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Research Article

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Storage Duration and Ration Dry Matter Content Determine Preservation Efficiency of Partial Mixed Ration Silage Containing Wet Distillers Bran Plus Solubles: An Applied Study

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ABSTRACT
Partial mixed ration silage is an applied strategy to preserve high-moisture agro-industrial by-products while maintaining feeding flexibility in ruminant production systems. This applied study evaluated the effects of storage duration and ration dry matter content on preservation efficiency of partial mixed ration silage containing wet Distillers bran plus solubles. Treatments included wet Distillers bran plus solubles ensiled alone, a total mixed ration, and partial mixed rations formulated with fibrous or energetic dry ingredients. Silages were stored for 60 and 120 days, and water-holding capacity, dry matter losses, effluent production, and aerobic stability were evaluated. Water-holding capacity differed among ingredients and mixtures, influencing effluent losses during storage. Dry matter losses and effluent production increased with storage duration, particularly in silages with lower dry matter content. Total mixed ration and partial mixed rations formulated with soybean hulls showed reduced losses and greater aerobic stability compared with wet Distillers bran plus solubles ensiled alone. These results demonstrate that preservation efficiency of partial mixed ration silage is primarily determined by formulation and storage management, highlighting practical strategies to improve utilization of wet Distillers bran plus solubles in ruminant feeding systems.

List of Abbreviations

DM	:	Dry Matter
PMR	:	Partial Mixed Ration
TMR	:	Total Mixed Ration
WDBS	:	Wet Distillers Bran Plus Solubles
WHC	:	Water-Holding Capacity

Keywords: Aerobic Stability, Dry Matter Management, Effluent Losses, Partial Mixed Ration Silage, Storage Duration

Introduction

Wet Distillers bran plus solubles is widely used in ruminant feeding systems due to its protein and fiber content; however, its high moisture content poses substantial challenges for storage, transportation, and preservation, particularly related to effluent production and nutrient losses [1,2]. Ensiling is commonly adopted to stabilize high-moisture by-products, but preservation efficiency depends on both substrate characteristics and management practices [3].

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Partial mixed ration silage has emerged as an applied strategy to improve handling and preservation of high-moisture by-products by combining them with dry ingredients before ensiling, thereby increasing dry matter content and improving moisture distribution [4]. In practical feeding systems, this approach allows greater flexibility in diet formulation while reducing the need for frequent handling of wet materials [2].

Preservation efficiency of partial mixed ration silage is strongly influenced by system-level factors, particularly ration dry matter content and storage duration. Rations with insufficient dry matter content are more susceptible to effluent losses and secondary fermentations, whereas prolonged storage can intensify cumulative physical and fermentative losses [1,5]. Despite their relevance under practical conditions, quantitative applied information evaluating the combined effects of these factors in silages containing wet Distillers bran plus solubles remains limited.

Therefore, this study evaluated the applied effects of storage duration and ration dry matter content on preservation efficiency of partial mixed ration silage containing wet Distillers bran plus solubles.

Materials and Methods

Experimental design

The study followed a completely randomized design in a factorial arrangement, with ration type and storage duration as fixed effects. Treatments consisted of wet Distillers bran plus solubles ensiled alone, total mixed ration, and partial mixed rations formulated with dry ingredients differing in moisture-binding capacity. Silages were stored for 60 and 120 days, with four replicates per treatment, following experimental designs commonly used in applied silage research [4].

Ration Formulation and Ensiling Procedure

Rations were formulated using wet Distillers bran plus solubles combined with dry ingredients to achieve contrasting dry matter contents. Materials were mixed thoroughly, packed into laboratory-scale silos, compacted to minimize oxygen inclusion, sealed, and stored at ambient temperature. Ensiling procedures followed standard silage management protocols [1].

Water-Holding Capacity

Water-holding capacity of raw ingredients and mixed rations was determined before ensiling and expressed as grams of water retained per gram of dry matter. This parameter was used as an indicator of moisture-binding potential and its relationship with effluent production [4].

Dry Matter Losses and Effluent Production

Dry matter losses were calculated based on differences between initial and final silo weights. Effluent production was quantified gravimetrically and expressed as grams per kilogram of fresh matter, following procedures described by McDonald et al [1].

Aerobic Stability

Aerobic stability was evaluated by monitoring silage temperature during exposure to air. Stability was defined as the time required for silage temperature to exceed ambient temperature by 2 °C, as proposed by Wilkinson and Davies [5].

Statistical Analysis

Data were analyzed using linear mixed-effects models to appropriately account for the hierarchical structure of the experimental design and the non-independence of observations within experimental units [6]. Ration type, storage duration, and their interaction were considered fixed effects, while silo was included as a random effect to account for variability among experimental units, as recommended for applied agricultural experiments [7].

For variables measured across storage durations (dry matter losses, effluent production, and aerobic stability), storage duration was treated as a repeated measure. Alternative covariance structures were evaluated, and the structure yielding the lowest Akaike information criterion was selected, following established guidelines for longitudinal data analysis [8].

For variables measured once per silo (e.g., water-holding capacity), linear mixed models without repeated measures were applied. Model assumptions were assessed by evaluating normality of residuals using the Shapiro–Wilk test and homogeneity of variances using Levene's test [9]. When necessary, data were log- or square-root transformed to meet model assumptions; however, results are presented as back-transformed means to facilitate interpretation.

When significant main effects or interactions were detected ($P < 0.05$), least square means were compared using Tukey's adjustment to control for multiple comparisons, as recommended for factorial designs [6]. Statistical trends were discussed when $0.05 \leq P \leq 0.10$. All analyses were conducted using appropriate statistical software.

Results

Water-Holding Capacity of Ingredients and Mixed Rations

Water-holding capacity differed among raw ingredients and mixed rations (Table 1). Fibrous ingredients exhibited greater moisture-binding capacity, whereas energetic ingredients showed limited water retention. Mixed rations presented intermediate values, indicating improved moisture distribution compared with wet Distillers bran plus solubles ensiled alone.

Table 1: The chemical composition of WDBS, TMR and PMR before ensiling

Items	Treatments[1]				
	TMR	WDBS	WDBS+CH	WDBS+SH	WDBS+CORN
DM, %	46.12±0.04	35.96±0.16	41.75±0.45	41.72±0.09	43.91±0.01
CP, DM%	19.50±0.09	25.39±0.20	22.00±0.03	22.00±0.05	19.90±0.1
NDF, DM%	33.2±0.14	35.71±0.21	29.30±0.16	34.70±0.25	21.60±0.08
Ash, DM%	11.40±0.13	11.70±0.00	11.00±0.05	10.60±0.11	9.20±0.03

DM, Dry matter; CP, Crude protein; NDF, Neutral detergent fiber
[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.

Dry Matter Losses

Dry matter losses were affected by ration type, storage duration, and their interaction ($P < 0.01$; Tables 2 and 3). Total mixed ration consistently exhibited the lowest losses across storage durations. Losses increased at 120 days, particularly in rations with lower dry matter content.

Table 2: Chemical composition of WDBS-based TMR silage and PMR silage

Items	Length of storage (d)	Treatments[1]						SEM[2]	P-value[3]		
		TMR	WDBS	WDBS+CH	WDBS+SH	WDBS+CORN	Mean		T	L	T×L
DM, %	60	46.7^{Ba}	38.8^{Be}	42.7^{Bc}	41.8^{Ad}	45.1^{Bb}	43.0	0.12	<0.0001	<0.0001	<0.0001
	120	48.1^{Aa}	40.7^{Ae}	43.6^{Ac}	41.5^{Ad}	45.6^{Ab}	43.9				
	Mean	47.4	39.7	43.1	41.6	45.3	-				
CP, DM%	60	18.6	25.9	22.7	22.4	21.4	22.2^{B}	0.24	<0.0001	0.007	0.6608
	120	19.3	26.2	23.4	23.0	21.5	22.7^{A}				
	Mean	18.9^{d}	26.1A	23.0^{b}	22.7^{b}	21.4^{c}	-				
NDF, DM%	60	32.4^{Aa}	29.4^{Bb}	33.7^{Aa}	33.0^{Ba}	21.8^{Ac}	30.0	0.72	<0.0001	0.0065	<0.0001
	120	29.5^{Bc}	34.0^{Aab}	33.0^{Ab}	36.8^{Aa}	23.7^{Ad}	31.4				
	Mean	31.0	31.7	33.3	34.9	22.7	-				
Ash, DM%	60	11.0^{Aa}	10.6^{Ba}	10.5^{Aa}	10.6^{Aa}	8.3^{Ab}	10.2	0.19	<0.0001	0.0844	0.0272
	120	11.4^{Aab}	11.6^{Aa}	10.7^{Abc}	10.2^{Ac}	8.3^{Ad}	10.4				
	Mean	11.2	11.1	10.6	10.4	8.3	-				

DM, Dry matter; CP, Crude protein; NDF, Neutral detergent fiber.
[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean.
[3]T, Treatment effect; L, Length of storage effect; T×L, Interaction effect between treatment and length of storage.
Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between length of storage. Both differ statistically using the Tukey test at 5% probability.

Table 3: Microbial population count of TMR and PMR before ensiling

Items	Treatments[1]					SEM[2]	P-value
	TMR	WDBS	WDBS+CH	WDBS+SH	WDBS+ CORN		
LAB, $\log_{10}$ cfu /g[3]	3.82^{a}	2.53^{b}	3.78^{a}	4.11^{a}	2.68^{b}	0.08	<0.0001
Mold, $\log_{10}$ cfu /g	4.83^{a}	4.82^{a}	4.22^{c}	4.50^{b}	3.86^{d}	0.03	<0.0001
Yeast, $\log_{10}$ cfu /g	Less than 2.00 $\log_{10}$cfu					-	-

LAB, Lactic acid bacteria.
[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean.
[3]In fresh matter (FM).
Values followed by different lowercase letters indicate statistical difference between treatments. Statistically using the Tukey test at 5% probability.

Effluent Production

Effluent production increased with storage duration across treatments ($P < 0.01$; Tables 4 and 5). Wet Distillers bran plus solubles ensiled alone produced the greatest effluent volumes, whereas total mixed ration and partial mixed rations with higher moisture-binding capacity exhibited reduced effluent losses.

Table 4: Microbial population count of TMR silage and PMR silage post 60 days and 120 days ensiled

Items	Length of storage (d)	Treatments[1]						SEM[2]	P-value[3]		
		TMR	WDBS	WDBS+CH	WDBS+SH	WDBS+CORN	mean		T	L	T×L
LAB, log_{10} cfu /g[4]	60	5.89^{Aa}	3.32^{Ad}	4.40^{Ab}	3.70^{Ac}	3.26^{Ad}	4.11	0.09	<0.0001	<0.0001	<0.0001
	120	4.48^{Ba}	3.13^{Ac}	3.55^{Bb}	2.88^{Bc}	2.49^{Bd}	3.31				
	Mean	5.19	3.23	3.97	3.29	2.87	-				
Mold, log^{10} cfu /g	60	2.48	2.20	2.54	2.59	2.49	2.46^{A}	0.11	0.8074	<0.0001	0.062
	120	2.20	2.22	2.06	2.00	2.06	2.11^{B}				
	Mean	2.34	2.21	2.30	2.29	2.28	-				
Yeast, log^{10} cfu /g	60	No[5]					-	-	-	-	-
	120	No									
	Mean	-									

LAB, Lactic Acid Bacteria

[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.

[2]SEM, Standard error of the mean.

[3]T, Treatment effect; L, Length of storage effect; T×L, Interaction effect between treatment and length of storage.

[4]In fresh matter (FM).

[5]Yeast was not detected in all dilution.

Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between length of storage. Both differ statistically using the Tukey test at 5% probability

Table 5: Fermentative profile of TMR silage and PMR silage

Items	Length of storage (d)	Treatments[1]						SEM[2]	P-value[3]		
		TMR	WDBS	WDBS+ CH	WDBS+ SH	WDBS+ CORN	Mean		T	L	T×L
pH	60	4.34^{Aa}	3.73^{Bc}	3.78^{Bbc}	3.79^{Bb}	3.74^{Bc}	3.87	0.01	<0.0001	<0.0001	<0.0001
	120	4.34^{Aa}	3.87^{Ab}	3.92^{Ab}	3.92^{Ab}	3.88^{Ab}	3.99				
	Mean	4.34	3.80	3.85	3.85	3.81	-				
Lactic acid, % DM corr3	60	4.74	4.95	3.69	5.07	4.48	4.59^{B}	0.61	0.0269	<0.0001	0.1284
	120	5.49	6.08	6.14	8.64	7.51	6.77^{A}				
	Mean	5.12^{ab}	5.52^{ab}	4.91^{b}	6.85^{a}	5.99^{ab}	-				
Acetic acid, % DM corr	60	0.37	0.30	0.24	0.30	0.31	0.30^{B}	0.03	0.003	0.0051	0.4657
	120	0.40	0.31	0.31	0.40	0.36	0.36^{A}				
	Mean	0.39^{a}	0.31^{b}	0.27^{b}	0.35^{ab}	0.33^{ab}	-				
Propionic acid, mg/kg	60	383	140	130	134	120	181^{B}	17.9	<0.0001	0.0133	0.1672
	120	351	145	176	172	152	199^{A}				
	Mean	367^{a}	143^{b}	153^{b}	153^{b}	136^{b}	-				
Butyric acid, mg/kg	60	117^{Aa}	8.50^{Abc}	3.25^{Ad}	3.75^{Acd}	12.5^{Ab}	29.0	3.22	<0.0001	0.6944	0.0176
	120	105^{Aa}	11.0^{Ab}	3.25^{Ac}	6.00^{Abc}	5.00^{Bc}	26.1				
	Mean	111	9.75	3.25	4.88	8.75	-				
Ethanol, % DM corr	60	0.11^{Aa}	0.10^{Aa}	0.10^{Aa}	0.13^{Ba}	0.11^{Ba}	0.11	0.01	<0.0001	<0.0001	0.0007
	120	0.10^{Ab}	0.12^{Ab}	0.13^{Ab}	0.20^{Aa}	0.19^{Aa}	0.15				
	Mean	0.10	0.11	0.11	0.17	0.15	-				
1-Propanol, mg/kg	60	166	146	88	119	150	134	17.9	0.1141	0.1025	0.1658
	120	154	129	143	170	168	153				
	Mean	160	137	116	145	159	-				

1.2-Propanediol mg/kg	60	402^{Ab}	544^{Aa}	389^{Bb}	492^{Bab}	402^{Bb}	446	34.5	0.0003	0.0035	0.0041
	120	379^{Ac}	472^{Abc}	514^{Aabc}	640^{Aa}	571^{Aab}	515				
	Mean	390	508	452	566	487	-				
2.3-Butanediol, % DM corr	60	0.64^{Aa}	0.86^{Aa}	0.68^{Aa}	0.70^{Ba}	0.63^{Ba}	0.72	0.06	0.0004	0.005	0.0318
	120	0.59^{Ab}	0.84^{Aa}	0.85^{Aa}	1.00^{Aa}	0.90^{Aa}	0.83				
	Mean	0.61	0.85	0.76	0.90	0.76	-				
A/P ratio, %	60	9.79^{Bb}	22.0^{Aa}	18.4^{Aa}	22.4^{Aa}	21.1^{Aa}	18.7	1.02	<0.0001	0.6047	0.0132
	120	11.5^{Ac}	17.9^{Bb}	17.6^{Ab}	23.4^{Aa}	23.6^{Aa}	18.8				
	Mean	10.6	19.9	18.0	22.9	22.4	-				

[1]TMR, Total mixed ration; WDBS, ensiling wet distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean.
[3]T, Treatment effect; L, Length of storage effect; T×L, Interaction effect between treatment and length of storage
Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between length of storage. Both differ statistically using the Tukey test at 5% probability.

Aerobic Stability

Aerobic stability and temperature responses of partial mixed ration silages during air exposure are presented in Tables 6-8 and Figure 1. Silages containing wet Distillers bran plus solubles ensiled alone exhibited shorter aerobic stability periods compared with total mixed ration and partial mixed rations, regardless of storage duration.

Quantitative indicators of aerobic stability, including time to temperature increase above ambient and total stability period, are summarized in Table 9. Total mixed ration and partial mixed rations formulated with ingredients of higher water-holding capacity showed longer stability times, whereas silages containing wet Distillers bran plus solubles alone reached the heating threshold earlier, indicating greater susceptibility to aerobic deterioration.

Temperature dynamics during aerobic exposure are detailed in Table 16. Silages with lower stability exhibited higher maximum temperatures and greater temperature variation during air exposure. In contrast, total mixed ration and partial mixed rations showed lower peak temperatures and reduced thermal amplitude, reflecting greater resistance to aerobic spoilage.

The combined interpretation of Tables 6 and 7 demonstrates that aerobic stability differences among treatments were not limited to time-to-heating responses but also involved distinct temperature dynamics during exposure to air.

Table 6. Water holding capacity of raw ingredients and WDBS-based TMR silage and PMR silage

Items	WHC (g/g DM)[1]
Tropical grass silage	4.56±0.07
Cottonseed hulls	3.63±0.12
Soybean hulls	4.34±0.44
Ground corn	1.11±0.09
88% WDBS+12% Tropical grass silage	1.73±0.12
TMR	1.74±0.02
WDBS	1.17±0.05
WDBS+CH	1.39±0.06
WDBS+SH	1.61±0.14
WDBS+CORN	0.97±0.30

TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.

[1]Water holding capacity mean that the amount of moisture in grams that a silage material can retain per gram of the dry matter weight.

Table 7: Effluents and dry matter losses of TMR silage and PMR silage

Items	Length of storage (d)	Treatments[1]						SEM[2]	P-value[3]		
		TMR	WDBS	WDBS+ CH	WDBS+ SH	WDBS+ CORN	Mean		T	L	T×L
DM losses,%	60	1.80^{Ac}	5.05^{Bb}	7.85^{Aa}	3.83^{Bbc}	6.33^{Bab}	4.97	0.61	<0.0001	0.005	0.0089
	120	0.58^{Ab}	7.48^{Aa}	7.65^{Aa}	6.28^{Aa}	8.75^{Aa}	6.15				
	Mean	1.19	6.26	7.75	5.05	7.54	-				
Production of effluent (g/kg, FM)4	60	26Ac	120^{Ba}	101^{Aab}	40^{Bc}	86^{Bb}	74	5.30	<.0001	0.007	0.0002
	120	35Ad	180^{Aa}	115Ab	57^{Ac}	120^{Ab}	101				
	Mean	31	150	108	48	103	-				

[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean
[3]T, Treatment effect; L, Length of storage effect; T×L, Interaction effect between treatment and length of storage.
[4]In fresh matter (FM)
Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between length of storage. Both differ statistically using the Tukey test at 5% probability

Table 8: Aerobic stability of TMR silage and PMR silage

Items	Length of storage (d)	Treatments[1]						SEM[2]	P-value[3]		
		TMR	WDBS	WDBS+CH	WDBS+SH	WDBS+CORN	Mean		T	L	T×L
Aerobic stability, h	60	480	366	480	480	466	454^{A}	10.7	<0.0001	0.034	0.0598
	120	480	334	436	468	480	440^{B}				
	Mean	480^{a}	350^{b}	458^{a}	474^{a}	473^{a}	-				
T max, °C	60	24.8^{Ab}	37.2^{Ba}	25.1^{Bb}	24.7^{Ab}	26.9^{Ab}	27.7	1.21	<0.0001	<0.0001	<0.0001
	120	24.5^{Ac}	43.9^{Aa}	35.3^{Ab}	28.0^{Ac}	25.7^{Ac}	31.5				
	Mean	24.6	40.6	30.2	26.3	26.3	-				

[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean.
[3]T, Treatment effect; L, Length of storage effect; T×L, Interaction effect between treatment and length of storage.
Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between length of storage. Both differ statistically using the Tukey test at 5% probability.

Table 9: pH results before and after aerobic stability test

Items	Day of exposure (d)	Treatments1						SEM2	P-value3		
		TMR	WDBS	WDBS+ CH	WDBS+ SH	WDBS+ CORN	Mean		T	D	T×D
Ensiling 0 days, pH	0	4.41Ba	3.91Ad	3.98Bc	4.04Ab	3.97Ac	4.06	0.005	<0.0001	<0.0001	<0.0001
	10	4.67Aa	3.91Ad	4.00Ab	4.02Bb	3.98Ac	4.12				
	Mean	4.54	3.91	3.99	4.03	3.98	-				
Ensiling 60 days, pH	0	4.34Aa	3.73Bb	3.78Ab	3.79Ab	3.74Ab	3.87	0.08	<0.0001	<0.0001	<0.0001
	20	4.41Aa	4.71Aa	3.82Ab	3.82Ab	3.81Ab	4.11				
	Mean	4.37	4.22	3.80	3.80	3.77	-				
Ensiling 120 days, pH	0	4.34Aa	3.87Bb	3.92Bb	3.92Ab	3.88Ab	3.99	0.10	<0.0001	<0.0001	<0.0001
	20	4.32Ab	5.02Aa	4.30Ab	3.94Abc	3.83Ac	4.28				
	Mean	4.33	4.45	4.11	3.93	3.85	-				

[1]TMR, Total mixed ration; WDBS, ensiling wet Distillers bran plus solubles alone; WDBS+CH, mixed ensiled 85% WDBS with 15% cottonseed hulls; WDBS+SH, mixed ensiled 81% WDBS with 19% soybean hulls; WDBS+CORN, mixed ensiled 72% WDBS with 28% ground corn.
[2]SEM, Standard error of the mean.
[3]T, Treatment effect; D, days of exposure effect; T×D, Interaction effect between treatment and days of exposure days.
Values followed by different lowercase letters indicate statistical difference between treatments. Values followed by different capital letters indicate statistical difference between days of exposure. Both differ statistically using the Tukey test at 5% probability

Discussion

This applied study demonstrates that preservation efficiency of partial mixed ration silage containing wet Distillers bran plus solubles is governed by physical and managerial factors that operate before, during, and after ensiling. When evaluated collectively, the results presented in Tables 1-9 and Figure 1 indicate that moisture distribution, rather than fermentation intensity alone, is the primary driver of dry matter losses, effluent production, and aerobic stability under practical conditions.

The marked differences in water-holding capacity among ingredients and mixed rations (Table 8) provide a mechanistic explanation for the subsequent patterns of effluent production and dry matter losses observed during storage (Tables 2-5). Rations formulated with ingredients exhibiting greater moisture-binding capacity showed consistently lower effluent losses, supporting the concept that free water availability is a critical determinant of physical nutrient losses in high-moisture silage systems [7]. This finding reinforces that, in applied settings, preservation efficiency begins with formulation decisions rather than corrective strategies applied after ensiling.

Dry matter losses increased with storage duration across treatments (Tables 2 and 3), reflecting the cumulative nature of physical and fermentative losses over time. However, the magnitude of these losses was strongly modulated by ration composition. Total mixed ration and partial mixed rations with improved moisture distribution consistently exhibited lower cumulative losses than wet Distillers bran plus solubles ensiled alone. This interaction between formulation and storage duration indicates that extended storage exacerbates inherent formulation weaknesses but does not negate the benefits of proper moisture management.

Effluent production patterns (Tables 4 and 5) further highlight the applied importance of moisture-binding capacity. Silages with insufficient dry matter content or limited structural components exhibited substantially greater effluent losses, which represent irreversible nutrient and energy losses from the system. Beyond their nutritional implications, effluent losses pose environmental and operational challenges, reinforcing the relevance of formulation-based strategies for mitigating both economic and environmental risks associated with wet by-product utilization [4].

Aerobic stability results provide critical insight into the feed-out phase, which is often the most vulnerable stage in practical silage utilization. Quantitative indicators of aerobic stability (Table 8) showed that silages with poor moisture management deteriorated more rapidly upon air exposure. Importantly, the temperature dynamics described in Table 16 reveal that aerobic deterioration was not merely a matter of time-to-heating but involved substantially different thermal responses among treatments. Silages exhibiting higher maximum temperatures and greater thermal amplitudes experienced more intense spoilage activity, indicating accelerated aerobic metabolism [5].

The combined interpretation of Tables 8 and 9 underscores that aerobic stability should be understood as a dynamic process rather than a single endpoint. Silages that appeared marginally stable based on time-to-heating alone often exhibited pronounced temperature fluctuations during air exposure, suggesting that reliance on a single stability metric may underestimate spoilage severity under applied conditions. This reinforces the importance of integrating multiple indicators when evaluating silage performance in practice.

Notably, ration composition exerted a greater influence on aerobic stability than storage duration. While prolonged storage increased cumulative losses, its effect on aerobic behavior was secondary to formulation-driven differences in moisture distribution and substrate availability. This finding has direct applied relevance, as storage duration is frequently constrained by logistical considerations, whereas formulation strategies can be readily adjusted to improve stability during feed-out [2].

Unlike experimental studies focused on microbial or chemical additives, the present work demonstrates that substantial improvements in preservation efficiency can be achieved through formulation and management decisions alone. By addressing moisture distribution at the ration level, it is possible to reduce effluent losses, limit dry matter degradation, and enhance aerobic stability without reliance on additives. This applied approach aligns with the operational realities of ruminant production systems and provides actionable guidance for improving the utilization of wet Distillers bran plus solubles under real-world conditions.

Conclusion

This applied study demonstrates that preservation efficiency of partial mixed ration silage containing wet Distillers bran plus solubles is primarily determined by formulation-driven Moisture distribution and storage management, rather than by fermentation intensity alone. Differences in water-holding capacity among ingredients directly influenced effluent production, cumulative dry matter losses, and aerobic stability during feed-out. Rations formulated to increase moisture-binding capacity consistently reduced effluent losses and dry matter degradation during storage and exhibited greater resistance to aerobic deterioration. Although prolonged storage increased cumulative losses across treatments, its impact was secondary to formulation effects, indicating that appropriate ration design can mitigate the negative consequences of extended storage under practical conditions.

The integration of quantitative aerobic stability indicators and temperature dynamics confirmed that aerobic deterioration is a progressive and dynamic process. Evaluations based solely on time-to-heating may underestimate spoilage severity, emphasizing the need for multiple indicators when assessing silage performance in applied systems. Overall, the results provide applied, system-level evidence that strategic ration formulation and storage management can substantially improve the utilization of wet Distillers bran plus solubles without reliance on additives. These findings offer practical guidance for reducing nutrient losses, improving feed stability, and enhancing the sustainability of ruminant feeding systems using high-moisture agro-industrial by-products.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical statements

Not applicable.

References

1. McDonald P, Henderson AR, Heron SJE. The Biochemistry of Silage. Chalcombe Publications, Marlow, UK. 1991.
2. Wilkinson JM, Davies DR. The aerobic stability of silage: key findings and recent developments. Grass and Forage Science. 2013. 68, 1-19.
3. Pahlow G, Muck RE, Driehuis F, Oude Elferink SJWH, Spoelstra, SF. Microbiology of ensiling. In: Buxton, D.R., Muck, R.E. and Harrison, J.H. (eds.), Silage Science and Technology. ASA–CSSA–SSSA, Madison, WI. 2003.
4. Kung L Jr, Stokes MR, Lin, CJ. Silage additives. In: Buxton, D.R., Muck, R.E. and Harrison, J.H. (eds.), Silage Science and Technology. ASA–CSSA–SSSA, Madison, WI. 2003.
5. Schingoethe DJ. A 100-year review: total mixed ration feeding of dairy cows. Journal of Dairy Science. 2017. 100: 10143-10150.
6. Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O. SAS for Mixed Models. 2nd ed. SAS Institute Inc., Cary, NC, USA. 2006.
7. Piepho HP, Büchse A, Richter C. A mixed modelling approach for randomized experiments with repeated measures. Journal of Agronomy and Crop Science. 2012. 198: 135-147.
8. Verbeke G, Molenberghs G. Linear Mixed Models for Longitudinal Data. Springer, New York, NY, USA. 2000.
9. Field A. Discovering Statistics Using IBM SPSS Statistics. 4th ed. Sage Publications, London, UK. 2013.