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Research Article
Physical Characteristics, Nutritional Qualities and *In vitro* Digestibility of Silage From Various Sources of Fiber

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Abstract
Background and Objective: Forage, as a source of fiber for ruminants, consists of fresh forages (grass and legumes) and agricultural wastes such as corn straw and rice straw. The weaknesses of agricultural wastes are their high crude fiber content and low protein content, which limit their use as ruminant feed. Fermentation technology or silage can be applied to make these agricultural wastes usable. Silage can increase the nutritional value of agricultural wastes and the silage can be stored for a long time (up to one year) for use as feed during the dry season. This study aimed to compare physical and nutritional characteristics and *in vitro* digestibility of silages from various sources of fiber, such as elephant grass, native grasses, corn straw and rice straw. **Materials and Methods:** The study used a completely randomized design (CRD) with four treatments and five replications. The four silage treatments were treatment A: Silage with elephant grass as the fiber source, B: Silage with native grasses as the fiber source, C: Silage with corn straw as the fiber source and D: Silage with rice straw as the fiber source. The silage was made using 10% molasses and 10% pollard as additives. The observed variables were acidity (pH), physical characteristics, chemical characteristics and *in vitro* digestibility. **Results:** The experiment showed that the pH values of silage from elephant grass, native grasses, corn straw and rice straw ranged from 4.01-4.58, which met the criteria for good silage. The physical characteristics, i.e., fungus, texture, color and odor, met the criteria for good to moderate silage. The highest dry matter and ash contents were observed in treatment D and were significantly different from those in the other treatments. In addition, the highest organic matter and water contents were observed in treatment C and were significantly different from those in the other treatments. The experiment showed that elephant grass silage had the highest *in vitro* digestibility for dry and organic matter but there was no significant difference in digestibility between elephant grass silage and corn straw silage and the highest vollatil fatty acid (VFA) and ammonia (NH_3) levels were observed in elephant grass silage. **Conclusion:** Silage with corn straw as the fiber source tends to provide the best results in terms of physical and nutritional characteristics and *In vitro* digestibility.

Key words: Silage physical characteristics, silage technology, *in vitro* digestibility, elephant grass, native grasses, corn straw, rice straw

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

An increase in the human population is always followed by an increase in food needs, especially the need for animal protein sources and more livestock thus need to be raised. This trend is inversely proportional to the amount of land available to grow animal feed because the increase in population increases the amount of land used for settlements. The needs of livestock for forage are increasingly pressing. Forage, as a source of fiber for ruminants, consists of fresh forages (grass and legumes) and agricultural wastes. Fresh forage, including elephant grass and native grasses, can be stored as silage when its availability is high for use when forage is limited. Alternative sources of forage derived from agricultural wastes include corn straw and rice straw.

The content of crude fiber in feed materials is largely derived from the lignin cellulose component (complex carbohydrate) so that it is difficult for livestock to digest[1]. The high crude fiber content and the low protein content of agricultural wastes are limiting factors for their use as animal feed. One technique that can be used to make these wastes usable for animal feed is fermentation or silage technology. Silage can increase the nutritional value and digestibility of forages; it can also be stored for a long time (up to one year), so it can be used as a forage reserve in the dry season.

Silage is the most feasible technology for animal forage. Silage is a fresh preservative (±60% water content) animal feed stored in silos[2]. Silage is a feed material produced by fermentation under anaerobic conditions[3]. In this fermentation process, the silage can be stored for a long period of time without significantly reducing the nutrient content of the materials[1].

Elephant grass silage from various sources and the addition of fermentable carbohydrates with a good drying process (±60% water content) using 1-3% molasses and 5-15% polished rice could maintain the characteristics and nutrient content of king grass silage better than fermentation with 5-15% cassava cake. Furthermore, it was found that ensilage for 28 days did not increase or decrease the physical characteristics of king grass silage[4]. The nutritional value of corn straw of the Manado Kuning variety fermented with EM4 yielded the following results: crude fiber 16.79%, protein 8.90% and energy 284.11%; this result was better than that of Hybrid Bisi 2, with crude fiber 19.64%, protein 8.32% and energy 267.21%[5]. Carbohydrate absorb ability is determined by the absorption surface area or particle size and the presence of coatings such as fibers and fats, which can reduce the water absorption of materials[6]. Based on the above findings, research was carried out on the physical and nutritional characteristics and *in vitro* digestibility of silage from various sources of fiber.

MATERIALS AND METHODS

Experimental location: Silage analysis was carried out at the Laboratory of Nutrition, Faculty of Animal Husbandry, Udayana University, for six months from preparation to the end of the experiment.

Treatment and experimental design: The materials used for silage were elephant grass, native grasses, corn straw and rice straw with molasses and pollard additives. The materials for making silage were cut to 3-5 cm in size and sprinkled with 10% pollard and 10% molasses by the total weight of the silage material. The cut pieces were mixed well with the pollard and molasses and placed in a plastic bag. The bag was compressed until all the air was removed to create anaerobic conditions and then tightly bound and placed in a covered bucket. The samples were stored in a cool place and not exposed to the sun. The observation of the silage was performed after fermentation for three weeks.

The research used a completely randomized design (CRD) with four treatments and five replications. The four silage treatments were as follows; A: Silage with elephant grass as the fiber source, B: Silage with native grasses as the fiber source, C: Silage with corn straw as the fiber source and D: Silage with rice straw as the fiber source. The silage was made by adding 10% molasses and 10% pollard[7].

Silage analysis: The nutritional characteristics of the silage (dry matter, organic matter, ash, water, crude protein and crude fiber contents, ether extract and nitrogen-free extract) were determined with the AOAC method[8]. *In vitro* fermentation was performed with the Minson and McLeod methods[9]. $N\text{-}NH_3$ levels were determined by the phenol-hypochlorite method with aspectrophotometer[10]. The measurement of the total concentration of VFAs was performed with the steam distillation method.

Variable observations and data analysis: The variables observed were acidity (pH), physical and nutritional characteristics and *in vitro* digestibility. The data obtained were analyzed using two-way ANOVA to determine whether the treatment had a significant effect on the mean values of the variables, followed by Duncan's test at a significance level of 5%[11].

RESULTS

The pH values of elephant grass (A), native grass (B), corn straw (C) and rice straw (D) silage ranged from 4.01-4.58. There were no significant differences ($p>0.05$) in fungi, color, odor, or texture among treatments A, B, C and D.

The dry matter, organic matter and water contents and the ether extract and nitrogen-free extract were significantly different in all treatments and the differences in crude protein content in treatments A, B and C were non-significant but significant in treatment D. The differences in crude protein content in treatments A and B were non-significant but were significant in treatments C and D.

VFA showed no significant differences among the treatments. The highest $N\text{-}NH_3$ level was in treatment A, which was significantly different from the other treatments. The highest dry and organic matter levels were observed in treatment A and were not significantly different from treatments B and C but those in the A, B and C treatments were significantly different from those in treatment D.

DISCUSSION

The pH values of elephant grass, native grass, corn straw and rice straw silage ranged from 4.01-4.58; a range of 4.2-4.5 is considered good[12]. The average pH value of silage in treatment D (silage with rice straw as the fiber source) was higher ($p<0.05$) than that of treatments; A: Silage with elephant grass as the fiber source, B: Silage with native grasses as the fiber source) and C: Silage with corn straw as the fiber source). This may have been due to the differences in the water content of the silage; in treatment D, the water content was the lowest ($p<0.05$) of all the other silage water contents. The difference in the silage water content was caused by the differences in the water content of the material used to make the silage (Table 1). The water content greatly determines the concentration of lactic acid in silage, which affects its pH value. The pH of silage in treatment D was 4.58, which is classified as moderate (within a pH range of 4.5-4.8). The pH values of silage from elephant grass, native grasses and corn straw ranged from 4.01-4.11, which are classified as very good (within a pH range of 3.2- 4.2)[12]. Silage with a pH value of less than 4.2 is of good quality, while silage with a pH value between 4.5 and 5.2 is of adequate quality[13].

The number of fungi showed no significant differences ($p>0.05$)among treatments and the range of values from 2.24-2.84 classified the silages as good to moderate[11]. The presence of fungi in silage is determined by the presence of oxygen contamination due to silo leakage or because it is less dense in compacting or compressing silage in the silo, so that the anaerobic condition is not maximal. The texture of the silage is determined by the source of fiber used as the material for making silage. The average silage texture in this study ranged from 2.16-2.96. The texture of native grass silage was significantly different ($p<0.05$) from that of corn straw silage but was not significantly different ($p>0.05$) from those of elephant grass and rice straw silages. This was probably due to the age of the plants; the older the plant, the higher the crude fiber content. Silages at various cutting ages (20-80 days) showed texture scores between 2 and 3, while in this study, scores of 2.93-3.00 were obtained[14].

The native grasses in this study were local grasses of various species. The native grasses were cut at older ages, which led to the higher crude fiber content in native grasses than in corn straw (Table 2). The native grass, elephant grass and rice straw silages were less smooth, while the corn silage tended to be somewhat smooth; overall, the four silages with different fiber sources had rather fine-less smooth textures[12].

The silage color in treatment D was slightly brownish-yellow, which is classified as good-moderate[12]. Treatments A, B and C had yellowish-green silage; yellow silage is classified as very good[12]. The color of silage is determined by the color of the material used as silage. The color of the rice straw silage was significantly different ($p<0.05$) from the colors of the elephant grass, native grass and corn straw silages. All silages were yellow-brownish and were classified as relatively good-moderate[12]. The elephant grass, native grass

Table 1: The physical characteristics of silage from various sources of fiber

	Treatments[1]				
Variables	A	B	C	D	SEM[3]
pH	4.06[a2]	4.01[a]	4.11[a]	4.58[b]	0.039
Fungi*	2.32[a]	2.32[a]	2.24[a]	2.84[a]	0.104
Texture**	2.52[ab]	2.96[a]	2.16[b]	2.60[ab]	0.117
Color***	1.64[a]	1.60[a]	1.24[a]	2.36[b]	0.211
Odor****	2.68[a]	2.88[a]	2.20[a]	2.96[a]	0.116

*1: None, 2: Few, 3: More, 4: Many, **1: Smooth, 2: Somewhat smooth, 3: Less smooth, 4: Rough, ***1: Yellowish-green, 2: Yellow, 3: Brownish, 4: Black-brown, ****1: Very acidic, 2: Acidic, 3: Less acidic, 4: Rotten, A: Silage with elephant grass as the fiber source, B: Silage with native grasses as the fiber source, C: Silage with corn straw as the fiber source and D: Silage with rice straw as the fiber source, Values with the same superscript on the same line showed non significant differences, SEM: Standard error of the treatment means and corn straw silages showed no significant differences in color ($p>0.05$) and had scores of 1-2, which is classified as excellent-good[12]. Silage with a score of 2 is dark green or brownish-yellow; a score of 3 indicates natural green or yellowish-green color[15]. Good-quality silage is light brown (yellowish) with an acidic odor[13].

The silage odor was classified as good-moderate[12]. The silage was slightly smooth to less smooth, classified as good to moderate, respectively[12]. There were no significant differences ($p>0.05$) in silage odor among the four silage treatments with different fiber sources because of the good ensilage process, as indicated by the number of fungi formed and the odor of the silage. The acidic odor of silage comes from the change of carbohydrates to lactic acid during the ensilage process. Good silage has an acidic odor and is fragrant[16]. This is due to the production of lactic acid during the fermentation process. Fragrant acidic silage is caused by anaerobic bacteria that actively work to produce organic acids in the process of making silage.

The dry matter content of a material depends on the water content of the material. The average dry matter content of rice straw silage (D) was significantly ($p<0.05$) different from the dry matter content of elephant grass, native grass and corn straw silages (A, B and C). The water content in rice straw silage was the lowest ($p<0.05$) of all the silages, at 7.21%. The dry matter content of the corn straw silage (C), with a water content of 10.35%, was the lowest ($p<0.05$) of all the silages (Table 2). The average organic matter content of the rice straw silage (treatment D) was the lowest ($p<0.05$) of all the silage treatments (Table 2). The organic matter content is related to the ash content of silage; the ash content of the rice straw silage (treatment D) was significantly ($p<0.05$) higher than that of the treatments A, B and C. The rice straw silage (D) had the highest ash content because rice straw contains more minerals than other fiber sources, such as elephant grass, native grasses and corn straw.

The nutrient content of silage, including the crude protein content, ether extract and nitrogen-free extract, is largely determined by the basic materials used in making the silage. The average crude protein content, ether extract and nitrogen-free extract of rice straw silage (D) was the lowest ($p<0.05$) compared with the nutrient contents of the silages in treatments A, B and C (Table 2). This is related to the nutrient quality of the silage material; the rice straw had the lowest nutrient quality compared with elephant grass, native grasses and corn straw. The average nutrient contents of silage treatments A, B and C were not significantly different in terms of crude protein, ether extract, or nitrogen-free extract.

Volatile fatty acids (VFAs) and ammonia (NH_3) are products of fermentation that can indicate the quality of the silage materials. The average content of NH_3 in silage treatment A (elephant grass silage) was higher ($p<0.05$) than that of the native grass, corn straw and rice straw silages (Table 3). The average N-NH_3 level in silage ranges from 13-19 mM, which is the optimum range for microbial protein synthesis in the rumen[3]. The silage in treatment A (elephant grass) contained more protein (approximately 9.9% dry matter) compared with the silage from the other materials, such as rice straw (approximately 5.4% dry matter) and native grasses (approximately 6.69% dry matter)[17]. The average VFA levels of the silage in treatments A, B, C and D were not significantly different because the carbohydrate content of the silage was not different. The additives used were molasses and pollard, which are water-soluble carbohydrates that can be used by bacteria as an energy source in the fermentation process.

The dry matter, organic matter and *in vitro* digestibility of silage in treatment D was the lowest ($p<0.05$) compared with those of the silages in treatments A, B and C. This was due to the high ash and dry matter content in rice straw silage compared with those of the elephant grass, native grass and corn straw silage. Crude fiber consists of neutral detergent

Table 2: The nutritional characteristics of silage from various sources of fiber

	Treatments[1]				
Variables	A	B	C	D	SEM[2]
Dry matter (%)	91.60[b]	91.66[b]	89.65[c]	92.79[a]	0.930
Organic matter (%)	88.50[c]	89.39[b]	90.51[a]	77.13[d]	0.130
Ash (%)	11.50[b]	10.61[c]	9.49[d]	22.87[a]	0.130
Water (%)	8.40[b]	8.34[b]	10.35[a]	7.21[c]	0.930
Crude protein (%)	13.18[a]	12.73[a]	12.89[a]	9.24[b]	0.110
Crude fiber (%)	21.84[a]	21.93[a]	16.32[b]	18.07[b]	0.561
Ether extract (%)	14.03[b]	13.18[b]	15.65[a]	11.97[c]	0.170
Nitrogen free extract (NFE)	31.06[b]	33.23[ab]	35.30[a]	30.65[b]	0.620

A: Silage with elephant grass as the fiber source), B: Silage with native grasses as the fiber source), C: Silage with corn straw as the fiber source) and D: Silage with rice straw as the fiber source, Values with the same superscript on the same line showed non significant differences, SEM: Standard error of the treatment means.

Table 3: Volatile fatty acids, N-NH_3, dry matter digestibility and organic matter digestibility of silage with different sources of fiber

	Treaments[1]				
Variables	A	B	C	D	SEM[3]
VFA total (mMol)	58.26[a2)]	31.16[a]	39.65[a]	46.47[a]	3.790
N-NH_3 (mMol)	4.38[a]	2.62[b]	2.90[b]	2.38[b]	0.240
pH (beginning)	7.59[a]	7.49[a]	7.74[a]	7.52[a]	0.076
pH (final)	6.41[a]	6.32[a]	6.47[a]	6.34[a]	0.070
Dry matter digestibility (%)	76.07[a]	66.33[b]	73.72[ab]	54.35[c]	1.270
Organic matter digestibility (%)	77.70[a]	68.81[bc]	75.56[ab]	62.52[c]	1.230

A: Silage with elephant grass as the fiber source), B: Silage with native grasses as the fiber source), C: Silage with corn straw as the fiber source) and D: Silage with rice straw as the fiber source, Values with the same superscript on the same line showed non significant differences, SEM: Standard error of the treatment means

fiber (NDF), acid detergent fiber (ADF) and lignin, which are the components of plant cell walls. These components are difficult to digest and require a longer time to be degraded by rumen microbes. This causes a decrease in the digestibility of silage containing high levels of fiber. In all cases, the decreased lignin levels in plant organs increased the digestibility of dry matter[18]. Based on our research, silage with corn straw as the fiber source can provide the best results in terms of physical and nutritional characteristics, fermentation and *in vitro* digestibility.

CONCLUSION

The pH values of silage from elephant grass, native grass, corn straw and rice straw ranged from 4,01-4,58 (classified as good) The physical characteristics, i.e., mold, texture, color and aroma, were classified as good to moderate. The highest dry matter and ash contents were observed in the treatment D silage, while the highest contents of organic matter, water, crude protein, crude fat and NFE were found in the treatment C silage. The highest VFAs and NH_3 were found in elephant grass silage. The *in vitro* digestibility of dry matter and organic matter were the highest in elephant grass silage but there was no difference between the digestibility of elephant grass and corn straw silages. The silage with corn straw fiber as the source tended to provide the best results in terms of physical and nutritional characteristics, fermentation and *in vitro* digestibility.

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