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Nutritional characterization of banana by-products under irrigation (In case of Arba Minch, South Ethiopia)

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Abstract

The present study evaluated the nutritional values of banana by-products (BBP) obtained from irrigated areas of Arba minch, Gamo Zone Southern Ethiopia. By-product fractions (leaf, shoot, rhizome, fruit bunch and whole mixture) were collected from farmers' gardens during fruit harvesting. Collected fractions were separately chopped and air-dried in shades lined with plastic sheets until transported to Hawassa University, Animal Nutrition Laboratory, where chemical composition and existence of associative effects were evaluated using an *in vitro* system. The dry matter (DM) content of BBP was 18.5, 7.6, 8.3, 6.2 and 10.2% for leaves, pseudostem, rhizome, FB-stem and whole mixture, respectively. The CP values obtained ranged from 2.5 to 8.6%, the lowest for the pseudostem, while the highest was for the leaf. The IVDMDs of leaves, pseudostem, rhizome, FB-stem, and the whole BBP mixture were 35.5, 41.3, 35.4, 46.21, and 39.6%, respectively. Potential gas production (a+b) was rated highest for Wmix (41.3 ml) and rhizome (40.0 ml) and lowest for leaf (18.8 ml). The ranges of metabolisable energy (ME), organic matter digestibility (OMD) and short-chain fatty acids (SCFA) values were 2.7 to 4.5 MJ/kg dry weights, 29.26 to 33.27% and 0.22 to 0.33 µmol, respectively. ME, OMD and SCFA values ranked as, pseudo stem > Wmix > rhizome > Fb stem > leaf. The higher values obtained for potential gas production (a+b), ME, OMD and SCFA in pseudostem and Wmix could mean higher availability of nutrients for rumen microorganisms. The results showed that pseudostem and Wmix could have higher nutritional value in ruminant feed than other fractions, but appropriate treatment/supplementation with high-quality feed or additives is needed to balance nutrients.

Keywords: Banana by-products; Nutritive value; Gas production; *In-vitro* assessment

1. Introduction

Livestock productivity in Ethiopia is currently constrained by complex systemic issues, of which limited feed supply is commonly cited as the biggest problem to look for in any option (Balehegn et al., 2020). One possible alternative to solve the shortage of feed for livestock is the use of agricultural residues such as banana waste (Beigh et al., 2017). Bananas are among the world's major cash crops and one of the world's best-selling fresh fruits. However, large amounts of waste and by-products are generated during the harvesting and consumption of bananas, including stems, leaves, inflorescences and peels (Zou et al., 2022). After harvest, almost 60% of banana biomass is left as waste (Alzate et al., 2021). It is reported that each ton of harvested bananas generates about 4 tons of waste, including 100 kg of waste fruit, 3 tons of pseudostems, 160 kg of stalks, 480 kg of leaves, and about 440 kg of inflorescences and peels (Fernandes et al., 2013).

Despite the abundance of these by-products, its use in ruminant diets is limited due to some factors such as moisture, which limits intake and digestibility in the rumen. Therefore, huge stocks of these products accumulate in banana growing areas and consequently farmers sometimes face the problem of their disposal (Saraiva et al., 2012).

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Unfortunately, while these by-products have been used as a major feed source in some developed countries; little has been done in Ethiopia to promote their use in overcoming nutritional deficiencies during critical periods. Instead, they are left to rot in the fields. The current study was designed to evaluate the nutritional value of botanical fractions of banana by-products (BBP) for future use in ruminant nutrition.

To evaluate the chemical composition, *In-vitro* digestibility and gas production characteristics of banana by products.

2. Materials and methods

2.1. Description of the study area

The samples were collected from Arba-Minch Zuria Woreda, located about 505 km south of Addis Ababa and 275 km southwest of the regional capital. It is part of the Gamo Goffa zone, which is located almost in the center of the region with an astronomical position of roughly 5070"-6021"N latitude and 37031"-37067"E longitude. According to (CSA, 2012), the district has a total area of 1214.1 km2 with a population of 164,529 and consists of 29 kebeles of which 10 are major banana producers. The area receives 800-1200 mm of annual rainfall and averages 16oC and 37oC minimum and maximum temperatures, respectively, with an altitude of 1200-3310 m above sea level. Climatically, the Woreda is classified into three ecological zones i.e. dega, woina-dega and kola comprising 30.1%, 41.44% and 28.46% respectively.

The topography of the area is characterized by an undulating feature that supports the existence of different climatic zones in the area, which forms some parts of the Great Rift Valley and the Lowlands. It is an area of high human and livestock density with estimated livestock numbers of 111910, 35226, 20894, 4616 and 56555 for cattle, sheep, goats, horses and poultry respectively (Experts of Woreda Board, personal communication).

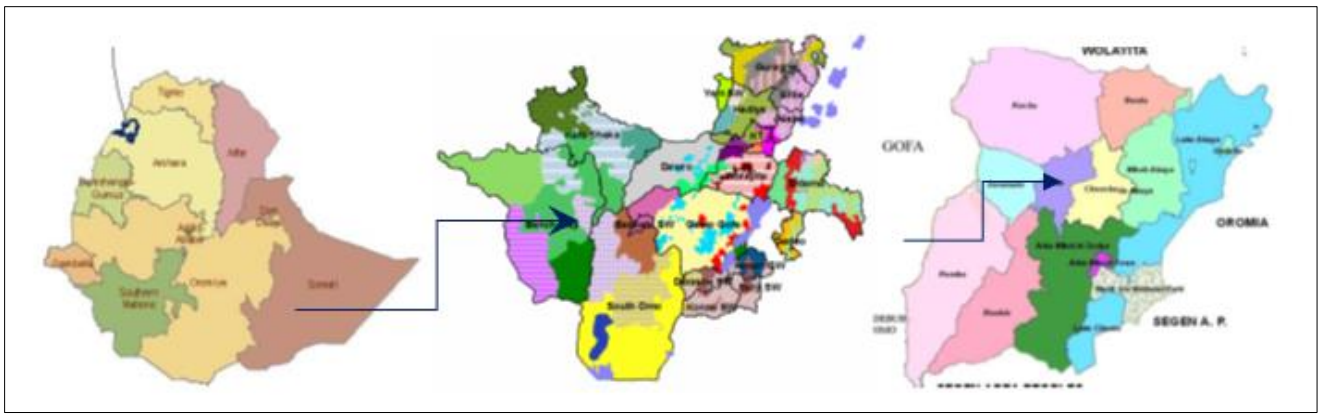

Figure 1 Location of the study area (Adapted from Habte, 2013)

2.2. Preliminary data collection

A rapid exploratory survey was conducted to gather information on production systems (both crop and livestock), population dynamics and distribution of livestock species, agro-ecological and climatic conditions, topography, soil fertility, infrastructure, demographic and other socio-economic conditions. The Zonal Office of Agriculture and Extension and the Woreda BOARD helped to access the important information before the actual experiment. A semi-structured questionnaire (checklists) was used to collect available information on the intensity and distribution of banana production and by-product utilization, farmers and animals preferring banana by-products as a feed source, other alternatives to conventional and non-conventional feed, and conservation practices in periods of feed scarcity, feeding systems and related problems.

2.3. *In vitro* digestibility

Ruminant feed digestion is simulated *in vitro* in two steps to mimic what happens in the entire digestive tract (FAO, 2011). First, the sample weighed in a test tube was incubated with buffered rumen fluid for 48 hours to remove digestible carbohydrates. The residue after 48 h of *in vitro* fermentation was then treated with neutral detergent solution (NDS) to dissolve digestible proteins, microbial residues and any remaining soluble fractions based on the procedure described by Goering and Van Soest (1970). After filtration, the residue was dried, ashed and weighed. The percentage of actual *in vitro* dry matter digestibility (%IVTDMD) was therefore calculated as: IVTDMD (%) =(100-(W3-

(W1 X C1)))/(W2 X DM%) x 100 where: IVTDMD = Actual dry matter digestibility *in vitro* (Tilley and Terry, 1963), where: W1 = weight of bag wrapper, W2 = weight of sample, W3 = weight of final bag after *in vitro* and subsequent NDS treatment, and C1 = correction of empty bag (final oven-dried weight / weight of original empty bag). The obtained values were finally converted to in vivo digestibility levels using standard samples with known in vivo digestibility, measured in each sample series (y = 0.99X - 1.01), where Y = percent dry matter digestibility in vivo and X = percent dry matter digestibility *in vitro*. The procedure was based on (Tilley and Terry, 1963).

2.4. *In vitro* gas production

The Menke and Steingasse (1988) technique described in (Abdulrazak et al., 2000) was used to assess gas production *in vitro* and was performed at Hawassa University, Animal Nutrition Laboratory. Rumen fluid was collected from 2 sheep fed twice a day a diet containing 60% roughage (hay) and 40% concentrate (nougat cake). The liquid was strained through two layers of cheesecloth into a preheated thermos and incubated with 100 ml calibrated syringes in three batches at 39°C. All laboratory handling of rumen fluid and buffer solutions was maintained under continuous CO2 flow to maintain anaerobic conditions and ensure a representative microbial population for *in vitro* fermentation.

An oven-dried and ground sample of 200 mg of each diet was weighed in triplicate and transferred into 100 mL calibrated glass syringes equipped with plungers. Syringes were injected with 30 mL of a 1:2 mixture of rumen fluid and buffer (medium) followed by incubation in a water bath at 39 °C. Three syringes containing only buffered rumen fluid were included and considered blank. The syringes were gently shaken 30 minutes after the start of incubation and every hour for the first 8 hours of incubation. Gas production readings were recorded before incubation (0) and 3, 6, 12, 24, 48, 72 and 96 h after incubation and values were corrected for blank and concentrate standards with known gas production. Thus, the volume of gas production characteristics was estimated using the equation

$$Y = a + b (1 – ect)$$ [Ørskov and McDonald, 1979],

Where:
Y = volume of gas produced in time (t),
a = capture (gas produced from immediately soluble fraction),
b = gas produced from non-fermentable (insoluble but degradable) fraction,
a + b = total/potential gas production,
c = rate constant of gas production for non-fermentable fraction (b),
t = incubation time.

Post-incubation parameters such as metabolisable energy (ME, MJ/kg dry matter), organic matter digestibility (OMD%) and short-chain fatty acids (SCFA) were estimated 24 and 48 hours after gas sampling and calculated from the equations: 1) ME (KJ/g DM) = 2.20 + 0.136 GP (in 24 hours) + 0.057 CP, 2) OMD (%) = 18.53 + 0.9239 GP (in 48 hours) + 0.0540 CP and 3) SCFA = -0.0601 + (0.0239GP) according to (Bensalem et al., 2006), where: GP = net gas production per 24/48 h (ml/200 mg) incubation; CP = crude protein content of feed samples, OMD = 48-hour organic matter digestibility, and SCFA = short-chain fatty acids. At the end of 24 h of incubation, 5 mL of 10 N NaOH was added to the substrate in each of the syringes to determine methane production (Fievez et al., 2005). The addition of sodium hydroxide was to absorb the carbon dioxide produced during the fermentation process and the remaining volume of gas was recorded as methane according to the method (Edwards et al., 2012).

2.5. Sample preparation and laboratory analysis

Banana leaves, stems, rhizomes and fb-stems were collected from farmers' fields during fruit harvest. They were separately chopped with an electric chopper (ALR, CLNR-6500TT) into lengths of 1-3 cm and air-dried in shades lined with clean plastic film. However, the banana rhizome was washed with tap water to remove sand and hand cut with a knife to about 1 cm, weighed and properly mixed on a plastic sheet until it was sent to Hawassa University, Animal Nutrition Laboratory. The dry matter of the samples was determined after keeping at a low temperature (40 °C) for 24 h, while the ash content was determined after drying in a muffle furnace at 550 °C for 3 h. CF, EE and Kjeldahl nitrogen analysis was performed using the procedure described in (AOAC, 2005) and CP was calculated as N x 6.25. On the other hand, NDF, ADF and ADL were determined according to (Van Soest and Robertson, 1985) using an Ankom220 fiber analyzer, while WSC was calculated using the equation of NRC, 2001; WSC = 100 – (NDF + CP + EE + ash).

2.6. Statistical methods

The statistical models used to analyze the experimental results were: $Yj = \mu + Aj + ei$, where: Y = experimental response variable; μ = total mean; Ai = variation due to botanical difference; ei= Random error. Data were subjected to analysis

of variance using the one-way ANOVA procedure of the Statistical Package for the Social Science (SPSS, 2011), and multiple (pairwise) comparisons were determined using Tukey's test to separation of means (P<0.05).

3. Results and discussion

3.1. Chemical composition characteristics of fresh BBPs

The chemical composition among the morphological fractions of BBP is shown in Table 4. The study showed that all fractions of fresh banana by-products except leaves showed high moisture content, consistent with the findings of Wang et al., (2016) and (Li et al., 2010). The leaf had the highest (P<0.05) CP content than other fractions. The lowest (P< 0.05) CP content was for the pseudostrain. Leaves and FB stem had the lowest (P<0.05) WSC content. The leaf and rhizome had the lowest ash content. The lowest (P<0.05) NDF and ADF were for FB stem and rhizome, respectively. Leaf and pseudostem NDF and ADF in the current study were also comparable to the ranges of 56.5–67.3% NDF and 31.6–40.2% ADF in DM reported by (Pacheco et al., 2011b). The pseudo-strain had the lowest (P< 0.05) ADL content. All had lower ether extract (EE) except leaves (3.25%).

Table 1 The chemical composition of fractions of BBPs

Nutrients (%DM)	Morphological fractions					SEM	Sig.
	Leaf	Pseudo_stem	Rhizome	FB_stem	Whole mix		
Dry matter %	18.5^{c}	7.6^{ab}	8.3^{ab}	6.2^{a}	10.2^{b}	0.337	0.000
Crude protein	8.6^{c}	2.5^{a}	4.7^{b}	5.3^{b}	5.3^{b}	0.244	0.000
Crude fiber	25.5^{b}	24.7^{b}	13.7^{a}	24.4^{b}	22.1^{b}	0.628	0.000
WSC	4.7^{a}	12.4^{b}	17.27^{c}	4.6^{a}	9.7^{b}	0.266	0.000
Ash	16.4^{a}	21.5^{b}	17.4^{a}	42.3^{c}	24.4^{b}	0.316	0.000
NDF	67.3^{d}	62.4^{c}	59.4^{b}	56.5^{a}	61.4^{c}	0.520	0.000
ADF	37.3^{b}	37.1^{b}	31.8^{a}	40.6^{c}	36.7^{b}	0.585	0.000
ADL	13.3^{c}	6.7^{a}	16.2^{d}	9.9^{b}	11.5^{c}	0.262	0.000
Ether extract	3.25^{c}	0.82^{a}	0.67^{a}	0.04^{a}	1.2^{b}	0.296	0.000

Row means with different superscripts differ significantly (P<0.05); FB: fruit bunch, WSC: Water soluble carbohydrate, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, ADL: Acid detergent lignin, Sig: Level of significance, SEM: Standard error mean

3.2. *In-Vitro* true DM digestibility (IVTDMD %) of BBPs

Table 2 *In vitro* true DM digestibility profiles of BBPs

Treatment diets	IVTDMD%	*In vivo DMD%*	SEM	Sig.
Leaves (L)	35.54^{a}	34.2^{a}	1.39	0.002
Pseudo-Stem (Ps)	41.27^{b}	39.8^{b}		
Rhizome (R)	35.44^{a}	34.1^{a}		
Fruit bunch-stem (FBs)	46.21^{c}	44.7^{c}		
Whole mixture (Wmix)	39.62^{b}	38.2^{b}		

Means with the same superscript letter were not significantly (P<0.05) different; IVTDMD: *In vitro* true dry matter digestibility, DMD: Dry matter digestibility, %: Percent, SEM: Standard error mean and Sig. Significance

Data on *in vitro* DM digestibility characteristics are shown in Table 7. The results showed that there was a significant variation among the morphological fractions of BBP in IVTDMD, which could be attributed to variations in their cell wall content. Fruit bunch-stem showed the highest value in IVDMD followed by pseudo-stem. In this study, leaves and rhizomes had lower IVTDMD due to high NDF, as the amount and lignification of plant cell walls (NDF) affect the digestibility of forage by rumen microbes and ruminants (Forbes, 2007). IVTDMD is negatively related to NDF, ADF and

ADL, but positively related to WSC content in forages (Kamalak et al., 2004). This finding is in agreement with (Van Soest, 1994), who suggested that a relatively low fiber content may facilitate the colonization of the feed by microbial populations in the rumen, which in turn may induce a higher rate of fermentation and thereby improve digestibility. It is also comparable to the finding of (Forbes, 2007), which recommended that an NDF content of 36% dry matter of the whole ration, regardless of the type of forage offered, was optimal and could avoid risks.

3.3. Gas production kinetics of BBPs

The total volume (ml/200 mg dry weight) of gas production from *in vitro* incubation of BBP samples at different incubation times are shown in Table 3 and Figure 2. The total volume of gas production differed between the morphological fractions. Cumulative gas volumes from incubation of 200 mg of banana by-products ranged from 21.95 to 25.33 mL. The volume of gas produced at 24 h incubation from leaf, pseudo-stem, rhizome, FB-stem and Wmix was 11.71, 15.96, 12.97, 16.23 and 14.31 ml, respectively. The FB stem had the highest volume followed by the pseudo-stem, while the lowest volume was for the leaf. The observed measurements of cumulative gas production in the current study were consistent with the findings of Amarnath and Balakrishnan (2007). The observed low value for banana leaf in the current study is likely to be due to the higher protein content in the leaves, the degradation of which can produce ammonia, which combines with H+ from the buffer to form NH4+, which remains in solution indirectly inhibiting gas production (Wang et al., 2001).

Table 3 Volume of gas produced (ml/200 mg DM) from fresh BBPs at different incubation times

Treatments	Incubation time (hr)						
	4	**8**	**12**	**24**	**48**	**72**	**96**
Leaves	2.24^{bc}	3.24^{ab}	4.98^{a}	11.71^{a}	18.69^{a}	20.19^{a}	21.95^{a}
Ps-Stem	0.75^{a}	1.00^{a}	7.24^{c}	15.96^{bc}	19.71^{a}	23.45^{a}	23.29^{a}
Rhizome	2.99^{c}	4.74^{ab}	6.23^{b}	12.97^{ab}	20.45^{a}	22.20^{a}	23.51^{a}
FB-Stem	1.75^{b}	3.73^{ab}	8.49^{d}	16.23^{c}	19.98^{a}	24.72^{b}	25.33^{b}
Wmix.	1.93^{b}	3.20^{ab}	6.74^{c}	14.31^{b}	19.71^{a}	22.39^{a}	23.52^{a}

Means with different superscript letters within a column for each item were different at (*P<0.05)*.

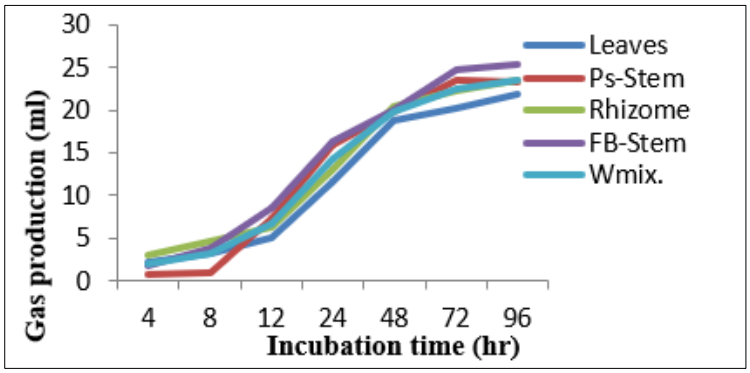

Figure 2 Gas production pattern (ml/200 mg) of BBPs at different incubation times

3.4. Gas production characteristics and estimated parameters of fresh BBPs

The gas production characteristics and estimated parameters (OMD, SCFA, ME and CH_4) of fresh BBPs are presented in Table 4. The results showed that, gas production characteristics at 24hrs incubation differed significantly (P<0.05) for all the parameters assessed. The potential gas production (a + b) that ranged from 18.8 to 41.3ml followed a similar pattern of variation as observed in gas production from the insoluble but degradable fraction (b). The a+b values obtained in Wmix and rhizome were higher than other treatments except Ps-stem. The observed low value in leaf could be a reflection of low gas production from the insoluble but degradable fraction (b) that result from low microbial

activity due to high fiber content or higher protein content of leaf whose degradation can cause ammonia production (Okoruwa *et al*., 2012 and Wang *et al*., 2001).

The rate of gas production ranged from 3 to 7% per hour. It was higher (P<0.05) for Wmix than the other fractions except rhizome and Ps-stem. This was thought to have been possibly influenced by the soluble carbohydrate fraction readily available to the microbial population. The findings agree with (Cerillo and Juarez, 2004) who indicated that, intake of a feed is mostly explained by the rate of gas production (c) which affects the rumen whereas the potential gas production (a+b) is associated with the degradability of the feed. The lag time that ranged from 3.2 to 5.1hrs was significantly (P<0.05) highest in FB stem of fresh BBPs and lowest in leaf. This observation indicates that more time was taken by rumen microbes to ferment the fiber components in FB stem compared to other morphological fractions. This is in agreement with the report of (Okoruwa *et al*., 2012) that rumen microbes take longer time to ferment feed with high fiber content than feed with low fiber content.

Sommart *et al*. (2000) demonstrated that gas volume is a good parameter for predicting digestibility, fermentation end products and microbial protein synthesis of the substrate by rumen microbes in the *in vitro* system. The observed variations in OMD and SCFA were inversely related to their fiber content because fiber influences the extent of organic matter digested by rumen microbes. The lower OMD and SCFA values recorded in leaf could be related with low organic matter digested due to high fiber content compared to other morphological fractions (Okoruwa *et al*., 2012). For feed ingredients in which cell content is high while the cell wall is low, rumen fermentation would be expected to result in a reduction in acetate and an increase in propionate (Widiawati and Thalib, 2009). The synthesis of acetate in the rumen results in an increase of H^+ production which increases methanogenic bacteria activities to synthesize methane (Adeyosoye *et al*., 2010). Hence, it is better to use BBPs with additive treatment or supplement with high quality forages which could balance nutrients and have no adverse environmental as well as energetic concern to animals.

Table 4 Gas production characteristics and estimated parameters of BBPs

BBPs	GP characteristics						Estimated parameters			
	a(ml)	b(ml)	a+b (ml)	E_{GP} (ml)	C (ml h^{-1})	Lag time	ME(MJ/kg DM	OMD %	SCFA(mmol)	CH_4
Leaves	2.5^{a}	16.3^{a}	18.8^{a}	4.3^{a}	0.03^{a}	3.2^{a}	4.3^{a}	29.26^{a}	0.22^{a}	10.9^{ab}
Ps-Stem	10.2^{bc}	28.7^{b}	38.9^{bc}	9.7^{c}	0.05^{bc}	4.1^{ab}	4.5^{a}	31.41^{ab}	0.32^{b}	11.4^{c}
Rhizome	12.1^{c}	27.9^{b}	40.0^{c}	7.5^{bc}	0.06^{bc}	4.6^{b}	4.2^{a}	29.35^{a}	0.25^{ab}	8.2^{a}
FB-Stem	8.6^{b}	19.5^{a}	28.1^{ab}	3.3^{a}	0.02^{a}	5.1^{b}	2.7^{a}	33.27^{b}	0.33^{b}	10.2^{ab}
Wmix.	10.9^{bc}	30.4^{c}	41.3^{c}	5.8^{b}	0.07^{c}	4.3^{ab}	3.9^{a}	31.93^{ab}	0.28^{ab}	12.9^{c}
SEM	.470	.765	.312	.830	.561	.925	.113	.794	.020	.447
Sig.	.001	.000	.001	.001	.012	.015	.057	.065	.010	.001

Means in each column with unlike superscript letters for each item differ significantly at (P <0.05); a: gas production from soluble fraction (ml/200 mg DM), b: gas production from insoluble but fermentable fraction (ml/200 mg DM), c: rate constant of gas production during incubation (ml/h), a + b: the potential gas production (ml/200 mg DM), E_{GP}: Effective gas production and SEM: Mean standard error, L: lag time

4. Conclusion

Nutritional value of banana by-products varied with botanical fractions, but in general, the highest nutritional value was found in whole mixture, followed by Rhizome and pseudo-stem. Banana by-products have high potential with huge biomass yield but unbalanced nutritional value. Banana by-products with suitable treatment and supplement could be a good ruminant feed and good animal product gain can be attained by feeding ruminants with treated banana by-products.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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