

Table S1 Composition and nutrient levels of the basal diet

Sample	Moisture%	Dry matter%	Crude fat %	Coarse ash %	Crude protein %	Neutral washing fiberNDF %	Acid washing fiberADF %
S1	44.76	97.81	3.66	10.60	18.23	26.02	12.21
S2	54.78	98.03	4.33	10.90	18.13	34.21	15.97
S3	50.64	97.86	4.11	10.55	19.13	33.61	13.23
S4	46.79	97.70	4.61	6.72	18.20	33.48	14.77
S5	46.15	97.83	4.03	9.74	18.38	27.47	13.71
S6	49.83	97.85	3.84	9.75	17.64	30.52	13.74
S7	56.31	97.67	3.84	8.87	17.43	28.38	11.04
S8	52.28	97.40	3.31	9.60	17.32	27.63	12.34
S9	50.90	97.54	3.90	8.06	18.50	27.78	10.18
S10	41.02	97.78	4.95	10.08	18.83	29.34	12.99
S11	46.33	97.67	4.87	9.35	17.82	35.45	11.43
S12	49.03	97.71	4.66	8.83	18.59	27.71	11.95
S13	51.83	97.16	2.01	7.81	17.17	42.67	25.81
S14	64.02	96.71	4.81	6.78	14.38	54.68	25.89
S15	46.26	97.16	4.16	8.60	17.40	32.30	19.25
S16	43.26	97.09	3.25	8.13	18.14	36.56	20.51
S17	53.77	97.08	2.05	8.25	16.97	38.44	17.46
S18	48.32	97.31	4.33	9.98	17.87	36.52	16.33
S19	51.44	96.74	2.98	8.93	19.19	31.36	22.92
S20	51.55	96.83	3.82	7.16	18.07	41.34	18.71

Table S2 Composition and nutrient levels of the basal diet

Item	component	content
Microelement solution	CaCl \cdot 2H $_2$ O	13.2g
	MnCl $_2\cdot$ 4H $_2$ O	10.0g
	CoCl $_2\cdot$ 6H $_2$ O	1.0 g
	FeCl $_3\cdot$ 6H $_2$ O	8.0g
	Distilled water	100 mL
Buffer bicarbonate	NH $_4$ HCO $_3$	4.0g
	NaHCO $_3$	35.0 g
	Distilled water	1000 mL
Phosphate buffer	Na $_2$ HPO $_4$	5.7 g
	KH $_2$ PO $_4$	6.2 g
	MgSO $_4\cdot$ H $_2$ O	0.6g
	Distilled water	1 000 mL
Indicator	Resazurin	0.1g
	Distilled water	100mL
Reduction solution	NaOH	160 mg
	Na $_2$ S \cdot 9H $_2$ O	625 mg
	Distilled water	100 mL

Table S3 PanelOLS Estimation Summary

	Before optimization				After optimization			
	R-squared:	F-statistic:	P-value:	Log-likelihood:	R-squared:	F-statistic:	P-value:	Log-likelihood:
pH	0.7293	1.2434	0.4159	73.809	0.4599	4.5409	0.0174*	66.902
Dry matter	0.9235	5.5697	0.0224*	-32.056	0.6173	13.712	0.0003*	-48.152
disappearance rate								
NH ₃ -N	0.9499	8.746	0.0071*	-48.936	0.4309	6.4365	0.0083*	-73.23
Acetate	0.7637	1.4918	0.3243	-47.485	0.5549	3.4914	0.0294*	-53.817
Propionate	0.7485	1.3733	0.3647	-32.413	0.2631	3.0343	0.0747	-43.162
Isobutyrate	0.5647	0.5986	0.7942	19.301	Unable optimize	Unable optimize	Unable optimize	Unable optimize
Butyrate	0.7598	1.4598	0.3347	-19.689	0.2195	2.39	0.1217	-31.473
Isovalerate	0.6232	0.7633	0.6805	6.3232	0.3121	2.4203	0.1039	0.305
Valerate	0.5109	0.4821	0.8728	13.111	Unable optimize	Unable optimize	Unable optimize	Unable optimize

* Means $p < 0.05$.

Table S4 Moudle Parameter Summary before and after PanelOLS

			const	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
pH	Before optimization	Parameter	6.72	-0.08	0.00	-0.03	-0.01	0.16	0.00	0.01	-0.05	0.04	-0.10	0.03	-0.02	-0.02
		Std. Err.	0.03	0.07	0.03	0.02	0.02	0.11	0.01	0.03	0.05	0.10	0.11	0.04	0.03	0.08
		T-stat	267.79	-1.19	-0.09	-1.60	-0.57	1.48	0.34	0.16	-0.93	0.38	-0.99	0.75	-0.63	-0.30
		P-value	0.00	0.28	0.93	0.16	0.59	0.19	0.74	0.88	0.39	0.72	0.36	0.48	0.55	0.78
	After optimization	Parameter	6.69	-0.05				0.03							-0.01	
		Std. Err.	0.01	0.02				0.01							0.01	
		T-stat	1092.10	-3.10				2.39							-2.33	
		P-value	0.00	0.01				0.03							0.03	
disappearance	Before optimization	Parameter	57.45	-26.23	15.38	0.69	-9.26	29.98	1.26	6.48	9.63	-53.08	53.65	24.71	-3.15	35.16
		Std. Err.	4.99	13.99	5.47	3.48	4.36	21.05	2.60	6.75	10.54	19.17	21.06	7.96	5.90	16.42
		T-stat	11.51	-1.87	2.81	0.20	-2.12	1.42	0.49	0.96	0.91	-2.77	2.55	3.10	-0.53	2.14
		P-value	0.00	0.11	0.03	0.85	0.08	0.20	0.64	0.37	0.40	0.03	0.04	0.02	0.61	0.08
	After optimization	Parameter	63.02											26.82		9.65
		Std. Err.	1.97											7.45		2.99
		T-stat	32.03											3.60		3.23
		P-value	0.00											0.00		0.00
NH3-N	Before optimization	Parameter	47.87	-24.08	-4.45	-17.96	2.84	56.88	-16.55	-4.27	67.30	64.57	1.80	-29.57	-4.53	-65.78
		Std. Err.	11.61	32.54	12.73	8.09	10.15	48.95	6.04	15.70	24.51	44.59	48.97	18.51	13.71	38.18
		T-stat	4.12	-0.74	-0.35	-2.22	0.28	1.16	-2.74	-0.27	2.75	1.45	0.04	-1.60	-0.33	-1.72
		P-value	0.01	0.49	0.74	0.07	0.79	0.29	0.03	0.79	0.03	0.20	0.97	0.16	0.75	0.14

	After optimization	Parameter	24.88							-13.31		70.77				
		Std. Err.	5.11							4.42		29.22				
		T-stat	4.87							-3.01		2.42				
		P-value	0.00							0.01		0.03				
Acetate	Before optimization	Parameter	64.45	9.66	-16.06	-9.97	5.02	1.55	13.91	-26.62	-20.56	77.89	-100.07	0.30	7.02	-33.39
		Std. Err.	10.80	30.26	11.84	7.52	9.44	45.53	5.62	14.60	22.80	41.47	45.55	17.21	12.75	35.51
		T-stat	5.97	0.32	-1.36	-1.33	0.53	0.03	2.48	-1.82	-0.90	1.88	-2.20	0.02	0.55	-0.94
		P-value	0.00	0.76	0.22	0.23	0.61	0.97	0.05	0.12	0.40	0.11	0.07	0.99	0.60	0.38
	After optimization	Parameter	51.58							8.65	-14.04		43.52	-61.39		
		Std. Err.	5.20							4.14	6.34		11.46	24.18		
		T-stat	9.92							2.09	-2.22		3.80	-2.54		
		P-value	0.00							0.06	0.04		0.00	0.02		
Propionate	Before optimization	Parameter	29.58	7.86	-8.83	-3.84	3.41	-4.97	6.00	-12.61	-8.40	40.96	-47.19	0.14	3.63	-19.22
		Std. Err.	5.08	14.24	5.57	3.54	4.44	21.43	2.64	6.87	10.73	19.52	21.44	8.10	6.00	16.72
		T-stat	5.82	0.55	-1.59	-1.08	0.77	-0.23	2.27	-1.84	-0.78	2.10	-2.20	0.02	0.61	-1.15
		P-value	0.00	0.60	0.16	0.32	0.47	0.82	0.06	0.12	0.46	0.08	0.07	0.99	0.57	0.29
	After optimization	Parameter	18.67										12.83			
		Std. Err.	1.30										5.21			
		T-stat	14.38										2.46			
		P-value	0.00										0.02			
Isobutyrate	Before optimization	Parameter	1.82	1.12	-0.59	-0.04	0.39	-1.49	0.24	-0.92	-0.11	1.49	-2.80	-0.41	0.54	-1.28
		Std. Err.	0.38	1.07	0.42	0.27	0.33	1.61	0.20	0.52	0.81	1.47	1.62	0.61	0.45	1.26
		T-stat	4.76	1.04	-1.41	-0.15	1.15	-0.92	1.22	-1.78	-0.14	1.01	-1.73	-0.68	1.19	-1.02

		P-value	0.00	0.34	0.21	0.88	0.29	0.39	0.27	0.13	0.89	0.35	0.13	0.52	0.28	0.35
	After optimization	Parameter														
		Std. Err.														
		T-stat														
		P-value														
Butyrate	Before optimization	Parameter	15.67	5.24	-5.93	-2.40	2.72	-4.94	2.44	-7.30	-4.95	23.40	-26.05	-1.07	2.34	-11.45
		Std. Err.	2.69	7.54	2.95	1.87	2.35	11.34	1.40	3.64	5.68	10.33	11.35	4.29	3.18	8.85
		T-stat	5.83	0.70	-2.01	-1.28	1.16	-0.44	1.74	-2.01	-0.87	2.26	-2.30	-0.25	0.74	-1.29
		P-value	0.00	0.51	0.09	0.25	0.29	0.68	0.13	0.09	0.42	0.06	0.06	0.81	0.49	0.24
	After optimization	Parameter	9.31			-0.88						6.20				
		Std. Err.	0.72			0.47						2.90				
		T-stat	12.85			-1.86						2.14				
		P-value	0.00			0.08						0.05				
Isovalerate	Before optimization	Parameter	3.46	0.69	-1.13	-0.35	0.44	-0.94	0.30	-1.04	-0.43	3.48	-3.49	-1.01	0.54	-2.15
		Std. Err.	0.73	2.05	0.80	0.51	0.64	3.09	0.38	0.99	1.55	2.81	3.09	1.17	0.87	2.41
		T-stat	4.72	0.33	-1.41	-0.69	0.69	-0.31	0.78	-1.05	-0.28	1.24	-1.13	-0.86	0.63	-0.89
		P-value	0.00	0.75	0.21	0.52	0.51	0.77	0.47	0.33	0.79	0.26	0.30	0.42	0.55	0.41
	After optimization	Parameter	2.59		-0.40	-0.18						1.30				
		Std. Err.	0.19		0.18	0.10						0.64				
		T-stat	13.94		-2.25	-1.79						2.03				
		P-value	0.00		0.04	0.09						0.06				
Valerate	Before optimization	Parameter	3.72	1.36	-0.95	-0.17	0.57	-1.68	0.28	-1.23	-0.39	2.27	-3.18	-0.10	0.55	-1.84
		Std. Err.	0.52	1.46	0.57	0.36	0.46	2.20	0.27	0.71	1.10	2.00	2.20	0.83	0.62	1.72

[illegible]