ELSEVIER

JOURNAL ON COMMUNICATIONS

ISSN:1000-436X

Scopus

REGISTERED

www.jocs.review

Evaluation of the effects of storage time, salt addition and type of additive on the fermentation, microbiological and organoleptic quality of Maralfalfa silage in Niger.

Maman Lawal Abdoul Aziz1 [1]*, Seydou Korombé Hamza [2], Djibo Ibrahim [3], Abdou Moussa Mahaman Maaouia[4], Gagara Hima Mariama [5], Aliou Barazi Aminatou [6], Amadou Abdoulaye M. Bahari [1], Nourou Abdou [1], Soumana Gouro Abdoulaye [4]

[1] *National Institute of Agronomic Research of Niger, P.O. Box 429, Niamey, Niger*
[2] *Livestock Breeding Center, P.O. Box 827, Niamey, Niger*
[3] *Faculty of Sciences, University of Agadez, P.O. Box 199, Agadez, Niger*
[4] *Faculty of Agronomy, Abdou Moumouni University of Niamey, P.O. Box 10960, Niamey, Niger*
[5] *Central Livestock Laboratory, P.O. Box 485, Niamey, Niger*
[6] *National Program for the Genetic Improvement of Local Cattle, P.O. Box 12091, Niamey, Niger*

* **Corresponding author:** Maman Lawal Abdoul Aziz.

Abstract

This study aimed to improve the quality of Maralfalfa silage to address the seasonal forage deficit in Niger. The effect of storage duration (30, 45, 60 days), the addition of 4% salt, and enrichment with locally available by-products (wheat bran, rice bran, cottonseed meal) on microbiological and organoleptic parameters was evaluated.
The results indicate that 60-day storage improves stability by significantly reducing the butyric acid bacteria population. The addition of salt proved crucial, significantly lowering the pH (from 4.85 to 4.08) and eliminating undesirable odors and a slimy texture. The best performance was achieved through the synergy between salt and an energy by-product. The Maralfalfa + wheat bran + salt and Maralfalfa + rice bran + salt treatments consistently produced silage with a low pH, increased stability, 100% good odors, and a firm texture.
For a simple and economical approach, adding 4% salt (Maralfalfa + salt treatment) is recommended. For optimal quality and enhanced nutritional value, treatments combining salt and bran (Maralfalfa + wheat bran + salt or Maralfala + rice bran + salt) are preferable. These accessible techniques allow for the sustainable use of Maralfalfa and the creation of high-quality forage reserves for the dry season.

Keywords: **Feed, Conservation, Microorganism, Fermentation, Fodder, Anaerobic.**

1. Introduction

Livestock food and nutritional security in semi-arid regions like the Sahel is highly dependent on the availability and quality of fodder, particularly during the long dry season (Rutagongwa, 2003; Amole et al., 2022). Seasonal pastoral production is insufficient to meet animal needs during this critical period, making the conservation of fodder harvested during the rainy season essential. Simultaneously, the intensification of livestock farming in some tropical countries requires the development of productive fodder crops and the storage of a significant portion of plant biomass (Rutagongwa, 2003).

In Niger, Maralfalfa (*Pennisetum purpureum* Schumach) is attracting increasing interest as a high-yield forage capable of addressing the energy and protein deficits of tropical pastures during the dry season (Rutagongwa, 2003; Lawal, 2024; RECA, 2025). However, its optimal conservation remains a technical challenge.

Silage, a preservation technique using anaerobic fermentation, helps maintain the nutritional value of moist forages through the action of Lactic Acid Bacteria (LAB), which produce lactic acid and lower the pH. A stable pH below 4.5 is a key indicator of successful fermentation and good stability, thus limiting the activity of undesirable microorganisms (Pahlow et al., 2003; Valacta, 2017). However, like many tropical forages, Maralfalfa often has insufficient dry matter and fermentable carbohydrate content, which can compromise the speed and efficiency of lactic acid fermentation (McDonald, 1981; Santos et al., 2013). These limitations can lead to undesirable fermentations, nutritional losses, and low animal palatability (Weinberg and Chen, 2013).

To overcome these constraints, the use of silage additives is a common practice. They fall into two main categories: fermentation stimulators (bacterial inoculants, sources of simple sugars) and inhibitors (acids, salts, antiseptics) (Kung et al., 2018; Muck et al., 2018). Table salt (NaCl) occupies a special place: its main effect is physicochemical. Indeed, by creating osmotic stress, it causes the lysis of plant cells, thus releasing cellular sugars that are readily available to lactic acid bacteria, which can accelerate acidification (Rabelo et al., 2014; Muck et al., 2018). This effect has been demonstrated in sorghum and sugarcane silage (Cai et al., 1997; Rabelo et al., 2014). In parallel, enrichment with agro-industrial by-products (brans, oilseed cakes) constitutes a complementary strategy to correct the deficit in fermentable substrates and improve the nutritional value of silage (Ávila and Carvalho, 2020; Wang et al., 2020).

While recent studies have assessed the effect of salt on millet silage in Niger (Korombé et al., 2023b; Korombé, 2024), little research has focused on optimizing Maralfalfa silage under Nigerien conditions. The potential synergy between salt addition and enrichment in energy by-products remains to be elucidated, as does the optimal storage duration to ensure stability and organoleptic quality.

The present study therefore aims to evaluate the combined effect of storage time (30, 45 and 60 days), the addition of salt (4%) and enrichment with different agro- industrial by-products (wheat bran, rice bran, cottonseed cakes) on the chemical, microbiological and organoleptic parameters of Maralfalfa silage in Niger.

The hypotheses tested are that (i) 60 days of storage improves microbiological stability compared to 30 days, (ii) the addition of salt significantly lowers pH and improves sensory characteristics, and (iii) the combination of salt and energy by-product produces a synergistic effect, resulting in superior quality silage.

This research will help to propose conservation protocols adapted to local constraints, in order to sustainably enhance Maralfalfa as a strategic forage resource for livestock food security in Niger.

2. Materials and Methods

2.1. Materials

2.1.1. Study area

The study was conducted at the experimental station of the Regional Center for Agronomic Research (CERRA) in Kollo, located in N'Dounga, 7 km from the center. This station is situated between 13° 22' North latitude and 2° 14' East longitude, at an altitude of 192 m. It covers an area of 7 hectares. The soil is sandy and suitable for various rainfed and irrigated crops. The climate of the area is Sahelian, characterized by a long dry season (October to June), comprising a cool period (October to February) followed by a hot period (February to June), with temperatures reaching up to 45°C locally. The short rainy season extends from July to September, with an average annual rainfall of 500 mm. The wettest months are July and August (Abdou et al., 2019).

2.1.2. Equipment for preparing silage

Table 1 shows the equipment used for silage preparation.

Table 1. Equipment requirements for silage preparation

Section	Units	Actual quantity	Increased quantity
Maralfalfa (MAR)	kg	434.4	500
Wheat bran (WB)	50 kg bag	1	1
Cottonseed cake (CSC)	50 kg bag	1	1
Rice bran (RB)	50 kg bag	1	1
Salt	25 kg bag	1	1
6 kg capacity pot	Unit	96	110
Plastic bags	Unit	96	110
Roll of black plastic	Unit	1	1
Adhesive tape	Unit	4	4

2.2. Methods

2.2.1. Experiment design

Three factors were evaluated: salt addition (with or without salt), additive type (wheat bran, cottonseed cake, rice bran, and no additive), and storage duration (30, 45, and 60 days), resulting in a factorial design of 2 x 4 x 3 = 24 treatments or silage types. Each combination of salt addition and additive type (2 x 4 = 8 treatments) was repeated 3 times, corresponding to the three storage durations (30, 45, and 60 days). Four repetitions were considered for each of the 24 treatments, for a total of 96 repetitions.
Table 2 gives the chemical composition of the additives used.

Table 2. Chemical composition of different types of additives

	Type of additive		
Settings	Rice Bran (RB)	Wheat Bran (WB)	Cottonseed cake (CSC)
DM (%)	93.82	94.42	94.62
MM (%)	14.91	17.51	3.18
CP (%)	15,028	13,296	6,803
CF (%)	9.48	20.66	47.90

DM: Dry Matter; MM: Mineral Matter; CP: Crude Protein; CC: Crude Fiber.

2.2.2. Silage preparation

Maralfalfa forage was produced at the CERRA experimental station in Kollo, N'dounga, and harvested after two months of regrowth, as reported by Silva et al. (2020). The forage was then chopped into uniform strands of approximately 1 cm using an electric grinder. These chopped maralfalfa strands were used as a base ingredient in silage preparation.
For each type of silage, 4 repetitions of 5 kg each were considered, for a total of 96 repetitions.

Wheat bran, cottonseed cake (CSC), and rice bran were each incorporated at 10%, and salt at 4%, into the various silages. The different ingredients were weighed and mixed as follows, depending on the treatment (Table 3).

Table 3: Quantity of different ingredients incorporated according to the treatment

Treatments	Maralfalfa (kg)	Wheat bran (kg)	Rice bran (kg)	CSC (kg)	Salt (kg)	Total (kg)
T1	5	0	0	0	0	5
T2	4.5	0.5	0	0	0	5
T3	4.3	0.5	0	0	0.2	5
T4	4.8	0	0	0	0.2	5
T5	4.5	0	0.5	0	0	5
T6	4.3	0	0.5	0	0.2	5
T7	4.5	0	0	0.5	0	5
T8	4.3	0	0	0.5	0.2	5

T1: 100% Maralfalfa forage; T2: Maralfalfa forage + 10% wheat bran; T3: Maralfalfa forage + 10% wheat bran + 4% salt; T4: Maralfalfa forage + 4% salt; T5: Maralfalfa forage + 10% rice bran; T6: Maralfalfa forage + 10% rice bran + 4% salt; T7: Maralfalfa forage + 10% cottonseed cake; T8: Maralfalfa forage + 10% cottonseed cake + 4% salt.

2.2.3. Bromatological analysis of additives

Samples of the additives were collected and analyzed according to AOAC (1990) methods at the Animal Nutrition Laboratory of the Faculty of Agronomy at Abdou Moumouni University in Niamey. The analyses focused on: Dry Matter (DM) content, Crude Fiber (CF), ash or Mineral Matter (MM) and Nitrogen (N) to calculate Crude Protein (CP). The various samples were ground to 1 mm before analysis.

2.2.4. Determination of microbiological parameters

The microbiological analyses were carried out at the Central Livestock Laboratory of Niger (LABOCEL).
The enumeration and detection of the different microorganisms in all samples were carried out according to the ISO 7218 standard, which sets out the general rules for microbiological examinations throughout the entire laboratory analysis process.

2.2.5. Determination of organoleptic parameters

The sensory evaluation was conducted by a panel of seven experts previously trained on the defined descriptors. Three parameters were studied: color, odor, and appearance. For each open sample, the evaluators independently and confidentially assigned a rating to each parameter based on their sensory perception. The results were then consolidated using a majority rule: the rating assigned to the sample was the one chosen by more than half of the panel members.

Table 4: The different modalities defined according to the parameters studied

Settings	Terms and conditions
Color	Light green
	Dark green
	Olive green
	Light yellowish green
	Dark yellowish green

	Other details to be specified
Smell	Very good
	Good
	Pretty good
	Bad
Appearance	Normal, not slimy
	Normal, not very slimy
	Normal slimy
	Abnormal, non-slimy
	Abnormal, slightly slimy
	Abnormal slimy

2.2.6. Statistical analysis of data

The collected data were entered into Excel. Excel was also used to design the figures and tables. Mean comparisons were performed using the General Linear Model (GLM) procedure in the Statistical Package for Social Sciences (SPSS). In all analyses, the parameters studied were considered dependent variables, while salt addition, shelf life, and type of additive were used as fixed variables.

3. Results and Discussion

3.1. Results

3.1.1. Evaluation of the effect of storage time on pH, dry matter content before and after ensiling and microbiological parameters

The effect of storage duration on pH, dry matter content before and after ensiling, and microbiological parameters of Maralfalfa silage was evaluated (Table 5). The results show that storage duration has a significant effect (P-value <0.05) on some parameters, including Silage Dry Matter Content (S-DMC), Dry Matter Loss (DML), and Butyric Acid Bacteria (BAB) population. Silage stored for 45 days resulted in the highest S-DMC (32.56 ± 6.01) and butyric acid bacteria count (3.88 ± 0.42 log (CFU)), while dry matter loss was the lowest (-12.15 ± 20.17).

Table 5: Evolution of pH, dry matter content before and after ensiling, and microbiological parameters as a function of storage time

	Number of days				
Settings	30 days	45 days	60 days	Average	P-value
pH	4.35±0.46 a	4.38±0.39 a	4.64 ± 0.53 a	4.46±0.48	0.074
DM Before S (%)	29.10 ± 5.90 a	29.08±6.04 a	29.30 ± 5.95 a	29.16±5.88	0.990
S-DMC (%)	25.80 ± 3.93 b	32.56±6.01 a	25.89 ± 4.15 b	28.05±5.68	0.000
DML (%)	11.10 ± 13.23 a	-12.15±20.17 b	11.03±18.21 a	3.44±20.36	0.000
WL (kg)	0.07±0.03 a	0.09±0.04 a	0.10±0.05 a	0.09±0.04	0.093
BAB log (CFU)	3.42 ± 1.16 ab	3.88 ± 0.42 a	2.73 ± 1.26 b	3.34 ± 1.11	0.001
LAB log (CFU)	3.52 ± 1.64 a	3.52 ± 1.27 a	3.99±0.90 a	3.67±1.31	0.375
SF log (CFU)	3.23 ± 1.97 a	3.52 ± 1.77 a	3.58±1.79 a	3.44±1.83	0.782

In the rows, means with at least one identical letter are not statistically different from each other at the 5% significance level.

DM Before S: Dry Matter Before silage; S-DMC: Silage Dry Matter Content; DML: Dry Matter Loss; WL: Weight Loss; BAB: Butyric Acid Bacteria; LAB: Lactic Acid Bacteria; SF: Spoilage Flora; CFU: Colony Forming Unit.

3.1.2. Evaluation of the effect of salt addition on pH, dry matter content before and after ensiling and microbiological parameters

Table 6 presents the pH, dry matter content before and after ensiling, and microbiological parameters according to salt addition. The pH is significantly lower in silages with salt (4.08) than in silages without salt (4.85), while the dry matter content, both before and after ensiling, is significantly higher in silages with salt. The difference in dry matter content between the two groups (4.89% and 1.90%) is not statistically significant (P-value = 0.544). However, weight loss is significantly higher in silages with salt (0.12 kg) than in those without salt (0.06 kg). Regarding the number of butyric acid bacteria (BAB) and lactic acid bacteria (LAB), No significant difference was observed based on the addition of salt. For the Spoilage Flora (SF), although the P-value (0.231) indicates a non-significant difference, the mean numerical value is lower in the "With salt" group (3.18 log CFU) than in the "Without salt" group (3.71 log CFU).

Table 6: Evolution of pH, dry matter content before and after ensiling, and microbiological parameters as a function of salt addition

Adding salt				
Settings	With salt	Without Salt	Average	P-value
pH	4.08 ± 0.29 b	4.85±0.26 a	4.46±0.48	0.000
DM Before S (%)	32.10±6.54 a	26.05 ± 2.74 b	29.16±5.88	0.000
S-DMC (%)	30.33 ± 5.88 a	25.64 ± 4.37 b	28.05±5.68	0.000
DML (%)	4.89±21.68 a	1.90±19.06 a	3.44±20.36	0.544
WL (kg)	0.12 ± 0.03 a	0.06 ± 0.02 b	0.09±0.04	0.000
BAB log (CFU)	3.24 ± 1.15 a	3.45±1.07 a	3.34 ± 1.11	0.443
LAB log (CFU)	3.72 ± 1.36 a	3.62 ± 1.26 a	3.67±1.31	0.746
SF log (CFU)	3.18±2.09 a	3.71±1.48 a	3.44±1.83	0.231

In the rows, means with identical letters are not statistically different from each other at the 5% significance level.
DM Before S: Dry Matter Before silage; S-DMC: Silage Dry Matter Content; DML: Dry Matter Loss; WL: Weight Loss; BB: Butyric Bacteria; LB: Lactic Bacteria; SF: Spoilage Flora; CFU: Colony Forming Unit.

3.1.3. Evaluation of the effect of different additives on pH, dry matter content before and after ensiling and microbiological parameters

The pH, dry matter content before and after ensiling, and microbiological parameters of Maralfalfa silage are presented in Table 7. The pH varied significantly (P-value <0.001) from 3.94 to 5.00. The treatments in the "Salt-free" group (Maralfalfa 100%, MAR + WB, MAR + RB, MAR + CSC) had the highest pH values (> 4.63), indicating low lactic acid fermentation. The addition of salt, alone or in combination, significantly lowered the pH (between 3.94 and 4.22). A highly significant difference was also observed between treatments for the Silage Dry Matter Content (S-DMC). Silages with added additives had higher dry matter content than the control (MAR 100%). DML and WL varied significantly (P-value <0.001), from -18.89% (MAR + CSC) to 21.19% (MAR + CSC + Salt) and from 0.04 kg (MAR + CSC) to 0.13 kg (MAR + WB + Salt), respectively. No treatment had a statistically significant effect (P-value >0.05) on the populations of Butyric Acid Bacteria (BAB), Lactic Acid Bacteria (LAB), and Spoilage Flora (SF).

Table 7: Evolution of pH, dry matter content before and after ensiling, and microbiological parameters according to treatment

Treatments	pH	DM Before S (%)	S-DMC (%)	DML (%)	WL (kg)	BAB log (CFU)	LAB log (CFU)	SF log (CFU)
MAR 100%	4.88 ± 0.10 [a]	24.41± 0.00	20.58 ± 3.36 [b]	16.62 ± 13.75 [a]	0.06± 0.02 [bc]	3.71 ± 0.68 [a]	3.53 ± 1.46 [a]	4.02 ± 1.66 [a]
MAR+ WB	4.63 ± 0.14 [a]	27.86± 0.00	27.80± 2.52 [a]	1.22 ± 8.95 [ab]	0.05 ± 0.00 [c]	3.43 ± 0.85 [a]	3.29 ± 1.33 [a]	4.09± 0.60 [a]
MAR+ WB+Salt	3.94 ± 0.27 [b]	31.00± 0.00	31.99± 3.39 [a]	-0.49± 10.54 [ab]	0.13± 0.03 [a]	3.44 ± 0.71 [a]	3.12 ± 1.78 [a]	3.88± 1.65 [a]
MAR+ Salt	4.22 ± 0.34 [b]	22.22 ± 0.00	26.22 ± 4.43 [ab]	-15.76± 19.30 [b]	0.09± 0.04 [ab]	3.02 ± 1.30 [a]	3.61±1.40 [a]	2.10± 2.06 [a]
MAR+ RB	4.91 ± 0.22 [a]	29.46± 0.00	26.51 ± 3.31 [ab]	11.35± 11.05 [a]	0.08± 0.03 [bc]	3.29 ± 1.43 [a]	3.81 ± 1.55 [a]	3.93 ± 0.56 [a]
MAR+ RB+Salt	4.13 ± 0.34 [b]	35.72± 0.00	31.25 ± 7.63 [a]	14.60± 20.94 [a]	0.12± 0.04 [a]	3.82 ± 0.44 [a]	3.84± 1.44 [a]	2.68± 2.56 [a]
MAR+ CSC	5.00 ± 0.37 [a]	22.67± 0.00	27.19 ± 4.32 [ab]	-18.89± 18.80 [b]	0.04 ± 0.02 [c]	3.37± 1.30 [a]	3.87± 0.78 [a]	2.86± 2.21 [a]
MAR+ CSC+Salt	4.02 ± 0.11 [b]	39.46± 0.00	31.87± 6.01 [a]	21.19± 14.76 [a]	0.12 ± 0.03 [a]	2.69± 1.60 [a]	4.34 ± 0.19 [a]	4.06± 1.62 [a]
Average	4.46± 0.48	29.16± 5.88	28.05± 5.68	3.44± 20.36	0.09± 0.04	3.34 ± 1.11	3.67± 1.31	3.44± 1.83
p-value	0.000	-	0.000	0.000	0.000	0.485	0.638	0.115

In the columns, averages with at least one identical letter are not statistically different from each other at the 5% significance level.
MAR 100%: Silage made from 100% Maralfalfa forage; MAR + WB: Silage made from Maralfalfa forage + 10% wheat bran; MAR + WB + Salt : Silage made from Maralfalfa forage + 10% wheat bran + 4% salt; MAR + Salt: Silage made from Maralfalfa forage + 4% salt; MAR + RB: Silage made from Maralfalfa forage + 10% rice bran; MAR + RB + Salt: Silage made from Maralfalfa forage + 10% rice bran + 4% salt; MAR + CSC: Silage made from Maralfalfa forage + 10% cottonseed cake; MAR + CSC + Salt: Silage made from Maralfalfa forage + 10% cottonseed cake + 4% salt; DM Before S : Dry Matter Before silage; S-DMS : Silage Dry Matter Content; DML : Dry Matter Loss; WL : Weight Loss; BAB : Butyric Acid Bacteria; LAB : Lactic Acid Bacteria; SF : Spoilage Flora; CFU : Colony Forming Unit.

3.1.4. Organoleptic characteristics of Maralfalfa silage according to storage time

Table 8 shows the evolution of the organoleptic characteristics (color, odor, appearance) of Maralfalfa silage as a function of storage duration (30, 45, and 60 days). Regarding silage color, the chi-square value is extremely low ($p < 0.001$), indicating a highly significant correlation between the shelf life and the color of the silage. The change is very clear, at At 30 days, the dominant color is "dark yellowish-green" (75%), while at 45 days, there is a radical change. The color "light yellowish-green" becomes by far the most prevalent (91.67%). The other green colors (dark, olive) have almost disappeared. After 60 days, the distribution is more mixed. The "light yellowish-green" color remains important (41.67%), but the "olive green" color becomes predominant (45.83%).

Regarding odor, the chi-square value is high ($p > 0.05$), indicating no statistically significant difference in silage odor across storage duration. However, the "Good" category is predominant at all times, with values of 54.17%, 62.5%, and 66.67% for silage stored for 30, 45, and 60 days, respectively. The "Fairly Good" and "Poor" categories are present in a relatively stable manner, without any marked trend. The "Very Good" category, low at 30 days (8.33%), disappears completely at 45 and 60 days.
Regarding the appearance of the silage, the chi-square value is low ($p < 0.01$), indicating a highly significant relationship between storage time and appearance. The "normal, non-slimy" appearance is dominant at all periods (from 62.5% to 87.5%). However, variations are observed. The "normal, slightly slimy" appearance is very common at 60 days (37.5%) after being low at 45 days (0%). Conversely, the "normal, slimy" appearance only appears at 45 days (12.5%).

Table 8: Organoleptic characteristics of silage according to storage time

Shelf life					
Variables	Terms and conditions	30 days	45 days	60 days	Chi-square
Color	Light Green (%)	4.17	0	0	0.000
	Dark green (%)	4.17	0	12.5	
	Olive green (%)	0	0	45.83	
	Light yellowish green (%)	16.67	91.67	41.67	
	Dark yellowish green (%)	75	8.33	0	
Smell	Very good (%)	8.33	0	0	0.488
	Good (%)	54.17	62.5	66.67	
	Fairly good (%)	16.67	25	20.83	
	Bad (%)	20.83	12.5	12.5	
Appearance	normal slimy (%)	0	12.5	0	0.003
	normal slightly slimy (%)	20.83	0	37.5	
	normal non-sticky (%)	79.17	87.5	62.5	

3.1.5. Organoleptic characteristics of Maralfalfa silage as a function of salt addition

Table 9 presents the organoleptic characteristics of Maralfalfa silage according to the addition of salt. The addition of salt appears to promote lighter colors. The "With salt" group is dominated by "light yellowish-green" (63.89%), while the "Without salt" group shows a more balanced distribution between "light yellowish-green" (36.11%) and "dark yellowish-green" (38.89%). However, the chi-square value (0.089) is above the 5% significance threshold. This indicates that the observed difference in color distribution is not statistically significant. Regarding the silage odor, the chi-square value is extremely low (0.000). This indicates a highly significant relationship between the addition of salt and the odor. The effect of salt is very pronounced and beneficial here. Indeed, the vast majority of silages with salt (88.89%) have a "Good" odor, and none are classified as "Bad" (0%). As for silages without salt, the odor quality deteriorates significantly. Only 33.33% are "Good," while 30.56% are "Bad" and 36.11% are "Fairly Good." Regarding the appearance of the silages, the chi-square value (0.008) is significant ($p < 0.01$). Salt has a positive and statistically proven effect on reducing the sliminess of the silage. Almost all samples of silage with salt (91.67%) have a "Normal, non-slimy" appearance. Whereas for silages without salt, the proportion of a "Normal, non-slimy" appearance drops to 61.11%. There is a notable increase in the "Normal slightly slimy" (30.56%) and even "Normal slimy" (8.33%) aspects, which is absent from the "With salt" group.

Table 9: Organoleptic characteristics of silages according to salt addition

Adding salt				
Variables	Terms and conditions	With salt	Without Salt	Chi-square
Color	Light Green (%)	2.78	0	0.089
	Dark green (%)	2.78	8.33	
	olive green (%)	13.89	16.67	
	light yellowish green (%)	63.89	36.11	
	dark yellowish green (%)	16.67	38.89	
Smell	Very good (%)	5.56	0	0.000
	Good (%)	88.89	33.33	
	Fairly good (%)	5.56	36.11	
	Bad (%)	0	30.56	
Appearance	Normal slime (%)	0	8.33	0.008
	Normal, slightly slimy (%)	8.33	30.56	
	Normal non-sticky (%)	91.67	61.11	

3.1.6. Organoleptic characteristics of Maralfalfa silage according to treatments

Table 10 assesses the impact of different additives on the organoleptic characteristics (color, odor, appearance) of Maralfalfa-based silages. Statistical analysis indicates that the treatments had no significant effect on color (p=0.262). The control silages (100% MAR) were predominantly "Dark yellowish-green" (44.44%) and "Light yellowish-green" (22.22%). The majority of treatments (especially those with salt) resulted in a light yellowish-green color. The silage odor was statistically impacted (p=0.000) by the addition of additives. The control (MAR 100%) had a predominantly "Bad" (55.56%) or "Fairly Good" (33.33%) odor. The addition of Wheat Bran (WB) and Rice Bran (RB), especially when combined with salt, gave excellent results. MAR + WB + Salt, MAR + RB + Salt, and MAR + RB all achieved a "Good" odor in 100% of cases. Cottonseed cake, with or without salt, also gave very good results (66.67% to 77.78% "Good"). The appearance was also statistically impacted (p=0.000) by the addition of additives. For the control silages (MAR) At 100 % of the samples, a certain degree of stickiness ("Normal Stickiness" or "Normal Slight Stickiness") was observed. Virtually all additives drastically improved the appearance. The MAR + WB, MAR + WB + Salt, MAR + RB + Salt, MAR + CSC, and MAR + CSC + Salt treatments produced between 88.89% and 100% "Normal Non-Sticky" silage. However, the addition of rice bran alone (MAR + RB) was not as effective (0% "non-sticky"), but the addition of salt (MAR + RB + Salt) corrected this problem, achieving 100% "non-sticky" silage.

Table 10: Organoleptic characteristics of silage according to treatment

Treatments										
Variables	Terms and conditions	MAR 100%	MAR +WB	MAR+WB+Salt	MAR +Salt	MAR +RB	MAR+RB+Salt	MAR +CSC	MAR+CSC+Salt	Chi-square
Color	Light Green (%)	0	0	0	11.11	0	0	0	0	0.262
	Dark green (%)	22.22	0	0	0	0	0	11.11	11.11	
	Olive green (%)	11.11	0	0	11.11	33.33	33.33	22.22	11.11	

	Light yellowish green (%)	22.22	55.56	77.78	77.78	33.33	44.44	33.33	55.56	
	Dark yellowish green (%)	44.44	44.44	22.22	0	33.33	22.22	33.33	22.22	
Smell	Very good (%)	0	0	0	0	0	0	0	22.22	0.000
	Good (%)	11.11	44.44	100	77.78	11.11	100	66.67	77.78	
	Fairly good (%)	33.33	44.44	0	22.22	44.44	0	22.22	0	
	Bad (%)	55.56	11.11	0	0	44.44	0	11.11	0	
Appearance	Normal slime (%)	0	0	0	0	33.33	0	0	0	0.000
	Normal, slightly slimy (%)	66.67	0	0	33.33	44.44	0	11.11	0	
	Normal non-sticky (%)	33.33	100	100	66.67	22.22	100	88.89	100	

MAR 100%: Silage made from 100% Maralfalfa forage; MAR + WB: Silage made from Maralfalfa forage + 10% Wheat Bran; MAR + WB + Salt : Silage made from Maralfalfa forage + 10% Wheat Bran + 4% Salt; MAR + Salt: Silage made from Maralfalfa forage + 4% Salt; MAR + RB: Silage made from Maralfalfa forage + 10% Rice Bran; MAR + RB + Salt: Silage made from Maralfalfa forage + 10% Rice Bran + 4% Salt; MAR + CSC: Silage made from Maralfalfa forage + 10% Cottonseed cake; MAR + CSC + Salt: Silage made from Maralfalfa forage + 10% Cottonseed cake + 4% Salt.

3.2. Discussion

3.2.1. Analysis of the Effect of Storage Duration on the Quality of Maralfalfa Silage

The pH changed without statistically significant difference (P-value > 0.05) depending on the storage duration. All averages are below 4.7, which is considered a satisfactory pH for stable silage, indicating good acid fermentation (Valacta, 2017; Kung et al., 2018). The absence of a significant difference suggests that the main acidification process was completed by 30 days. The slight, non-significant increase at 60 days could suggest a slight long-term loss of acidity, potentially due to the depletion of fermentable substrates or residual spoilage flora activity (McDonald, 1981; Weinberg and Chen, 2013; Korombé et al., 2023a; Korombé, 2024).

The significant reduction in Butyric Acid Bacteria (BAB) populations after 60 days is a key indicator of improved long-term anaerobic stability. BAB, which degrades lactic acid and amino acids, is progressively inhibited in a stable acidic environment (Pahlow et al., 2003). Thus, extended storage to 60 days allowed for greater microbial selection in favor of Lactic Acid Bacteria (LAB), resulting in safer and more stable silage. This is corroborated by the relative abundance of lactic acid bacteria populations, which are essential for preservation (Santos et al., 2013).

The significant change in color, from dark green (day 30) to olive green (day 60), reflects the ongoing biochemical transformations during storage, particularly pigment degradation (Kung et al., 2018). The olive hue at 60 days can be associated with an advanced but stable maturation phase, which is consistent with the improved microbiological profile (Buxton et al., 2003; Kung et al., 2018).

3.2.2. Analysis of the Effect of Salt on the Quality of Maralfalfa Silage

The addition of salt induced a significant and beneficial decrease in pH (4.08 vs. 4.85). This effect does not result from a direct antimicrobial action, as evidenced by the lack of significant difference in microbial populations (Butyric Acid Bacteria, Lactic Acid Bacteria, Spoilage Flora). Its mechanism is primarily physicochemical and indirect (Muck et al., 2018): i) salt reduces water activity, causing partial lysis of plant cells and a rapid concentration of soluble sugars in the aqueous phase; ii) the resulting stressful osmotic environment, rich in substrates, favors the selection of certain naturally more tolerant strains of lactic acid bacteria , while slowing down less adapted competitors; iii) the advantaged LAB rapidly metabolize the available sugars, producing lactic acid at a higher rate and level. It is this increased acidity, and not the salt itself, that becomes the main inhibitory agent of undesirable microorganisms (Pahlow et al., 2003).

This effect of salt translates concretely into a major improvement in organoleptic characteristics. Indeed, the addition of salt leads to a reduction in undesirable odors (putrid, ammoniacal) and an elimination of the slimy texture often associated with yeast activity or proteolytic fermentations (Kung et al., 2018). The increase in silage dry matter with the addition of salt is consistent with its dehydrating effect, limiting hydrolytic degradation (Roberge and Toutain, 1999; Rabelo et al., 2014; Korombé et al., 2023b, Korombé, 2024).

The tendency towards slightly higher weight and dry matter losses with the addition of salt could be attributed to increased gas production (CO_2) linked to intense lactic fermentation, an effect sometimes observed with additives that strongly stimulate bacterial activity (Cai et al., 1999). This result contradicts that of Korombé et al. (2023b), who found that the addition of salt appears to influence the decrease in the dry matter loss in millet silage was observed, although the difference between the means was not statistically significant at the 5% level. These results also differ from those of Cai et al. (1997) and Rabelo et al. (2014), who found significant differences in dry matter loss after adding 4%, 2%, and 1% salt to sorghum and sugarcane silage, respectively. However, in our study, the losses were low on average in both cases, which is a positive finding.

3.2.3. Analysis of Maralfalfa silage quality based on treatments

Analysis of the different treatments confirms the principle that the quality of silage depends on the availability of fermentable substrates and the microbial environment.

The control (100% Maralfalfa) exhibited poor quality, indicating an insufficiency of rapidly fermentable carbohydrates to support increased lactic acid production. This made the silage vulnerable to the detrimental effects of spoilage flora (Muck et al., 2018).

Energy-rich additives (wheat/rice bran, cottonseed cake) provide additional substrates, allowing lactic acid bacteria to dominate the fermentation process. Their combination with salt (MAR + WB + Salt, MAR + RB + Salt, MAR + CSC + Salt) yields the best results, demonstrating a synergistic effect. Indeed, the additives (wheat/rice bran, cottonseed cake) provide the food, while the salt optimizes the environmental conditions for the lactic acid bacteria, resulting in silage with 100% good odor and a firm texture (Li et al., 2014; Santos et al., 2016; Ni et al., 2017; Kung et al., 2018; Muck et al., 2018; Avila and Carvalho, 2020; Wang et al., 2020).

MAR + Salt treatment alone constitutes a simple and economical alternative. In the absence of external energy input, salt maximizes the efficiency of the fermentation of endogenous sugars, offering a very clear improvement compared to the control (Korombé et al., 2023a, b; Korombé, 2024).

4. Conclusion

In a context marked by a seasonal fodder deficit, this study aimed to evaluate simple techniques to improve the quality of Maralfalfa silage, a promising resource in Niger.

60-day storage is beneficial, leading to improved microbiological stability through a significant reduction in butyric acid bacteria, without altering the already satisfactory pH. The addition of 4% salt proved effective in significantly lowering the pH (from 4.85 to 4.08) and improving the silage's odor and texture, eliminating undesirable characteristics.
The results also demonstrate the synergistic action between salt and energy by-products (wheat bran, rice bran, or cottonseed cake). These treatments produced very high-quality silage, combining a low pH, preserved dry matter, excellent stability, and optimal organoleptic characteristics (100% good odors, firm texture).
In conclusion, for a simple and economical improvement, the addition of 4% salt (MAR + Salt) is recommended. For optimal and stable silage quality, aiming for nutritional supplementation, the MAR + WB + Salt or MAR + RB + Salt treatments are the most effective. Adopting these practices would improve the utilization of Maralfalfa, thus contributing to securing livestock feed during the long dry season in Niger.

5. References Cited

[1] Amole, T., Augustine, A., Balehegn, M., Adesogoan, AT, 2022. Livestock feed resources in the West African Sahel. Agronomy Journal, 114 (1): 26-45. https://doi.org/10.1002/agj2.20955

[2] Abdou, MM, Issa, S., Maman, N, 2019. Improving fodder availability through the diversification of millet-based cropping systems in agricultural areas of Niger. Afrique Science, 15 (5), 328-339.

[3] Avila, CL S and Carvalho, B. F, 2020. Silage fermentation—updates focusing on the performance of micro-organisms. Journal of Applied Microbiology, 128 (4), 966-984. https://doi.org/10.1111/jam.14450

[4] Buxton, DR, Muck, RE, Harrison, JH (Eds.). 2003. *Silage Science and Technology.* Agronomy Monograph No. 42. ASA, CSSA, SSSA, Madison, WI.

[5] Cai Y., Ohmomo S., Ogawa M., Kumai S. (1997). Effect of NaCl-tolerant lactic acid bacteria and NaCl on the fermentation characteristics and aerobic stability of silage. Journal of Applied Microbiology, 83 (3), 307-313.

[6] Cai, Y., Benno, Y., Ogawa, M., Kumai, S., 1999. Effect of applying lactic acid bacteria isolated from forage crops on fermentation characteristics and aerobic deterioration of silage. Journal of Dairy Science, 82:520-526. https://doi.org/10.3168/jds.S0022-0302(99)75263-X

[7] Korombé, HS, 2024. Characterization of millet silage and its effects on the zootechnical performance of Fulani herds from Niger. Doctoral thesis from Abdou Moumouni University of Niamey/Niger. 147 p.

[8] Korombé, HS, Bado, VB, Abdou, N., Umutoni, C., Ibrahima, A., Gouro, AS, 2023a. Evaluation of fermentation progress during storage of millet silage stoves based on pH-indicators. Online Journal of Animal and Feed Research, 13 (2), 116-126. https://doi.org/10.51227/ojafr.2023.18

[9] Korombé, HS, Abdou, N., Bado, VB, Umutoni, C., Ibrahima, A., Gouro, A. S, 2023b. Chemical characteristics, in vitro digestibility and dry matter loss of different types of forage silage and millet residues (*Pennisetum glaucum* (L.) R. Br). Fourrages 256, 55-65

[10] Kung, L.Jr., Shaver, RDS, Grant, RJ, Schmidt, RJ, 2018. Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. Journal of Dairy Science, 101(5), 4020-4033. https://doi.org/10.3168/jds.2017-13909

[11] Lawal, MAA, Korombé, SH, Djibo, I., Djibo, IA, Saley, HA, Laouali, OR, Gouro, SA, 2024. Evaluation of the Effects of the Addition of Salt, Type of Additive and the Shelf Life, on Chemical Composition of Pennisetum purpureum (Schumach) (Maralfalfa) Silages in Niger. American Journal of Animal and Veterinary Sciences, 19 (3): 280-289. https://doi.org/10.3844/ajavsp.2024.280.289

[12] Li, M., Zi, X., Zhou, H., Hou, G., Cai, Y, 2014. Effects of sucrose, glucose, molasses and cellulase on fermentation quality and in vitro gas production of king grass silage. Animal Feed Science and Technology, 197, 206-212. https://doi.org/10.1016/j.anifeedsci.2014.06.016

[13] Mcdonald P, 1981. Clostridia, The Biochemistry of Silage, P. McDonald ed., John Wiley & Sons, 77-90.

[14] Muck, RE, Nadeau, EMG, McAllister, TA, Contreras-Govea, FE, Santos, MC, Kung Jr, L, 2018. Silage review: Recent advances and future uses of silage additives. Journal of Dairy Science, 101 (5), 3980-4000. https://doi.org/10.3168/jds.2017-13839

[15] Ni, K., Wang, F., Zhu, B., Yang, J., Zhou, G., Pan, Y., Tao, Y., Zhong, J, 2017. Effects of lactic acid bacteria and molasses additives on the microbial community and fermentation quality of soybean silage. Bioresource Technology, 238, 706-715. https://doi.org/10.1016/j.biortech.2017.04.055

[16] Pahlow, G., Muck, RE, Driehuis, F., Oude Elferink, SJWH, Spoelstra, SF, 2003. Microbiology of Ensiling. In Buxton DR., Muck RE and Harrison JH. Silage Science and Technology, (*ed*) American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc. Book Series: Agronomy Monograph, p1 - 30 . https://doi.org/10.2134/agronmonogr42.c2

[17] Rabelo, CHS, Costa, AP, Rezende, AV, Härter, CJ, Florentino, LA, Rabelo, FHS, 2014. What is the best additive to use at the ensiling of sugarcane SP81-3250? Animal Production Science, 54 (10), 1682-1686.

[18] RECA, 2025. Forage cultivation of Maralfalfa. Technical sheet. 3 p. https://reca-niger.org/IMG/pdf/ft_maralfalfa-3.pdf

[19] Roberge, G and Toutain, B., 1999. Tropical forage crops, CIRAD, Montpellier (France): (Repères: CIRAD) ISBN 2-87614-361-5, 374 p.
[20] Rutagongwa G, 2003. Literature Review: Elephant grass and its silage. Master's thesis in Animal Production in Hot Regions. University of Montpellier II; Sciences and Techniques of Languedoc. Place Eugène Bataillon ; 34095 Montpellier Cedex 5 and CIRAD-EMVT TA30/B. Baillarguet International Campus 34398 Montpellier Cedex 5.
[21] Santos, AO, Ávila, CLS ., Schwan RF, 2013. Selection of tropical lactic acid bacteria for enhancing the quality of maize silage. Journal of Dairy Science. 96 (12), 7777-7789. https://doi.org/10.3168/jds.2013-6782
[22] Santos, AO, Ávila, CLS, Pinto, JC, Carvalho, BF, Dias, DR, Schwan, R. F, 2016. Fermentative profile and bacterial diversity of corn silages inoculated with new tropical lactic acid bacteria. Journal of Applied Microbiology*,* 120(2), 266-279.
[23] Valacta, 2017. Guide on the interpretation of silage analyses. Cultivons l'avenir 2 Québec (Canada), ISBN 978-2-921692-19-9, 47 p.
[24] Weinberg, ZG and Chen, Y, 2013. Effects of storage period on the composition of whole crop wheat and corn silages. Animal Feed Science and Technology. 185(3-4), 196-200. https://doi.org/10.1016/j.anifeedsci.2013.08.009
[25] Wang M., Franco M., Cai Y, 2020. Dynamics of fermentation profile and bacterial community of silage prepared with alfalfa, whole-plant corn and their mixture. Animal Feed Science and Technology. 270, 114702.https://doi.org/10.1016/j.anifeedsci.2020.114702