavier ($P < 0.01$) at d 70 than d 42 and d 42 than d 28 (28.5, 16.3, and 7.04 g, respectively). Furthermore, the omasum was heavier ($P < 0.01$) at d 84 than d 70, d 70 than d 56, and d 56 than d 28 (30.1, 24.0, and 3.82 g, respectively). In addition, the abomasum weight showed a quadratic increase ($P < 0.01$) over time; it was heavier at d 56 than d 14 (46.6 vs. 32.8 g) and d 70 than d 28 (49.1 vs. 34.1 g). In addition, the highest abomasum weight was 66.9 g at d 84. Moreover, complex stomach weight was heavier ($P < 0.01$) at d 42 than d 28 (126 vs. 75.4 g) and d 84 than d 70 (316 vs. 239 g).

The forestomach chambers indices as a percentage of the complex stomach are shown in Table 3. The rumen index increased quadratically ($P < 0.01$) over time (Table 3); it was higher at d 28 (40.9%) than d 14 (28.8%) and lower than d 42 (53.1%). Moreover, the reticulum index at d 42 was higher than d 7 ($P < 0.01$; 12.8 vs. 8.58%). In addition, the omasum index

Table 2. Organ development from colostrum to postweaning in goats (n = 47)

Item ¹	MC			MM			MMSD			OSD			P-value ²		
	Diet ¹														
	d 1	d 7	d 14	d 28	d 42	d 56	d 70	d 84	SEM	Lin	Qua	Cub			
Organ weight, g															
Heart	25.2 ^c	29.6 ^{bc}	33.8 ^{bc}	32.4 ^{bc}	40.1 ^{ab}	46.6 ^a	47.8 ^a	49.2 ^a	1.66	<0.01	0.45	0.62			
Liver	92.6 ^d	107 ^{cd}	122 ^{cd}	134 ^{bcd}	142 ^{bc}	171 ^{ab}	197 ^a	201 ^a	7.10	<0.01	0.92	0.91			
Spleen	6.50 ^d	7.40 ^d	10.6 ^{cd}	13.9 ^{bc}	15.2 ^{abc}	20.4 ^a	19.9 ^{ab}	18.0 ^{ab}	0.93	<0.01	<0.01	0.36			
Lungs	48.5 ^d	53.6 ^d	64.5 ^{cd}	68.4 ^{cd}	85.2 ^{bc}	112 ^{ab}	117 ^a	108 ^{ab}	4.68	<0.01	0.18	0.09			
Kidney	25.1 ^b	27.6 ^{ab}	29.0 ^{ab}	31.9 ^{ab}	34.1 ^{ab}	38.7 ^a	38.3 ^a	37.0 ^{ab}	1.31	<0.01	0.24	0.64			
Head	253 ^e	276 ^{de}	317 ^{de}	339 ^d	431 ^c	494 ^{bc}	523 ^b	617 ^a	19.3	<0.01	0.61	0.92			
Hoof	90.8 ^e	106 ^{de}	122 ^{cde}	135 ^{bcd}	135 ^{bcd}	154 ^{abc}	159 ^{ab}	179 ^a	5.07	<0.01	0.56	0.18			
Skin	450 ^e	533 ^e	663 ^{cde}	592 ^{de}	809 ^{bcd}	883 ^{abc}	924 ^{ab}	1,033 ^a	34.7	<0.01	0.69	0.85			
Percentage of BW, %															
Heart	0.87 ^a	0.86 ^a	0.79 ^a	0.67 ^b	0.60 ^{bc}	0.59 ^{bc}	0.54 ^{cd}	0.48 ^d	0.02	<0.01	0.04	0.43			
Liver	3.19 ^a	3.14 ^a	2.78 ^a	2.79 ^a	2.14 ^b	2.18 ^b	2.22 ^b	1.95 ^b	0.08	<0.01	0.08	0.82			
Spleen	0.22 ^{ab}	0.22 ^{ab}	0.25 ^{ab}	0.30 ^a	0.23 ^{ab}	0.26 ^{ab}	0.23 ^{ab}	0.18 ^b	0.01	0.20	0.01	0.91			
Lungs	1.65 ^a	1.59 ^{ab}	1.49 ^{ab}	1.42 ^{ab}	1.29 ^{bc}	1.41 ^{ab}	1.33 ^{bc}	1.05 ^c	0.04	<0.01	0.88	0.07			
Kidney	0.88 ^a	0.80 ^{ab}	0.67 ^{bc}	0.66 ^{bc}	0.52 ^{cd}	0.49 ^d	0.44 ^d	0.36 ^d	0.03	<0.01	0.17	0.38			
Head	8.81 ^a	8.16 ^{ab}	7.35 ^{bc}	7.10 ^{cd}	6.89 ^{cde}	6.24 ^{de}	5.92 ^{de}	6.08 ^e	0.18	<0.01	0.03	0.60			
Hoof	3.13 ^a	3.13 ^a	2.85 ^a	2.84 ^a	2.08 ^b	1.93 ^b	1.79 ^b	1.74 ^b	0.10	<0.01	0.13	0.14			
Skin	15.3 ^a	15.7 ^a	15.3 ^a	12.3 ^b	12.5 ^b	11.0 ^{bc}	10.4 ^{bc}	10.0 ^c	0.39	<0.01	0.15	0.62			

^{a-c}Means within the same rows with different letters are significantly different ($P < 0.05$).¹Diets: maternal colostrum (MC), maternal milk (MM), maternal milk plus solid diet (MMSD), and only solid diet (OSD).²Lin = linear effect of age; Qua = quadratic effect of age; Cub = cubic effect of age.

Table 3. The development of forestomach chambers and rumen volume from colostrum to postweaning in goats (n = 47)

Item ¹	Diet ¹												P-value ²		
	MC			MM			MMSD			OSD					
	d 1	d 7	d 14	d 28	d 42	d 56	d 70	d 84	SEM	Lin	Qua	Cub			
Rumen volume, mL	13.6 ^d	20.0 ^d	54.2 ^d	190 ^{cd}	376 ^{bc}	483 ^b	750 ^a	967 ^a	53.5	<0.01	0.03	0.86			
Complex stomach chambers, g															
Rumen	10.6 ^d	12.6 ^d	17.5 ^d	30.4 ^d	67.4 ^c	82.5 ^c	138 ^b	189 ^a	9.35	<0.01	<0.01	0.72			
Reticulum	5.50 ^c	4.74 ^c	5.41 ^c	7.04 ^c	16.3 ^b	23.2 ^{ab}	28.5 ^a	30.3 ^a	1.65	<0.01	0.32	0.01			
Omasum	2.47 ^d	2.64 ^d	3.94 ^d	3.82 ^d	6.47 ^{cd}	11.1 ^c	24.0 ^b	30.1 ^a	1.57	<0.01	<0.01	0.96			
Abomasum	28.6 ^d	33.7 ^{cd}	32.8 ^d	34.1 ^{cd}	35.4 ^{bcd}	46.6 ^{bc}	49.1 ^b	66.9 ^a	2.15	<0.01	0.01	0.33			
Complex stomach	47.1 ^e	53.7 ^e	59.6 ^e	75.4 ^e	126 ^d	163 ^c	239 ^b	316 ^a	14.0	<0.01	<0.01	0.96			
Percentage of complex stomach, %															
Rumen	22.5 ^c	24.3 ^c	28.8 ^c	40.9 ^b	53.1 ^a	50.6 ^{ab}	57.3 ^a	59.6 ^a	2.26	<0.01	<0.01	0.97			
Reticulum	11.8 ^{abc}	8.58 ^c	9.27 ^{bc}	9.20 ^{bc}	12.8 ^{ab}	13.8 ^a	12.0 ^{abc}	9.60 ^{bc}	0.45	<0.01	0.06	<0.01			
Omasum	5.29 ^b	5.07 ^b	6.78 ^b	5.06 ^b	5.34 ^b	6.75 ^b	9.85 ^a	9.65 ^a	0.38	<0.01	0.02	0.71			
Abomasum	60.4 ^a	61.6 ^a	55.1 ^a	44.8 ^b	28.7 ^c	28.8 ^c	20.9 ^c	21.1 ^c	2.53	<0.01	<0.01	0.13			
Percentage of BW, %															
Rumen	0.37 ^d	0.38 ^d	0.41 ^d	0.66 ^d	1.06 ^c	1.05 ^c	1.55 ^b	1.85 ^a	0.08	<0.01	0.08	0.90			
Reticulum	0.19 ^c	0.14 ^c	0.13 ^c	0.15 ^{bc}	0.27 ^{ab}	0.30 ^a	0.32 ^a	0.29 ^a	0.02	<0.01	0.78	0.01			
Omasum	0.09 ^{bc}	0.08 ^c	0.09 ^{bc}	0.08 ^{bc}	0.11 ^{bc}	0.14 ^b	0.27 ^a	0.30 ^a	0.01	<0.01	<0.01	0.48			
Abomasum	0.97 ^a	0.96 ^a	0.76 ^b	0.70 ^b	0.56 ^b	0.60 ^b	0.56 ^b	0.66 ^b	0.03	<0.01	<0.01	0.93			
Complex stomach	1.61 ^c	1.73 ^c	1.39 ^c	1.58 ^c	1.99 ^{bc}	2.61 ^{ab}	2.70 ^{ab}	3.10 ^a	0.10	<0.01	0.13	0.16			

^{a-c}Means within the same rows with different letters are significantly different ($P < 0.05$).¹Diets: maternal colostrum (MC), maternal milk (MM), maternal milk plus solid diet (MMSD), and only solid diet (OSD).²Lin = linear effect of age; Qua = quadratic effect of age; Cub = cubic effect of age.

was higher at d 70 than d 56 ($P < 0.05$; 9.85 vs. 6.75). However, the abomasum index showed a significant quadratic decrease ($P < 0.01$) over time; it was higher at d 28 than older goats.

Moreover, the complex stomach parts indices expressed a percentage of BW in Table 3 showed that the rumen index was higher ($P < 0.01$) at d 84 than d 70, d 70 than d 42, and d 42 than d 28 (1.85, 1.55, 1.06, and 0.66, respectively; Table 3). In addition, the reticulum index was higher at d 42 than d 14 ($P < 0.01$; 0.27 vs. 0.13%). Moreover, the omasum index at d 70 was lower than d 56 ($P < 0.01$; 0.27 vs. 0.14%). In addition, the complex stomach index was higher ($P < 0.01$) at d 56 than d 28 (2.61 vs. 1.58%), and d 84 than d 42 (3.10 vs. 1.99%). However, the abomasum percentage of d 14 (0.76%) and onwards were lower ($P < 0.01$) than d 7 (0.96%).

As shown in Figure 2, the OSD phase had the highest ($P < 0.01$) absolute growth of rumen volume (17.3 ± 1.66 mL; linear effect), rumen weight (3.8 ± 0.23 g; quadratic effect), and omasum weight (0.68 ± 0.04 g; quadratic effect). The goats showed the highest ($P < 0.01$) reticulum absolute growth in the MMSD phase (0.58 ± 0.10 g; cubic effect). Absolute growth of the abomasum was quadratically higher ($P < 0.01$) in the MC and OSD phases than in the MM phase (0.84 ± 0.23 , 0.72 ± 0.10 , and 0.13 ± 0.06 g, respectively).

Rumen Morphology

Rumen morphology results (Table 4 and Supplemental Figure S1, <https://doi.org/10.6084/m9.figshare.17111312.v1>) revealed that the rumen papillae height was higher ($P < 0.05$) at d 28 than d 14 (769 vs. 618 μ m) and d 70 than d 56 (1,046 vs. 838 μ m). The rumen papillae width was wider at d 42 than d 28 ($P < 0.01$; 332 vs. 272 μ m). The lamina propria thickness was higher ($P < 0.01$) at d 56 than d 1 (182 vs. 127 μ m) and d 84 than d 56 (237 vs. 182 μ m). The ruminal muscle layer thickness was thicker ($P < 0.01$) at d 70 than d 28 (915 vs. 734 μ m) and d 84 than d 56 (1,031 vs. 819 μ m). In addition, the ruminal epithelial thickness was thicker at d 7 than d 1 ($P < 0.01$; 62.2 vs. 49.2 μ m), and the thickest value was 90.6 μ m at d 84. Furthermore, the stratum corneum thickness increased cubically ($P < 0.01$) over time; it was higher at d 42 than d 28 (21.7 vs. 10.2 μ m) and d 56 than d 42 (31.3 vs. 21.7 μ m).

Intestinal Morphology

The colonic mucosal thickness showed a quadratic increase over time ($P < 0.01$; Table 5 and Supplemental Figure S2, <https://doi.org/10.6084/m9.figshare.17111312.v1>).

Table 4. Rumen tissue measurement from colostrum to postweaning in goats ($n = 47$)

Item ¹	Diet ¹												P-value ²
	MC			MM			MMSD			OSD			
	d 1	d 7	d 14	d 28	d 42	d 56	d 70	d 84	SEM	Lin	Qua	Cub	
Papillae height, μm	499 ^e	620 ^e	618 ^c	769 ^b	784 ^b	838 ^b	1,046 ^a	1162 ^a	16.4	<0.01	0.15	0.03	
Papillae width, μm	236 ^b	250 ^b	250 ^b	272 ^b	332 ^a	323 ^a	342 ^a	359 ^a	4.17	<0.01	0.12	0.41	
Lamina propria thickness, μm	127 ^d	143 ^{bcd}	137 ^{cd}	150 ^{bcd}	152 ^{bcd}	182 ^{bc}	191 ^{ab}	237 ^a	5.04	<0.01	<0.01	0.11	
Muscle layer thickness, μm	683 ^c	732 ^c	730 ^c	734 ^c	781 ^{bc}	819 ^{bc}	915 ^{ab}	1,031 ^a	13.5	<0.01	0.01	0.34	
Epithelial thickness, μm	49.2 ^d	62.2 ^c	74.9 ^b	73.9 ^{bc}	72.4 ^{bc}	71.4 ^{bc}	74.6 ^{bc}	90.6 ^a	1.26	<0.01	0.78	<0.01	
Stratum corneum thickness, μm	9.20 ^c	9.80 ^c	10.7 ^c	10.2 ^c	21.7 ^b	31.3 ^a	32.3 ^a	39.2 ^a	0.87	<0.01	0.39	<0.01	

^{a-d}Means within the same rows with different letters are significantly different ($P < 0.05$).

¹Diets: maternal colostrum (MC), maternal milk (MM), maternal milk plus solid diet (MMSD), and only solid diet (OSD).

²Lin = linear effect of age; Qua = quadratic effect of age; Cub = cubic effect of age.

tal Figure S2, <https://doi.org/10.6084/m9.figshare.17111312.v1>); it was higher at d 28 than d 14 (536 vs. 411 μm) and d 70 than d 42 (619 vs. 539 μm). In addition, the colonic muscle layer thickness increased quadratically ($P < 0.01$) over time; it was higher at d 7 than d 1 (239 vs. 179 μm) and d 84 than d 14 (277 vs. 240 μm). However, no significant differences were detected in the colonic epithelial thickness.

The ileal villus height did not show significant differences from birth to d 60, whereas at d 70 it was higher ($P < 0.01$) than d 42 (601 vs. 533 μm ; Table 5 and Supplemental Figure S3, <https://doi.org/10.6084/m9.figshare.17111312.v1>). In addition, the ileal crypt depth increased linearly ($P < 0.01$) over time; it was higher at d 42 than d 14 (243 vs. 191 μm) and d 84 than d 28 (275 vs. 228 μm). In addition, ileal epithelial thickness and muscle layer thickness increased cubically ($P < 0.01$) over time. The ileal epithelial thickness was higher ($P < 0.01$) at d 7 than d 1 (22.3 vs. 19.5 μm). The ileal muscle layer thickness was higher at d 14 than d 1 (143 vs. 103 μm), and the highest value was 163 μm at d 84.

Moreover, the jejunal crypt depth showed a quadratic increase ($P < 0.01$) over time (Table 5 and Supplemental Figure S4, <https://doi.org/10.6084/m9.figshare.17111312.v1>); it was higher at d 70 than d 28 and d 28 than d 14 (360, 290, and 230 μm , respectively). Moreover, the jejunal muscle layer thickness was higher ($P < 0.01$) at d 42 than d 14 (147 vs. 119 μm) and d 70 than d 28 (160 vs. 131 μm). However, the jejunal villus height and epithelial thickness showed a nonsignificant increase over time.

Moreover, the duodenal crypt depth was higher ($P < 0.01$) at d 56 than d 7 and d 7 than d 1 (306, 267, and 216 μm , respectively; Table 5 and Supplemental Figure S5, <https://doi.org/10.6084/m9.figshare.17111312.v1>). In addition, the duodenal muscle layer thickness was higher ($P < 0.05$) at d 7 than d 1 (130 vs. 105 μm), d 28 (155 μm) than d 7, d 70 (178 μm) than d 28, and d 84 than d 42 (190 vs. 155 μm). The duodenal epithelial thickness was higher ($P < 0.05$) at d 42 than d 28 (27.7 vs. 24.1 μm). However, the duodenal villus height did not show significant differences over time.

DISCUSSION

Body Weight and Carcass Weight

Age was the main factor influencing the BW and HCW from birth to d 70, whereas the feeding system (supplemental feeding vs. grazing) had no significant effect (Jiao et al., 2015b). However, in this study, the MMSD phase showed the highest absolute growth of

BW and HCW and the highest dressing percentage. The improvement of body size indices was slow in the milk phase, whereas it was remarkable in the MMSD phase. In addition, the weaning transition is an essential phase for the manipulation of rumen development using nutritional strategies, which can affect ruminant growth performance and health (Sun et al., 2021). The current study results confirmed the beneficial effects of solid feed to enhance the preweaning growth and overcome the weaning stress. Providing solid diet, even in a small quantity during suckling, allows the development of rumen, which is necessary to counteract the stress caused by lack of nutrients, digestion inefficiency, and weight loss after weaning (Khan et al., 2011; Guzman et al., 2016). Alfalfa and starter before weaning improved rumen development and growth performance in lambs (Yang et al., 2015, 2018) and calves (Cui et al., 2020).

Organ Development

Organ development is important (e.g., the liver serves as the primary site of ketogenesis in the preruminant, and its ketogenic function decreases in the ruminant animal; Baldwin, 1999). This study showed a significant increase in organ weight over time, and the organ percentage to BW decreased. Similarly, the slaughter weight increased with the decline in noncarcass components and internal organ percentage in goats (Marichal et al., 2003; Peña et al., 2007; Kaić et al., 2012). In addition, solid feed stimulates rumen development to achieve better organ growth (e.g., liver and heart; Hamada et al., 1976).

Anatomic Development of Stomach

Our outcomes revealed that the rumen development in goats continued to increase significantly until d 70. Similarly, Jiao et al. (2015b) found that the rumen anatomic development is achieved after 2 mo. The results showed an increased rumen growth rate in the OSD phase. At the same time, the OSD phase showed a subtle decline in the absolute growth of BW and a significant decrease in the absolute growth of HCW when compared with the MMSD phase. During the transition weaning phase, the animals experienced a slight decline in BW as a substitute to supply the development of the ruminal tissue and its microbial communities (Heinrichs, 2005). Similarly, lower BW and higher rumen weight were observed in newborn calves offered milk and starter than calves offered only milk (Guzman et al., 2016). Therefore, there is a priority for developing the rumen and its digestive function, which could af-

Table 5. Large and small intestine tissue measurement (μm) from colostrum to postweaning in goats ($n = 47$)

Item ¹	Diet ¹												P-value ²			
	MC			MM			MMSD									
	OSD			MMSD			OSD						SEM	Lin	Qua	Cub
	d 1	d 7	d 14	d 28	d 42	d 56	d 70	d 84								
Colon																
Mucosal thickness, μm	378 ^d	378 ^d	411 ^d	536 ^c	539 ^c	570 ^{bc}	619 ^{ab}	651 ^a	6.70	<0.01	<0.01	<0.01	0.20			
Muscle layer thickness, μm	179 ^e	239 ^b	240 ^b	243 ^{ab}	274 ^{ab}	271 ^{ab}	273 ^{ab}	277 ^a	3.79	<0.01	<0.01	<0.01	0.06			
Epithelial thickness, μm	22.9	22.6	24.0	23.7	23.2	24.0	23.5	24.4	0.20	0.07	0.89	0.24				
Ileum																
Villus height, μm	518 ^b	520 ^b	526 ^b	532 ^b	533 ^b	574 ^{ab}	601 ^a	600 ^a	6.54	<0.01	0.42	0.40				
Crypt depth, μm	197 ^c	192 ^c	191 ^c	228 ^{bc}	243 ^{ab}	258 ^{ab}	268 ^{ab}	275 ^a	4.42	<0.01	0.31	0.43				
Muscle layer thickness, μm	103 ^c	131 ^{bc}	143 ^b	142 ^{bc}	139 ^{bc}	148 ^b	163 ^b	227 ^a	4.14	<0.01	0.01	<0.01				
Epithelial thickness, μm	19.5 ^b	22.3 ^a	22.2 ^a	22.7 ^a	22.3 ^a	21.9 ^a	21.0 ^a	22.6 ^a	0.27	0.52	0.34	0.01				
Jejunum																
Villus height, μm	633	637	641	643	643	667	667	671	8.06	0.11	0.91	0.85				
Crypt depth, μm	213 ^c	217 ^c	230 ^c	290 ^b	317 ^{ab}	340 ^{ab}	360 ^a	361 ^a	5.72	<0.01	0.01	0.52				
Muscle layer thickness, μm	111 ^c	118 ^c	119 ^c	131 ^{bc}	147 ^{ab}	153 ^{ab}	160 ^a	173 ^a	2.78	<0.01	0.87	0.95				
Epithelial thickness, μm	20.6	20.3	21.3	21.8	21.8	21.4	21.1	22.1	0.22	0.12	0.39	0.16				
Duodenum																
Villus height, μm	652	667	662	683	681	677	703	703	7.15	0.99	0.97	0.94				
Crypt depth, μm	216 ^c	267 ^b	288 ^{ab}	294 ^{ab}	291 ^{ab}	306 ^a	313 ^a	317 ^a	3.64	<0.01	<0.01	0.01				
Muscle layer thickness, μm	105 ^f	130 ^e	147 ^{ed}	155 ^{cd}	155 ^{bcd}	177 ^{abc}	178 ^{ab}	190 ^a	2.43	<0.01	0.03	0.04				
Epithelial thickness, μm	22.1 ^c	21.2 ^c	22.3 ^c	24.1 ^{bc}	27.7 ^a	27.0 ^{ab}	27.2 ^{ab}	28.1 ^a	0.32	<0.01	0.04	0.57				

^{a-f}Means within the same rows with different letters are significantly different ($P < 0.05$).¹Diets: maternal colostrum (MC), maternal milk (MM), maternal milk plus solid diet (MMSD), and only solid diet (OSD).²Lin = linear effect of age; Qua = quadratic effect of age; Cub = cubic effect of age.

fect the substantial growth of small ruminants (Jelínek, 1995; Paez Lama et al., 2014).

Furthermore, the early solid feed promoted rumen development and its microbial contents and total VFA concentration (Sun et al., 2018; Lv et al., 2019; Wang et al., 2019). The newborn calves that received only MM or MR without solid feed had a limited capacity of ruminal fermentation, absorption of VFA, and metabolic activity in the rumen epithelium (Cozzi et al., 2002; Heinrichs, 2005). Similarly, Wang et al. (2016a) stated that the starter diet decreased milk intake, increased rumen fiber, and modulated the rumen bacteria. Accordingly, solid feed is associated with increased rumen weight and better health and growth (Baldwin et al., 2004; Sun et al., 2018). In addition, the starter diet increased the reticulorumen weight and volume as well as papillae height (Wang et al., 2016b). Furthermore, the starter diet increased total, epithelial, and muscle wet weights of the rumen and omasum as a percentage of the empty BW (Baldwin, 1999). In contrast, the reticulum and abomasum were not affected by dietary treatment (Baldwin, 1999). The abilities of solid feed as a stimulator for rumen development depend on its nutrient compositions, which can fulfill the rumen nutritional requirement for growth (Yáñez-Ruiz et al., 2015). In addition, age and BW are vital factors for rumen development (Frandsen et al., 2009). Therefore, Zhuang et al. (2020) demonstrated that age, solid feeds, and weaning factors play a crucial role in shaping the gut microbiota and modulating rumen development.

Rumen Histomorphology

A well-developed rumen is essential for the absorption and metabolism of nutrients such as VFA to maintain rumen homeostasis and provide energy for the host, which has a long-term effect on later performance and health (Heinrichs and Heinrichs, 2011; Yáñez-Ruiz et al., 2015). The papillae height is an essential indicator for evaluating rumen anatomic development, followed by papillae width and the muscle layer thickness (Lesmeister et al., 2004). In the present study, the rumen papillae height and width increased significantly over time. Similar results were observed in goats with natural grazing and supplementary feeds (Jiao et al., 2015b) and calves fed concentrate with different carbohydrate sources (Suárez et al., 2006). The corneum thickness, the number of cells in the corneum, epithelium thickness, and the spinosum and basal layer thicknesses increased more in weaned calves than preweaning calves (van Niekerk et al., 2021). The structural rumen development positively relates to rumen fermentation products produced by microorganisms (Zou et al., 2020). The

ruminal VFA concentration increased with increasing age from birth to d 70 (Jiao et al., 2015b), which could be related to the effect of age on gut microorganisms (Jiao et al., 2015a; Li et al., 2019a; Zhang et al., 2019). Therefore, age is the primary factor regulating rumen epithelial proliferation (Baldwin et al., 2004).

Newborn goats have a smooth rumen epithelium with no prominent rumen papillae. Declines in ruminal weight, rumen papillae, degree of keratinization, pigmentation, and muscular wall development have been observed in calves fed liquid feeds (Gilliland et al., 1962; Tamate et al., 1962). In preruminant animals, milk flows into the abomasum through the esophageal groove, resulting in less fermentation substrates for rumen development (Jiao et al., 2015a). The rumen growth in the absence of VFA is driven by the nutrient content of milk (Khan et al., 2016). Liquid feeds limit the metabolic activity in the rumen epithelium and the VFA absorption (Heinrichs, 2005), which slows down the development (Foley et al., 2009).

As the goats increased in age and the liquid diet changed to solid, the rumen development increased. The solid feed is the main diet for rumen epithelium development (Sun et al., 2021). The solid meal is the source of readily fermentable carbohydrates. It provides more carbon and nitrogen to produce microbial CP and VFA (Yang, 2002; Jiao et al., 2015b; Cui et al., 2020). In addition, the AA and fatty acid metabolism function in the rumen epithelia increases with the introduction of concentrate starters (Sun et al., 2021). The VFA provide an energy source for rumen development during early life (Baldwin, 1999; Jiao et al., 2015b; Lv et al., 2019). Diet energy is associated with rumen epithelium development and future growth performance (Shen et al., 2004). Moreover, solid feed enhances the expression of genes involved in VFA absorption and cell proliferation in the rumen (Metzler-Zebeli et al., 2013; Yan et al., 2014). The concentrate diet introduction to calves activates molecular pathways and biological processes in the morphological and functional development of the rumen wall (Connor et al., 2014). In addition, solid feeds decrease rumen pH, increasing the blood flow to rumen tissues (Castillejos et al., 2006). Subsequently, the rumen volume, rumen tissue growth, and rumen papillary are higher in dry feed than milk (Suárez et al., 2006). In addition, starter feeding promotes rumen papillae height and width, epithelial thickness, and stratum corneum thickness of rumen epithelium tissue (Sun et al., 2018). Moreover, Cui et al. (2020) showed the increased rumen papillae height and width, and muscle layer thickness of rumen by starter intake. The rumen epithelial thickness and rumen papillary were improved in solid feed (Sun et al., 2021).

Intestine Histomorphology

The morphology of intestinal villus and crypt is an important indicator for evaluating intestinal health and the absorptive capacity of nutrients (Li et al., 2016). The intestinal tract is the central part of the liquid feed absorption and metabolism in preweaning ruminants (Zhang et al., 2021). However, few studies have been conducted about intestine development compared with rumen development (Hou et al., 2018). The short-chain fatty acid and lactic acid concentrations were higher in the colon than rumen during the first 4 wk of Holstein calves (Castro et al., 2016), indicating better fermentation activity. The colonic muscle layer thickness, duodenal muscle layer thickness and crypt depth, and the ileal epithelial thickness increased in the MC phase. Similarly, the colonic mucosal thickness, jejunal crypt depth, and duodenal muscle layer thickness increased in the colostrum and milk diets (Gerrits et al., 1998; Shen et al., 2004; Blum, 2006). However, a negative effect on intestinal development in calves was observed by delaying the first colostrum (Fischer-Tlustos et al., 2020) and MR feeding instead of colostrum (Blättler et al., 2001).

The roles of MC and MM intestinal development have been studied extensively in neonatal ruminants (Blum and Baumrucker, 2002), whereas the intestinal response to weaning, nutrition, and rumen development require further investigations. The rumen development that can be used to evaluate weaning programs has a close relationship with intestinal tract development (Górka et al., 2011). The rumen becomes the main digestion and absorption site instead of the intestine during the weaning transition (Dias et al., 2018), affecting the intestine development. The growth of the intestine is affected by different metabolic and atrophic hormones and chemical and physical dietary factors. Accordingly, the increased metabolic energy intake and dietary forage increased ruminal and intestinal growth through cellular hyperplasia in lambs (McLeod and Baldwin, 2000). Therefore, the morphology of small and large intestine sections improved in starter diet and VFA-infused groups (Baldwin, 1999). The high-concentrate diet improved the duodenal villus height and crypt depth and jejunal villus height (Zitnan et al., 2003). Moreover, the intestinal digestion-absorption function and the villus height and crypt depth of the duodenum, jejunum, and ileum were improved in calves fed alfalfa and starter diet (Cui et al., 2020). In the current study, the crypt depth of ileum and muscle layer thickness of jejunum increased in the MMSD phase. Moreover, the villus height of ileum and crypt depth of jejunum increased in the OSD phase.

It has been reported that the intestinal mass is not affected by the physical form of feed for either MR or pelleted lamb starter (Baldwin, 1999). The intestinal capacity for nutrient assimilation may increase over time (Baldwin, 1999). The cecum and colon varied over 3 time points (1, 42, and 70 d), indicating the role of age (Li et al., 2019b). The ileal villus height and crypt depth in newborn calves increased over time (Zhang et al., 2017). The small intestine morphology was affected by age and feeding system, especially the proximal portions (duodenum and jejunum) compared to the ileum (Li et al., 2016). For instance, Li et al. (2016) showed an increase of crypt depth in the jejunum and ileum with increasing age, which agrees with our study. In addition, the changes in intestine morphology parameters over time in this study showed the earlier stage of maturation of the intestine compared with rumen, which agrees with Li et al. (2016).

CONCLUSIONS

The absolute growth of carcass and the dressing percentage was lower at the post- than the preweaning stage, indicating weaning stress. The rumen weight and morphology improved from pre- to postweaning, and its development was achieved after 2 mo of age. The solid starter displayed a crucial role in promoting rumen development. Adequate nutrition and solid feed before weaning are recommended for the rapid development of the gastrointestinal tract and the improvement of growth performance of goats. The intestine morphological parameters increased over time, mainly at the earlier stages of milk feeding, indicating the critical role of the small intestine for milk digestion. In comparison, the morphological evolution of the intestine after weaning could be associated with rumen development and hence the nutrient availability. In addition, beyond feed composition, age was an important factor in increasing the structural development of rumen papillary to endure the shortage of MM and the consumption of solid feed to favor the digestive function and performance of the host.

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