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The Potential for Endozoochorous Dispersal of *Vachellia nilotica* Seeds by Goats: Implications for Bush Encroachment

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Abstract: Seed dispersal has become an important component in understanding plant–animal interaction. Recently, there have been concerns about the role of ruminants, particularly browsers, in the dispersal of woody plant seeds. This study aimed to determine whether including *Vachellia nilotica* seeds in livestock, diets could reduce the spread of viable seeds in the rangelands and control bush encroachment. The shoots and seed pods of *Vachellia nilotica* were harvested and analyzed for fiber, protein, and mineral nutrients at different seed pods inclusion rates, with or without a feed additive. Six diets were selected for feeding 24 goats and quantifying seed recovery and germination after ingestion. Results indicated that including seed pods and feed additives to *Vachellia nilotica* shoots significantly improved the quality of the fodder. Chipping the seed pods prior to including them in the diet resulted in 13% intact seed recovery, and approximately 2% of these seeds were recovered after ingestion. These recovered seeds were mostly still viable but were still dormant as seed coats were not sufficiently damaged after ingestion. Therefore, viable seeds may still be dispersed in the rangeland, leading to further bush encroachment.

Keywords: chipping; dispersal; encroachment; feed additives; seed germination; seed pods

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1. Introduction

Many researchers consider bush encroachment as a significant rangeland management problem that negatively affects livestock production and the livelihoods of farmers [1–3]. This is because bush encroachment suppresses the growth of herbaceous vegetation and therefore reduces productivity and the quality of rangeland forage resources [3,4]. Furthermore, increasing tree densities in rangelands reduces forage accessibility to livestock, further negatively affecting the utilization of rangelands by livestock [1,3,5]. Although there has been significant financial investment into the eradication of the encroaching woody plant species, the interventions have not yielded conclusive management strategies due to the persistent and adaptive nature of the encroaching species [3]. In addition, extensively reared livestock often make use of the encroaching tree species, making them useful resources to farmers, which makes it difficult to motivate the eradication of the encroaching woody plant species [6].

Seed dispersal by herbivores has become an important issue in plant ecology, where both wild game animals and domestic livestock play an important role in endozoochorous seed dispersal [6]. Many reasons have been given for the increased rate and extent of encroaching species [3]. One among many drivers of this is the influence of endozoochory, i.e., seeds that are ingested and subsequently dispersed by livestock [7–9]. This is because the pods of many woody plants form an important part of the diet of livestock and wildlife during the dry season due to their high nutritive value [8] compared to grasses and

herbaceous vegetation in this season. However, some of the seeds that remain intact after ingestion passes through the gut, where they are scarified, which in turn allows for greater efficiency in the dispersal and effective seedling establishment of the encroaching plant species [8,9]. Endozoochorous seed dispersal is influenced by several factors, such as seed size, hardness, number of seeds consumed, and animal species, to survive chewing and rumination [6,8–10]. Other studies show that small seeds (<2.5 mm in width) are most likely to escape chewing and rumination compared to large seeds, while hard-coated seeds have higher chances of passing through the gut without physical harm [9,11,12].

To limit the further spreading of encroaching tree species in rangelands and, at the same time, improve rangeland conditions and reduce dry season feed gaps, the active harvesting of the encroaching tree species as a feed source has been proposed [2,13–16]. There are positive effects that thinning and/or eradication of the encroaching trees have on rangeland conditions [3,14,15,17]. However, limited information exists to show how these trees could potentially be used as alternative feed sources by livestock, other than their use as leaf meal [2,6,17,18]. It has been observed that encroaching tree species are highly nutritious and have a high potential of being used as supplementary feed [13,19,20]. On the contrary, some of the woody plant species have very low dry matter digestibility and high levels of secondary compounds and, thus, have low potential to use as a feed source without additional processing [21]. The digestibility of these fodder trees can, however, be improved through different processing techniques. Furthermore, most studies focus on using the trees as a cut-and-carry resource without the addition of feed additives and mostly neglect the impacts of seed ingestion on the potential for contributing to further bush encroachment [17,19,22,23]. This, in turn, leaves a gap in our understanding of how these species could be used effectively without causing further encroachment through endozoochory.

This study, therefore, evaluated the quality of *Vachellia nilotica* fodders with and without seeds and the inclusion of feed additives. Thereafter, the best quality diet treatments were fed to livestock from where feed intake, seed intake, seed recovery, and the germination potential of the recovered seeds were determined. The study aimed to answer the questions (1) Will the inclusion of seed pods as well as feed additives improve the nutritional quality of the *Vachellia nilotica* fodders? and (2) whether the inclusion of the seed pods and feed additive could lead to dormancy breaking while passing through the gut and therefore improve or not seed germination.

2. Materials and Methods

2.1. Seed Collection, Preparation, and Initial Viability Screening

Vachellia nilotica seed pods were hand-picked at the Agricultural Research Council (ARC)—Roodeplaat Experimental Farm (28°19′ E, 25°35′ S) in Pretoria, South Africa. Seed pods were separated from the shoots and stored in a cool, dry area pending feed formulation. Five replicates of whole seed pods were weighed to a mass of 250 g, and the number of seed pods within each replicate was counted [9,24]. Thereafter, the seeds were removed from the seed pods, and the number of seeds was counted. Secondly, an additional ten replicates of 250 g seed pods were chipped using a Tandem 6.5 hp chipper, and the number of whole seeds (i.e., undamaged seeds) recovered was quantified after chipping. Thereafter, a representative number of chipped and un-chipped seeds were used to determine the initial viability of the seeds. Thirdly, the un-chipped seeds were scarified by clipping the seed coat with a clipper to expose the embryo. The seeds were immersed in a 1% Tetrazolium chloride solution (3,5-triphynyl chloride) for 18 h in a dark germination chamber and stored at room temperature. Thereafter, each seed was cut longitudinally through the endosperm to expose the embryo and evaluated for staining through a light microscope [25,26]. Seeds that stained red were regarded as viable, while unstained seeds were regarded as dead.

2.2. Feed Creation and Nutritional Quality Determination

Edible *Vachellia nilotica* shoots consisting of edible branches and leaves (30 cm long and approximately 1.0 cm diameter) were harvested using the tree pruner at the end of the wet season (March–April 2021) at the fruiting stage (i.e., plants with seed pods). During this time, all plant material still contained green leaves were harvested, but the seed pods were harvested towards the end of this period at maturity. The shoots and pods were collected from 70 different trees; seed pods were collected when matured and dry and were kept separate from shoots and merged differently to form a composite sample. The samples of shoots were chipped using a woodchipper (Tandem 6.5 hp chipper/shredder) and mixed thoroughly to obtain a uniform mixture. A uniform sample of 250 g chipped shoots was used as the base, and chipped seed pods were included in a 4:1, 4:2, 4:3, and 4:4 ratio. For each feed treatment created, the seed pods were chipped separately and included into the chipped shoots and mixed. Four replicates of each treatment were developed, as well as two control treatments which consisted of only 250 g chipped shoots and another consisting of only 250 g chipped seed pods. Additionally, a feed additive (Voermol LS33) at a recommended rate of 800 mL/10 kg for the small stock was added in all six treatments, resulting in a total of 12 feed treatments (i.e., six with the feed additives and six without the feed additives). A sub-sample of 150 g of each feed was collected, oven-dried at 60 °C until a constant mass was achieved, and milled to pass through a 3 mm mesh and stored for chemical analyses.

From the dried and milled feed samples, a 0.5 g sub-sample was digested using a technique described by Zasoski et al. [27]. After digestion, an aliquot of the digested solution was used for the determination of calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na), manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu) using an ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometer—Agilent 725 (700 Series), Agilent Technologies, Santa Clara, CA, USA). The ICP-OES can determine the quantity of each element in each sample simultaneously. Prior to analyses, the instrument was calibrated against a series of standard solutions containing all the elements of interest in alignment with the operating procedures of the manufacturer. Furthermore, 8–12 g of the plant samples were used to determine the total nitrogen (N) concentrations using the dry oxidation method [28,29] in a Flash 2000 CHNS-O Analyzer (Thero Scientific, Waltham, MA, USA). For each analysis, the instrument was calibrated against a known standard (Phenylalanine) which contained 8.48% N. Total N was converted to crude protein (CP) by multiplying %N with 6.25 [30]. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using a Dosi fiber analyzer system (Labex (Pty) Ltd., Edenvale, South Africa) according to the methods of van Soest et al. [31]. The NDF and ADF values obtained were used to calculate the digestible dry matter (DDM) [32], metabolizable energy (ME) [33], total digestible nutrients (TDN) [34], digestible forage energy (DFE) [33], digestible organic matter (DOM) [33], net energy for lactation (NE_L) [32], net energy for maintenance (NE_M) [32], and net energy for gain/growth (NE_G) [32] using Equations (1)–(8).

$$\text{DDM (\%)} = 88.9 - (\text{ADF} \times 0.779) \quad (1)$$

$$\text{ME (Mcal/kg DM)} = (1.01 \times \text{DFE}) - 0.45 \quad (2)$$

$$\text{TDN (\%)} = 87.84 - (0.7 \times \text{ADF}) \quad (3)$$

$$\text{DFE (Mcal/kg DM)} = 0.04409 \times \text{TDN} \quad (4)$$

$$\text{DOM (\%)} = \text{TDN} \div 1.05 \quad (5)$$

$$NE_L \text{ (Mcal/kg DM)} = 1.044 - (0.0119 \times \text{\% ADF}) \quad (6)$$

$$NE_M \text{ (Mcal/kg DM)} = ((1.37 \times ME) - (0.3042 \times ME) + (0.051 \times ME)) - 0.508 \quad (7)$$

$$NE_G \text{ (Mcal/kg DM)} = ((1.42 \times ME) - (0.3836 \times ME) + (0.0593 \times ME)) - 0.7484 \quad (8)$$

2.3. Feeding Trial and Seed Recovery

Based on the nutritional analyses, six experimental diets, each representing an experimental treatment, were used for the feeding trial (Table 1). The feeding and seed recovery trial was conducted at the ARC, Irene Experimental farm, Gauteng province, South Africa. A total of twenty-four female indigenous veld goats (South African veld goats) of approximately two years old with an average body weight of 29.6 ± 1.33 kg were used in the study. The twenty-four goats were divided into four groups of six per group. Each animal in a group was regarded as a replicate. The animals were acclimatized to the experimental conditions for 14 days prior to the start of data collection, during which time they were fed chipped *Vachellia nilotica* shoots and grass hay. The goats were housed in individual metabolic pens (2 m × 1 m) with slatted floors, each fitted with feed and water troughs in a well-ventilated covered area. After acclimatization, each animal was fed the experimental diet at 3% of their body weight and hay grass as a basal diet. All experimental animals were allowed to consume their assigned diets within 24 h, after which the remaining materials were collected [8]. Left-over feed was weighed, and feed intake was determined by calculating the difference between the feed offered to the animals and the remaining feed. The number of seeds in the feeds was also quantified. The fecal collection commenced immediately after the experimental feeding period started and continued until no seeds were recovered in the feces for three consecutive days. The number of seeds recovered per day per animal was recorded in order to calculate the seed recovery percentage. The collected feces were immersed in cold water until soft and then washed with tap water through a wire mesh until the water was clear. A cabinet with a light source below a glass surface was used to separate seeds from the fecal remains. Seeds recovered from each animal per day were counted and stored in brown paper bags prior to the germination trial. Using these counts, the number of days when the first seeds were recovered from the fecal matter after ingestion was recorded. At the end of the trial, the number of days to 10%, 50%, and 90% of the total number of seeds recovered was calculated. From these calculations, the time taken from 10% to 90% seed recovery was determined and used as an indication of seed recovery uniformity".

Table 1. Experimental diets used for feeding goats.

	Experimental Diets
1	100% *Vachellia nilotica* seed pods (un-chipped)
2	100% *Vachellia nilotica* seed pods (chipped)
3	100% *Vachellia nilotica* seed pods (un-chipped) + Feed Additive
4	100% *Vachellia nilotica* seed pods (chipped) + Feed Additive
5	4:4 (*Vachellia nilotica* Shoots: *Vachellia nilotica* chipped seed pods)
6	4:4 (*Vachellia nilotica* Shoots: *Vachellia nilotica* chipped seed pods) + Feed Additive

2.4. Germination of Recovered Seeds

Germination tests were performed at the ARC National Forage Genebank Seed Laboratory according to the International Seed Testing Association standards. The recovered seeds per animal per day were counted and stored in a brown paper bag resulting in six replicates per experimental feed treatment pending germination trial. The three control treatments, i.e., unscarified seeds, seeds that passed through the chipper, and mechanically scarified seeds by scarifying the seed coat with a clipper, were created. All seeds were germinated in 12 cm petri dishes on a single disk of Whatman No. 1 filter paper. The petri dishes were maintained in seed germination chambers at a temperature of 25 °C [8] for the duration of the trial. The seeds were watered with 5 mL

of dH_2O, and watering was done as needed throughout the duration of the germination period. Seed germination was recorded daily for 28 days, and germinated seeds were removed from the petri dishes on a daily basis to minimize excessive water uptake by germinated seeds. The total germination percentage was calculated at the end of the germination period following the technique by Armke and Scott [35]. All seeds that did not germinate at the end of 28 days were counted and subjected to a tetrazolium chloride viability test [8]. Seeds were scarified and soaked in 1% tetrazolium solution (3,5-triphynyl chloride) for 18 h in an incubator at 25 °C. Thereafter, each seed was cut longitudinally through the endosperm to expose the embryo, and staining was recorded by viewing the seeds under a stereo microscope [25,26].

2.5. Statistical Analysis

SPSS Version 22 (SPSS Inc., Chicago, IL, USA, 2013) was used for all statistical analyses. Nutritional quality, seed recovery, and seed viability data were subjected to a one-way analysis of variance (ANOVA) using a Fishers' LSD post hoc test to separate means and identify statistically significant differences ($p < 0.05$) between the different treatments.

3. Results

3.1. Seed Pods and Seed Characteristics

The collected seed pods contained, on average, 10 ± 0.2 seeds per pod and had an average weight of 2.7 ± 0.1 g. After chipping ten replicates of 250 g intact seed pods, with each replicate containing approximately 1108 ± 24 seeds, approximately 141 ± 22 intact seeds (13% ± 0.3) were recovered. The viability of the intact seeds recovered after chipping was 97%, and the seeds directly tested after removal from the seeds pods had a viability of 96%.

3.2. Nutritional Quality of Vachellia nilotica Fodders

Significantly ($p < 0.05$) higher concentrations of N, K, Mg, P, Zn (Table 2), CP, and TDN (Table 3) were found in the 100% *Vachellia nilotica* seed pods compared to the 100% *Vachellia nilotica* shoots. Furthermore, the *Vachellia nilotica* fodders created from 100% *Vachellia nilotica* seed pods also had significantly ($p < 0.05$) higher digestibility, i.e., lower ADF and NDF, higher DDM, DOM, and higher energy content (ME, NE_L, and NE_G) compared to the fodders containing 100% *Vachellia nilotica* shoots (Table 3). When the seed pods were added to the shoots, N, P, K (Table 2), and CP (Table 3) concentrations significantly increased ($p < 0.05$) from the 100% pure shoot fodder concentrations. The DDM, TDN, DOM, ME, NE_L, and NE_G (Table 3) content only significantly increased ($p < 0.05$) in the 100% shoot fodders at the highest seed pod inclusion levels, i.e., 4:4 shoots/pods. No significant differences ($p \geq 0.05$) were found in any of the other mineral nutrients between the 100% shoot fodders and the shoots + seed pod fodders, irrespective of the seed pod inclusion levels (Table 2). Neutral detergent fiber content significantly decreased ($p < 0.05$) when seed pods were added to the shoots, irrespective of the seed pod inclusion levels, while ADF content (Table 3) only decreased at the highest seed pod inclusion levels (Table 3).

Table 2. Mean (±SEM) Mineral nutrient content in experimental diets created from *Vachellia nilotica* shoots and seed pods with or without the addition of a feed additive (Voermol LS33). Different letters for each variable measured indicate statistically significant differences ($p \geq 0.05$) between different experimental diets within a column. P = probability, F = ratio of statistics.

Experimental Diet	N%	K g/kg	Ca g/kg	Mg g/kg	P g/kg	Na g/kg	Fe g/kg	Mn g/kg	Zn g/kg	Cu g/kg
100% Seed pods	2.2 ± 0.1^{b}	16.1 ± 0.3^{f}	5.8 ± 0.3^{a}	16.7 ± 0.2^{cd}	1.7 ± 0.1^{f}	0.1 ± 0.003^{a}	0.06 ± 0.003^{a}	0.02 ± 0.001^{a}	0.03 ± 0.001^{b}	0.01 ± 0.0004^{a}
100% Shoots	1.1 ± 0.1^{a}	6.7 ± 0.1^{a}	6.4 ± 0.4^{a}	11.6 ± 1.6^{ab}	0.7 ± 0.1^{a}	0.2 ± 0.003^{a}	0.16 ± 0.02^{bc}	0.03 ± 0.005^{bc}	0.03 ± 0.001^{a}	0.01 ± 0.0004^{b}
4:1 (Shoots/Seed pods)	1.5 ± 0.01^{a}	8.6 ± 0.2^{b}	6.6 ± 0.2^{a}	14.3 ± 1.3^{bc}	0.8 ± 0.03^{b}	0.1 ± 0.004^{a}	0.18 ± 0.02^{bcd}	0.03 ± 0.004^{c}	0.02 ± 0.001^{a}	0.01 ± 0.0011^{b}
4:2 (Shoots/Seed pods)	1.4 ± 0.02^{a}	10.0 ± 0.2^{c}	6.2 ± 0.03^{a}	12.6 ± 0.1^{ab}	0.9 ± 0.01^{bc}	0.2 ± 0.01^{a}	0.19 ± 0.02^{cd}	0.03 ± 0.001^{bc}	0.03 ± 0.001^{ab}	0.01 ± 0.0003^{b}
4:3 (Shoots/Seed pods)	1.5 ± 0.03^{b}	10.7 ± 0.03^{cd}	5.8 ± 0.1^{a}	11.8 ± 0.3^{a}	1.0 ± 0.02^{de}	0.2 ± 0.01^{a}	0.16 ± 0.03^{bc}	0.03 ± 0.002^{ab}	0.03 ± 0.0004^{a}	0.01 ± 0.0005^{b}
4:4 (Shoots/Seed pods)	1.5 ± 0.04^{b}	10.7 ± 0.03^{cd}	5.1 ± 0.2^{a}	12.2 ± 0.5^{ab}	1.1 ± 0.01^{e}	0.2 ± 0.01^{a}	0.15 ± 0.004^{bc}	0.03 ± 0.001^{ab}	0.02 ± 0.001^{a}	0.01 ± 0.0005^{b}
100% Seed pods + LS33	2.5 ± 0.04^{c}	17.4 ± 0.3^{g}	5.7 ± 0.3^{a}	20.3 ± 0.2^{f}	1.6 ± 0.1^{f}	1.5 ± 0.2^{b}	0.08 ± 0.002^{a}	0.04 ± 0.001^{c}	0.04 ± 0.002^{c}	0.01 ± 0.0005^{b}
100% Shoots + LS33	2.3 ± 0.01^{b}	11.1 ± 0.1^{d}	8.3 ± 0.1^{a}	22.9 ± 1.0^{g}	0.9 ± 0.03^{cde}	2.1 ± 0.1^{c}	0.23 ± 0.01^{cd}	0.07 ± 0.004^{f}	0.05 ± 0.002^{c}	0.02 ± 0.0013^{d}
4:1 (Shoots/Seed pods) + LS33	2.1 ± 0.18^{b}	13.0 ± 0.6^{e}	6.5 ± 0.1^{a}	19.7 ± 1.2^{ef}	0.9 ± 0.02^{bc}	2.6 ± 0.4^{d}	0.19 ± 0.01^{cd}	0.06 ± 0.003^{e}	0.06 ± 0.004^{d}	0.02 ± 0.0003^{cd}
4:2 (Shoots/Seed pods) + LS33	1.9 ± 0.03^{b}	13.2 ± 0.3^{e}	5.7 ± 0.2^{a}	18.2 ± 0.3^{def}	1.0 ± 0.1^{e}	1.7 ± 0.1^{bc}	0.16 ± 0.01^{bc}	0.05 ± 0.001^{d}	0.05 ± 0.001^{c}	0.01 ± 0.0006^{c}
4:3 (Shoots/Seed pods) + LS33	2.0 ± 0.03^{b}	13.9 ± 0.4^{e}	5.7 ± 0.1^{a}	17.3 ± 0.3^{de}	1.1 ± 0.02^{e}	1.9 ± 0.1^{bc}	0.15 ± 0.01^{bc}	0.05 ± 0.001^{d}	0.05 ± 0.003^{c}	0.01 ± 0.0004^{c}
4:4 (Shoots/Seed pods) + LS33	2.0 ± 0.11^{b}	13.8 ± 0.2^{e}	5.5 ± 0.2^{a}	17.7 ± 0.8^{de}	1.0 ± 0.1^{e}	1.8 ± 0.4^{bc}	0.14 ± 0.01^{b}	0.05 ± 0.003^{d}	0.05 ± 0.004^{c}	0.01 ± 0.0005^{c}
Significance	$F_{(11,36)} = 9.5$ $p \leq 0.001$	$F_{(11,36)} = 118.2$ $p \leq 0.001$	$F_{(11,36)} = 1.0$ $p = 0.474$	$F_{(11,36)} = 21.1$ $p \leq 0.001$	$F_{(11,36)} = 54.0$ $p \leq 0.001$	$F_{(11,36)} = 38.1$ $p \leq 0.001$	$F_{(11,36)} = 9.5$ $p \leq 0.001$	$F_{(11,36)} = 32.9$ $p \leq 0.001$	$F_{(11,36)} = 32.3$ $p \leq 0.001$	$F_{(11,36)} = 16.5$ $p \leq 0.001$

N = Nitrogen, K = Potassium, Ca = Calcium, Mg = Magnesium, P = Phosphorus, Na = Sodium, Fe = Iron, Mn = Manganese, Zn = Zinc, Cu = Copper.

Table 3. Mean (±SEM) Crude protein, fiber, digestibility, and energy content in experimental diets created from *Vachellia nilotica* shoots and seed pods with or without the addition of a feed additive (Voermol LS33). Statistically significant differences ($p \geq 0.05$) between different experimental diets are indicated by different letters for each variable measured. P = probability, F = ratio of statistics.

Experimental Diet	CP%	ADF%	NDF%	DDM%	TDN%	DOM%	DFE Mcal/kg	ME Mcal/kg	NE_L Mcal/kg	NE_M Mcal/kg	NE_G Mcal/kg
100% Seed pods	13 ± 0.4^{de}	28.3 ± 0.9^{a}	29.3 ± 1.1^{ab}	66.1 ± 2.1^{de}	67.4 ± 0.6^{cd}	64.2 ± 0.6^{cd}	3.0 ± 0.03^{a}	2.6 ± 0.03^{b}	0.7 ± 0.01^{d}	2.3 ± 0.03^{a}	2.1 ± 0.03^{d}
100% Shoots	7 ± 0.8^{a}	39.6 ± 2.9^{b}	48.6 ± 3.1^{e}	58.0 ± 2.3^{a}	60.1 ± 2.0^{a}	57.2 ± 1.9^{a}	2.7 ± 0.09^{a}	2.2 ± 0.09^{a}	0.6 ± 0.03^{a}	2.0 ± 0.10^{a}	1.7 ± 0.10^{a}
4:1 (Shoots/Seed pods)	9 ± 0.1^{b}	35.9 ± 0.8^{b}	39.7 ± 2.7^{d}	60.9 ± 0.6^{ab}	62.7 ± 0.6^{ab}	59.7 ± 0.5^{ab}	2.8 ± 0.02^{a}	2.3 ± 0.03^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.03^{a}	1.8 ± 0.03^{ab}
4:2 (Shoots/Seed pods)	9 ± 0.1^{b}	36.0 ± 1.1^{b}	39.5 ± 0.4^{d}	60.9 ± 0.9^{ab}	62.7 ± 0.8^{ab}	59.7 ± 0.7^{ab}	2.8 ± 0.03^{a}	2.3 ± 0.03^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.04^{a}	1.8 ± 0.04^{ab}
4:3 (Shoots/Seed pods)	9 ± 0.2^{b}	31.9 ± 0.4^{b}	35.8 ± 1.6^{abc}	61.0 ± 0.3^{ab}	62.7 ± 0.3^{ab}	59.8 ± 0.3^{ab}	2.8 ± 0.01^{a}	2.3 ± 0.01^{a}	0.6 ± 0.01^{ab}	2.1 ± 0.01^{a}	1.8 ± 0.01^{ab}
4:4 (Shoots/Seed pods)	10 ± 0.2^{b}	29.3 ± 1.9^{a}	30.0 ± 1.1^{ab}	66.1 ± 1.5^{de}	67.3 ± 1.3^{cd}	64.1 ± 1.3^{cd}	3.0 ± 0.06^{a}	2.6 ± 0.06^{b}	0.7 ± 0.02^{d}	2.3 ± 0.07^{a}	2.0 ± 0.06^{d}
100% Seed pods + LS33	16 ± 0.3^{f}	25.6 ± 1.2^{a}	30.0 ± 1.6^{ab}	65.8 ± 0.9^{cde}	67.1 ± 0.8^{cd}	63.9 ± 0.8^{cd}	3.0 ± 0.04^{a}	2.5 ± 0.04^{b}	0.7 ± 0.01^{cd}	2.3 ± 0.04^{a}	2.0 ± 0.04^{cd}
100% Shoots + LS33	14 ± 0.1^{e}	30.1 ± 0.7^{a}	32.9 ± 0.9^{bc}	65.5 ± 0.5^{cd}	66.8 ± 0.5^{cd}	63.6 ± 0.5^{cd}	2.9 ± 0.02^{a}	2.5 ± 0.02^{ab}	0.7 ± 0.01^{cd}	2.3 ± 0.02^{a}	2.0 ± 0.02^{cd}
4:1 (Shoots/Seed pods) + LS33	12 ± 1.1^{c}	34.5 ± 1.4^{b}	48.1 ± 1.4^{bcd}	62.0 ± 1.1^{bc}	63.7 ± 1.0^{bc}	60.7 ± 1.0^{bc}	2.8 ± 0.04^{a}	2.4 ± 0.05^{a}	0.6 ± 0.02^{bc}	2.2 ± 0.05^{a}	1.9 ± 0.05^{bc}
4:2 (Shoots/Seed pods) + LS33	12 ± 0.2^{c}	29.7 ± 2.7^{a}	30.5 ± 1.0^{ab}	65.8 ± 2.1^{cde}	67.0 ± 1.9^{cd}	63.9 ± 1.8^{cd}	3.0 ± 0.08^{a}	2.5 ± 0.08^{b}	0.7 ± 0.03^{cd}	2.3 ± 0.09^{a}	2.0 ± 0.09^{cd}
4:3 (Shoots/Seed pods) + LS33	12 ± 0.2^{c}	27.2 ± 1.2^{a}	31.1 ± 1.0^{ab}	67.7 ± 1.0^{de}	68.8 ± 0.9^{d}	65.5 ± 0.8^{d}	3.0 ± 0.04^{a}	2.6 ± 0.04^{b}	0.7 ± 0.01^{d}	2.4 ± 0.04^{a}	2.1 ± 0.04^{d}
4:4 (Shoots/Seed pods) + LS33	12 ± 0.7^{c}	24.9 ± 1.1^{a}	37.9 ± 4.2^{cd}	69.5 ± 0.9^{e}	70.4 ± 0.8^{d}	67.1 ± 0.8^{d}	3.1 ± 0.03^{a}	2.7 ± 0.04^{b}	0.8 ± 0.01^{d}	2.5 ± 0.04^{a}	2.2 ± 0.04^{d}
Significance	$F_{(11,36)} = 29.0$ $p \leq 0.001$	$F_{(11,36)} = 8.0$ $p \leq 0.001$	$F_{(11,36)} = 10.1$ $p \leq 0.001$	$F_{(11,36)} = 8.1$ $p \leq 0.001$	$F_{(11,36)} = 7.9$ $p \leq 0.001$	$F_{(11,36)} = 7.4$ $p \leq 0.001$	$F_{(11,36)} = 1.0$ $p = 0.474$	$F_{(11,36)} = 3.6$ $p = 0.004$	$F_{(11,36)} = 8.3$ $p \leq 0.001$	$F_{(11,36)} = 1.0$ $p = 0.474$	$F_{(11,36)} = 8.0$ $p \leq 0.001$

CP = Crude protein, ADF = Acid detergent fiber, NDF = Neutral detergent fiber, DDM = Digestible dry matter, TDN = Total digestible nutrients, DOM = Digestible organic matter, DFE = Digestible forage energy, ME = Metabolizable energy, NE_L = Net energy for lactation, NE_M = Net energy for maintenance, NE_G = net energy for gain/growth.

The addition of the feed additive (Voermol LS33- molasses-based protein, vitamin, and mineral supplement) to the 100% *Vachellia nilotica* seed pods and 100% *Vachellia nilotica* shoot fodders significantly increased ($p < 0.05$) the concentrations of N, K, Mg, Na, Mn, and Zn. Phosphorus concentrations were only significantly increased ($p < 0.05$) when the additive was added to the shoots (Table 2). Similarly, the addition of the feed additives to the 100% seed pod and 100% shoot fodders significantly ($p < 0.05$) increased the CP content (Table 3). Feed additive added to 100% seed pods significantly decreased ($p \geq 0.05$) ADF and NDF content; however, no significant differences ($p \geq 0.05$) were observed on DDM, TDN, DOM, NE_L, and NE_G, whereas there was a significant increase ($p < 0.05$) when feed additives were added to the 100% *Vachellia nilotica* shoot fodders (Table 3). The addition of feed additive to the fodders created from the pure *Vachellia nilotica* shoot + the different seed pod inclusion levels, irrespective of the inclusion levels, resulted in significantly higher ($p < 0.05$) concentrations of K, Mg, Na, Mn, Zn, and Cu (Table 2) and CP (Table 3), while N only increased at the 4:1 and 4:2 seed pod inclusion levels (Table 2) and DDM, TDN, DOM, NE_L, and NE_G only increased at the 4:2 and 4:3 seed pod inclusion levels (Table 3).

3.3. Selection of Diets, Feeding Trial, and Seed Recovery after Ingestion

Vachellia nilotica feeds were selected for the feeding trial as experimental diets (Table 3). Generally, the total amount of feed consumed and the remaining after the experimental period did not differ statistically among the six experimental diets ($p > 0.05$; Table 4). However, the number of seeds ingested was significantly higher ($p < 0.05$) when the seed pods were chipped, irrespective of the addition of the feed additives (Table 4). The number of seeds recovered was significantly lower ($p < 0.05$) in the diets containing chipped seed pods compared to those with the control, i.e., whole seed pods (Table 4). Less than 2% of the chipped seed pods were recovered after ingestion, while 3% and 6% of seeds in the diets containing whole seed pods with or without Voermol LS33 were recovered (Table 4). No differences ($p \geq 0.05$) were found between the experimental diets in regard to when the first seeds were recovered from the feces (Table 4), while significant differences ($p < 0.05$) were observed in the number of seeds recovered between experimental diets. However, it was evident that the seed retention rate generally remained longer ($p < 0.05$) in the digestive tract of goats when they were fed diets containing whole seed pods, irrespective of the addition of the feed additive (Table 4). Furthermore, uniformity in seed recovery, calculated as the time taken between 10% and 90% of seeds recovered, indicated that the diets containing chipped seed pods with the addition of the feed additives resulted in a significantly ($p < 0.05$) shorter retention period in the gut, i.e., two days, while the recovery of the seed from the fecal matter was spread over 5–6 days long (Table 4).

3.4. Germination Potential of Recovered Seeds

The unscarified seeds that were not fed to the goats were mostly dormant (88%), with only 3.2% of the seeds being able to germinate (Table 5). Mechanically scarified seeds had a germination percentage of 79% (Table 5). Although chipping of the seed pods significantly increased ($p < 0.05$) the germination potential compared to control (unscarified seeds), more than 65% of the recovered seeds remained dormant (Table 5). Approximately 80% of the recovered seeds from whole seed pods diets were dormant, which was similar to the control (unscarified seeds) treatment (Table 5).

Table 4. Mean (±SEM) Feed, seed ingested, and seed recovery from the goats. Statistically significant differences ($p \geq 0.05$) between different experimental diets are indicated by different letters for each variable measured. P = probability, F = ratio of statistics.

Treatments	Feed Ingested	Feed Remains	% Seed Ingested	% Seed Remains	% Recovery	1st Recovery	50% Recovery	90% Recovery	Uniformity
Whole Seed pods	64.7 ± 9.8^{a}	35.3 ± 9.8^{a}	58.8 ± 9.7^{a}	41.2 ± 9.7^{b}	3.5 ± 1.3^{b}	1.7 ± 0.2^{a}	3.8 ± 0.3^{c}	5.7 ± 0.3^{c}	3.0 ± 0.4^{cd}
Whole Seed pods + LS33	65.7 ± 9.7^{a}	34.3 ± 9.7^{a}	57.4 ± 9.9^{a}	42.6 ± 9.9^{b}	6.1 ± 2.2^{c}	1.0 ± 0.0^{a}	3.5 ± 0.2^{bc}	6.2 ± 0.6^{c}	4.0 ± 0.6^{d}
Chipped seed pods	68.9 ± 10.9^{a}	31.1 ± 10.9^{a}	90.1 ± 6.7^{b}	9.9 ± 6.7^{a}	0.6 ± 0.2^{a}	1.5 ± 0.2^{a}	2.3 ± 0.5^{a}	3.7 ± 1.0^{a}	2.2 ± 0.9^{bc}
Chipped seed pods + LS33	83.0 ± 8.6^{a}	17.0 ± 8.6^{a}	85.2 ± 6.7^{b}	14.8 ± 6.7^{a}	0.8 ± 0.3^{a}	1.5 ± 0.2^{a}	2.8 ± 0.4^{ab}	3.8 ± 0.3^{b}	1.8 ± 0.2^{a}
Chipped (shoots, seed pods)	57.9 ± 6.4^{a}	42.1 ± 6.4^{a}	90.8 ± 6.8^{b}	9.2 ± 6.8^{a}	0.8 ± 0.2^{a}	1.7 ± 0.3^{a}	3.0 ± 0.4^{bc}	4.3 ± 0.5^{b}	2.3 ± 0.6^{bc}
Chipped (shoots, seed pods) + LS33	78.1 ± 7.6^{a}	21.9 ± 7.6^{a}	71.4 ± 8.3^{b}	28.6 ± 8.3^{a}	1.9 ± 1.2^{a}	1.8 ± 0.3^{a}	3.2 ± 0.5^{bc}	4.0 ± 0.5^{b}	1.7 ± 0.4^{a}
Significance	$F_{(5,36)} = 1.10$ $p = 0.382$	$F_{(5,36)} = 1.08$ $p = 0.391$	$F_{(5,36)} = 3.58$ $p = 0.012$	$F_{(5,36)} = 3.58$ $p = 0.012$	$F_{(5,36)} = 3.55$ $p = 0.012$	$F_{(5,36)} = 0.61$ $p = 0.693$	$F_{(5,36)} = 3.60$ $p = 0.014$	$F_{(5,36)} = 10.31$ $p \leq 0.001$	$F_{(5,36)} = 6.13$ $p \leq 0.001$

Table 5. Mean (±SEM) Germination trial and uniformity for seed recovered from the feces. Statistically significant differences ($p \geq 0.05$) between different experimental diets are indicated by different letters for each variable measured. P = probability, F = ratio of statistics.

Treatments	Germination (%)	Dormant Seed (%)	Dead Seed (%)
Seed pods	14.1 ± 2.8^{c}	83.0 ± 3.6^{d}	3.0 ± 1.3^{a}
Seed pods + LS33	8.7 ± 1.1^{b}	87.6 ± 1.7^{d}	3.7 ± 0.7^{a}
Chipped seed pods	16.8 ± 1.1^{c}	79.5 ± 3.0^{c}	3.7 ± 2.6^{a}
Chipped seed pods + LS33	17.1 ± 2.1^{c}	77.1 ± 2.4^{c}	5.7 ± 2.7^{a}
Chipped (shoots+ seed pods)	14.4 ± 2.2^{c}	77.8 ± 3.0^{c}	7.8 ± 1.0^{a}
Chipped (shoots+ seed pods) + LS33	13.1 ± 2.1^{c}	79.4 ± 3.2^{c}	7.4 ± 2.3^{a}
Unscarified	3.2 ± 1.0^{a}	88.4 ± 3.5^{d}	8.4 ± 2.9^{a}
Scarified	78.8 ± 2.2^{e}	0.0 ± 0.0^{a}	21.2 ± 2.2^{b}
Chipped	29.6 ± 2.9^{d}	65.2 ± 3.4^{b}	5.2 ± 1.0^{a}
Significance	$F_{(8,45)} = 121.3$ $p \leq 0.001$	$F_{(8,45)} = 89.6$ $p \leq 0.001$	$F_{(8,45)} = 7.8$ $p \leq 0.001$

4. Discussion

4.1. Nutritional Quality of Vachellia nilotica Fodders

Browse plants such as *Vachellia nilotica* are major sources of livestock feed during the dry season, partially due to their ability to retain their nutritional value during the dry season [36], contrary to grasses. This, along with their rate and extent of encroachment, have the potential to be a good alternative source of feed for livestock. At the end of the active growing period, the nutritional value of browse plants may not be sufficient to sustain livestock. An example of this is reported by Britz et al. [37], who indicated that maturing of browse plants resulted in a decline in the nutritional quality in terms of their mineral nutrients, digestibility, protein, and energy content. Thus, the best time to harvest the material for fodder is during the vegetative or early reproductive stages [20,37,38]. However, other studies have shown that some of the browse seed pods during the end of the wet season have higher nutritional value and could be used to improve the quality of the fodders created by these encroaching tree species [2,16,20,38,39]. These findings are in accordance with the findings of the current study, where results indicated that seed pods generally contained relatively higher quality mineral nutrients, crude protein, and lower amounts of fiber and therefore increased digestibility and energy content compared to the edible shoots. Both seed pods and shoots in the current study contained sufficient concentrations of K, Ca, Mg, Fe, Mn, Zn, Cu, and crude protein to meet the minimum requirements of 5–15 g/kg, 1.8–10 g/kg, 1 g/kg, 0.03–0.1 g/kg, 0.02–0.04 g/kg, 0.02–0.05 g/kg, 0.005–0.1 g/kg, and 7–8%, respectively, to maintain livestock condition [30,33]. However, only the 100% seed pod diet contained sufficient P concentrations to meet the maintenance requirements of (1.6–6 g/kg) ruminants. In addition, neither the seed pods nor the shoots contained sufficient Na concentrations to meet the minimum requirements of 0.4–1.8 g/kg to maintain livestock conditions [30]. The fiber content in the shoots of *Vachellia nilotica* had 28% (ADF) and 29% (NDF), and the seed pods had 39% (ADF) and 48% (NDF), which both fall within the adequate range of 19–40% ADF and 25–40% NDF for normal rumen functions [31,39–41]. Small ruminants such as goats and sheep require high concentrations of degradable fiber in their daily diets for rumen function [40]. However, a high level of fiber is often associated with decreased forage intake [40–42]. Furthermore, forages with a digestible dry matter (DDM) content of greater than 60% are regarded as high-quality forages as intake will not be impacted [31,40]. According to the study results, the *Vachellia nilotica* shoots alone contained 58% DDM while the seed pods had a DDM content of 66%, indicating the importance of the inclusion of the seed pods in livestock diets. The energy content of the *Vachellia nilotica* shoots and seed pods individually was sufficient to sustain the energy requirements for small ruminants (goats/sheep) during the dry season [30]. In addition, both shoots and seed pods had sufficient metabolizable energy (ME) content to meet the energy requirements of lambs up to 20 kg (3.9–10.5 MJ kg^{-1} DM)

as well as those of 40–60 kg dry ewes (7.6–10.2 MJ kg^{-1} DM). However, neither shoots nor pods were found to have sufficient ME content (14.5–17.7 MJ kg^{-1} DM) to sustain pregnant and lactating (15.5–19.4 MJ kg^{-1} DM) ewes.

The nutritional value of shoots with the addition of seed pods was found to be higher compared to shoots alone, and it contained sufficient levels of mineral nutrients, CP, digestibility, and energy content to maintain livestock conditions during the dry season [30,33,42] Furthermore, the addition of seed pods to the shoots improved the mineral nutrient content of the forages and was found to meet the minimum requirements to maintain small stock conditions. This was true for all mineral nutrients, except for P and Na, which was below the minimum requirements levels of small stock [30,33]. Moreover, the addition of the feed additives to the pure seed pods and pure shoots further increased the nutritional quality of the *Vachellia nilotica* shoots, resulting in a CP content that was suitable for maintaining highly productive livestock herds, which have a minimum requirement of 13–14% CP.

4.2. Feed Intake, Seed Recovery, and Seed Germination Potential of Recovered Seeds

Hard-coated seeds tend to be protected against damage during ingestion and rumination, which in turn results in the recovery of more undamaged seeds in the feces [8,43,44]. Therefore, diets containing the chipped seed pods were found to be consumed in higher amounts than when seed pods were offered as a whole, irrespective of the addition of the feed additive in this study. Furthermore, the seed recovery was relatively high for whole seed pod diets and low for chipped seed pod diets. This might be because chipping the seed pods before feeding results in easy ingestion, making it easier to digest and thus reducing the recovery of intact seeds. The first seed recovery for all treatments ranged between 1–2 days; however, the time to 90% recovery was longer for diets that contained whole seed pods compared to chipped seed pods.

Seed recovery and survival after passage through the gut depends on factors such as the hardness of the seed coat, the size of the seeds, the associated diet fed with the seed pods as well as the number of seeds ingested [8,44,45]. Furthermore, seed recovery and germination after ingestion may be influenced by factors such as chewing and rumination [9,22]. Results from the current study showed that there was a low percentage of intact seeds that passed through the digestive tract of goats, especially from chipped seed pods diets. However, those seeds remained viable and had substantial germination potential. Although the relative viability of seeds that passed through the rumen was lower than those that were mechanically scarified and chipped seeds, it was significantly higher than untreated seeds. The relatively low loss in viability of ingested seeds is a good trade-off for the likelihood of these seeds being dispersed by animals away from the parent tree. Therefore, the study partially supported the hypothesis that feed additives will improve the digestibility of seed pods consumed by goats, thus reducing seed dispersals and viability.

5. Conclusions

Edible *Vachellia nilotica* shoots in this study were found to contain insufficient crude protein content for maintaining livestock conditions during the dry season. However, adding seed pods to the shoots significantly increased the nutritional quality. Chipping of the seed pods before inclusion in livestock diets resulted in significantly lower numbers of seeds recovered, with more than 85% of seeds being broken and damaged to the point where they did not germinate. Feeding the remaining seeds led to a further reduction in seeds recovered, with only 2% of the whole seeds fed to the livestock being recovered. Therefore, processing the seed pods prior to adding these to the shoot material in diets already significantly reduces the number of seeds that could potentially be dispersed throughout the rangeland. However, it is important to remember that the majority of the 2% of seeds recovered were dormant but still viable. These seeds could potentially still lead to further bush encroachment. Therefore, further research is required to determine

whether these seeds passing through the gut of the livestock will survive the dry season to germinate and establish in the next wet season.

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