Optimization design and experiment of double-helix total mixed rations preparation mixer for silage straw feed

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Supplementary Material

Table S1. Advantages and disadvantages of total mixed ration mixer.

Structure	Vertical	Horizontal	Drum-type	Paddle
Advantage	Simple; lower energy consumption; simplified repairs and maintenance; high processing quality	Narrow shape; Low overall height	Mixing shear; mixing uniformity	Bidirectional convective; mixing uniformity
Disadvantage	Poor mixing effect	High energy consumption; short service life	High energy consumption; complex maintenance	Large size; poor mixing effect

Table S2. Main technical parameters of the double-helix total mixed ration preparation mixer.

Project	Value
Volume/m3	24
Tractor power/HP	130
Overall dimension (length×width×height)/mm	5790×2570×2250
Auger count	2
Number of moving blades	16
Mixing time/min	5~15
Mixing uniformity/%	≥85

Table S3. Material mechanical properties.

Material	Poisson's ratio	Shear elasticity/Pa	Density/(kg·m-3)
Corn silage	0.3	2.1×107	420
Corn meal	0.4	1.37×108	1256
TMR mixer	0.3	7.7×109	7850

TMR, total mixed ration.

Table S4. Properties of material interactions.

Interacting material	Recovery coefficient	Static friction coefficient	Coefficient of kinetic friction
Corn meal to corn meal	0.182	0.231	0.0782
Particle to particle	0.25	0.7	0.05
Particles and walls	0.30	0.5	0.01

Table S5. Coding and level of experimental factors.

Coding	Factors		
	x1/r·min-1	x2/min	x3/%
+1.682	50.0	20.0	70.0
+1	41.9	18.0	61.9
0	30.0	15.0	50.0
-1	18.1	12.0	38.1
-1.682	10.0	10.0	30.0

Table S6. Schemes and results of experiment.

No.	Factor level			Evaluation index		
	X1	**X2**	**X3**	**Y1/%**	**Y2/%**	**Y3/kW·h·t-1**
1	-1	-1	-1	86.76	66.62	3.891
2	1	-1	-1	89.32	76.12	4.084
3	-1	1	-1	88.86	71.92	5.722
4	1	1	-1	90.07	79.44	6.039
5	-1	-1	1	89.62	65.67	1.871
6	1	-1	1	90.23	71.12	2.552
7	-1	1	1	90.02	71.05	2.887
8	1	1	1	89.16	74.65	3.682
9	-1.682	0	0	88.95	66.51	3.241
10	1.682	0	0	90.47	78.18	4.083
11	0	-1.682	0	87.81	68.89	2.452
12	0	1.682	0	88.71	77.04	4.903
13	0	0	-1.682	89.67	73.05	6.079
14	0	0	1.682	90.76	68.48	2.179
15	0	0	0	92.19	71.84	3.687
16	0	0	0	92.41	71.21	3.699
17	0	0	0	91.98	71.24	3.672
18	0	0	0	92.01	70.42	3.619
19	0	0	0	91.89	70.48	3.679
20	0	0	0	92.08	71.39	3.681
21	0	0	0	92.21	71.21	3.731
22	0	0	0	92.42	70.87	3.644
23	0	0	0	92.37	70.38	3.638

Table S7. Significance test of the model.

Variables	Y1/%		Y2/%		Y3/kW·h·t-1	
	F	P	F	P	F	P
Model	205.05	<0.0001	166.29	<0.0001	1531.39	<0.0001
X1	83.55	<0.0001	839.53	<0.0001	444.45	<0.0001
X2	30.87	<0.0001	392.28	<0.0001	3881.68	<0.0001
X3	77.52	<0.0001	149.69	<0.0001	8992.65	<0.0001
X1X2	30.72	<0.0001	10.07	0.0073	3.71	0.0761
X1X3	62.43	<0.0001	43.60	<0.0001	61.17	<0.0001
X2X3	47.86	<0.0001	0.058	0.8139	176.31	<0.0001
X12	367.41	<0.0001	19.37	0.0007	0.025	0.8761
X22	931.96	<0.0001	41.59	<0.0001	0.12	0.7384
X32	231.39	<0.0001	0.67	0.4291	222.40	<0.0001
Lack of fit	0.57	0.7225	0.28	0.9095	2.66	0.1055

P<0.05 (significant); P<0.01 (highly significant).

Table S8. Importance of effects of factors on response functions.

Evaluation index	Contribution rate			Ranking
	x1	x2	x3	
Y1	2.961	2.940	2.964	x3>x1>x2
Y2	2.896	2.430	1.483	x1>x2>x3
Y3	1.489	1.497	2.984	x3>x2>x1

Table S9. Comparison between model optimization and validation test value.

Item	Evaluation index		
	Y1/%	Y2/%	Y3/kW·h·t-1
Predicted value	91.62	70.03	2.93
Test value	91.11	72.13	2.99
Error/%	0.56	2.91	2.01