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Characterization of the nutritional values of agro-industrial by-products in Namibia as potential supplements of the bush-based feeds

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Abstract

The objective of this study was to characterize the nutritional values of Namibian agro-industrial by-products (AIBPs) as potential supplements for bush-based feeds. Fourteen AIBPs' samples were collected from Namibian local cereals and oilseed processing companies. Cereal by-products were malt dust fine (MDF), pearl millet bran (PMB), malt dust coarse(MDC), white maize chop (WMC), wheat bran(WB), brewer's spent grains(BSG), sorghum brew residue (SBR) and sorghum spent grains (SSG), while oil seed byproducts were olive oil cake(OIC), marula oil press (MOP), jojoba oil cake (JOC), !nara oil cake(NAC), manketti oil cake (KOC) and marula oil cake (MOC). Chemical compositions, *in vitro* gas production, *in vitro* organic matter digestibility and metabolizable energy of the AIBPs were determined in a randomized complete block design and the data were statistically analyzed using a Statistical Package for Social Science. Crude protein, ether extract, neutral detergent fiber, and acid detergent fiber ranged from 7.90 (SSG)-21.95 %(BSG), 1.37(MDF)-9.29%(PMB), 22.23(WMC)-73.06%(BSG), 7.22 (PMB) -30.46% (BSG) respectively for cereal by-products and 7.55(OIC)-37.3% (MOP), 8.11(KOC)-53.55%(MOC), 11.40 (MOC)-58.26%(KOC) and 8.21(MOP)-52.26%(MOP) in oil seeds by-products respectively. The *in vitro* gas production, *in vitro* organic matter digestibility, and metabolizable energy ranges for cereal and oilseed by-products were 31.50 (BSG)-70.20ml/200mgDM(WMC), 55.55 (BSG)-83.50%DM(WMC), 9.30(BSG)-14.00MJ/Kg(white maize chop), and 3.80 (MOP)-35.30ml/200mgDM(jojoba oil cake), 38.95(MOP)-59.35%(JOC), and 7.45(MOC)-15.95MJ/Kg(MOP), respectively. The AIBPs investigated in this study comprised of minimal fiber contents, adequate crude protein, and metabolizable energy contents above minimum requirements for ruminant animals. However, promotion to maximally utilize these AIBPs in animal diets requires further evaluation.

Keywords: By-products, Chemical composition, Organic matter digestibility, Marula oil cake, Pearl millet bran.

1. Introduction

Namibian livestock productivity is threatened by numerous factors including the expansion of encroacher bushes. Bush encroachment affects approximately 30 to 45 million hectares of farmland in Namibia (~30% of Namibia' land area), reducing the country's rangeland production capacity (Honsbein et al., 2017). Bush encroachment has numerous negative impacts such as reduction of rangeland carrying capacity, suppression

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of palatable grasses and herbs growth (Schrőiter, 2011), reduction of groundwater recharge and biodiversity through habitat loss, which therefore result in massive economic and ecological damage (de Klerk, 2004). Bush feed production has emerged as one of the prominent value chains in controlling bush encroachment (Rothauge, 2014). Although there is an increase in the current activities of bush feed in Namibia, this innovation date back to the 1980s (Honsbein et al., 2017). A typical bush-based feed production process in Namibia involves harvesting of twigs and branches (less than 2cm in diameter) from species such as *Senegalia mellifera, Cataphractes alexandrii and Terminalia sericea*, milling and mixing with energy and/or protein rich supplements. Supplementation is mainly done to improve the nutritional quality, digestibility and palatability of the bush-based feed (Honsbein et al., 2017). Generally, bushes as browse make an essential supplement feed to rangeland feeding particularly during dry seasons when the crude protein (CP) content in pastures diminishes below 7% (Wesuls *et al*., 2009). In summer, the CP content *S. mellifera* (dominant encroacher thorn) fodder ranges from 5.85-15.50% (Honsbein *et al*., 2017), which is above the minimum maintenance requirements for ruminants (NRC, 2001). However, due to its high fiber content (49.57-65.20% NDF and 32.41-60.36% ADF), its organic matter digestibility (OMD) and metabolizable energy (ME) are low (38.1-46.4% and 4.4-6.6% MJ/Kg, respectively), making the bush feed material less attractive to ruminant livestock (Honsbein et al., 2017). Some of the supplements used to improve the nutritional value, and intake of bush feed such as Lucerne, molasses, cottonseed cake and maize are often imported (Annual Trade Statistics Bulletin, 2016) and increase the cost of producing bush based feed. The cost of bush feed production could be reduced through the use of locally available and affordable agro-supplements such as industrial by-products (AIBPs). Agro-industrial by-products are residues derived from agro-industries during the processing of main products such as cereal grains, fruits and oilseed crops to manufacture food products for sale (Jeon et al., 2016). Several studies have concluded that AIBPs are relatively affordable and have a great potential for use as alternative sources of energy and protein in livestock feed (Maneerat et al., 2015). By-products such as molasses are rich in fermentable carbohydrates and make good sources of energy, while oilseed cakes such as coconut oil cake and soybean meal rich protein sources (Habib et al., 2014). On the other hand, by-products such as cereal and brewers' grains are considered as both protein and energy sources (Habib et al., 2014). The utilization of AIBPs in developing countries as livestock feed is limited, mainly due to lack of farmers knowledge about AIBP's nutritive values for livestock feeding among other challenges (Alniamy, 2017). There is a lack of data and information regarding the nutritional value of by-products generated by Namibian agro-industries Namibia host agro-industries that are involved in processing of crops for flour, starch, beer, oil, wines and spirits productions (as listed in Trade Policy Framework, 2016). Therefore, the objective of this study was to determine the nutritional values of agro-industrial by-products in Namibia as potential supplement for bush-based feeds.

2. Materials and Methods

2.1. Collection of AIBPs and preparation

Agro-industrial by-products produced in all the 14 regions of Namibia were identified and quantified in a survey by Kamati (2019). Based on the information from the survey, fourteen different AIBP samples (~3 kg per AIBPs) were collected from agro-processing companies located in different regions across Namibia. By-products samples collected and studied this study were strictly of plant origin mainly cereal grains and oilseed by-products. Cereal grains byproducts were malt dust fine, pearl millet bran, malt dust coarse, white maize chop, wheat bran, brewer's spent grains, sorghum brew residue and sorghum-spent grains. Oilseed by-products were olive oil cake, marula oil press, jojoba oil cake, !nara oil cake, manketti oil cake and marula oil cake. Samples were then transported to the University of Namibia, Neudamm campus, Department of Animal Science laboratory and dried at 60 ^{0}C overnight. Dried samples were ground using a Wiley-milling machine through a 1 mm sieve and transferred into airtight containers pending analyses.

2.2 Chemical Analysis

Dry matter (DM), organic matter (OM), ether extracts and crude protein were determined according to the standard methods of the Association of Official Analytical Chemists [AOAC] (1991). Briefly, the DM was analyzed by drying samples in forced-air oven at 105ºC over night. The ash content was determined by igniting the samples in a muffle furnace at 550 ºC for 6 hours while the OM was calculated as the difference between DM and ash content. Ether extract (EE) was analyzed by Soxhlet methods using petroleum ether as a dissolving reagent. Nitrogen (N) content was determined by the standard Kjeldhal method and the amount of crude protein was calculated by multiplying the nitrogen content by a factor of 6.25. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) was determined according to Van Soest et al. (1991) using ANKOM fiber analyzer. Calcium and phosphorus were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) (icap 6000 series). All chemical analyses were carried out in duplicate.

2.3 In vitro organic matter digestibility and metabolizable energy

The *in vitro* gas production experiment was carried out according to the *in vitro* gas test procedure of Menke and Steingass (1988). The rumen fluid was collected in the morning from a cannulated Simmentaler steer fed a lucerne-based diet at Bervleg Veterinary Research Station in Windhoek. Rumen fluid collection was performed with a manual pump and transferred into a pre-warmed thermos flask, flushed with carbon dioxide (CO_2) and then immediately transported to the laboratory. Rumen fluid was squeezed into a beaker through 1mm four layers of cheesecloth, homogenized and kept at 39 ºC in the water bath under continuous flow of CO_2. One part of rumen fluid was added to two parts of buffer mineral solution (1:2, volume / volume) (Onodera & Henderson, 1980), which was maintained in a water bath at 39°C. For each by-product, a ground sample of 0.203 mg was weighed into pre-warmed 100 ml calibrated glass syringes in duplicates. Pistons were lubricated with Vaseline and inserted into the syringes. The syringes with a mixture of AIBPs sample and buffered rumen fluid were immediately placed into an incubator with a rotating disc maintained at 39 ^{0}C. Three syringes with only buffered rumen fluid were incubated and considered as the blank incubations. Hay and concentrate feed samples provided by Hohenheim University, each in three syringes was used as standards. 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 at 30ml position and put back into the incubator. The incubation of syringes was terminated after 24 after incubation had commenced and the final reading of *in vitro* gas production was taken. Total gas values were corrected for blank incubation and hay and concentrate standards. The reported 24 h gas values were expressed per 200 mg of DM. Organic matter digestibility (OMD) and metabolizable (ME) was calculated according to the equations of Close and Menke (1986) and Menke and Steingass (1988), respectively as follow:

$$\text{OMD (\%)} = 14.88 + 0.889\text{GP} + 0.45\text{CP} + 0.0651 \text{ ash (\%DM)} \quad (1)$$

$$\text{ME (MJ /kg DM)} = 1.06 + 0.157 \text{ GP} + 0.084\text{CP} - 0.081\text{ash (\%DM)} \quad (2)$$

Where: OMD (%) is the percentage of organic matter digestibility, GP is the net gas production (ml/200 mg DM) after 24 h of incubation, CP (%) is crude protein and ME is the metabolizable energy

2.5 Statistical Analysis

The experiments were performed in a random complete block design and data was statistically analyzed using a statistical Package for Social Science (SPSS, version 20) per by-product category. Duncan's New Multiple Range Tests established statistical differences within means in by-products categories. Differences were considered significant at $p \leq 0.05$.

3. Results

3.1. Chemical composition, in vitro organic matter digestibility and metabolizable energy of cereal by-products

Chemical compositions of cereal by-products are presented in Table 1. Cereal by-products varied significantly ($p \leq 0.05$) in DM (dry matter) contents, which ranged from 86.75 (SSG) to 97.71% (SBR). The ash content was significantly higher ($p \leq 0.05$) in malt dust coarse (5.39%) and lowest in sorghum spent grains (1.34%). Organic matter content ranged from 85.41% (SSG) to 95.46% in sorghum brew residue. There were significant variations ($p \leq 0.05$) in the CP content in the range of 7.90% (sorghum-spent grains) to 21.95% (brewers' spent grains). However, there were no significant differences ($p > 0.05$) observed between malt dust fine (15.55%) and wheat bran (15.45%) as well as between pearl millet bran (12.55%) and white maize chop (9.30%) in terms of CP content. Ether extract contents was highest ($P < 0.05$) in pearl millet bran (9.29%) and lowest in malt dust fine (1.37%). The NDF content of the cereal by-products varied significantly ($p \leq 0.05$) from 23.62% in white maize chop to 73.06% in brewers' spent grains. Pearl millet bran and sorghum brew residue had similar NDF content. Brewers' spent grains also contained the highest ($P \leq 0.05$) ADF content (30.46%) pearl millet bran contained the lowest (7.22%). There was no significant difference ($p > 0.05$) in the ADF of pearl millet bran (7.22%) and white maize chop (7.82%) and between wheat bran (14.47%) and sorghum brew residue (15.08%). Calcium concentrations of the cereal by-products ranged from 0.05% for sorghum-spent grains to 0.21% for sorghum brew residue. Wheat bran had the highest ($p \leq 0.05$) phosphorus content of 0.97% while sorghum spent grains had the lowest phosphorus content of 0.15%.

The results on *in vitro* gas production, organic matter digestibility (OMD) and metabolizable energy (ME) of cereal by-products are shown in Table 2. White maize chop had the highest ($P \leq 0.05$) net *in vitro* gas production of 70.20 ml/ 200g DM while brewers' spent grains had the lowest *in vitro* gas production of 31.50 ml/200g DM. *In vitro* organic matter digestibility ranged between 55.55 % (brewers' spent grains) to 83.50% (white maize chops) while metabolizable energy (ME) ranged from 9.30 MJ/Kg (brewers' spent grains) to 14.00 MJ/Kg (white maize chop).

Table 1. Chemical composition of cereal by-products expressed as % per 100% DM.

Cereal by-products	DM %	Ash%	OM%	CP%	EE%	NDF%	ADF%	Ca%	P%
MDF	95.50 ±0.43[c]	4.82 ±0.02[b]	90.68 ±0.41[c]	15.55±0.05[d]	1.37±0.06[h]	39.87±0.0[b]	12.21± 0.05[c]	0.15±0.01[b]	0.35±0.01[c]
PMB	93.19 ±0.01[d]	3.23 ±0.01[d]	89.96 ±0.01[d]	12.55±0.05[e]	9.29±0.06[a]	32.04±0.18[d]	7.22± 0.00[e]	0.03±0.00[c]	0.62±0.00[b]
MDC	96.27 ±0.06[b]	5.39 ±0.02[a]	90.89±0.08[c]	18.75±0.05[b]	1.66±0.01[g]	34.46±0.33[c]	10.16±0.30[d]	0.09±0.00[b c]	0.62±0.01[b]
WMC	92.67 0.08[de]	2.27±0.01[e]	90.40 ±0.07[cd]	9.30±0.10[e]	7.53±0.02[c]	23.62±0.50[e]	7.82±0.19[e]	0.07±0.06[c]	0.55±0.08[b]
WB	92.38±0.30[e]	4.31±0.42[c]	88.07±0.12[e]	15.45±0.05[d]	4.06±0.03[e]	38.59±0.56[b]	14.47±0.20[b]	0.08±0.01[c]	0.97±0.03[a]
BSG	97.55 ±0.02[a]	3.63±0.06[d]	93.92 ±0.04[b]	21.95±0.25[a]	7.95±0.05[b]	73.06±0.43[a]	30.46±0.58[a]	0.21±0.00[a]	0.50±0.01[b]
SBR	97.71 ±0.03[a]	2.26±0.04[e]	95.46 ±0.07[a]	17.35±0.25[c]	5.70±0.07[d]	32.65±0.07[d]	15.08±0.19[b]	0.05±0.00[c]	0.28±0.01[d]
SSG	86.75±0.02[f]	1.34±0.01[f]	85.41±0.03[f]	7.90±0.00[f]	3.32±0.12[f]	22.23±0.62[e]	9.91±0.18[d]	0.05±0.00[c]	0.15±0.00[e]

MDF=Malt dust fine, **PMB**=Pearl millet bran, **MDC**=Malt dust coarse, **WMC**=White maize chop, **WB**=Wheat bran, **BSG=** Brewer's spent grains, **SBR** = Sorghum brew residue, **SSG=** Sorghum Spent grains. DM=dry matter, **OM**=organic matter, **CP** =Crude protein, EE=ether extract, **NDF**=Neutral detergent Fiber**, ADF=**acid detergent fiber**, Ca=**Calcium, **P**=Phosphorus. ([a,b,c]) Means±SE with different superscript letter across column are significantly different ($p < 0.05$).

Table 2. Chemical composition of oilseed by-products % per 100% DM.

Oilseed by-products	**DM%**	**Ash%**	**OM%**	**CP%**	**EE%**	**NDF%**	**ADF%**	**Ca%**	**P%**
OIC	95.02±0.02[c]	5.31±0.00[a]	89.72±0.08[d]	7.55±0.05[d]	13.4±0.14[c]	46.51±0.51[c]	37.07±0.97 [c]	0.15 ±0.00 [a]	0.18±0.00 [c]
MOP	95.87±0.03[b]	4.66±0.05[c]	91.21±0.07[c]	37.3±0.20[a]	48.8±0.24[b]	37.31±0.4[d]	8.21±1.21[e]	0.15±0.00[a]	1.09±0.05[a]
JOC	95.15±0.02[c]	2.75±0.03[d]	92.40±0.01[b]	23.9±0.30[c]	12.9±0.02[c]	35.16±0.08[e]	24.29 ±0.18 [d]	0.10 ±0.00 [a]	0.37±0.01[b]
NAC	92.90±0.01[d]	4.87±0.14[b]	88.08±0.14[e]	26.1±0.05[b]	8.16±0.10[d]	49.46±0.21[b]	44.83 ±0.15 [b]	0.09 ±0.01[a]	0.71±0.03[ab]
KOC	92.88±0.10[d]	5.02±0.08[ab]	87.86±0.18[e]	23.9±0.15[c]	8.11±0.09 [d]	58.26±0.35[a]	52.26 ±0.57 [a]	0.26 ±0.22 [a]	0.45±0.30[b]
MOC	98.05±0.02[a]	4.54±0.15[c]	93.51±0.14[a]	32.3±0.05[b]	53.5±0.08[a]	11.40±0.06[f]	9.57±0.17 [e]	0.14± 0.00 [a]	0.80±0.25[ab]

OIC=Olive oil cake, **MOP**=Marula oil Press, **JOC**=Jojoba oil cake, **NAC**=!nara oil cake, **KOC**=Manketti Oil cake, **MOC**=Marula oil cake, **DM**=dry matter, **OM**=organic matter, **CP** =Crude Protein, **EE**=ether extract, **NDF**=Neutral detergent Fiber**, ADF**=acid detergent fiber **Ca**=Calcium, **P**=Phosphorus, means with different superscript letter across column are significantly different ($p < 0.05$).

Table 3. The *in vitro* gas production, organic matter digestibility (OMD) and metabolizable energy (ME) of cereal by-products.

Cereal by-products	Mean corrected GP at 24 hrs (ml/200mgDM)	IVOMD%	ME (MJ/kg)/DM
MDF	52.55±0.33^{d}	72.95±0.25^{b}	10.50±0.00^{g}
PMB	60.10±2.40^{bc}	76.60±0.00^{b}	13.20±0.00^{b}
MDC	57.30±0.50^{bcd}	79.60±1.40^{b}	11.40±0.00^{f}
WMC	70.20±1.30^{a}	83.5±0.30^{a}	14.00±0.00^{a}
WB	56.30±0.50^{cd}	75.50±0.10^{b}	11.60±0.00^{e}
BSG	31.50±2.40^{e}	55.55±0.50^{c}	9.30±0.00^{h}
SBR	54.10±3.50^{cd}	72.45±0.15^{b}	11.70±0.00^{d}
SG	63.05±1.65^{b}	76.00±00^{b}	11.95±0.00^{c}

MDF=malt Dust Fine, **PMB**=pearl millet bran, **MDC**=malt dust coarse, white maize chop, wheat bran, **BSG**= brewer's spent grains, **SBR** = sorghum brew residue, **SSG**= sorghum spent grains.
GP= *in vitro* gas produced, **IVDMD** = in vitro dry mater digestibility; **ME** = metabolizable energy; means (^{a,b,c}) with different superscript letter across column are significantly different (p< 0.05).

3.2. Chemical composition, in vitro organic matter digestibility and metabolizable energy of oilseed by-products

Table.2 above shows the chemical composition of oilseed by-products. Oilseed by-products had significantly different dry matter contents in the range of 92.88 (in manketti oil cake) to 98.05 (in marula oil cake). Conversely, the DM content of live oil cake did not differ significantly (p>0.05) from jojoba oil cake (95.15%). The organic matter varied (p≤0.05) from 88.08% (! nara oil cake) to 93.51% (marula oil cake) while ash content ranged from 2.75 (jojoba oil cake) to 5.31% (olive oil). Crude protein content of oil seed by-products was in the range of 7.55 (olive oil cake) to 37.30% (marula oil press). However, jojoba oil cake and manketti oil cake had similar (p>0.05) CP content of 23.90 and 23.95%, respectively. The EE content was notably high in oilseed by-products in the range of 8.16 (Manketti oil cake) to 53.50% (marula oil cake). The !nara oil cake and manketti oil cake had similar (p>0.05) EE contents of 8.16% and 8.11%, respectively. The oilseed by-products had the NDF content varying (p≤0.05) from 11.40% (marula oil cake) to 58.26 (manketti oil cake), while ADF contents ranged from 8.21% (marula oil press) to 52.26% (manketti oil cake). There was no significant difference (p>0.05) in the ADF content of marula oil cake and marula oil cake (9.57%). There were no statistical differences (p≤0.05) in calcium percentages of all the oilseed by-products, which ranged from 0.09% (!nara oil cake) to 0.26% (manketti oil cake) . The phosphorus content varied (p≤0.05) across oilseed by-products, ranging from 0.18% in olive oil cake to 1.09% in marula oil press.

The *in vitro* gas production, organic matter digestibility (OMD) and metabolizable energy (ME) of oilseed by-products are presented in Table 4. The *in vitro* gas production of oil seed by-products ranged from 3.80ml/200mgDM in marula oil press to 35.30 ml/200mgDM in jojoba oil cake. Jojoba oil cake had the highest (p≤.05) *in vitro* OMD of 59.35% while marura oil press had the lowest (p≤0.05 OMD of 38.95%. Similarity (p>0.05) in the extent OMD was observed between olive oil cake (46.25%) and !nara oil cake (46.65). Marula oil press had the highest (p≤0.05) metabolizable energy (ME) of 15.95 MJ/Kg while marula oil cake had the lowest ME of 7.45MJ/ kg.

Table 4. The *in vitro* gas production, organic matter digestibility (OMD) and Metabolizable energy

(ME) of oilseed by-products.

Oilseed by-products	Mean corrected GP at 24 hrs (ml/200mgDM)	IVOMD %	ME (MJ/kg)/DM
OIC	27.15±0.05^{b}	46.25±0.05^{c}	8.90±0.00^{c}
MOP	3.80±0.40^{e}	38.95±0.15^{e}	15.95±0.05^{a}
JOC	35.30±0.90^{a}	59.35±0.15^{a}	12.00±0.00^{b}
NAC	19.65±0.55^{cd}	46.65±0.15^{c}	7.75±0.05^{d}
KOC	16.85±0.05^{d}	44.10±0.20^{d}	7.75±0.05^{e}
MOC	19.50±0.40^{c}	50.10±0.10^{b}	7.45±0.05^{e}

OIC=olive oil cake, **MOP**=marula oil Press, **JOC**=jojoba oil cake, **NAC**=!nara oil cake, **KOC**=manketti oil cake, **MOC**=marula oil cake. **GP**=in vitro gas production, **IVOMD** = *in vitro* organic matter digestibility; **ME** = metabolizable energy; means with different superscript letter across column are significantly different ($p < 0.05$)

4. Discussion

Agro-industrial by-products are less fibrous, more concentrated and less costly (Mirzaei-Aghsaghali & Maheri-Sis, 2008). Thus, using AIBPs as livestock feed reduces the cost of production and improve the quality of feed during dry seasons (Sindhu *et al*., 2002). Therefore, a comprehensive analysis of AIBPs' nutritive value is a fundamental step towards their inclusion in animal diet formulations (Guerma & Maertens, 2016). DM (dry matter) content of any feed material is an indicator of nutrients concentration in any feedstuff. The DM contents of pearl millet bran, white maize chop and wheat bran in this study were comparable to the findings of Abdou *et al.* (2011), Ondiek et al. (1999), and Habib et al. (2013), respectively. The DM content of sorghum spent grains was 2.25% lower than the DM reported by Welker et al. (2014) in sorghum dry distiller's grains. Differences could be explained by possible variations in the nutrient composition of the parent grains (Penner & Christensen, 2009), drying method, and heat intensity used in brewing (Schroder, 2010). The DM of jojoba oil cake was 3.25% higher than the values reported by Nasser (2009), while the DM content of olive oil cake was 7.02% higher compared to the values of Fadel and El-Ghonemy (2015). According to Dhillon *et al.* (2016), chemical compositions of oilseed by-products tend to vary due to the quality of the seeds and oil extraction methods used.

Crude protein (CP) content of AIBPs investigated in this study was above the minimum protein requirement (6.0-8.0% CP) for rumen microorganisms' activities (Van Soest, 1994; NRC, 2001). Moreover, the CP content for most cereal by-products (malt dust fine, pearl millet bran, malt dust coarse, wheat bran, brewer's spent grains and sorghum brew residue) and all the oilseed by-products investigated in exception of olive oil cake were above 10 - 15% CP required for ruminant fattening and high milk production diets (Ayisi *et al*., 2002). These by-products could serve as important CP supplements to bush-based feed commonly harvested by Namibian farmers around June/July at about 6. 47% and 9.55% CP level (Honsbein et al., 2017).

Fiber is an important component in a diet of ruminant animals as it maintains optimal rumen functions by forming a rumen mat, influences feed intake and chewing activities (Kung, 2014). A good quality ruminant diet consists of NDF percentage ranging between 35 and 70 % DM, and ADF below 31 % DM (Geleti *et al*., 2013). The fiber contents of AIBPs such as pearl millet bran, malt dust fine, white maize chop, marula oil cake and marula oil press investigated in this study were minimal (NDF below 70% and ADF below 35%). Low fiber contents of AIBPs make them good supplements for fibrous ruminants' diets (Sindhu *et al*., 2002), such as bush based feeds.

While oil seed by-products are classified as protein and energy ingredients in livestock feeds, special attention must be given to their ether extract contents which vary considerably according to the extraction method used (Oliveira et al., 2007). Feeding ruminants animals with diets containing more than 32.1% of crude fat can reduce intake (Molina-Alcaide & Yáñez-Ruiz., 2008) and rumen fermentation (Zaidi *et al*., 2008, Álvarez-Rodríguez et al., 2009). High ether extract content also present difficulties with storage for a longer time as it easily oxidize and become rancid. Moreover, oil seed by-products are also known to be associated with anti-nutrient components (e.g. lectins and trypsin inhibitors) which may be deleterious to animal health and performance, hence a safety test is highly recommended before use (Stein et al., 2016). Therefore, farmers are advised to be cautions when including oilseed by-products such as marula oil cake and marula oil press in ruminant diets, as they contain high fat (EE) content. The difference in EE contents between marula oil press (a by-product cold pressing method) and marula oil cake (a by-product of expeller method) reported in this study was in agreement with Lee *et al.* (2018). Oilseeds by-products resulting from oil extraction method involving heating tend have a high oil concentration compared to those of cold pressing (Lee *et al*., 2018).

In *vitro* gas produced is directly proportional to the extent at which the substrate is degraded in the rumen according to Deadville and Givens (2001). In this study, cereal (white maize chop) and oilseed AIBPs (jojoba oil cake) with the highest *in vitro* gas production resulted in the highest OMD. It was also observed that oilseed by-products had lower *in vitro* gas production compared to the cereal by-products, which could have been inhabited by their high fat contents (Álvarez-Rodríguez *et al*., 2009). The OMD of wheat bran in this study was inconsistent with the findings of Kumar *et al.* (2015), while for brewer's spent grains was inconsistent with Habib et al. (2011). The differences could be due to crop varieties, chemical compositions, and protocol used as well as rumen fluid characteristics (Moate *et al*. 2011). In particular, high NDF content (73.06%) in brewer's spent grains could have contributed to its lower OMD (Getachew *et al.* 2004). The metabolizable energy of wheat bran (11.60 MJ/Kg) was consistent with the findings (11.50 MJ/Kg) of Hamid *et al.* (2007). Metabolizable energy values are valuable for purposes of ration formulation and to set the economic value of feeds for trading purposes (Getachew *et al*., 2004).

5. Conclusion

The chemical composition differed significantly among the cereal and oil seeds by-products categories. All the agro-industrial by-products investigated in this study were within or above the recommended CP content required for rumen microbial activities. Their fiber contents were also minimal making them attractive to be potential supplements of the bush feeds characterized by high fiber contents. Although some of the oilseed by-products identified were rich in protein, their high fat content could present a challenge in storage and might as well interfere with rumen fiber digestibility. It is important for farmers to note that many factors such as processing methods have huge impacts on nutrient contents of resulting by-product and should therefore take by-products to the laboratories for analysis before introducing them in livestock to avoid metabolic upsets and poisoning. Further research is required to characterize the AIBPs in this study in terms of palatability, intake, *in vivo* digestibility, animal response trials and anti-nutritional factors, which could enable to determine the optimal inclusion levels for different classes of ruminants.

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7. Disclosure of conflict of interest

The authors declare not conflict of interest.

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