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Nutritional assessment of three baled rice straw varieties intended for use as ruminant feed in Namibia

Oscar Madzingira[1*], Venaune Hepute[2], Evelyn Nanjeke Mwenda[1], Erick Kandiwa[1], Borden Mushonga[1] and John F. Mupangwa[3]

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*Corresponding author: Oscar Madzingira, School of Veterinary Medicine, Faculty of Agriculture and Natural Resources, University of Namibia, 13301, Pioneerspark, Windhoek, Namibia
E-mail: omuzembe@gmail.com

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Pedro González-Redondo, University of Seville, Seville SPAIN

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Abstract: This study determined and compared the proximate and chemical composition of Angola, IRGA 418 and SUPA rice straw varieties harvested and baled in 2016 and 2017. In both 2016 and 2017, SUPA straw had the highest dry matter (DM) content (960.7 ± 0.50 g/kg and 939.4 ± 0.10 g/kg), neutral detergent fibre (NDF) (575.2 ± 9.90 g/kg and 594.7 ± 9.00 g/kg), acid detergent fibre (ADF) levels (374.7 ± 6.30 g/kg and 379.9 ± 9.90 g/kg) and cellulose (CL) content. Angola straw had the highest crude protein (CP) content (39.1 ± 2.00 g/kg, $p < 0.05$; 60.7 ± 2.70 g/kg) and acid detergent lignin (ADL) concentration ($p < 0.05$) in both years. Organic matter (OM), hemicellulose (HC), ash, fat and mineral content varied with year in all rice straw varieties. Angola straw had the lowest metabolisable energy (ME) of the three straw varieties. All straw varieties were deficient in at least one or more essential nutrient components. Nutritional and chemical composition varied with

Oscar Madzingira

ABOUT THE AUTHOR

Oscar Madzingira's is a Senior Lecturer in the Department of Animal Health. He is a holder of a BVSc, MPhil and MMedVet (Veterinary Public Health) qualifications. His research focus is on zoonotic diseases and safety and on areas that benefit the community. Venaune Hepute is an Agronomist Researcher at the Ministry of Agriculture, Water and Forestry (Kalimbeza National Rice Project) and holds an MSc in Sustainable Agriculture, BSc in Agricultural Management and a Diploma in Agriculture. Evelyn N Mwenda is a Laboratory Technologist (Department of Animal Health) with a BSc in Environmental, Physiological and Molecular Biology. Erick Kandiwa has a BSc (Hons) in Physiology, BVSc and MSc in Veterinary Physiology. He is a Senior Lecturer in the Department of Biomedical Sciences. Borden Mushonga is a Senior Lecturer in the Department of Biomedical Sciences. He holds an MSc in Veterinary Pathology, a BVSc and BSc (Hons) in Veterinary Anatomy. J. F. Mupangwa is a Professor in the Department of Animal Science with a PhD in Animal Science and an MSc in Grassland Science. All authors are affiliated to the University of Namibia, except for the second author.

PUBLIC INTEREST STATEMENT

This study determined the composition of three rice straw varieties (Angola, IRGA 418 and SUPA) that were harvested and baled in 2016 and 2017 to determine their value as ruminant feed and recommend appropriate ways of utilising them. In both 2016 and 2017, SUPA straw had the highest dry bulk (960.7 ± 0.50 g/kg and 939.4 ± 0.10 g/kg) and indigestible fibre content (neutral detergent fibre (NDF): 575.2 ± 9.90 g/kg and 594.7 ± 9.00 g/kg; acid detergent fibre (ADF) levels: 374.7 ± 6.30 g/kg and 379.9 ± 9.90 g/kg and cellulose (CL) content). Angola straw had the highest protein content (39.1 ± 2.00 g/kg, $p < 0.05$; 60.7 ± 2.70 g/kg) in both years. In all rice straw varieties, nutritional components such as bulk, mineral and fat content varied with straw variety, year of cultivation and baling. All straw varieties were deficient in one or more essential nutrient components. Therefore, prior chemical treatment or supplementation of deficient nutrients is recommended before use as ruminant feed.

rice straw variety, year of cultivation and baling. Therefore, pre-treatment to improve digestibility and supplementation of deficient nutrients is recommended for effective use as ruminant feed. IRGA 418 straw was recommended as the best choice for ruminant feeding based on higher digestibility (IVOMD) and ME values.

Subjects: Agriculture & Environmental Sciences; Nutrition; Nutrition

Keywords: Chemical composition; digestibility; Namibia; proximate analysis; rice

1. Introduction

The Kalimbeza Rice Project, a brainchild of the Ministry of Agriculture, Water and Forestry (MAWF) to promote food security in Namibia, started as an experimental flood irrigation rice production project in the Zambezi region in 2007. Three rice varieties, namely IRGA 418, SUPA Rice and Angola are currently grown on 30 hectares of land. The gradual commercialization of rice production at Kalimbeza has over the last decade, resulted in large quantities of rice straw. Rice straw is the fibrous part of the rice crop-biomass which is left after harvesting grain (Kumar et al., 2014).

The production of large quantities of rice straw residue presents major disposal challenges (Rathod et al., 2017). According to literature, about 1–1.5 tons of straw is produced for every ton of rice grain harvested (Schiere, 2010). Rice straw provides livestock bulk feed and is the backbone of the livestock production industry in the major rice producing countries of the world such as the Indian subcontinent and South East Asia (Kadam et al., 2000; Tang, 2018; Van Hung et al., 2020). In Bangladesh, for instance, rice straw is reported to make up to 81% of the total roughage for ruminants. Elsewhere, rice straw constitutes between 60% and 90% of dry matter intake by ruminants (Rahman et al. 2010). Rice straw can be fed to cattle either straight as bulk feed (Kaur et al., 2007; Kumar et al., 2014; Rathod et al., 2017) or after limited enrichment or processing using various physical, chemical or biological methods (FAO, 2011; Jetana, 2017; Naik, 2010; Shrinivasa & Maski, 2017). Feeding of abundant crop residues, such as straws to livestock plays a major role in mitigating dry season forage scarcity (Ansah & Issaka, 2018; Kumar et al., 2014; Shrinivasa & Maski, 2017) which limit livestock productivity in tropical, arid, and semi-arid regions of the world (Ansah & Issaka, 2018; Sheikh et al., 2017; Thakur et al., 2007) including Namibia. Disposal of rice straw residue by burning releases greenhouse gases, which promote global warming and contribute to climate change (Malik et al., 2015; Rathod et al., 2017). Therefore, use of rice straw as alternative animal feed provides an environmentally friendly way of disposing this by-product (Aquino et al., 2020). There are a number of reports dealing with the use of rice straw as livestock feed on the African continent (Ansah et al., 2017; Ansah & Issaka, 2018; Asmare & Yayeh, 2018; Wuanor & Ayoade, 2017), but limited reports from the Southern Africa subregion.

Cattle production is a significant source of income and wealth for communal and commercial cattle farmers in Namibia (Jones & Dieckmann, 2013; Lohmann et al., 2014). At present, cattle are raised on natural pastures, whose availability is limited or unpredictable due to the erratic rainfall pattern. The use of crop residues as livestock feed is limited to a few areas in the northern part of the country where small-scale grain crop production is practiced. The availability of rice straw as a feed resource provides an opportunity for farmers to sell finished cattle and fetch better prices instead of marketing weaners to South Africa as is currently and widely practiced in Namibia (Lohmann et al., 2014). Effective and appropriate utilization of straw as a livestock feed can only occur if its chemical and nutritional composition are known as this can vary with several factors including geographical location, soil fertilization, rice variety, environmental conditions, stage of plant maturity at harvesting, season, postharvest storage and year of harvest (Malik et al., 2015).

Previous studies in other countries have indicated that rice straw contains about 900.0–954.9 g/kg dry matter, 50–120 g/kg lignin, 30–59.6 g/kg crude protein, 298–370 g/kg crude fibre, 1.4–10 g/

kg crude fat, 0.2–1.6 g/kg phosphorus, 1.4–5.5 g/kg calcium, 44% total digestible nutrients, 7.95 MJ/kg of digestible energy, 80–158 g/kg silica and high oxalates conferring poor digestibility (Singh et al., 1995; Van Soest, 2006; Hadizadeh et al., 2015; Ansah et al. 2017) and in some cases toxicity (Bakshi & Wadhwa, 2017; .Drake et al., 2002). Notwithstanding its role as a livestock feed resource in many developing countries, rice straw is rich in polysaccharides on one side, and a high level of lignin conferring it poor nutritive value due to poor digestibility and palatability on the other side (Malik et al., 2015; Selcuk et al., 2016).

Angola and IRGA 418 are short rice varieties, while SUPA rice is a tall, late maturing and low yielding variety that prefers deeper waters. The potential use of these three rice straw varieties as animal feed under the Namibian environmental production conditions has not been previously evaluated and has, therefore, not been reported. The objective of this study was to determine the nutritive value, chemical composition and *in vitro* organic matter digestibility (IVOMD) of the three rice varieties cultivated at the Kalimbeza Rice Project and to recommend the best variety for use as animal feed.

2. Materials and methods

2.1. Study area

The Kalimbeza Rice Project is located about 40 km from Katima Mulilo town in the Zambezi Region of Namibia (17°30′00′′S and longitude 24°16′00′′E) in a flat flood plain ecosystem that is ideal for rice production (Jones & Dieckmann, 2013). Rice production started in 2007 on four hectares of land in collaboration with the University of Namibia and production has increased over the years. The Zambezi region receives the highest annual rainfalls in the country with an average of about 700 mm. According to Country Pilot Partnership in Namibia (CPPN) (2005), the Kalimbeza area receives about 500 mm to 600 mm of rainfall annually. Summer temperatures range from 23°C to 30°C, while winter temperatures are between 15°C and 18°C. In 2016 and 2017, the Kalimbeza area experienced average monthly air temperatures of 4.0–40.3°C and 5.4–40.1°C; relative humidity of 27.6–76.2% and 33.5–81.5%; annual rainfall of 539.4 mm and 676.0 mm respectively (SASSCAL, 2021).

2.2. Rice straw sampling

Rice straw was randomly sampled from baled IRGA 418 (n = 10, n = 10), SUPA (n = 12, n = 10) and Angola (n = 5, n = 8) rice straw produced in 2016 and 2017, respectively, at Kalimbeza Rice Project. Straw samples were taken from bales prepared from mature rice crop after grain harvesting. Sampling of each rice straw variety was by pooling subsamples from the exterior, middle and central part of the bale.

Straw samples were chopped to 3–4 cm size and ground in a Wiley mill (CYCLOTC1 993, Sample Mill Tecator, Sweden) through a 1.0 mm size sieve and stored in black polyethylene bags at room temperature until proximate analysis was done at the Agricultural Laboratory (Ministry of Agriculture, Water and Forestry) in Windhoek.

3. Chemical analysis

Rice straw samples were analysed for chemical composition at the Agricultural Laboratory (Ministry of Agriculture, Water and Forestry) in Windhoek. From each straw sample bag, triplicate samples were taken and analysed for nutrient parameters based on the procedures of the Association of Official Analytical Chemists (AOAC 1995). The value of each nutrient parameter per straw sample was determined by computing the average of the results of the three samples.

Dry Matter (DM) content was analyzed by drying a 200 g sample for 5 h at 105°C in a convection oven (AOAC, 1995). The weight of the sample after drying was expressed as a percentage of the initial weight. Nitrogen (N) content was determined using the Kjeldahl procedure (AOAC, 2016) and multiplied by 6.25 to estimate the crude protein (CP) content. Neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991). Hemicellulose content was determined as the difference between ADF and NDF. The crude fat fraction was measured using the Soxhlet extraction method, whereby fat was extracted using petroleum ether (AOAC, 1995). Total ash was obtained by igniting a dried sample in a muffle furnace at 500°C for 24 hours. For sample preparation in the determination of the minerals calcium (Ca) and phosphorus (P), the dry ashing procedure was used, after which P was analyzed by colorimetry using the UV/VIS Spectrophotometer and Ca by Inductively Coupled Plasma—Optical Emission Spectroscopy (ICP-OES, icap 6000 series).

4. Determination of Organic matter Digestibility (OMD)

The *in vitro* gas production procedure as described by Menke and Steingass (1988) was used to estimate organic matter digestibility (OMD) and Metabolisable Energy (ME) using the following equation:

$$\mathrm{OMdigestibility}(\%) = 14.88 + 0.889 \times \mathrm{Gv}(\mathrm{ml}) + 0.45 \times \mathrm{CP}(\%)$$

$$\mathrm{ME}(\mathrm{MJ/kgDM}) = 2.20 + 0.136 \times \mathrm{Gv}(\mathrm{ml}) + 0.057 \times \mathrm{CP}(\%)$$

5. Source of rumen liquor

Rumen liquor was obtained from a rumen fistulated Simmentaler ox (at 3 and 4 years old) that was raised on natural pastures at Bervleg Veterinary Research Station in Windhoek, but fed on a pure Lucerne diet 24 hours prior to rumen fluid collection. Rumen liquor was collected in the morning before the animal was fed, using a manual pump and immediately transferred to a pre-warmed (39°C) insulated thermos flask filled with carbon dioxide. At the laboratory, rumen liquor was filtered through two layers of cheese cloth. Rumen fluid from the same animal was used as inoculum for samples collected in 2016 and 2017. The *in vitro* digestibility studies were carried out using rumen fluid obtained from an animal that was restrained following standard veterinary procedures and the study proposal was approved by the Research and Ethics Committee of the University of Namibia.

Samples from three rice straw varieties (IRGA 418, Angola and SUPA) were put through the procedure of *in vitro* gas production as described by Menke and Steingass (1988). For each sample, approximately 200 mg milled and sieved sample were prepared in triplicate and placed in graduated glass incubation syringes (100 ml) to which a lubricated piston was inserted. One part of rumen liquor was added to two parts of buffered mineral solution (1:2, v/v). The buffered rumen fluid (30 ml) was then pumped into incubation syringes containing the test samples. Air bubbles were cleared from the incubation syringes and the plastic clip on the silicon tube was closed. This procedure was performed under continuous flushing with carbon dioxide to maintain anaerobic conditions. Loaded incubation syringes were placed in an incubator at 39°C. The position of the piston was read and recorded. Gas production was read and recorded after the first 8 hours of incubation by opening the clip to let the air out and moving the piston back to 30 ml position. The incubation process was terminated after 24 hours and the final reading of gas production was made.

5.1. Data analyses

Data was stored in Microsoft Excel ® and analysed as a 2 × 3 factorial arrangement using the Analysis of Variance (ANOVA) technique in SPSS (Landau & Everitt, 2004). The differences in the means of the treatment combinations were analysed using Duncan's post-hoc test. The analytical model used was as follows:

$$Y_{ijk} = \mu + V_i + Y_j + (VY)_{ij} + e_{ijk}$$

where:

$Y_{ijklm=}$ = DM, CP, NDF, ME etc

μ = overall mean

V_i = effect of variety (i = 1,2,3)

$Y_{j=}$ = effect of year (j = 1, 2)

$(VY)_{ij}$ = effect of interaction between variety and year

e_{ijk} = error term.

The study was authorised by AGRIBUSDEV (Ministry of Agriculture, Water and Forestry), the company responsible for the rice research project. Sampling was carried out without disturbing the ongoing experiments on rice production. The rice straw sampled in this study was a by-product of rice production.

6. Results

Results of proximate and chemical analyses carried out on the three rice varieties and subsequent statistical analyses are presented per year of cultivation in Tables 1 and 2. All nutrient components showed significant variation due to the interaction of rice straw variety and year of growth ($p < 0.05$) except for hemicellulose, calcium and IVOMD. In both 2016 and 2017, SUPA rice straw had the highest DM content. However, in 2016, the DM content of SUPA rice straw was not different from the other two straw varieties (p > 0.05), while in 2017, the DM content of SUPA rice straw was similar to that of IRGA, but higher than that of Angola straw (p < 0.05) (Figure 1). Per growing year, OM content was highest in SUPA rice straw in 2016 (773.5 ± 4.10 g/kg) and Angola rice straw in 2017 (748.2 ± 4.30 g/kg). In 2016, Angola straw had the highest CP content (39.1 ± 2.00 g/kg) (p < 0.05). Although the CP content of Angola straw was the highest among the straw varieties in 2017 (60.7 ± 2.70 g/kg), it was similar to the CP content of IRGA 418 straw, but different from the CP levels recorded in SUPA straw (p < 0.05). In terms of crude fat content, IRGA 418 from 2016 had significantly higher fat content (7.1 ± 0.10 g/kg) than both Angola and SUPA straw varieties grown in the same year ($p < 0.05$), while in 2017, Angola rice straw had significantly higher fat content (12.8 ± 2.30 g/kg) among the straw varieties. For all three straw varieties, fat content was significantly higher in 2017 samples than in those from 2016 ($p < 0.05$).

In both 2016 and 2017, SUPA rice straw had the highest NDF (575.2 ± 9.90 g/kg and 594.7 ± 9.00 g/kg) and ADF (374.7 ± 6.3 g/kg and 374.7 ± 6.3 g/kg) than both Angola and IRGA 418 straw varieties, but the differences were not significant ($p > 0.05$). The highest ADL levels were recorded in Angola rice straw in both study years, but the differences among the straw varieties were significant in 2016. SUPA rice straw was the variety with the highest CL content in both 2016 and 2017. Per year of study, the HC, Ca and IVOMD were not different (p > 0.05).

Ash content varied with year of growth. Ash content in Angola rice straw from 2016 (305.1 ± 18.600 g/kg) was higher than those of IRGA 418 and SUPA rice straws from the same year ($p < 0.05$), while SUPA rice straw from 2017 had the highest ash content (211.2 ± 4.50 g/kg). In 2016, SUPA rice straw had higher P content (0.38 ± 0.080 g/kg) than both Angola and IRGA 418 ($p < 0.05$), while in 2017, Angola rice straw had P levels that were similar to IRGA 418 ($p > 0.05$), but different from SUPA straw ($p < 0.05$). The ME was determined only on the 2016 straw and IRGA 418 (6.64 ± 0.120 MJ/kg) and SUPA rice straw (6.33 ± 0.280 MJ/kg) had significantly higher ME than Angola rice (5.32 ± 0.360 MJ/kg) (p < 0.05).

7. Discussion

Comparative chemical compositions of rice straw varieties have been reported by Rahman et al. (2010) in Pakistan and Singh (2016) and Ganai et al. (2017) in the Kashmir Valley of India. Results of this study showed variation in chemical and nutritional composition due to rice straw variety and year of cultivation, in agreement with observations by Shen et al. (1998). Elsewhere, it has

Table 1. Nutritional composition (± SEM) of Angola, IRGA 418 and SUPA rice straw varieties grown at Kalimbeza, Namibia in 2016 and 2017 (g/kg of DM unless specified)

Rice straw variety	Year	DM	Ash	OM	CP	Fat	NDF	ADF
Angola	2016	953.3^{a} ±1.1	305.1 ±18.6	648.2 ±17.9	$39.1^{c,d}$ ±2.0	4.3^{a} ±0.6	$541.8^{a,e,f}$ ±13.1	$341.5^{a,d}$ ±7.9
	2017	$934.1^{a,c}$ ±4.0	185.9^{a} ±5.2	$748.2^{a,c}$ ±4.3	60.7^{b} ±2.7	$12.8^{b,c,d}$ ±2.3	$564.9^{a,e,f}$ ±12.3	334.2^{a} ±5.3
IRGA 418	2016	$947^{a,b}$ ±1.3	$225.2^{b,d}$ ±8.0	721.8^{a} ±7.4	35.3^{a} ±1.7	7.1^{c} ±0.1	$536.1^{b,e}$ ±6.5	$333.7^{a,b}$ ±5.0
	2017	$935.5^{b,d}$ ±0.9	$200.9^{a,b,e,f}$ ±6.3	$734.6^{a,b}$ ±6.1	$50.5^{b,d}$ ±2.7	12.5^{d} ±0.6	$588^{c,f}$ ±7.3	$357.4^{a,b,e}$ ±5.9
SUPA	2016	960.7^{a} ±0.5	$187.1^{b,e}$ ±4.3	773.5 ± 4.1	28.1^{a} ±1.9	4.0^{a} ±0.6	$575.2^{d,e,f}$ ±9.9	$374.7^{c,d,e}$ ±6.3
	2017	$939.4^{c,d}$ ±0.1	$211.2^{d,f}$ ±4.5	$728.3^{b,c}$ ±4.7	31.7^{a} ±0.7	12.2^{b} ±0.5	$594.7^{d,f}$ ±9.0	$379.9^{c,d,e}$ ±9.9
Significance	V	*	**	**	**	*	**	*
	Y	*	**	**	*	**	**	NS
	V X Y	*	**	**	**	**	**	**

Column means without a common superscript (a, b, c, d) differ at $p < 0.05$

DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre

SEM: standard error of the mean

V: rice variety; Y: year

*: Significant at $p < 0.05$

**: Significant at $p < 0.01$

NS: Not significant

Table 2. Nutritional composition (± SEM) of Angola, IRGA 418 and SUPA rice straw varieties grown at Kalimbeza, Namibia in 2016 and 2017 (g/kg of DM unless specified)

Rice straw variety	Year	ADL	HC	CL	Ca	P	IVOMD (% of DM)	ME (MJ/kg DM)
Angola	2016	60.2^{a} ±3.9	$200.3^{a,b,c}$ ±8.3	$281.3^{a,d}$ ±10.2	1.7^{a} ±0.1	0.03^{c} ±0.01	56.54^{a} ±0.31	5.36^{a} ±0.32
	2017	51.4^{a} ±1.7	$230.7^{a,b,c}$ ±9.0	282.8^{a} ±4.4	ND	0.84^{b} ±0.05	ND	ND
IRGA 418	2016	$40.0^{b,d}$ ±2.0	202.4^{b} ±4.3	$293.7^{a,b}$ ±4.8	1.5^{a} ±0.2	0.22^{c} ±0.04	59.51^{a} ±0.81	6.64^{b} ±0.12
	2017	$40.6^{b,d}$ ±2.6	230.7^{c} ±6.5	$316.8^{b,c,d}$ ±5.6	ND	$0.77^{b,d}$ ±0.08	ND	ND
SUPA	2016	$33.3^{b,c}$ ±2.0	$200.6^{a,b,c}$ ±9.7	341.4^{c} ±6.1	1.7^{a} ±0.2	$0.38^{a,e}$ ±0.08	54.72^{a} ±1.83	$6.33^{a,b}$ ±0.28
	2017	$49.2^{a,d}$ ±2.1	$214.8^{a,b,c}$ ±13.6	$330.7^{c,d}$ ±9.6	ND	$0.47^{d,e}$ ±0.04	ND	ND
Significance	V	**	NS	*	NS	**	NS	**
	Y	**	*	NS	ND	**	ND	ND
	V X Y	**	NS	**	NS	**	NS	*

Column means without a common superscript (a, b, c, d) differ at $p < 0.05$

ADL: acid detergent lignin; HC: hemi-cellulose; CL: cellulose; Ca: calcium; P: phosphorus; IVOMD: in vitro organic matter digestibility; ME: metabolisable energy; ND: not determined

SEM: standard error of the mean

V: rice variety; Y: year

*: Significant at $p < 0.05$

**: Significant at $p < 0.01$

NS: Not significant

been reported that different rice straw varieties, or indeed the same variety under different growing conditions show variable chemical compositions (Blanchard et al., 2014; Van Soest, 2006) and may be affected by the ratios of leaf: sheath: stem (Vadiveloo, 1995). The differences in nutritional and chemical compositions of rice straw varieties observed in this study suggest differences in the ability of the rice plant varieties to take up nutrients from the soil (Ansah et al., 2017). Results of the present study show ranges of the nutrient content similar to reports from the Indian subcontinent (Rahman et al. 2010; Ansah et al., 2017; Ganai et al., 2017; Singh, 2016).

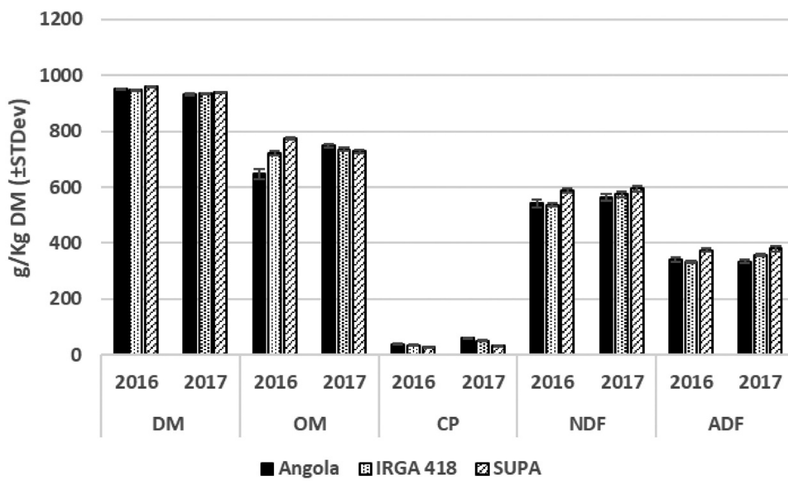
The average DM content in our study was within 1–2% of what was reported by other studies (Rahman et al. 2010; Ansah et al., 2017; Ganai et al., 2017; Singh, 2016). The differences in DM content between straw varieties may be explained by the differences in stages of maturity at the time of harvesting (Singh, 2016). In the present study, the shorter season or early maturing varieties (Angola and IRGA 418) had a lower DM content than the tall and late maturing SUPA rice variety in which prolonged photosynthesis (Juliano, 1985) results in increased dry matter content (Deren et al., 1994). The general trend with regard to the OM in our study, is that its content was about 10% lower than results of recent studies (Rahman et al. 2010; Ansah et al., 2017; Ganai et al., 2017; Singh, 2016). .

Crude protein is generally considered a good determinant of forage quality. The low CP values of 30–50 g/kg reported in the current study (Table 1) are consistent with a number of previous studies (Sophal et al., 2010; Rahman et al. 2010; Peripolli et al., 2016; Singh, 2016; Ganai et al., 2017), but lower than the 50–80 g/kg reported by Dong et al. (2013) and fall short of the 110–130 g/kg recommended for ruminant maintenance diets (National Research Council (NRC), 2007). Results of this study also showed that per growing and baling year, Angola straw had the highest CP content, while the late maturing SUPA rice had the lowest CP content. Therefore, if rice straw is to be considered as a major feed source for ruminants, supplementation of dietary protein is a pre-requisite. This may include pre-treating the rice straw with urea to improve crude protein levels and palatability.

NDF was about 10–20% lower than the figures reported by other workers (Vadiveloo, 1995; Rahman et al. 2010; Singh, 2016; Ganai et al., 2017). The ADF values of between 334 g/kg and 377 g/kg, reported in our study, were about 5–10% lower than reported by Rahman et al. (2010) and Singh (2016). The average ADL was in the range of 41 g/kg to 51 g/kg. Although this figure is lower than the 43 to 69.7 g/kg reported by Rahman et al. (2010), the present results confirm the high lignocellulosic content of rice straw as reported by other studies (Hadizadeh et al., 2015; Selcuk et al., 2016; Sheikh et al., 2017; Van Soest, 2006). The fact that Angola rice straw had the least cellulose content implies that it is the better digestible straw. In this study, NDF, ADF, CL and ADL, the fractions which represent the poorly digestible components of plant cells, were higher in the late maturing (SUPA rice straw) than in the shorter season straw varieties (Angola and IRGA 418) indicating accumulation of these components with maturity, as has been observed in other studies (Juliano, 1985). Reports indicate that tall rice straw varieties, such as SUPA rice, have more leaf than stem, with the stem having a higher digestibility than leaves, due to lesser structural components. In addition, the relatively high ambient temperatures, as experienced in the study area, promote rapid growth of the rice plant, resulting in accumulation of both fibre and silica in the straws (Van Soest, 2006).

The highest hemicellulose content was recorded in IRGA 418 and Angola rice straws and this was lower than the 260–333 g/kg DM reported in Brazil (Peripolli et al., 2016), but similar to the 190–250 g/kg reported in India (Malik et al., 2015). Compared to a study in India (Yoswathana & Phuriphipat, 2010), the average cellulose content of rice straw in this study was lower, while the ADL was comparable. Results of this study confirm the lignocellulosic nature of rice straw, which is a major constraint for microbial breakdown in the rumen (Balasubramanian, 2013). It has been reported that lignin physically encrusts cellulose and hemicellulose or forms strong covalent bonds with these fractions, making them less available for digestion by rumen microbial enzymes (Srivastava et al., 2012).

Figure 1. Comparison of selected nutrients (± SEM) among the three rice straw varieties (Angola, IRGA 418 and SUPA) grown at Kalimbeza, Namibia in 2016 and 2017.



The IVOMD determined by this study (547.2–595.1 g/kg) was within the range of 353–563 g/kg reported for rice straw in Brazil (Peripolli et al., 2016). Given the above, especially the relatively high content of NDF, ADF, ADL, CL and HC in rice straws in this study, it is imperative that methods for the improvement of rice straw digestibility such as the pre-treatment with lignocellulosic enzymes be harnessed if its use as ruminant feed is to be maximised (Kumar et al., 2014; Selcuk et al., 2016).

Average ash levels (213 g/kg) were 5–10% higher than reported in earlier studies (Vadiveloo, 1995; Rahman et al. 2010; Singh, 2016; Ganai et al., 2017), but consistent with the low levels of Ca and P reported in a number of rice straw varieties worldwide. The higher levels of ash may be related to the high silicate levels (Ansah et al., 2017) which, together with lignin, have been identified as limiting voluntary intake and degradability of rice straw (Kumar et al., 2014; Singh, 2016). The levels of Ca reported in this study (1.6 g/kg) were approximately half the levels reported by Singh (2016), while the phosphorus content (0.03–0.84 g/kg) was below the 0.3% required for normal animal growth (Malik et al., 2015). As a result, the Ca:P ratio of 1:3.3 was below the ratio of 2:1 recommended in ruminant diets (McDowell, 1985). Therefore, supplementation of Ca and P to ruminants when feeding any of the three rice straw varieties is recommended to ensure a balance of the ratio at 2:1.

The crude fat concentration varied with year. The highest fat levels were determined in Angola rice straw (2017), which gives this variety an additional secondary source of energy for ruminants. IRGA 418 had the highest ME, which was not significantly different from that of SUPA rice straw and was lower than the 6.76 MJ/kg determined for rice straw by a previous study (Wei et al., 2018). Therefore, rumen microbes are likely to derive more energy from utilising these two rice straw varieties than Angola rice.

All rice straw varieties in this study were found lacking in at least one or more essential nutrient components and are therefore not suitable for use as the only feed for ruminants. For example, the CP was about 6%, which falls short of the 100 g/kg threshold set for ruminants (Hassan & Umar, 2004) and the digestible organic matter was less than 60% on a DM basis. Our results are consistent with previous reports by Smith (1993) that crop residues are deficient in crude protein, fermentable carbohydrate or essential minerals. The high DM content of rice straw can be used to provide the bulk base required in ruminant mixed rations. Since all three straw varieties were poorly digestible and had low levels of essential nutrient components such as crude protein, pre-treatment (physical, chemical or biological) such as with the addition of urea, ammonia or the use of lignolytic fungi or supplementation by feeding a concentrate with a higher CP and digestibility

(Kumar et al., 2014; Malik et al., 2015; Selcuk et al., 2016) is recommended. IRGA 418 straw could be the straw of choice as it had moderate metabolisable energy, CP, better digestibility and lower NDF, ADF, CL and ADL values than the other straws.

The findings of this study lend support to the theory that the chemical composition of rice straw depends on year as reported by other authors (Ansah et al., 2017; Blanchard et al., 2014; Van Soest, 2006). The novelty of this study is that it is the first of its kind to report proximate values of rice straw varieties in the Southern African region. However, further studies are required on *in-vivo* digestibility, the best pre-treatment options and on the performance of ruminants fed rice straw-based diets.

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Author details
Oscar Madzingira[1]
E-mail: omuzembe@gmail.com
ORCID ID: http://orcid.org/0000-0003-1145-9880
Venaune Hepute[2]
Evelyn Nanjeke Mwenda[1]
Erick Kandiwa[1]
ORCID ID: http://orcid.org/0000-0003-0424-3002
Borden Mushonga[1]
ORCID ID: http://orcid.org/0000-0003-1062-2201
John F. Mupangwa[3]
[1] School of Veterinary Medicine, Faculty of Agriculture and Natural Resources, University of Namibia, Windhoek, Namibia.
[2] Kalimbeza National Rice Project, Ministry of Agriculture, Water and Forestry, P. Bag 13184, Windhoek, Namibia.
[3] Department of Animal Science, Faculty of Agriculture and Natural Resources, University of Namibia, Windhoek, 13301, Namibia.

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The authors declare no competing interests.

Data availability
Data may be shared on request.

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