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The nutritive value of *Dichrostachys cinerea* subspecies *nyasana* pod meal as an alternative feed resource for weaned rabbits and piglets in Southern Africa

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Abstract

This study investigated the nutritional value of *Dichrostachys cinerea* subsp. *nyassana* pod meal (DCNPM), an abundant freely available feed resource derived from an invasive plant in Southern Africa, for weaned rabbits and piglets, and the ameliorative effect of wood ash extract (WAE) against deleterious effects of DCNPM tannins. In a completely randomised design (CRD), 16 weaned rabbits were randomly allocated to 4 dietary treatments (DCNPM at 0, 5, 10, and 20 %) with 4 replicate animals each, for 6 weeks (Exp. 1). Also, in a 6-week CRD study (Exp. 2), 16 weaned piglets were randomly allocated to 4 dietary treatments (DCNPM at 0 %, 10 %, 20 % – WAE, and 20 % + WAE) each with 4 replicate piglets. Results showed DCNPM had (in g per kg DM) moderate crude protein (CP: 113.1) and ether extract (EE: 16.7) but high crude fibre (CF: 260.6) and ash (70.0) contents; it further contained Ca (1.2), P (0.6), K (15.5), Mg (1.1), Cu (0.05), Fe (0.04), Mn (0.03) and Zn (0.03). For both rabbits and piglets, body weight gain (BWG) and feed conversion efficiency (FCE) were not influenced ($p > 0.05$) by dietary DCNPM supplementation. Similarly, there were no effects of DCNPM on rabbit carcass characteristics ($p > 0.05$). However, DCNPM linearly increased feed intake (FI) in rabbits ($p < 0.001$). In piglets, FI was increased at 10 %, but decreased at 20 %, DCNPM; interestingly WAE treatment reversed the decrease in FI induced by 20 % DCNPM ($p < 0.001$). In conclusion, our results demonstrate DCNPM to have moderate CP but high CF, with reasonable contents of trace minerals. It can be incorporated at 20 % in rabbit diets without further amendment; and at the same level in piglet diets provided it is treated with WAE.

Keywords: *Dichrostachys cinerea*, nutritional value, non-ruminants, performance, carcass characteristics, wood ash extract

1 Introduction

One of the most formidable socio-economic challenges facing developing countries especially in sub-Saharan Africa (SSA) is the rapid rate of human population growth and the concomitant increased demand for food particularly in the form of protein for human nutrition (OECD/FAO, 2016). The Kingdom of Eswatini (formerly Swaziland), for example, has a predominantly rural (80 %) population of 1.13 million that grows at approximately 1.2 % annually (UNECA, 2017), about 70 % of which is dependent on subsistence agriculture for their livelihoods (FAO/WFP, 2015; Nindi & Odhiambo, 2015; Thompson, 2015). With 73 % of the population living below the national poverty line (UNECA, 2017), the country is in desperate need of protein-rich food. However, lack of access to animal feed of high nutritive value that can sustainably ensure improved animal productivity (Martens *et al.*, 2012) compromises the production of protein-rich livestock-derived food by the predominantly smallholder farmers in SSA. These farmers are often compelled to use imported and expensive commercial feedstuffs that are largely unaffordable to most of them (Chivandi, 2012; Mhlanga, 2016). This necessitates investiga-

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tion of alternative locally available low-cost feed resources of promising nutritive value that would satisfy the nutrient requirements of farm animals (Martens et al., 2012; Mthiyane & Mhlanga, 2017).

Dichrostachys cinerea (L.) Wight and Arn. (Mimosaceae family) is a deciduous fast-growing low thorny leguminous shrub originating from tropical Africa that spread out to tropical Asia, Australia and America (Heuzé *et al.*, 2015). It occurs in two subspecies, *viz.* (a) *africana* (*Lusekwane* in siSwati and u*Gagane* in isiZulu) with three varieties (i.e. *africana*, *pubescens* and *setulosa*) and (b) *nyassana* (u*Mzilazembe* in both isiZulu and siSwati) (Germishuizen & Meyer, 2003). The latter subspecies tends to grow larger and has larger and less hairy leaves and leaflets (Orwa *et al.*, 2009) and produces much bigger fruits (pods). Both the *africana* and *nyassana* subspecies occur widely in Southern Africa. *D. cinerea* is considered an invasive plant that adversely affects the diversity of native herbaceous species (Mudzengi *et al.*, 2014) and a serious encroacher that threatens the productivity of grazing lands in Southern Africa (Nyamukanza & Scogings, 2008; Tjelele *et al.*, 2015) and in other tropical regions (Martín-Casas *et al.*, 2017). Therefore, its utilisation as animal feed might be helpful in resolving these environmental problems. *D. cinerea* is widespread in the Lowveld of Eswatini, a semi-arid savannah ecosystem where its trees extensively grow naturally (Tefera *et al.*, 2008), and its pods (seed and husk) are ubiquitously available (Mlambo *et al.* 2007).

D. cinerea pods are a potential feed resource for livestock in Southern Africa. They are much relished by cattle and game (Göhl, 1982; Hashim, 1990), are rich in protein (11–190 g CP per kg DM) and fibre (441–531 g NDF per kg DM) (Hashim, 1990; Mlambo *et al.*, 2004, 2008) and are highly (60 %) digestible (Mlambo *et al.*, 2004). Also, they are indehiscent, making it possible to collect and store them for use during times of nutritional stress (Sikosana *et al.*, 2002; Mlambo *et al.*, 2004). Previously, they have been intensively investigated as a potential candidate to replace commercial protein sources for ruminants, especially during the dry season (Mlambo *et al.*, 2004; Smith *et al.*, 2005; Mlambo *et al.*, 2007; Choongo *et al.*, 2008; Yayneshet *et al.*, 2008).

However, the major challenge with *D. cinerea* pods is their very high phenolic (almost 50 %) and tannin (18 % on DM basis) contents (Mlambo *et al.*, 2004). Based on their biochemical structures, tannins in terrestrial plants are broadly classified into condensed tannins (CT; also called proanthocyanidins) and hydrolysable tannins (HT) and the CT content of *D. cinerea* pods is about 1.3–7 × higher than that of common *Acacia* species (i.e. *A. nilotica*, *A. erioloba*, *A. erubiscens* and *A. sieberiana*) (Mlambo *et al.*, 2008). Tannins, especially at low levels, and particular generic classes thereof, have desirable and beneficial effects in non-ruminants. In this regard, HT have been found to decrease intestinal skatole production (Čandek-Potokar *et al.*, 2015) and boar taint-related indole compounds in pigs (Bee *et al.*, 2017). Also, in rabbits, tannins have been reported to improve productive performance (Garcia *et al.*, 2002; Kermauner, 2008). In particular, HT confer antimicrobial and antioxidant effects (Chung *et al.*, 1998; Lewis, 2003; Kermauner, 2008), enhance digestibility and absorption of nutrients (Hu *et al.*, 2002; Sotohy, 2004; Xia *et al.*, 2005), improve immunity and health (Martin-Martinez *et al.*, 2009; Hassan *et al.*, 2011) and reduce mortality rate (Atta & Mouneir, 2005; Maertens & Štruklec, 2006) in rabbits. Notwithstanding, evidence abounds demonstrating 'anti-nutritional' effects of tannins in non-ruminants. They decrease feed intake and palatability, growth rates and feed efficiencies due to their reduction of protein digestibility, lowering the activity of digestive enzymes, causing damage to intestinal mucosa and/or exertion of systemic toxic effects (Mueller-Harvey, 2006; Khanyile *et al.*, 2014). This has necessitated investigation of various strategies, including treatment with wood ash extract (WAE), for reducing detrimental effects of tannins in animals. In this regard, several studies have demonstrated reduction in tannin content and enhancement of the nutritive value of various tannin-rich tropical feedstuffs following their soaking in WAE (Makkar & Singh, 1992; Kyarissiima *et al.*, 2004; Ben Salem *et al.*, 2005). Wood ash is an alkaline substance (Etiegni & Campbell, 1991) and tannins are said to polymerize, forming non-toxic compounds, in an alkaline medium (Muindi *et al.*, 1981). However, no studies have hitherto investigated the ameliorative effect of WAE against deleterious effects of tannins in *D. cinerea* subspecies *nyassana* pod meal (DCNPM) on productive performance in non-ruminants. The objective of this study was therefore to investigate the nutritional value of DCNPM as a potential alternative protein and fibre source for weaned piglets and rabbits. The ameliorative effect of WAE on the deleterious effects of tannins in DCNPM on the performance of piglets was also investigated.

2 Materials and methods

Location of study, source and preparation of materials

The studies were conducted at the University of Eswatini (UNESWA) Luyengo Campus Farm, Faculty of Agriculture, Luyengo. Luyengo is located in the upper Middleveld of Eswatini at latitude 26° 32′ South and longitude 31° 14′ East, altitude 738 m asl, with a mean maximum and mean

minimum temperature of 23 °C and 11 °C. The annual rainfall ranges from 850 to 1000 mm (Monadjem & Garcelon, 2005), most of which occurs between October and April.

Sixteen New Zealand 2-month old unsexed weaned rabbits (average initial body weight = 1.2 kg ± 0.4) were obtained from Ludzidzini Royal Residence in Eswatini. Also 16 one-month old weaned Large White piglets (average initial body weight = 7.2 kg ± 0.5) were sourced from the UNESWA Piggery Unit. *D. cinerea* subsp. *nyassana* pods were collected from Dwaleni area in Manzini region, dried under shade on a concrete floor and milled through a 2 mm sieve to produce the pod meal. All the other feed ingredients were supplied by Arrowfeeds Pty Ltd.

DCNPM was treated with WAE prepared using the procedure of Kyarisiimaa *et al.* (2004). WAE was obtained by mixing wood ash from pine trees, collected from Bhunya Timber Mill, with distilled water in 200-litre plastic drums at the rate of 1 kg ash to 20 l of water. The mixture was stirred for 5–10 min and left to stand overnight. The resulting supernatant was carefully removed and filtered through a cotton cloth and its pH (= 12.0) measured. The DCNPM was then soaked overnight in WAE at a rate of 1 kg DCNPM to 2 l of WAE and subsequently dried in the sun for two days.

3 Experimental design, animals and diets

3.1 Experiment 1 (Rabbits)

In a completely randomized design (CRD), 16 rabbits were used in a 6-week study involving 4 dietary treatments with 4 replicate rabbits each. The rabbits were kept in steel-based battery cages (1 rabbit/cage) and fed iso-energetic and iso-nitrogenous hominy chop-based diets, in pellet form. Formulated to meet the nutritional requirements of weaner rabbits as recommended by Maertens (1995), De Blas & Mateos (1998) and Kermauner (2005), the diets were made to contain graded levels of DCNPM (0 % [Control], 5 %, 10 %, and 20 %) which was sequentially added in replacement of wheat bran (Table 1).

3.2 Experiment 2 (Piglets)

In a 6-week CRD study, 16 weaned piglets were randomly allocated to 4 dietary treatments each with 4 replicate piglets (1 piglet per pen). They were fed iso-energetic and iso-nitrogenous yellow maize and soya bean oil cake-based diets, in meal form. Formulated to meet the nutritional requirements of growing pigs as recommended by the NRC (2012), the diets were made to contain graded levels of DCNPM (0 % [Control], 10 %, 20 % – WAE [without WAE], and 20 % + WAE [with WAE]) (Table 2).

Table 1: *Ingredients (g per kg complete feed) and nutrient composition (g per kg DM) of experimental diets (as-fed basis) fed to weaning rabbits.*

	DCNPM level (%)			
Ingredients	*0*	*5*	*10*	*20*
Hominy chop	280	280	280	280
Wheat bran	200	150	100	–
DCNPM *	–	50	100	200
Lucerne meal	190	190	190	190
Sunflower oil cake meal	120	120	120	120
Full fat soyabean meal	100	100	100	100
Yellow maize	80	80	80	80
Soyabean oil cake meal	12.5	12.5	12.5	12.5
Limestone	11	11	11	11
Table salt	4	4	4	4
Mineral-vitamin premix †	0.25	0.25	0.25	0.25
Analysed proximate composition				
DM	966.5	966.5	973.5	973.5
CP	170.6	175.8	174.8	177.1
CF	165.0	170.0	170.0	170.0
EE	54.3	59.5	59.1	61.6
Ash	70.0	75.0	70.0	70.0

* DCNPM, *Dichrostachys cinerea* subsp. *nyassana* pod meal
† The mineral/vitamin premix supplied the following per kg of complete feed: vitamin A (retinol acetate), 2400 mg; vitamin D_3 (cholecalciferol), 20 mg; vitamin E (d-α-tocopherol), 66700 mg; vitamin K_3 (menadione), 2 g; vitamin B_1 (thiamine mononitrate), 6 g; vitamin B_2 (riboflavin), 6 g; vitamin B_3 (nicotinic acid), 10 g; panthenic acid, 6 g; vitamin B_6 (pyridoxine chlorhydrate), 4 g; folic acid, 4 g; vitamin B_{12} (cyanocobalamin), 50 mg; biotin, 200 mg; antioxidant, 125 000 mg; Mg, 200 g; Mn, 65.60 g; Fe, 65.60 g; Zn, 65.60 g; Cu, 16.40 g; I, 1 g; Se, 300 mg.
DM: dry matter; CP: crude protein; CF: crude fibre; EE: ether extract

3.3 General management

Both piglets and rabbits were maintained on natural light during the day and on continuous artificial light at night. They were allowed *ad libitum* access to feed and water and were inspected daily for any health-related problems. Proper ventilation was provided to reduce the risk of respiratory diseases. Both piglets and rabbits were not given any vaccines, anthelmintics, antibiotics or growth promoters during the course of the studies.

3.4 Measurements

Both piglets and rabbits were individually weighed at the beginning (day 0) and then weekly thereafter until the end of the experiments. Also, feed offered and left per animal (cage) was weighed daily in order to calculate average feed intake (FI) per animal per day from the difference

Table 2: *Ingredients (g per kg complete feed) and nutrient composition (g per kg DM) of experimental diets (as-fed basis) fed to weaning piglets.*

Ingredients	*DCNPM level (%)*			
	0	*10*	*20 – WAE*	*20 + WAE*
Yellow maize	500	477	534	534
Hominy chop	150	100	–	–
Wheat bran	150	125	80	80
Soyabean oil cake meal	124	118	158	158
Sunflower oil cake meal	50	50	–	–
DCNPM *	–	100	200	200
Limestone	12.0	12.0	8.0	8.0
L-lysine	4.0	5.0	5.0	5.0
Table salt	4.0	5.0	5.0	5.0
Vitamin-mineral premix †	4.0	4.0	4.0	4.0
Threonine	1.0	2.0	2.0	2.0
DL-Methionine	0.5	1.0	1.0	1.0
Mono-calcium phosphate	0.4	1.0	3.0	3.0
Tryptophan	0.1	0.2	0.3	0.3
Analysed proximate composition				
DM	915.0	920.0	935.0	940.0
CP	186.0	185.0	183.0	180.0
CF	68.0	78.0	80.0	78.0
Ash	27.0	24.0	23.0	22.0
EE	56.0	34.0	23.0	22.0

* DCNPM, *Dichrostachys cinerea* subsp. *nyassana* pod meal
† The vitamin–mineral premix supplied the following per kg of complete feed; vitamin A, 3000 mg; vitamin D_3, 50 mg; vitamin E, 40 020 mg; vitamin K_3 (menadione sodium bisulfite), 250 g; vitamin B_1, 2 g; vitamin B_2 (riboflavin), 4 g; niacin, 30 g; pantothenic acid, 15 g; vitamin B_6, 3 g; vitamin B_9 (folic acid), 1 g; vitamin B_7 (biotin), 250 mg; vitamin B_{12} (cobalamin), 35 mg; choline, 350 g; Cu, 175 g; I, 9 g; Fe, 100 g; Mn, 50 g; Se, 310 mg (of which Se methionine 160 mg); Zn, 100 g; additives (Axtra Phy 10 000 TPT, 100 g; Axtra XB 201 TPT, 100 g; Phytase units, 1000 Kftu; Bacitracine zinc 15 %, 334 g; Active Bacitracine, 50 g; Antioxidant, 250 g).
DM: dry matter; CP: crude protein; CF: crude fibre; EE: ether extract

between feed offered and refusals. The feed conversion efficiency (FCE) was calculated from average body weight gain (BWG) per animal per day (g) divided by the average FI per animal per day (g).

On the last day of the experiment, all rabbits were slaughtered by stunning with electric shock and slitting the throat of each rabbit with a sharp knife. Carcasses were then dressed and weighed in order to determine dressed weight. During evisceration, the internal organs were removed and weighed. Piglets were not slaughtered at the end of the experiment; only their performance was measured.

All procedures were performed following the ethical guidelines of UNESWA Department of Animal Science Board that approved the protocol used in the experiment.

3.5 Chemical assays

Proximate analyses of DCNPM and experimental diets were performed at the Nutrition Laboratory of the Department of Animal Science whilst mineral analyses were performed at the Soil Science Laboratory of the Department of Crop Production, UNESWA. The DM (930.15), ash (942.05), CP (954.01), EE (920.39) and CF were determined according to procedures of the AOAC (2000). CP was calculated using $N \times 6.25$.

The determination of minerals in DCNPM was performed using the method of Thomas *et al.* (1967) as modified by Mamba *et al.* (2016). The samples were then taken for analysis by atomic absorption (AA) spectrophotometry using a Varian Techtron AA Spectrophotometer (Model AA-200) as proposed by Lanyon & Healed (1982). K in the DCNPM extract was determined using a Jenway Flame Photometer (Model PFP7) following the method proposed by Knudsen *et al.* (1982). P was determined colorimetrically using the ammonium molybdate blue method proposed by Olsens & Sommers (1982). A Biochrom Spectrophotometer (model Libra S12) was used to measure the content of P in the DCNPM extracts. The content of the elements was then expressed as a percentage.

Table 3: *The proximate and mineral composition of Dichrostachys cinerea subsp. nyassana pod meal.*

Component	*Concentration*
DM (g per kg)	892.5
	(g per kg DM)
CP	113.1
EE	16.7
CF	260.6
Ash	70.0
Minerals:	
Ca	1.2
P	0.6
K	15.5
Mg	1.1
Cu	0.05
Fe	0.04
Mn	0.03
Zn	0.03

DM: dry matter; CP: crude protein; CF: crude fibre; EE: ether extract

3.6 Statistical analyses

Data on growth performance and carcass/organ weights were analysed using the GLM procedure of Minitab (2000). Statistical significance was accepted based on the 0.05 level of probability. Data are presented as least squares (LS) means with respective pooled standard errors of the mean (SEM). Where significant differences ($p < 0.05$) between treatments were observed, LS means were compared using the Tukey test.

4 Results

DCNPM had (in g per kg DM) rather moderate CP (113.1) and EE (16.7) but high CF (260.6) and ash (70.0) contents. In terms of mineral composition, DCNPM contained (in g per kg DM, respectively) Ca (1.2), P (0.6), K (15.5), Mg (1.1), Cu (0.05), Fe (0.04), Mn (0.03) and Zn (0.03) (Table 3).

The BWG, FI and FCE of weaned rabbits (Table 4) and piglets (Table 5) and carcass characteristics of rabbits (Table 6) fed the treatment diets are presented below. For both rabbits and piglets, BWG and FCE were not significantly influenced by dietary DCNPM supplementation ($p > 0.05$) (Tables 4 and 5). Similarly, there were no significant effects of DCNPM supplementation on the weight of various organs of weaned rabbits ($p > 0.05$) (Table 6). Also, no visible abnormalities were observed in the rabbit carcasses and internal organs. Interestingly, however, dietary DCNPM supplementation linearly increased FI ($p < 0.001$) in rabbits (Table 4). With regard to piglets, FI was significantly increased at 10 %, but significantly decreased at 20 %, of dietary DCNPM supplementation; and the WAE treatment significantly reversed the decrease in FI induced by 20 % DCNPM supplementation ($p < 0.001$) (Table 5).

5 Discussion

The primary objective of this study was to investigate the nutritional value of DCNPM as a potential alternative protein and fibre source for weaned rabbits and piglets. In terms of chemical composition, our results corroborate those (CP: 114.0, EE: 12.0, CF: 256.0 and ash: 65 g per kg DM) reported by IBPGR (1984). In particular, the CP values are also in agreement with those (in g per kg DM: 115.0, 113.0 and 113.0) of Ndlovu *et al.* (1995), Mlambo *et al.* (2008) and Matekenya *et al.* (2017), respectively. Other researchers reported CP values of *D. cinerea* pods that range between

Table 4: *Body weight gain (BWG), feed intake (FI) and feed conversion efficiency (FCE) of weaned rabbits fed diets containing graded levels of Dichrostachys cinerea subsp. nyassana pod meal (DCNPM).*

Parameters	*DCNPM level (%)*				*SEM* *	*p-value*
	0	5	10	20		
BWG (g per rabbit and day)	33.1 [a]	30.0 [a]	31.5 [a]	30.93 [a]	1.76	$p > 0.05$
FI (g per rabbit and day)	118.0 [a]	132.3 [b]	135.9 [c]	138.1 [d]	1.27	$p < 0.001$
FCE (BWG / FI)	0.28 [a]	0.23 [a]	0.23 [a]	0.22 [a]	0.02	$p > 0.05$

* SEM based on pooled estimate of variation ($n = 4$).
[a], [b], [c], [d] Means with different superscripts differ significantly ($p < 0.001$).

Table 5: *Body weight gain (BWG), feed intake (FI) and feed conversion efficiency (FCE) of weaned piglets fed diets supplemented with graded levels of Dichrostachys cinerea subsp. nyassana pod meal (DCNPM) treated with or without wood ash extract (WAE) at 20 % DCNPM level.*

Parameters	*DCNPM level (%)*				*SEM* *	*p-value*
	0	10	20 – WAE	20 + WAE		
BWG (g per pig and day)	650.0 [a]	585.7 [a]	532.1 [a]	678.6 [a]	23.73	$p > 0.05$
FI (g per pig and day)	1683.0 [a]	1719.0 [b]	1582.0 [c]	1723.0 [b]	12.47	$p < 0.001$
FCE (BWG / FI)	0.39 [a]	0.34 [a]	0.34 [a]	0.39 [a]	0.02	$p > 0.05$

* SEM based on pooled estimate of variation ($n = 4$).
[a], [b], [c] Means with different superscripts differ significantly ($p < 0.001$).
20 – WAE: 20 % DCNPM minus WAE; 20 + WAE: 20 % DCNPM plus WAE

Table 6: *Carcass characteristics (g) of growing rabbits fed diets containing graded levels of Dichrostachys cinerea subsp. nyassana pod meal (DCNPM).*

Parameters	*DCNPM level (%)*				*SEM* *	*p-value*
	0	5	10	20		
Dressed weight	1261.0	1255.0	1173.0	1180.0	42.90	$p > 0.05$
Liver weight	53.8	56.6	56.1	54.6	1.81	$p > 0.05$
Heart weight	6.4	6.3	6.1	6.3	0.26	$p > 0.05$
Spleen weight	1.8	1.2	1.3	1.3	0.13	$p > 0.05$
Lungs weight	10.8	10.0	9.8	11.8	0.50	$p > 0.05$
Kidneys weight	15.8	14.8	14.4	13.8	0.37	$p > 0.05$
Gastrointestinal tract weight	128.9	109.5	121.5	113.5	5.12	$p > 0.05$

* SEM based on pooled estimate of variation ($n = 4$).

109 and 199.0 g per kg DM (Hashim, 1990; Rubanza *et al.*, 2003; Smith *et al.*, 2005; Yayneshet *et al.*, 2008; Maphosa *et al.*, 2009; Heuzé *et al.*, 2015; Martín-Casas *et al.*, 2017). The variation in the literature values might be due to seasonal differences as well as differences in pod harvesting stage, soil fertility status and subspecies differences. Indeed, the nutritive value of *D. cinerea* has been reported to vary widely between seasons and to depend on temperature and rainfall (Aganga *et al.*, 2005) as well as soil composition (Aganga *et al.*, 1994; Tefera *et al.*, 2008). Also, the age of the tree has been reported to have an effect on its CP content (McDonald *et al.*, 2011). Further, there are two recognized subspecies of *D. cinerea*, viz. *africana* and *nyassana* (Germishuizen & Meyer, 2003), the nutritive values of which might be different. Unfortunately, previous studies on the nutritive value of *D. cinerea* pods did not specify the subspecies investigated.

Of particular interest also is the high CF content (260.6 g per kg DM) of DCNPM observed in the current study. High CF is desirable for rabbits as they can utilise up to 30 % as opposed to 10 % CF by most poultry species (Egbo *et al.*, 2001). Their digestive physiology is well adapted to high intake of plant cell walls, with dietary fibres invariably being the main constituent of a rabbit feed, often ranging from 15 to 50 % (Gidenne, 2003). Also, dietary fibre is essential in rabbits for the prevention of digestive disorders (Gidenne, 1997) and conferment of resistance to pathogenic agents (Licois & Gidenne, 1999). Notwithstanding, the high CF in DCNPM might be a disadvantage to the pig's digestive system, which is not suited to digest high fibre diets.

Whilst the Ca content corroborates the observation (1.3 g per kg DM) of Matekenya *et al.* (2017), that of P is significantly lower than the value found by these authors (21.0 g per kg DM). On the other hand, the K, Mg and Cu values were higher whilst that of Fe was lower than values [in g per kg DM: K (1.5), Mg (0.25), Cu (0.02) and Fe (0.20)] previously observed by Martín-Casas *et al.* (2015). The Zn value was similar to that (0.02 g per kg DM) of Martín-Casas *et al.* (2015). Unfortunately, no reports of Mn content of *D. cinerea* pods were found in the literature. The variation in the mineral levels between this study and the literature may be explained by differences in subspecies, plant age and pod maturity stage as well as soil characteristics. Generally, the observed contents of macro-minerals in the pods were rather low and may imply that the pods were harvested from trees growing on soils deficient in these minerals (Nherera, 1999).

Unfortunately there are no comparative data in the literature on performance and carcass trait responses of rabbits to dietary DCNPM supplementation as this appears the first study to investigate this forage supplement in rabbits. However, in a recent study in Cuba, Martín-Casas *et al.* (2017) also observed no significant effects of dietary supplementation with 15 % and 30 % *D. cinerea* pod meal on body weight gain in fattening pigs. In contrast, Choongo *et al.* (2008) observed significantly increased daily weight gain in cattle supplemented with *D. cinerea* pods. The improved BWG in the latter study was probably a result of the defaunation of the ciliate protozoal population by 55 % (Choongo *et al.* (2008). Notwithstanding, demonstrating no undesirable effects on rabbit and piglet performance as well as rabbit carcass characteristics, our results suggest that the pods can indeed be used as an alternative protein and fibre source to replace some of the expensive commercial ingredients used in formulating rabbit and piglet diets in Southern Africa and other tropical/subtropical countries where *D. cinerea* abundantly occurs.

High concentrations of total phenolics (129–204 g per kg DM) (Rubanza *et al.*, 2003; Matekenya *et al.*, 2017), total tannins (123 g per kg DM) (Rubanza *et al.*, 2003) and CT (11.5–43 g per kg DM) (Rubanza *et al.*, 2003; Matekenya *et al.*, 2017) have previously been found in *D. cinerea* pods. In one study, Theart *et al.* (2015) found *D. cinerea* leaves to have the highest total phenolic and tannin content of the 19 shrub and tree species they studied in South

Africa. Thus, the significant increase in rabbit FI following dietary DCNPM supplementation might be due to the proportional increase in the dietary tannin level as the proportion of DCNPM increased. Dietary tannins (Garcia *et al.*, 2002) and dietary inclusion of a high (0.5 %) level of tannic acid (Kermauner, 2008) have previously been found to significantly improve FI in weaning rabbits. Tannins are apparently desirable and beneficial to rabbits. Previous studies reported that tannins have beneficial effects on the activity of microbes by binding on their cell membranes in the hindgut of rabbits (Štruklec *et al.*, 1993; Butter *et al.*, 1999; McSweeney *et al.*, 2001). HT have also been reported to confer antimicrobial and antioxidant effects (Chung *et al.*, 1998; Lewis, 2003; Kermauner, 2008), enhance digestibility and absorption of nutrients due to reduction of pathogenic bacteria and diarrhoea (Hu *et al.*, 2002; Sotohy, 2004; Xia *et al.*, 2005), and improve the immunity and body health (Martin-Martinez *et al.*, 2009; Hassan *et al.*, 2011) in rabbits. It is probably through such mechanisms that dietary tannins have been found to improve production performance (Kermanuer, 2008) and reduce mortality rate in these animals (Atta & Mouneir, 2005; Maertens & Štruklec, 2006).

The second objective of our study was to investigate the ameliorative effect of WAE on the deleterious effects of DCNPM tannins on the performance of piglets. We observed that piglet FI was significantly increased at 10 %, but significantly decreased at 20 %, of dietary DCNPM supplementation. Interestingly, the decrease in FI induced by 20 % DCNPM supplementation was significantly reversed by WAE treatment. It is speculated that these changes in FI are due to the presence of tannins in *D. cinerea* pods. Our results suggest that low levels of tannins – as indicated by improved FI at 10 % DCNPM supplementation level – are desirable and enhance appetite in piglets, probably as a result of improved feed palatability or health benefits. The data further suggest that when the level of dietary tannins exceeds a certain maximum threshold, this has a negative effect on piglet FI – as indicated by decreased FI at 20 % DCNPM inclusion without WAE treatment. These findings corroborate those of Lee *et al.* (2016) who observed increases in DM and CP intakes in adult pigs only up to 10 % dietary inclusion of tannin-rich chestnut meal beyond which there was a decline in these parameters. Indeed, tannins are known to have anti-nutritional effects especially at high dietary levels in both ruminants and non-ruminants (Mueller-Harvey, 2006). Typically, tannins decrease FI, protein and DM digestibility, liveweight gain, milk yield and wool growth in both ruminants and non-ruminants (Kumar & Singh, 1984; Jansman, 1993; Reed, 1995). However, it seems that non-ruminants, including pigs, have some mechanisms of neutralizing the toxic effect of tannins up to a certain level (Bernays *et al.*, 1989) and tannins at low to moderate (2–4 % of DM) dietary levels appear to impart certain benefits to animals (Bhat *et al.*, 2013). Such beneficial effects include their depressive effects on gastrointestinal parasites, their antioxidant effects and improvement of animal performance (Koeleman, 2010). Also, tannins have been found to enhance intestinal cellular absorption of simple sugars (Mansoori *et al.*, 2007). Further, tannins display anti-bacterial (Ahn *et al.* 1998; Min *et al.* 2007), anti-diarrheal (Palombo, 2006), anti-genotoxic (Frankič & Salobir, 2011) and anti-cancerogenic effects (Mueller-Harvey, 2006) and decrease intestinal skatole production in entire male pigs (Čandek-Potokar *et al.*, 2015). Biagi *et al.* (2010) also found that feeding weaned piglets with a tannin-rich wood extract improved FCE and decreased intestinal bacterial proteolytic reactions.

The improvement in FI of piglets fed diets supplemented with 20 % DCNPM treated with WAE seems to be a consequence of deactivation or decreased content of tannins. Makkar & Singh (1992) also reported a 10 % solution of oak wood ash and pine wood ash to significantly decrease the content of total phenols, CT and protein precipitation capacity in oak leaves. Further, Kyarissiima *et al.* (2004) reported 5 % WAE to effectively decrease the tannin level and improve the nutritive value of high-tannin sorghum. Furthermore, Ben Salem *et al.* (2005) reported wood ash treatment to be a cost-effective way to deactivate tannins in *Acacia cyanophylla* foliage and to improve digestion of this foliage in sheep. The alkaline pH of wood ash leads to tannin precipitation and inactivation in response to oxidation of tannins mediated by high pH (Makkar & Singh, 1992). Notwithstanding, whilst the use of wood ash is a cost-effective strategy for detoxifying tannin-rich feedstuffs that would favour particularly smallholder farmers in developing countries such as Eswatini, this treatment method needs to be used with caution and still requires further validation as it may remove some nutrients (Bhat *et al.*, 2013).

6 Conclusion

This study demonstrated DCNPM to be a moderate source of CP with high CF and reasonable contents of trace minerals. It can be included at 20 % in diets for rabbits without detrimental effects on performance. For piglets, it can also be incorporated into the diet at the same level without detrimental effects on performance provided it is treated with WAE; when untreated, it should not exceed 10 % dietary level. DCNPM can therefore substitute some of the expensive commercial ingredients in rabbit and pig diets in Southern Africa and other tropical countries where it occurs in abundance.

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