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Nutrient-rich or anti-nutritional challenge? Evaluating *Senna spectabilis* (DC.) H.S. Irwin & Barneby for sustainable animal feed production

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Abstract

This study investigated the nutritional composition and anti-nutritional factors of *Senna spectabilis* as a potential fodder for animal feed. Key parameters such as crude protein, crude fiber, dry matter, digestibility and anti-nutritional factors like phenols, tannins, saponins and nitrates were analyzed from the five formulations named from SS_1 to SS_5. The results showed significant variations across the species in terms of digestibility and energy content, with formulations SS_1 and SS_4 demonstrating superior digestibility and higher Total Digestible Nutrients (TDN). On the other hand, formulation SS_5 exhibited higher crude fiber content and lower digestibility, making it less efficient as a feed source. Anti-nutritional factors such as saponins and nitrates were found to be highest in formulation SS_1, which could affect feed intake and livestock health if present in excessive amounts. The study also noted moderate levels of tannins and phenols in several species, which could impact nutrient absorption for animals. Additionally, concentrate feed mixtures were considered in comparison to fodder-based feeds for their influence on livestock growth and performance. These findings suggest that careful selection of feed ingredients, considering both nutritional and anti-nutritional parameters, is essential for optimizing livestock nutrition. Formulations with lower levels of anti-nutritional compounds like SS_2, offer more sustainable feed options, while further research is required to understand the effects of these compounds on livestock health and performance.

Keywords

animal feed pellets; anti-nutritional factors; nutritional composition; *Senna spectabilis*

Introduction

Invasive alien species cause significant damage to native ecosystems. These plant species are introduced by humans, either intentionally or accidentally, into regions outside their natural habitats. Without natural predators or competitors, these species can spread quickly, severely impacting native biodiversity, even in protected areas (1). Invasive plants often share traits that help them dominate; they tend to grow rapidly, have short life cycles, high reproductive capacity, strong competitive abilities and sometimes even release chemicals that harm other plants (allelopathy) (2). These adaptations enable them to outcompete native species, disturbing entire ecosystems. The effects of plant invasions are widespread and well-documented, making them one of the most serious threats to the integrity of natural and semi-natural ecosystems globally (3-7). Invasive Alien Plants (IAPs) often compete with native species for essential resources such as light, water and nutrients, leading to declines in the abundance and diversity of native plants (8). These invasions disrupt ecosystem balance, altering plant and animal community structures. Such changes can affect food webs, nutrient cycling and overall ecosystem health. Furthermore, IAPs can modify the physical and chemical environment, creating conditions that disadvantage native species even further (9).

Senna spectabilis is a fast-growing, medium-sized tree native to Central and South America. Its name is derived from its historical use as a laxative, with Arabic roots referring to its purgative effects. Part of the *Senna* genus, which includes over 200 species (10), it was first noticed in India in the Sathyamangalam Forest and Wayanad Wildlife Sanctuary of Kerala (11). This tree can grow over 10 meters tall, with young branches often covered in fine hair. Its leaves are large, with multiple pairs of leaflets averaging 20 per leaf. Each leaflet is lance-shaped, measuring 3-8 cm in length and 2 cm in width, with a hairy underside and a smoother, shiny top. Its yellow flowers appear in clusters at the ends of branches, with five unevenly sized petals, the largest reaching up to 2.5 cm. The plant also has three types of stamens, some of which are rudimentary. Its fruit is a long, flat pod that opens along one side (12) (Fig. 1).

Originally introduced to Indian gardens for its ornamental value, *S. spectabilis* has unfortunately spread beyond cultivation and invaded forested areas in regions like Mysore and Sikkim. This aggressive invader thrives in Wayanad and Tamil Nadu, producing numerous seedlings that threaten native species. As a result, it has been classified as an 'Invasive Alien Species', causing significant harm to biodiversity. What was once an ornamental tree has now become a serious ecological threat, overtaking large areas of natural forest and displacing native species (13). Even herbivores, which might typically help control its spread, inadvertently aid its expansion by consuming and dispersing its seeds (14). The real challenge, however, lies in the tree's incredible resilience. *S. spectabilis* is extremely difficult to remove, as its seeds remain viable for long periods and even damaged branches, cut stems, or uprooted trees can regenerate new growth. This persistence makes it a major obstacle in efforts to protect native biodiversity (15, 16).

Despite being considered a dangerous invader, *S. spectabilis* may offer an unexpected benefit to livestock farmers. The tree can form a symbiotic relationship with nitrogen-fixing bacteria called rhizobia. These bacteria help convert atmospheric nitrogen into usable forms, enriching the plant's leaves with nutrients like protein and fiber. As a result, these nutrient-dense leaves could serve as a supplementary feed source for livestock, including goats, sheep and cattle, particularly in times of scarcity, such as during droughts or periods of overgrazing (17, 18).

Additionally, the nutrient composition of *S. spectabilis* leaves suggests potential use as a component in livestock feed concentrates. Concentrates are feed blends that supply essential nutrients such as proteins, sugars and fats at elevated levels while containing less than 18 % crude fiber and over 60 % total digestible nutrients (TDN). These are categorized into energy-rich and protein-rich concentrates, depending on their crude protein content. Energy-rich concentrates contain less than 18 % crude protein, while protein-rich concentrates contain over 18 % (19). Given its nitrogen-fixing ability and high protein content, *S. spectabilis* leaves could be explored as an alternative protein-rich concentrate, reducing reliance on conventional feed sources. However, further research is necessary to assess its digestibility, anti-nutritional factors and long-term effects on livestock health. Based on these findings, *S. spectabilis* leaves have been selected for this study as a potential component in animal feed pellets. Their nitrogen-fixing ability, high protein content and resilience make them a promising alternative protein-rich feed source. Further analysis will focus on their nutritional composition, digestibility and anti-nutritional factors to determine their suitability for livestock feed formulations.

a. S. spectabilis coppiced shoots

b. *S. spectabilis* tree

Fig. 1. *S. spectabilis* (DC.) H.S. Irwin & Barneby.

Materials and Methods

Its ability to thrive in diverse ecosystems makes it a significant species in both natural and cultivated landscapes. To explore its viability in livestock nutrition, different feed pellet formulations were developed using *S. spectabilis* leaf powder as the primary ingredient. The formulations were supplemented with various oilcakes, rice bran, maize grain, mineral mixtures, molasses and salt to enhance nutritional value and palatability.

The tender leaves of *S. spectabilis* species were collected, shade dried, pulverized and formed into pellets using a pelleting machine in five formulations (SS_1 - SS_5), to explore their potential as a fodder resource. The table below presents the different formulations used in the study (Table 1.) (Fig. 2 and 3).

The nutritional profiling involved in assessing Dry Matter (DM) by oven-drying until a constant weight was achieved, while ash content was measured by incinerating the samples at 550 °C (20). Crude Protein (CP) was analyzed using the Micro-Kjeldahl method and Crude Fat (CF) was determined through Soxhlet extraction with ethanol (20). Crude Fiber was quantified through acid and alkali treatments, whereas Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) were assessed using detergent solutions (20). The Nitrogen-Free Extract (NFE) was calculated as 100 - [CP + CF + crude fiber + ash] (21). Digestible Dry Matter (DDM) was estimated using the formula DDM = 88.9 - (ADF × 0.779) (22) and Relative Feed Value (RFV) was derived from (DMI × DDM) ÷ 1.29. Anti-nutritional factors were evaluated using standard procedures. Total phenolic content and Folin tannin-reactive substances were determined through the Folin-Ciocalteu assay, followed by spectrophotometric measurements at 760 nm and 700 nm, respectively (23).

Table 1. Formulations of *S. spectabilis*-based animal feed pellets

Formulation No.	Formulations
SS_1	*S. spectabilis* leaf powder (Control) (100 %)
SS_2	*S. spectabilis* leaf powder (50 %) + Groundnut oilcake (15 %) + Rice bran (10 %) + Maize grain (20 %) + Mineral mixture (2 %) + Molasses (2 %) + Salt (1 %)
SS_3	*S. spectabilis* leaf powder (50 %) + Gingelly oilcake (15 %) + Rice bran (10 %) + Maize grain (20 %) + Mineral mixture (2 %) + Molasses (2 %) + Salt (1 %)
SS_4	*S. spectabilis* leaf powder (50 %) + Coconut oilcake (15 %) + Rice bran (10 %) + Maize grain (20 %) + Mineral mixture (2 %) + Molasses (2 %) + Salt (1 %)
SS_5	*S. spectabilis* leaf powder (50 %) + Sunflower oilcake (15 %) + Rice bran (10 %) + Maize grain (20 %) + Mineral mixture (2 %) + Molasses (2 %) + Salt (1 %)

a. Senna spectabilis leaf powder

b. Groundnut oil cake

c. Rice bran

d. Maize grain

e. Mineral mixture

f. Molasses

g. Salt

Fig. 2. Formulation of *S. spectabilis*-based animal feed pellets.

Fig. 3. *S. spectabilis* based animal feed pellets.

Total Nitrates were measured following a standard protocol (24), with potassium nitrate as the standard. Saponins were determined using a standard methodology (25) involving vanillin and sulfuric acid. These findings were employed to optimize nutritional value while minimizing anti-nutritional factors.

Statistical analysis

The design of the experiment was a Completely Randomized Design (CRD). Data focused initially on the Invasive Alien Species, *Senna spectabilis* with a total of five formulations. All statistical analyses were performed using the AGRES and TNAUSTAT software.

Results and Discussion

Table 2 presents the proximate composition of different formulations, highlighting variations in Dry Matter (DM), Moisture Content (MC), Ash Content (AC), Crude Protein (CP), Crude Fat (CFa) and Crude Fiber (CFi). These parameters play a crucial role in assessing the nutritional quality of the species, which can influence their suitability for animal feed. The observed differences in composition indicate species-specific variations in nutrient availability and forage quality.

SS_2 and SS_5 (5.50 %) and lowest in SS_3 and SS_4 (3.0 %), with a mean of 4.30 %. These findings were consistent with those of previous research which observed a similar crude fiber content in mulberry leaf-based pellets and a higher crude fiber content in pineapple leaf-based pellets (30, 31). The overall variations in nutritional composition indicate species-specific differences in feed quality, suggesting that selecting appropriate species can significantly enhance livestock nutrition and feed efficiency.

Table 2. Proximate composition of *S. spectabilis* based animal feed pellets

S. No	Formulations	DM (%)	MC (%)	AC (%)	CP (%)	CFa (%)	CFi (%)
1	SS_1	88.91*	11.09	11.55*	16.18	2.27	4.50*
2	SS_2	86.70	13.30*	11.07	15.75	2.43*	5.50*
3	SS_3	84.01	15.99*	10.17	16.62*	2.09	3.0
4	SS_4	88.95*	11.05	9.89	16.31	2.03	3.0
5	SS_5	86.44	13.56*	13.25*	16.18	2.67*	5.50*
	Mean	**87.00**	**12.99**	**11.18**	**16.20**	**2.29**	**4.30**
	SEd	0.831	0.189	0.134	0.194	0.033	0.077
	CD (0.05)	1.787	0.407	0.288	0.417	0.070	0.166

DM - Dry Matter, MC - Moisture Content, AC - Ash Content, CP - Crude Protein, CFa - Crude Fat, CFi - Crude Fibre

The proximate composition analysis of five different formulations (SS_1-SS_5) revealed significant variations in nutritional parameters, influencing their suitability as animal feed. The Dry Matter (DM) content ranged from 84.01 % in SS_3 to 88.95 % in SS_4, with a mean of 87.00 %. Dry matter content plays a crucial role in determining nutrient concentration and energy availability, affecting feed efficiency and animal performance (26), who discussed how dry matter varies based on species, plant parts and growing conditions. Moisture content (MC) varied between 11.05 % (SS_4) and 15.99 % (SS_3), staying within the acceptable limit of 12 % as per the SNI standard (SNI 8509:2018). Excess moisture content can negatively impact feed storage and stability, the water content in feed is influenced by the material type and environmental conditions (27). Ash Content (AC), representing the mineral composition of feed, was highest in SS_5 (13.25 %) and lowest in SS_4 (9.89 %), with a mean of 11.18 %, aligning with the previous findings (28), which noted that ash content in cattle feed is critical for maintaining mineral balance.

Crude Protein (CP), essential for livestock growth and nutrient absorption, ranged from 15.75 % (SS_2) to 16.62 % (SS_3), meeting the minimum requirement of 16 % recommended for cattle feed. This aligns with previous research (29), which recorded a minimum crude protein content of 10.80 % in cassava-based pellets. Crude fat (CFa), an important energy source in feed, varied between 2.03 % (SS_4) and 2.67 % (SS_5), aligning with the SNI standard (>2.0 %), consistent with earlier reports (30), which found 5.98 % crude fat in mulberry leaf-based pellets. Crude fiber (CFi), which plays a crucial role in digestion and gut health, was highest in

Table 3 summarizes the key nutritional parameters such as Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), Nitrogen-Free Extract (NFE), Digestible Dry Matter (DDM), Dry Matter Intake (DMI), Relative Feed Value (RFV) and Total Digestible Nutrients (TDN) for the various formulations (SS_1-SS_5), providing insights into their digestibility and feed quality. The nutritional analysis (SS_1-SS_5) revealed significant variations across multiple parameters, influencing their suitability as animal feed. The Acid Detergent Fiber (ADF) content ranged from 36.09 % (SS_1) to 40.94 % (SS_5), with a mean of 38.06 %, indicating moderate fiber levels. The Neutral Detergent Fiber (NDF) content varied between 60.74 % (SS_2) and 66.81 % (SS_5), with an average of 63.92 %. This suggests that species with higher NDF content, such as SS5, may have lower digestibility. The Nitrogen-Free Extract (NFE) content ranged from 62.4 % (SS_5) to 68.77 % (SS_4), with a mean of 66.00 %. This trend of increasing NFE is linked to a decrease in crude fiber content where reduction in crude fiber content resulted in an increase in NFE (32). Similar findings were observed in a study which reported that a pelleted feed mixture with lower fiber content improved the Total Digestible Nutrients (TDN) value (33).

Digestible Dry Matter (DDM) ranged from 57.00 % (SS_5) to 60.78 % (SS_1), with a mean of 59.24 %, reflecting significant differences in the digestibility of the feed. Dry Matter Intake (DMI) values ranged from 1.79 % (SS_5) to 1.97 % (SS_2), with a mean of 1.87 %, suggesting that species like SS_2 may have a higher intake potential. The Relative Feed Value (RFV), which indicates overall feed quality, ranged from 79.09 % (SS_5) to 89.88 % (SS_2), with a mean of 86.07 %. This implies that species with lower fiber content, such as SS_2, generally offer higher feed value. Finally, Total Digestible Nutrients (TDN) values ranged

Table 3. Nutritional composition and digestibility of different formulations of *S. spectabilis* based animal feed pellets (SS_1-SS_5)

S. No	Formulations	ADF (%)	NDF (%)	NFE (%)	DDM (%)	DMI (%)	RFV (%)	TDN (%)
1	SS_1	36.09	64.70	65.5	60.78	1.85	87.16	91.28
2	SS_2	38.56	60.74	65.25	58.86	1.97*	89.88*	91.96
3	SS_3	37.96	64.08	68.12	59.32	1.87	85.99	92.44
4	SS_4	36.78	63.29	68.77*	60.24	1.89	88.25	92.64
5	SS_5	40.94*	66.81*	62.4	57.00	1.79	79.09	90.08
	Mean	38.06	63.92	66.00	59.24	1.87	86.07	91.68
	SEd	0.406	0.406	1.028	1.087	0.026	1.081	1.446
	CD (0.05)	0.873	0.873	2.211	2.339	0.056	2.325	N/A

from 90.08 % (SS_5) to 92.64 % (SS_4), with a mean of 91.68 %, indicating high energy content and digestibility across all species. These results highlight the species-specific differences in feed quality, suggesting that selecting for lower fiber content and higher digestibility can significantly enhance livestock nutrition and feed efficiency.

Table 4 presents the concentrations of phenols, tannin, saponin and nitrates in different species (SS_1-SS_5). Significant differences in saponin and nitrate content were observed across the species, indicating variability in anti-nutritional factors that could influence the nutritional quality and suitability of these species for animal feed. The total phenol content ranged from 0.007 % (SS_1) to 0.011 % (SS_5), with a mean of 0.009 %. Phenols in feed provide crucial information regarding rumen fermentation, biohydrogenation, milk yield, cattle weight and potential anti-inflammatory properties (34). This finding aligns with previous research, where a total phenol content of 0.78 % in *Albizia lebbeck* + Prosopis pod-based feed pellets, highlighting the impact of phenol content on feed quality and livestock health (35).

Table 4. Anti-nutritional factors in different formulations of *S. spectabilis* based animal feed pellets (SS_1-SS_5)

S. No	Formulations	Phenols	Tannin	Saponin	Nitrates
1	SS_1	0.007	0.101	1.376*	0.317*
2	SS_2	0.009	0.120*	1.069	0.119
3	SS_3	0.010*	0.098	1.271*	0.281*
4	SS_4	0.008	0.100	1.011	0.198
5	SS_5	0.011*	0.112*	1.220*	0.297*
	Mean	0.009	0.106	1.189	0.242
	SEd	0.000	0.002	0.017	0.004
	CD (0.05)	0.000	0.003	0.036	0.009

ADF - Acid Detergent Fibre, NDF - Neutral Detergent Fibre, NFE - Nitrogen Free Extract, DDM - Digestible Dry Matter, DMI - Dry Matter Intake, RFV - Relative Feed Value, TDN - Total Digestible Nutrients

Tannin in a potential animal feed can affect nutrient digestibility and animal performance. The study found that the tannin content ranged from 0.1143 % (SS_4) to 0.1290 % (SS_2), with an average of 0.106 %. Excessive tannin consumption reduces feed intake and hinders growth (36). Similar studies reported a tannin content of 0.28 % in legume-based feed pellets (*Lablab purpureus*, *Mucuna pruriens* and *Calopogonium mucunoides*), indicating a consistent trend of tannin levels affecting feed quality (37). The nitrate content ranged from 1.0173 % (SS_3) to 1.2234 % (SS_5), with a mean of 1.189 %. High nitrate levels in feed can pose significant health risks, such as nitrate poisoning, if present in excessive amounts (38). This was reflected in a previous study where the nitrate value of 0.98 % was noted in *Swietenia mahagoni* + Prosopis pod-based feed pellets (35).

Saponins are glycosides with soap-like properties. The saponin content ranged from 0.8169 % (SS_4) to 0.9449 % (SS_5), with a mean of 0.9113 %. While saponins reduce feed intake and nutrient absorption, they also provide health benefits such as antimicrobial and anti-inflammatory effects. A similar study found that unpelleted legume feed had a saponin content of 6.17 %, while pelleted legume feed showed lower values (5.5 %), with *Lablab purpureus, Calopogonium mucunoides* and *Mucuna pruriens* having saponin values of 5.25 %, 5.75 % and 6.5 %, respectively (37). These studies highlight the species-specific variations in anti-nutritional factors and their potential impact on livestock nutrition and health.

Conclusion

The nutritional and anti-nutritional factor analysis of the five different formulations (SS_1-SS_5) reveals significant variations across all measured parameters. This study assessed essential nutritional factors, such as crude protein, crude fiber, dry matter and digestibility, alongside anti-nutritional factors including phenols, tannins, saponins and nitrates. The results highlight the importance of considering both the nutrient composition and anti-nutritional factors when evaluating feed quality for livestock.

The species under study exhibited substantial differences in their nutritional composition, with the formulations SS_1 and SS_4 showing better overall digestibility and energy content, as reflected by their higher Total Digestible Nutrients (TDN) and Digestible Dry Matter (DDM) values. This suggests these species may be more suitable for promoting livestock growth and improving feed efficiency. On the other hand, SS_5 demonstrated higher levels of crude fiber and lower digestibility, making it less optimal for efficient feed conversion and weight gain.

In terms of anti-nutritional factors, SS_1 exhibited the highest levels of saponins and nitrates, both of which can negatively impact animal health if consumed in excess. The presence of these compounds in feed ingredients can potentially lead to reduced feed intake and digestive issues. The study also found variations in phenol and tannin content, with formulations such as SS_2 and SS_5 showing moderate levels, impacts digestibility and overall feed efficiency. These findings support the need for careful selection and processing of feed materials to minimize the negative impacts of these compounds on livestock performance.

Overall, the study emphasizes the importance of balancing nutritional composition with anti-nutritional factors to optimize livestock feed. The feed formulations with lower levels of anti-nutritional compounds, like SS_2, offer more sustainable and cost-effective solutions for livestock nutrition. Moreover, future research should focus on understanding the precise mechanisms by which these anti-nutritional factors interact with livestock physiology, as well as exploring methods to mitigate their impact through feed processing or supplementation.

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Authors' contributions

BS worked in the collection of the literatures and writing the manuscript. BK guided in writing the manuscript and bringing it to a sequence. TM assisted in the correction of the manuscript. RR assisted in additional inputs that was needed in the manuscript. GKN, RKP and VM provided an outline and interpretation of the manuscript. RR and HP assisted in correcting the manuscript. KV and SD helped in reviewing and editing the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that there is no conflict of interest.

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