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The names and affiliations of all authors are provided below, following the references.

Comparative analysis of the nutritional value and in vitro digestibility of different varieties of Napier grass within the smallholder dairy farming system in Kenya

Kemboi F¹, Tura I², Githui M³, Kenana R⁴, Metto V⁵, Ndungu C⁶, Omariba R⁷, Nelima R⁸

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ABSTRACT

The purpose of this study was to assess the nutritional value and in vitro degradation characteristics of Pakchong Napier, Juncao Napier, and *Kakamega* 1 (KK1) varieties of Napier grass for smallholder dairy production systems in Kenya. Proximate composition analysis, mineral analysis, and in vitro fermentation techniques were used to evaluate these varieties. Data analysis showed remarkable differences across the various grass varieties in nutritional value as well as in the degradation profiles. Pakchong Napier had the highest crude protein level of 17.7%, metabolizable energy content of 9.5 MJ/kg, and superior In-vitro fermentation characteristics with the highest (35.30 ml/200 mg DM) cumulative gas production and peak fermentation rate at 48 hours. Juncao Napier showed an intermediate value of crude protein CP (15.3%), metabolizable energy (8.8 MJ/kg), and In-vitro fermentation characteristics with the lower (26.71 ml/200 mg DM) cumulative gas production compared to KK1 Napier at 48 hours. KK1 Napier grass had the lowest crude protein (9.9%), metabolizable energy (7.4 ml/200 mg DM), and ether extract (2.6%) content compared to Pakchong and Juncao Napier grass. Pakchong Napier and Juncao grass show promise as high-quality forages due to high crude protein content of 17.7% and 15.3%, respectively. Juncao Napier exhibited the highest concentrations of most major elements, with 4.3 g/kg DM of phosphorus, 22.9 g/kg DM of calcium, 28.5 g/kg DM of potassium, and 5.3 g/kg DM of magnesium. Pakchong Napier showed intermediate levels of these elements. Therefore, incorporating Pakchong Napier and Juncao grass into smallholder dairy production systems could enhance milk production and animal performance. However, further studies on adaptability to different agro-ecological zones and disease resistance are recommended. KK1 Napier grass requires supplementation of both protein, energy, and minerals if used as a basal diet. Additional research is also recommended to assess the varieties of animal performance in milk and meat production, in addition to animal health.

Keywords: Nutritional composition, In vitro fermentation, Pakchong, Juncao, *Kakamega* 1 Napier, Forage quality, Smallholder dairy feed, Agro-ecological adaptability

Introduction

Smallholder farmers dominate the Kenyan dairy industry and rely on forage-based diets for their milk-producing cattle (Paudyal, 2024) [1]. The major fodder crop is Napier grass (*Pennisetum purpureum*) or elephant grass due to its high biomass yield and suitability to many agroecological zones (Staal *et al.*, 2008) [2]. More recently, China's Pakchong Napier and Thailand's Juncao Napier Grass varieties have been introduced, along with the locally bred *Kakamega* 1 (KK1) variety, which exhibits higher biomass yields. These new varieties aim to improve the cost-effective feeding system for dairy cattle and alleviate auxiliary dependency on costly meals that cut into farmer profits.

Dairy development policy has focused on alleviating low yields and poor-quality feeds among smallholder dairy farmers (Lukuyu *et al.*, 2012). The need for these interventions comes at a time of increasing land resource pressures and the need for climate-smart agriculture as a strategy to mitigate climate change impacts (Kariuki *et al.*, 2021) [3]. Enhanced biomass production per unit area achieved with improved Napier grass varieties can mitigate the land dairy production systems allocate for fodder crops and enhance efficiency (Goopy *et al.*, 2020) [4].

In addition, the nutritional values of these new varieties may significantly improve the productivity of smallholder dairy farmers. It has been documented that the use of quality forages has a positive effect on the reduction of enteric methane emissions while improving milk production (Appuhamy *et al.*, 2016) [5]. This

Corresponding Author: Kemboi F

Kenya Agricultural and
Livestock Research
Organization, Beef
Research Institute, Lanet,
P.O. Box 3840 -20100,
Nakuru, Rift Valley, Kenya.

dual advantage is in harmony with socio-economic and ecological protection objectives for the Kenyan dairy industry and other developing countries (Ndung'u *et al.*, 2019) [6].

Also, very little is known about the newly released Napier grass varieties in terms of their relative nutritional value and degradation under Kenyan conditions. The goal of this research was to determine the nutritional values and *In-vitro* degradation of the three varieties to improve the nutritional and production decision-making process for smallholder dairy farmers.

Materials and methods

Grass cultivation and sampling

Under the same agronomic conditions within smallholder representative dairy farms in the highlands of Kenya, *Pakchong* Napier, *Juncao* Napier, and *Kakamega* 1 Napier grass varieties were grown and evaluated. The cultivation sites were chosen to capture the typical agro-ecological setup of the region with an altitude of 1500-2100 meters above sea level and an annual rainfall of 1000-1500 mm. The grasses were planted in randomized complete block design plots, each measuring 5m x 5m, with three replications per variety. Standard agronomic practices, including soil preparation, fertilization, and weed control, were followed. Nitrogen fertilizer was applied at 100 kg N/ha in split applications, with phosphorus and potassium applied based on soil test recommendations done recently by a reputable laboratory. Irrigation was provided as needed to ensure consistent growth across all plots. The grasses were allowed to establish for three months before the first harvest. Subsequent harvests were conducted at eight-week intervals to simulate typical smallholder management practices. Samples were collected at the same maturity stage, approximately 60 days after the previous harvest, when the grass height reached 1-1.5 meters. Sampling was done using a quadrat method, with three 1m² quadrats randomly placed within each plot. The grass was cut 15 cm above the ground to simulate grazing and promote regrowth. The harvested samples were immediately weighed for fresh biomass yield determination. Sub-samples of approximately 500g were then taken from each quadrat, chopped into 2-3 cm lengths, and thoroughly mixed. These sub-samples were dried in a forced-air oven at 65 °C for 72 hours to determine dry matter content. The dried samples were ground to pass through a 1 mm sieve using a hammer mill and stored in airtight containers for subsequent laboratory analyses.

Laboratory analysis: proximate and fiber assay of samples

The chemical composition of the grass samples, including dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), Metabolizable energy (ME), and ash content, was determined using standard methods (AOAC, 2005) [7]. The CP was calculated as Kjeldahl Nitrogen (N x 6.25). The fiber was analyzed according to the procedure described by Van Soest *et al.* (1994). Macro-elements- potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and micro-elements- copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) were analyzed using an atomic absorption spectrophotometer (AAS). Samples were prepared by wet digestion using 1:1 nitric acid and 1:4 HCL for 30 minutes for ion dissociation.

Statistical analysis

Data collected on proximate and fiber analysis were subjected to analysis of variance (ANOVA) in a completely randomized design (CRD) using the general linear model procedure of statistical analysis system (SAS 2002) version 9.0. Significant means were separated using Tukey's HSD (Tukey's Honestly Significant Difference Test) at 5% significance.

The model used for statistical analysis was:

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij}$$

where:

Y_{ij} = is the j^{th} observation of the i^{th} treatment

μ = is the population mean

τ_i = is the effect of treatment

ϵ_{ij} = random error term

In vitro gas production

The milled samples of *Pakchong* Napier, *Juncao* Napier, and *Kakamega* 1 Napier grasses, weighing 200 mg DM of each, were placed in 100 ml glass syringes in triplicate. The fermentative activity of the mixed microbial population was determined using the gas production technique described by Menke and Steingass (1988). The rumen fluid and buffer medium were mixed in a ratio of 1:2 (v/v). Then, 30 ml of the buffer-rumen fluid mixture was passed into triplicate syringes holding samples and incubated in a thermostatically controlled water bath at 39 °C for 0-96 hours. The samples and blank (rumen fluid + buffer) were run in triplicate. Then, the volume of gas produced was determined at 0, 3, 6, 9, 12, 18, 36, 48, 72, and 96 hours by reading the calibration of the piston. The gas produced was the total increase in volume minus the mean blank value from the recorded gas production of all samples to give the net gas production. The calculated values of gas production were fitted into the model of Ørskov and McDonald (1979) [8] to determine the degradability of the feed:

$$Y = a + b(1 - e^{-ct}) \quad \text{where:}$$

Y = the volume of gas produced with time (t)

a = initial gas production

b = gas produced during incubation

c = gas production rate constant (fraction /hour), and

$a+b$ represents the potential extent of gas production.

Results

Proximate composition

Table 1 presents the proximate composition of *Pakchong* Napier, *Juncao* Napier, and *Kakamega* 1 Napier grasses. *Pakchong* Napier exhibited the highest crude protein (17.7%) content, metabolizable energy (9.5 MJ/kg), and ash (13.7%) content among the three varieties. *Juncao* Napier had a lower crude protein (9.9%) content than *Pakchong* Napier but higher than *Kakamega* 1 Napier. *Kakamega* 1 Napier had the lowest crude protein (9.9 %) and ether extract (2.6 %) content, but a crude fiber content similar to the other two varieties. ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; EE, ether extracts; NDF, neutral detergent fiber; ME, metabolizable energy

Mineral profile

Table 2 presents the Macro and micro elements of *Pakchong* Napier, *Juncao* Napier, and *Kakamega* 1 Napier grass. Analysis of major and trace elements revealed notable differences among the three Napier grass varieties. *Juncao* Napier exhibited the highest concentrations of most major elements, with 4.3 g/kg DM of phosphorus, 22.9 g/kg DM of calcium, 28.5 g/kg DM of potassium, and 5.3 g/kg DM of magnesium. *Pakchong* Napier showed intermediate levels of these elements. At the same time, *Kakamega* 1 Napier had the lowest calcium (4.1 g/kg DM) and magnesium (3.2 g/kg DM) content but the highest potassium concentration (29.1 g/kg DM). Regarding trace elements, KK1 Napier contained the highest levels of manganese (98 mg/kg DM) and iron (100 mg/kg DM). Copper content was similar in *Juncao* and KK1 Napier (17 mg/kg DM), both higher than *Pakchong* Napier (12 mg/kg DM).

Table 1. Chemical composition of *Pakchong* Napier, *Juncao* Napier, and *Kakamega 1* Napier grass

Grasses	DM%	CP%	EE%	NDF%	ADF%	ADL%	CF%	ASH%	ME MJ/kg
<i>Pakchong</i> Napier	93.1 ^a	17.7 ^a	3.6 ^a	65.8 ^c	42.5 ^b	4.4 ^c	35.8 ^b	13.7 ^a	9.5 ^a
<i>Juncao</i> Napier	92.1 ^b	15.3 ^b	3.8 ^a	70.4 ^b	45.1 ^a	5.1 ^a	37.6 ^a	12.1 ^b	8.8 ^a
<i>Kakamega1</i> Napier	93.1 ^a	9.9 ^c	2.6 ^b	73.5 ^a	42.5 ^b	5.7 ^a	36.1 ^b	12.0 ^b	7.4 ^b
SEM	0.128	0.073	0.0211	0.198	0.161	0.032	0.065	0.046	0.024
P-value	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001	< .0001

Table 2. Macro and micro elements of *Pakchong* Napier, *Juncao* Napier, and *Kakamega 1* Napier grass

Browse species	Major elements (g/kg DM)				Trace elements (mg/kg DM)		
	P	Ca	K	Mg	Cu	Mn	Fe
<i>Pakchong</i> Napier	2.6	13.9	19.6	4.1	12	32.7	46.1
<i>Juncao</i> Napier	4.3	22.9	28.5	5.3	17	65.1	20.2
<i>Kakamega 1</i> Napier	2.7	4.1	29.1	3.2	17	98	100

Metabolizable Energy (ME), and Minerals in small holder dairy production systems.

Feeding and utilization

Table 3 shows a detailed breakdown of the supplementation levels and the type of supplementation needed for the three Napier grass varieties when used as a basal diet, with focus on Crude Protein (CP),

Table 3. Supplementation Levels and Types for the three Napier grass varieties as a basal diet with three feeding scenarios

Scenario	Forage Base	CP Supplementation (%)	ME Supplementation (%)	Mineral Supplementation (%)	Supplementation Type
Scenario 1 (<i>Pakchong</i>)	100% <i>Pakchong</i> Napier	2-4%	2-3%	5-10%	-Minimal protein concentrates: sunflower meal, lucerne, and desmodium. -Energy source: molasses or maize meal, maize silage. -Mineral mix: Ca, P, and Mg
Scenario 2 (<i>Juncao</i>)	100% <i>Juncao</i> Napier	5-7%	4-6%	3-5%	-Protein concentrates: cottonseed meal, lucerne, and desmodium. - Moderate energy source: maize meal, maize silage - Mineral mix: Mg
Scenario 3 (<i>KK1</i>)	100% <i>KK1</i> Napier	8-10%	7-9%	10-15%	-High protein concentrates: sunflower meal, cottonseed meal, and canola. -Energy source: whole maize meal, maize germ, molasses. -Mineral mix: Ca, P, and Mg

Pakchong Napier, with a higher CP and ME, will only require minimal supplementation on CP and ME, with focus on balancing the mineral profile, i.e., Ca, P, and Mg. *Juncao* Napier, with intermediate values for CP and ME, requires moderate supplementation with minimal mineral supplementation to meet the dairy cow's daily feed requirements, while *Kakamega 1* Napier, due to its lower nutritional quality, will require higher supplementation for protein, energy, and minerals.

In-vitro fermentation characteristics

Table 4 summarizes the fermentation characteristics of the grass samples, and **Figure 1** depicts the cumulative gas production curves. The *In-vitro* fermentation characteristics of the three Napier grass varieties showed notable differences in gas production and fermentation rates. *Pakchong* Napier exhibited the best fermentation traits with maxi-

mum cumulative gas production of 28.96 ml/200 mg DM at 24 hours and 35.30 ml/200 mg DM at 48 hours. *Kakamega 1* Napier came second with 25.0 ml/200 mg DM at 24 hours and 30.95 ml/200 mg DM at 48 hours. *Juncao* Napier had the least gas production of 17.50 ml/200 mg DM at 24 hours and 26.71 ml/200 mg DM at 48 hours. The fermentation kinetics, described by the constants A, B, and C (Ørskov *et al.*, 1979) [8], showed the differences more clearly. *Pakchong* Napier also had the highest potential extent of gas production with 9.36, followed by *Kakamega 1* Napier 6.64 and *Juncao* Napier 5.64. The greater value of these gas production and kinetic parameters for *Pakchong* Napier suggests it to be more digestible than *Juncao* and *Kakamega 1* Napier. These results suggest that *Pakchong* Napier has a greater potential for rumen and nutrient degradability in relation to the livestock's needs.

Table 4. *In-vitro* gas production (ml/200 mg DM) of Pakchong Napier, Juncao Napier, and Kakamega 1 Napier grass

Fermentation Characteristics							
Sample	24	48	A	B	C	A+B	RSD
Pakchong Napier	28.96	35.30	0.15	9.21	7.12	9.36	4.34
Juncao Napier	17.50	26.71	1.18	4.46	3.94	5.64	3.52
KK1 Napier	25.0	30.95	0.08	6.56	5.48	6.64	3.52

A, B, and C are constants (Ørskov and McDonald, 1979)

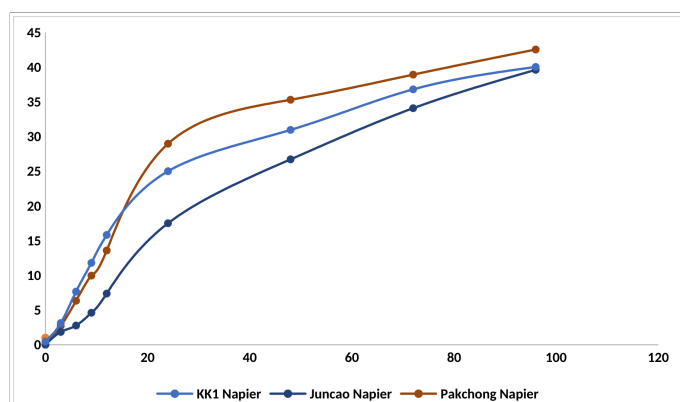


Figure 1. Patterns of *in vitro* cumulative gas production of Pakchong Napier, Juncao Napier, and Kakamega 1 Napier grass

Discussion

The superior nutritional value of Pakchong Napier over Juncao Napier and Kakamega 1 Napier is indicated by its higher crude protein and metabolizable energy contents, alongside lower fiber values. These results are in agreement with previous research focused on livestock nutritional needs, especially the uptake and performance benefits from feeding high-protein to low fiber diets (Jacovetti *et al.*, 2023) [9]. Pakchong Napier appears to have a better potential in enhancing dairy cattle feed efficiency because of the higher fermentation characteristics it supports. The 17.7% crude protein value of Pakchong Napier is remarkable since it surpasses the 15% CP minimum value prescribed for lactating cows (NRC, 2001). This value in protein may lessen the financial deficits involved with protein supplementation in smallholder dairy systems, elevating cost efficiency and milk yield instead (Mutimura *et al.*, 2018) [10]. Pakchong Napier's lower NDF and ADF also suggest improved digestibility, which is important in support of high dry matter intake in the dairy cows (Oba *et al.*, 1999) [11].

The intermediate fermentation characteristics and crude protein content of 15.3% makes Juncao Napier an option for smallholder dairy farmers. It appears as though it could serve as effective forage, stating nutrition in regions where Pakchong Napier would not adapt well. However, with the lower protein value of 9.9% crude protein and Kakamega 1 Napier's slower fermentation rate, it may be necessary to supplement the diet with higher protein feeds to fulfill the daily nutritional needs.

The analysis of the mineral composition revealed differences for the three samples being tested. Lactating cows could benefit greatly from lower mineral supplementation due to the higher concentration of calcium and phosphorus in Juncao Napier (Goff, 2018) [12]. His work regarding iron was supported by Spears *et al.* (2019) [13], where the higher iron content in Kakamega 1 Napier further adds to his statement regarding these areas being beneficial in locations stricken with iron deficiency.

The study on gas production *in vitro* also assisted in determining the fermentation kinetics of the three varieties of Napier grass. The improved cumulative gas production alongside the rate of fermentation in Pakchong Napier suggests an elevation in the completeness and rate of degradation within the rumen; therefore, increasing the nutrition and milk production of the animal. This supports the findings of

Meale *et al.* (2012) [14], demonstrating the correlation between *In-vitro* gas production and the *In-vivo* digestibility of ruminants.

The effective fermentation attributes of Pakchong Napier may affect methane production as well. Although not directly assessed in this research, faster fermentation rates are often associated with reduced methane yield per unit of feed intake (Jayanegara *et al.*, 2017) [15]. This might help reduce greenhouse gas emissions associated with the dairy industry, which is a major issue in the context of climate change (Hristov *et al.*, 2013) [16].

It is crucial to highlight that the *in-vitro* approach offers specific, valuable insights, but they may not fully represent the complex dynamics of the rumen environment. Passage rate, chewing time, and other dietary components may have an impact on digestibility and nutrient utilization *in vivo* (Huhtanen *et al.*, 2006) [17]. Hence, while these results are promising, additional *in-vivo* research and feeding experiments are necessary to confirm the expectations of the superior performance obtained from Pakchong Napier as well as Juncao Napier on the actual farm conditions.

Conclusion

and Recommendations

This research sheds new light on the nutritional values and the fermentation properties of Pakchong Napier, Juncao Napier, and Kakamega 1 Napier grasses for the smallholder dairy production systems in Kenya. The findings clearly show that Pakchong Napier has the highest nutritional quality and *in vitro* fermentation characteristics of all three Napier grasses, with a crude protein content of 17.7% and relatively lower fiber fractions than the other two Napier grasses. These qualities indicate that Pakchong Napier can substantially enhance the productivity of milk output and dairy farming in smallholder systems. Juncao Napier also shows promise as a high-quality, intermediate to the other two Napier grasses, and good mineral content, which makes this variety suitable in regions where Pakchong Napier may not thrive. Although the nutritional quality of Kakamega 1 Napier grass is relatively low, its adaptability to a wide range of agrological zones gives this grass a potential place in certain production systems, although needing protein supplementation. These findings highlight the potential of improved Napier grass varieties, particularly Pakchong Napier, to significantly enhance the productivity and sustainability of smallholder dairy systems in Kenya.

Based on these findings, we recommend:

1. Implementing feeding trials to assess animal performance fed on the three varieties of Napier grasses on milk yield, milk composition, meat quality, and animal health in dairy cattle under typical smallholder management conditions in different agro-ecological zones.
2. Conducting on-farm trials to evaluate the field performance of Pakchong and Juncao varieties under different agroecological conditions, including their biomass yield, persistence, and resistance to pests and diseases.
3. Evaluating the long-term sustainability of these improved varieties, including their impact on soil health, water use efficiency, and greenhouse gas emissions from dairy cattle production systems.
4. Economic analyses should be conducted to quantify the potential benefits of adopting these improved varieties.

- Investigating the ensiling characteristics of these Napier grass varieties to improve year-round feed availability for smallholder farmers.

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Authors

Kemboi F

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Tura I

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Githui M

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Kenana R

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Metto V

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Ndungu C

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Omariba R

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.

Nelima R

Kenya Agricultural and Livestock Research Organization, Beef Research Institute, Lanet, P.O. Box 3840 -20100, Nakuru, Rift Valley, Kenya.