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Chemical Composition, *In Situ* Degradability and *In Vitro* Gas Production of Tagasaste (*Chamaecytisus palmensis*) Forage Harvested at Different Stages

Getnet Assefa[1], Aemiro Kehaliew[1], Gezahegn Kebede[1], C Kijora[2], KJ Peters[2]
[1]*Ethiopian Institute of Agricultural Research, Holetta Research Centre, P.O.Box 2003, Addis Ababa, Ethiopia.*
[2]*Humboldt University of Berlin, Institute of Animal Sciences, Phillipstr. 13, Haus 9, 10115 Berlin, Germany*

አሕፅሮተ-ጥናት

በኢትዮጵያ ደጋማ አካባቢዎች ታጋሳስቴ የተባለው የቅንጠባ የመኖ ዛፍ በጥሩ ሁኔታ የሚበቅል ሲሆን ምርታማነቱም በጣም ከፍተኛ ነው፡፡ ነገር ግን የታጋሳስቴ የመኖ ጥራት ይዘት በተለያዩ የአመራረት፣ የአያያዝና የአጠቃቀም ምክንያቶች የሚለያይ ቢሆንም መረጃው በሚገባ ተጠናቅሮ አልተቀመጠም፡፡ ስለዚህ ይህ የምርምር ጥናት ታጭዶ እንደገና ያበለገውን የታጋሳስቴ ዛፍ በተለያየ የእድሜ ደረጃ ላይ መኖውን በማጨድ የንጥረ ምግብ ይዘቱንና፣ በእንስሳት የሆድ እቃ የመፈጨት መጠኑን በላብራቶሪና በእንስሳት በመታገዝ አጠቃላይ የመኖውን የጥራት ሁኔታን መገምገምን ትኩረት አድርጓል፡፡ በተተከለ የአንድ ዓመት እድሜ ላይ ያለ የታጋሳስቴ ዛፍ የክረምት የዝናብ ወቅት (ሐምሌ) በመጣ ጊዜ ታጭዶ እንደገና እንዲያበለግ የተደረገው የመኖ ዛፍ በ4ኛ፣ በ6ኛ፣ በ8ኛ እና በ10ኛ ወራት ላይ ታጭዶ የመኖ ናሙና ተወስዷል፡፡ የታጨደው መኖ ቅጠሉንና ከሚበላ ቅርንጫፍ (ቀንበጥ ቅርንጫፍ) ለየብቻ በመለያየት የመኖ የጥራት መረጃ ተወስዷል፡፡ የመኖውን ንጥረ መግብ ይዘት፣ ሆድ ዕቃቸው የተቀደዱ ከብቶችንና እንዲሁም ፈርሱን በመጠቀም የመኖውን የአፈጫጨት መጠንና ደረጃ ተገምግሟል፡፡ በአንድ ኪሎ ግራም የደረቀ የታጋሳስቴ ቅጠል ውስጥ ያለው የፐሮቲን ይዘት በ189 እና በ242 ግራም መካከል የሚገኝ ሲሆን በተለያዩ የእድሜ ደረጃ ላይ የታጨዱት የታጋሳስቴ ቅጠሎችም የፐሮቲን ይዘታቸው የነላ ልዩነት በመካከላቸው አላሳዩም፡፡ የመኖ የማጨጃ ጊዜው እየተራዘመ በሚሄድበት ጊዜ የቃጫ ይዘታቸውና የቅባት መጠናቸው (ether extracts) ጨምሯል፡፡ በታጋሳስቴ መኖ ውስጥ የሚገኘው የ ፐሮቲን ገንቢ ንጥረ ነገር ይዘት በከፍተኛ ደረጃ ሊዩሲን (leucine) እና ላይሲን (lysine)፤ በዝቅተኛ ደረጃ ደግሞ ሚትዮኒን (methionine) እና ሂስቲዲን (histidine) የተባሉትን በጣም አስፈላጊ የሆኑትን አሚኖ አሲዶች እንደያዘ ጥናቱ ያሳያል፡፡ በኢትዮጵያ ደጋማ አካባቢዎች የበቀለው ታጋሳስቴ ዛፍ በውስጡ የያዘው የፎስፈረስ፣ የሰልፈር እና የሶዲየም መጠን ዝቅተኛ ሲሆን እንደ ካልሲየም፣ ፖታሺየም፣ ዚንክ እና ኤይረን ያሉትን ማዕድናት ደግሞ በበቂ መጠን እንደያዘ ጥናቱ ያሳያል፡፡ አንድ ኪሎ ግራም የደረቀ የታጋሳስቴ ቅጠል በእንስሳት ሆድ ውስጥ የመፈጨት አቅም በአማካይ 795 ግራም ሲያሳይ ዝቅተኛ የመኖ አፈጫጨት ደረጃ የታየው ደግሞ በአስረኛው ወር ላይ ከታጨደው መኖ ነው፡፡ በታጋሳስቴ መኖ ውስጥ ከፍተኛ የሆነ የገንቢ ንጥረ ነገር ይዘት፣ በእንስሳት ሆድ ዕቃ ውስጥና በላብራቶሪ ውስጥ ከፍተኛ የመፈጨት አቅም እንዳለው ስለሚያሳይ ይህን መኖ ለአመንጭኪ እንስሳት እንደ ገንቢ የድጎማ መኖነት መጠቀም ይቻላል፡፡ በጥናቱ ከታዩት የመኖ የጥራት መረጃዎች በተጨማሪ መኖው በእንስሳቱ ምርትና ምርታማነተ ላይ የሚመጣውን ለውጥ ወደፊት በሌሎች ምርምሮች መረጋገጥ አለበት፡፡

Abstract

The leguminous tree tagasaste is highly productive in the Ethiopian highlands. However, its nutritional value, as affected by the different agronomic practices is not fully understood under the tropical highland conditions. This study investigated the quality profile of tagasaste forage harvested at different re-growth stages by measuring the chemical composition, in situ degradability and in vitro gas production. Tagasaste re-growths after one year of

establishment was harvested and the re-growths starting from the main rainy season (July) was harvested at 4, 6, 8 and 10 months. The harvested forages were fractionated into leaves and edible branches. Chemical composition, in situ degradability using rumen fistulated steers and in vitro gas production using rumen fluid from rumen fistulated dry cows were evaluated. The average crude protein (CP) content of tagasaste in the leaves ranged between 189 and 242 g kg^{-1} dry matter (DM) was not significantly affected by harvesting stage re-growth. The neutral detergent fibre, acid detergent fibre, acid detergent lignin and ether extract contents of tagasaste increased with length of re-growth. The amino acid profile of tagasaste protein showed high contents of the essential amino acids leucine and lysine but lower contents of methionine and histidine. Tagasaste grown under Ethiopian highland conditions was found deficient in phosphorus, sulphur, and sodium, but had adequate amounts of calcium, potassium, zinc and iron. The average in situ potential and effective degradability of leaves were 795 and 518 g kg^{-1} DM respectively and was lowest at the 10 months harvesting stage. The in vitro gas production declined with length of re-growth. Gas production was higher for leaves followed by branches with mean value of 43.7 and 39.1 ml 200^{-1} mg DM at 24 h respectively. The high CP content, degradability and in vitro gas production of tagasaste forage reveals its high potential to be used as a protein supplement for ruminants. The studied quality parameters should be further verified using animal performance.

Introduction

In most tropical countries natural grazing lands and crop residues are the major sources of roughage, which are characterized by low crude protein (CP) content. Thus, options which increases the supply of high protein feeds to improve livestock performance is a priority in feed resource development. Forage legumes could be among the alternative feed resources and more appropriate options to produce quality feed supplements in the tropics. Identifying species which best suit the environment, the farming system and the production practices are the first steps for a successful animal feed production. The browse tree tagasaste (*Chamaecytisus palmensis*) is well adapted and productive in the highlands of Ethiopia (Getnet, 1998). Its forage is used as a feed for ruminants and has also potential as feed for monogastric animals like poultry and pigs (Snook, 1986). However, production and agronomic practices and their effect on feed quality characteristics of tagasaste forage are not available for use in livestock feeding systems. Forage production should be supported by strategies which aim to acquire the maximum possible nutrients in the biomass.

Agronomic practices including harvesting stage and seasons, phenological stages, application of fertilizer, control of pests and diseases, postharvest processing techniques and conservation practices, could substantially change the nutritive value of a given forage (Borens and Poppi, 1990; Getnet, 1998; Reddy et al., 2003). In most forage crops, especially in herbaceous and annual forage crops, delay in harvesting from the optimum stage could dramatically reduce the CP content (Buxton, 1996). This in turn could affect the level of intake and digestibility of a feed, which are the determining factors in predicting feed quality (Coleman and Moore, 2003). Similarly, pre assessment of feed quality in terms of nutrient content including CP, amino acids, fibre, minerals and *in vitro* degradability parameters help not only to be able to maximize the nutrient yield per unit area and period of time but also gives a broad spectrum on how and to which animal type

should the produced forage be fed for its efficient utilization. Especially when chemical composition is supported by biological assays of *in vitro* and *in situ* techniques, it provides a more reliable assessment on the feeding value of given forage. Therefore, the objectives of this study were to evaluate the general quality profile of tagasaste forage and assess the effect of harvesting stage and plant parts on the chemical composition including amino acids and minerals, and on the *in situ* degradability and *in vitro* gas production of tagasaste forage.

Material and Methods

Forage establishment and field layout

Tagasaste variety "MoA", which is commonly grown by farmers in the highlands of Ethiopia was established from seedlings at Holetta Research Centre (9.05^{o}N latitude and 38.5^{o}E longitude) at the beginning of the main rainy season (early July). The area is located at 2400 meters above sea level altitude and receives 921 mm annual precipitation with an average minimum and maximum air temperatures of 6.1 and 22.3^{o}C, respectively. The experimental field was an acidic (pH 5.7) drained Nitosol with an average fertility condition. Seedlings were transplanted on a ploughed field in rows spaced at one meter apart and 0.5 m between plants. Fertilizer (100 kg ha^{-1} DAP, diammonium phosphate - $(NH_4)_2HPO_4$) was applied only during seedling transplanting for better root development. After transplanting the seedlings were allowed to establish and first pruned at the age of one year. Samples were collected from the re-growths in the following two years. Harvesting management experiment was implemented in this study. In the experiment, treatments were harvesting stages of tagasaste re-growths at 4, 6, 8 and 10 months starting the beginning of the main rainy season (July). The treatments were arranged in a randomized complete block design with three replications.

Harvesting and sample processing

Tagasaste samples were harvested according to the treatments. From each plot up to 60 plants excluding the guard rows were harvested at 50 cm height above the ground. Sub-samples from the whole plant were taken and fractionated into leaves and edible branches (< 3 mm diameter). The samples were partially dried in a forced air draft oven at 60^{o}C for 48 hours. The dried samples were ground to pass through a one mm sieve size for all quality analysis, except for the *in situ* degradability, for which samples were ground to pass through a 2 mm sieve size.

Chemical analyses

The samples of tagasaste were analysed for dry matter (DM), ash, ether extract (EE) and CP according to the procedures described by AOAC (1990). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined by the detergent method described in Naumann and Bassler (1997). Amino acids were determined by a Biochrom 20 amino acid analyzer (Pharmacia Biotech., Cambridge, U.K.). The extraction of the amino acids was done according to the methods described by Naumann and Bassler (1997). Hydrolysis was done by diluted hydrochloric acid and the quantity of the amino acids present in the hydrolysate was determined by ion exchange chromatography using amino acid analyser (high pressure liquid chromatography).

Samples were made to undergo an oxidation process to protect the sulphur containing amino acids (methionine and cysteine) from partial degradation during hydrolysis.
To determine macro and micro minerals the ground plant samples were ashed at 450°C for 4 hours in a furnace. The cooled ash was digested using 20% HNO_3 on a hot plate to boiling and the digested sample was filtered through a filter paper. In the filtrate, phosphorous (P) was determined by spectrophotometer (Murphy and Riley,1962), potassium (K) and sodium (Na) calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn) and copper (Cu) by atomic absorption spectrophotometer (Houba *et al*.,1989). Sulphur (S) was determined following the procedures described by Wolf (1982).

In situ degradability

In situ degradability of samples was determined according to the procedures of Ørskov and McDonald (1979). Each feed sample weighing 3 g was transferred into nylon bags with a dimension of 6 cm x 14 cm and a porosity of 40 - 42 μm and incubated in triplicate in three rumen fistulated Boran-Friesian crossbred steers kept under maintenance diet. The sample containing nylon bags were incubated for 4, 8, 12, 24, 48, 72 and 96 hours, and were hand washed using tap water after removal from the rumen. Zero hour solubility was also estimated by hand washing samples contained in nylon bags in a similar way to the incubated feed samples. The washed samples were oven dried at 60 °C to constant weight to determine DM degradability. The *in situ* degradability parameters were fitted using the equation $P = a + b\ (1- e^{-ct})$, where P is the DM disappearance at time *t*, *a* immediately soluble (wash loss) fraction, *b* the slowly degradable fraction, and *c* the rate of degradation (Ørskov and McDonald, 1979).

In vitro gas production

In vitro gas production of tagasaste samples was determined according to the procedures of Menke and Steingass (1988). Rumen fluid was collected from two rumen fistulated Holstein-Friesian dry cows on maintenance diet. A sample of about 200 mg DM was weighed into a 100 ml capacity glass syringe calibrated for gas measurement and incubated in triplicate at 39°C using 30 ml buffered rumen fluid. The syringes were kept in a horizontal position in a continuously and gently rotating rack. The gas volume produced was recorded at 4, 8, 12, 24, 48 and 72 h. The gas production was determined in two runs for each sample. In every run, blanks (buffered rumen fluid solution without samples) and standard samples of hay and concentrate were included. The gas volume measured was corrected with the blanks and standard samples. The potential and rate of gas production was fitted to the equation $Y = b\ (1- e^{-ct})$, where Y is the volume of gas produced at time *t, b* the potential gas production and *c* the rate of gas production (Ørskov and McDonald, 1979). The metabolizable energy (ME) was estimated from the gas production data using the equation $ME = 1.242 + 0.146\ GP + 0.007\ CP + 0.0224\ EE$, where GP is the net gas production (ml 200^{-1}mg DM) in 24 h of incubation (Menke and Steingass, 1988).

Data analysis

Data collected were subjected to analysis of variance using the general linear model (GLM) procedures and mean comparisons were done by Tukey's studentized range test (SAS, 2001). The following general model was used for analysis:

$Yijkl = \mu + hi + tj + bk + pl + (h*t)ij + eijkl$, where Y is the measured response, μ = over all mean, h_i = the effect of the i^{th} harvesting year, t_j = the effect of the j^{th} treatment (harvesting stage), b_k = the effect of the k^{th} block, p_l = the effect of the l^{th} plant part, $(h*t)_{ij}$= the harvesting year and treatment (stage) interaction and e_{ijkl}= the error term.

Results and Discussion

Crude protein, ash, fibre, lignin and EE contents

The CP, ash, fibre, lignin and ether extract contents in the different fractions of tagasaste harvested at different re-growth stages are given in Table 1. Year of harvesting had significant ($P<0.05$) effect on the CP contents of leaves but not on the edible branches. The CP content in the leaves were higher ($P<0.001$) than the edible branches. Harvesting stage at 4, 6, 8, and 10 months re-growth showed no significant ($P<0.05$) effects on the mean CP content of leaves and edible branches. There were no significant interaction effect between the harvesting year and the re-growth harvesting stages.

The average CP content of tagasaste leaves found in this study was similar to reports by Umunna *et al*., (1995) and Kaitho *et al*., (1998). Most annual and perennial herbaceous forage grasses and legumes such as alfalfa dramatically decline in their CP content when the optimum harvesting stage is prolonged for short time (Buxton, 1996). Though plant maturity affected the CP level in tagasaste forage, the differences among the harvesting stages in CP content were low. This might be due to its adaptation to moisture and temperature stresses and its well developed tap root systems, which helped to maintain its vegetative growth and quality for a longer period of time (González-Rodríguez *et al*., 2005). The high and relatively stable CP level over a long period of time gives a better option to prioritize other parameters such as forage yield and anti-nutritional compounds, when determining the optimum harvesting management. It is also an advantage in designing the time of harvest when it is required and allows flexibility to be integrated in the various production systems of the farming system. The non significant interaction between harvesting year and stage is attributed to the mild weather variations in the two years and the stable CP content in tagasaste over the growing period.

Harvesting year significantly ($P < 0.05$) affected the NDF, ADF and ADL content in leaves, while in edible branches it affected only the ash content. The leaf fraction was higher in ash and EE while lower in NDF, ADF and ADL content compared to the edible branches. The edible branches contained more than two times the ADF contents of the leaves. Length of re-growth significantly ($P<0.05$) affected most of the measured chemical composition parameters. The NDF and ADF contents in the leaves were higher ($P<0.01$) at 10 months re-growth, but were inconsistent and did not show any trend in the rest of the harvesting stages. The NDF and ADF contents in the edible branch fractions were generally lower when harvested at 4 and 6 months re-growth, while higher content of both constituents were observed at 8 and 10 months re-growth. The ADL content showed an increasing trend with prolonged harvesting stage in both the leaves and edible branches.

The average NDF, ADF and ADL contents of tagasaste in this study is consistent with other reports of tagasaste grown in the highlands of Ethiopia (Tolera *et al*., 1997; El Hassan *et al*., 2000; Becholie *et al*., 2005) and in Australia (Borens and Poppi, 1990). The variation in ash, NDF, ADF, ADL and EE is generally accounted to the type of plant part and length of re-growth. The leaves are low in fibre compared to branches or stems, and plant maturity, low moisture and high temperature stresses increased fibre content (Buxton, 1996), which is in agreement with the results of this study. In comparison to other forage legume species, the NDF, ADF and ADL contents of tagasaste forage is higher than *Sesbania sesban* and similar with *Leucaena leucocephala* and *Leucaena pallida* (El Hassan *et al*., 2000; Melaku *et al*., 2004). Forage legumes with low level of fibre contents are desired when used as supplements to low protein content roughages such as crop residues, while a high fibre content of forage legumes is an important problem next to the anti-nutritional compounds when feeding forage legumes to monogastric animals (DeMello, 1991; Lindberg and Andersson, 1998; Noblet and Goff, 2001).

Table 1. Dry matter (DM), ash, neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), ether extract (EE) and crude protein (CP) contents (g kg^{-1} DM) of tagasaste leaves and edible branches harvested at 4, 6, 8 and 10 months of re-growth age.

Harvesting year	Plant part	Harvesting stage (months)	DM (g kg^{-1})	Ash (g kg^{-1})	NDF (g kg^{-1})	ADF (g kg^{-1})	ADL (g kg^{-1})	EE (g kg^{-1})	CP (g kg^{-1})
2nd year Re-growth	Leaf	4	933.9	59.3^{ab}	272.7^{b}	183.1^{ab}	58.1^{c}	19.8^{b}	201.3^{b}
		6	938.7	51.6^{c}	368.4^{a}	183.3^{ab}	64.4^{b}	24.4^{b}	189.4^{b}
		8	941.8	54.8^{bc}	357.4^{a}	178.3^{b}	64.3^{b}	38.9^{a}	204.5^{ab}
		10	942.3	60.8^{a}	366.0^{a}	188.1^{a}	68.7^{a}	41.4^{a}	221.9^{a}
2rd year Re-growth	Branch	4	939.6	30.9^{ab}	664.6	478.4^{a}	81.9^{c}	5.7^{c}	93.6
		6	937.5	30.8^{ab}	647.6	450.5^{b}	87.2^{b}	10.1^{b}	87.5
		8	942.6	28.8^{b}	671.4	466.8^{ab}	88.4^{ab}	14.8^{a}	88.7
		10	939.6	32.4^{a}	667.9	482.8^{a}	91.1^{a}	14.6^{a}	88.8
3nd year Re-growth	Leaf	4	939.3	54.9^{ab}	385.1^{b}	199.0^{b}	66.1^{c}	25.0	240.9
		6	940.0	56.5^{a}	335.2^{c}	181.4^{c}	63.3^{c}	31.1	242.0
		8	936.7	56.8^{a}	403.2^{b}	205.2^{b}	71.8^{b}	28.1	235.1
		10	936.5	50.8^{b}	431.7^{a}	218.5^{a}	79.2^{a}	28.1	241.8
3rd year Re-growth	Branch	4	936.7	35.0	652.1^{c}	494.6^{a}	85.9^{b}	7.9^{c}	96.0
		6	935.4	32.9	629.0^{d}	458.3^{b}	83.5^{b}	10.4^{b}	86.6
		8	933.7	35.2	669.0^{b}	468.4^{b}	94.4^{a}	12.3^{a}	97.3
		10	933.9	32.1	700.4^{a}	491.9^{a}	92.9^{a}	10.4^{b}	95.0
Effect of year	Leaf		NS	NS	*	*	*	NS	*
	Branch		NS	*	NS	NS	NS	NS	NS

$^{a-c}$ Means within a column and within a year and plant part with different letters vary significantly ($P<0.05$)

* $P<0.05$, and NS – non significant,

Amino acid profile

The fresh forage (about 80% leaf and 20% edible branches) and dried tagasaste forage (about 98% leaf) were not significantly different in their contents of the different amino acids (Table 2). Similarly the re-growth harvesting stage at 6 and 10 months did not significantly affect the contents of the different amino acids except for proline, which was higher at 10 months harvesting stage. The content of the most essential amino acids leucine and lysine in tagasaste forage were found to be relatively higher as compared to the other amino acids. The non essential amino acids glutamine, asparagine and proline are also found in higher concentrations. Taking lysine as a reference (1 unit) for the ideal protein, most of the amino acids have a coefficient of more than 0.7, while cysteine and the essential amino acids methionine and histidine were found to be lower (< 0.4).

Table 2. Amino acid profile of fresh and dried tagasaste forage harvested at 6 and 10 months of re-growth

	Regrowth harvesting stages (months)				
	6		10		
Amino acid (g kg^{-1} DM)	Fresh[1]	Hay	Fresh	Hay	Mean
Cysteine	3.65	2.88	2.61	3.07	3.05
Methionine	4.94	3.84	3.63	3.95	4.09
Asparagine	18.97	17.67	17.62	18.71	18.24
Threonine	8.46	8.84	8.32	9.12	8.69
Serine	9.40	9.49	9.27	9.99	9.54
Glutamine	19.81	20.57	19.26	20.84	20.12
Proline	11.56	12.28	14.72	17.17	13.93
Glycine	9.08	9.45	8.86	9.70	9.27
Alanine	9.68	10.49	9.41	10.44	10.01
Valine	9.56	10.07	9.73	10.69	10.01
Isoleucine	7.44	8.03	7.56	8.30	7.83
Leucine	15.05	16.07	14.75	16.18	15.51
Tyrosine	7.55	8.04	7.56	8.44	7.90
Phenylalanine	9.54	10.08	9.30	10.54	9.87
Histidine	4.55	4.52	4.84	5.15	4.77
Lysine	12.36	13.20	12.27	13.01	12.71
Arginine	9.37	9.76	9.18	10.01	9.58

[1]The fresh tagasaste (edible forage) was freeze dried and composed of 79% leaf and 21% edible branch while the hay was sun dried with about 98% leaf and 2% fine branches.

There were no any significance effect of harvesting stage (6 and 10 months) and between the fresh and dried (hay) tagasaste forage except for the amino acid *proline*.

The amino acid profile of tagasaste forage is remarkable in its high contents of most important essential amino acids such as lysine and leucine. In ruminants proteins and amino acids are first subjected to microbial degradation in the rumen making it difficult to predict the quality and quantity of amino acids that are absorbed by the animal. Hence, dietary amino acids in ruminant nutrition is important if they are used as a bypass protein (Limin and Rode, 1996) and amino acids methionine and lysine are generally the first limiting amino acids for ruminants. Though tagasaste is high in lysine its methionine content is relatively low. Native birds in New Zealand notably *kereru* (wood pigeon), feed on the foliage and flowers of tagasaste in winter (Stace, 1998), which suggests its potential to be used as feed for poultry and other monogastric animals. Snook (1986) indicted the use of tagasaste for feeding monogastric animals including pigs and poultry. Thus,

tagasaste could be an alternative source of green forage, which could easily be available during the dry season for smallholder backyard poultry production in developing countries. However, in other experiments, feeding of legume tree foliages to monogastric animals has shown limits due to various anti-nutritional compounds, which are toxic to animals (DeMello, 1991). Hence, the effect of the various anti-nutritional compounds and the overall potential of tagasaste in feeding monogastric animals require further investigation.

Minerals

The mineral contents of the edible fractions of tagasaste (leaves and branches) harvested at different stages are given in Table 3. Calcium, Mg, Zn and Fe contents were higher in the leaves compared to the edible branches, while Cu, Na and K were found in higher concentration in edible branches. The length of re-growth significantly ($P<0.05$) affected the concentration of minerals in tagasaste forage. The Ca, Mg, and S contents increased with prolonged re-growth stages while P and K were comparatively higher for the 4th and 10th months' re-growth in the leaf fractions. Sodium content in the leaves significantly declined as harvesting stage prolonged. The micro minerals Zn, Fe and Cu in tagasaste leaf fractions were not affected by harvesting stage. The ratio of Ca to P was about 8:1 and 4.6:1 in the leaves and branches, respectively

It is reported that tagasaste forage is deficient in P, Na and S (Borens and Poppi, 1991; Bonsi *et al*., 1995), which is in agreement with the result of this study. Low level of K in tagasaste was reported by Bonsi *et al*., (1995) as compared to other browse. Based on dietary requirements of sheep (NRC, 1985) and dairy cattle (NRC, 2001), tagasaste produced under Ethiopian highland condition can fulfil the Ca, K, Fe and Zn requirements of both sheep and dairy cattle. The P content of tagasaste was found to be below the requirements for both sheep and dairy cattle. The calcium to phosphorous ratio in both the leaf and edible branches is also high compared to the recommended ratio of about 1:1 to 2:1 (McDonald *et al*., 2002). Similarly, Na, S and Mg levels in tagasaste are below the level of requirements of sheep and dairy cattle. The major feeds in tropical regions such as pasture, hay, barley and crop residues are deficient in P content (Khalili, 1991; Gizachew and Smit, 2005). Thus, a concentrate supplements with high P content such as noug (*Gizotia abyssinica*) seed cake (Gizachew and Smit, 2005) or a mineral blocks is required to correct for the P deficiencies in the basal feeds and tagasaste.

Table 3. Macro and micro mineral contents in the leaves and edible branches of tagasaste forage harvested at different re-growth stages

		Re-growth harvesting stage (months)					
Minerals	Plant part	4	6	8	10	Mean	SEM
P (g kg^{-1})	Leaf	1.07^{ab}	0.98^{ab}	0.91^{b}	1.10^{a}	1.02	0.03
	Branch	0.65^{a}	0.53^{b}	0.41^{b}	0.71^{a}	0.58	0.04
Ca (g kg^{-1})	Leaf	6.50^{b}	5.73^{b}	9.85^{a}	9.97^{a}	8.01	0.63
	Branch	1.53	1.86	2.20	2.02	1.90	0.17
K (g kg^{-1})	Leaf	10.00^{a}	8.40^{b}	8.33^{b}	9.60^{a}	9.08	0.26
	Branch	13.60^{a}	10.70^{b}	9.70^{b}	13.10^{a}	11.78	0.53
Na (g kg^{-1})	Leaf	0.10^{a}	0.06^{ab}	0.02^{b}	0.02^{b}	0.05	0.01
	Branch	0.26	0.15	0.26	0.24	0.23	0.03
Mg (g kg^{-1})	Leaf	0.74^{b}	0.75^{b}	1.33^{ab}	1.40^{a}	1.06	0.12
	Branch	0.35	0.42	0.60	0.41	0.45	0.04
S (g kg^{-1})	Leaf	1.97	1.70	1.87	2.17	1.93	0.12
	Branch	1.73^{a}	1.37^{ab}	1.17^{b}	0.70^{c}	1.24	0.13
Zn (mg kg^{-1})	Leaf	67.27	70.60	71.20	75.53	71.15	2.66
	Branch	26.20^{c}	30.20^{bc}	37.93^{ab}	42.40^{a}	34.18	2.29
Fe (mg kg^{-1})	Leaf	416.7	362.7	421.3	564.0	441.2	34.7
	Branch	288.7	432.0	484.0	383.3	397.0	29.2
Cu (mg kg^{-1})	Leaf	8.67	6.00	10.67	10.00	8.84	0.83
	Branch	9.33	9.67	12.00	10.00	10.25	0.97

$^{a-c}$ Means in a row with different letters vary significantly (P<0.05); P (Phosphorus), Ca (Calcium), K (Potassium), Na (Sodium), Mg (Magnesium), S (Sulphur), Zn (Zinc), Fe (Iron), Cu (Copper),

In situ degradability

The average *in situ* degradabilities of tagasaste leaves were higher than edible branches (Table 4), with an average potential degradability (PD) of 795 and 543 g kg^{-1} DM, and a rate of degradation of 0.041 and 0.028 h^{-1}, respectively. Harvesting stage significantly affected the different degradability parameters. The wash loss in the leaves was significantly lower (P<0.05) at the 8th months re-growth stage, while in the edible branches it significantly (P<0.05) declined with increased maturity. The PD in the leaves was not significantly different at the different length of re-growth, but the effective degradability (ED) was significantly lower (p<0.01) at the 10th months harvesting stage. In the edible branches, both PD and ED significantly declined (P<0.05) with re-growth length. The effect of re-growth stage on the degradability at each of the incubation hours was significantly (P<0.05) different and the trend was very similar at the different incubation hours. In most of the incubation hours degradability of leaves was higher at the 4th, 6th and 8th months but significantly (P<0.05) lower at the 10 months harvesting stage. Edible branches showed a more pronounced decline of degradability with length of re-growth. From the average PD, about 69% of leaves and 62% of edible branches was degraded during the first 24 hours.

Table 4. *In situ* degradability (g kg^{-1} DM) parameters of tagasaste leaves and edible branches harvested at different stages of re-growth.

Sample	Leaf				Branch			
	Harvesting stage (months)				Harvesting stage (months)			
Treat	4	6	8	10	4	6	8	10
Degradability parameters								
A	15.6^{a}	18.4^{a}	13.8^{b}	16.6^{a}	18.0^{a}	20.1^{a}	11.0^{b}	8.9^{b}
B	62.2^{b}	62.2^{b}	65.3^{a}	64.8^{a}	39.1^{a}	35.1^{b}	41.8^{a}	43.3^{a}
C	0.043^{ab}	0.041^{ab}	0.053^{a}	0.027^{b}	0.020	0.030	0.034	0.029
PD (g kg^{-1} DM)	778	806	781	814	571^{a}	551^{a}	528^{b}	522^{b}
ED (g kg^{-1} DM) (0.03 h^{-1})*	523^{a}	542^{a}	531^{a}	475^{b}	337^{b}	374^{a}	333^{b}	300^{c}
Degradability (g kg^{-1} DM)								
Incubation time(h)								
4	255^{ab}	278^{a}	220^{b}	233^{b}	211^{b}	240^{a}	164^{c}	136^{d}
8	337^{b}	357^{a}	327^{bc}	293^{c}	239^{b}	274^{a}	211^{c}	177^{d}
12	407^{a}	425^{a}	413^{a}	347^{b}	264^{b}	305^{a}	252^{b}	214^{c}
24	557^{a}	572^{a}	585^{a}	478^{b}	330^{bc}	378^{a}	345^{b}	303^{c}
48	700^{a}	718^{a}	726^{a}	639^{b}	423^{b}	466^{a}	448^{a}	412^{b}
72	750^{a}	773^{a}	766^{a}	723^{b}	480^{ab}	509^{a}	493^{a}	467^{b}
96	768	793	777	767	515^{a}	531^{a}	513^{a}	494^{b}

$^{a-c}$ Means in a row and within the plant part with different letters vary significantly (P<0.05); *a* – immediately soluble (wash loss) fraction; *b* - the slowly degradable fraction; *c* – the rate of degradation; PD – potential degradability; ED - effective degradability; * - Out flaw rate - fraction/hour (Umunna *et al*., 1995)

The *in situ* DM degradability of tagasaste forage was similar to results of other experiments (Ummuna *et al*., 1995; Kaitho *et al*., 1998; El Hassan *et al*., 2000). In these reports the potential and effective degradability for the different forage crops was in the descending order of *Sesbania*, tagasaste and *Leucaena*. On the other hand, Bonsi *et al*., (1995) reported lower values for tagasaste compared to *Sesbania* and *Leucaena.* The higher DM degradability of the leaves compared to the edible branches could be mainly due to the high CP and lower fibre content in the leaf fractions. Though harvesting stage had a significant effect on the DM degradability, it did not show a trend with re-growth plant maturity. The rate of degradation of tagasaste leaves at an outflow rate of 2 and 5%/h found in this study was consistent with other reports (Bonsi *et al*., 1995; Ummuna *et al*., 1995; Kaitho *et al*., 1998; El Hassan *et al*., 2000). In all the reports, rate of degradation of tagasaste was lower than *Sesbania* and higher than *Leucaena* forages.

In vitro gas production

The gas production at 24 and 48 hours of incubation and the potential digestibility (*b*) was higher (P<0.01) in the leaves compared to the edible branches and the rate of fermentation (*c*), was leaves was faster than the edible branches. The volume of gas produced declined significantly (P<0.01) as the re-growth stage extended from 4 to 10 months in the leaf and edible branches fractions. About 68% and 83% of the total potential

gas production of the leaves was produced during the first 12 and 24 hours of incubation, respectively. The values in the edible branches were 55% and 79%, respectively. Harvesting stage did not affect the potential gas production *(b)* significantly. The metabolizable energy (ME) content calculated from the gas production was highest in the leaves followed by the edible branches. The ME content did decline (P<0.01) with length of re-growth in both the plant parts.

Table 5. Volume of *in vitro* gas production (m l 200^{-1} mg DM) at the different hours of incubation, potential gas production *(b)*, rate of gas production *(c)* and estimated metabolizable energy (ME) of tagasaste leaves and edible branches harvested at different re-growth harvesting stages

Plant Part	Harvesting Stage (months)	Incubation hours 12	24	48	72	*b*	*c*	ME (MJ)
Leaf	4	40.3^{a}	48.6^{a}	54.0^{a}	56.3^{a}	56.6^{a}	0.118	8.52^{a}
	6	35.8^{b}	43.2^{b}	48.4^{b}	50.3^{b}	52.5^{b}	0.113	7.74^{b}
	8	34.7^{b}	42.4^{b}	46.9^{bc}	49.1^{bc}	51.9^{b}	0.111	7.66^{b}
	10	33.9^{b}	40.4^{b}	44.7^{c}	46.6^{c}	50.4^{b}	0.120	7.39^{b}
Branch	4	29.0^{a}	41.9^{a}	50.0^{a}	52.2^{a}	51.1^{a}	0.066	7.43^{a}
	6	29.1^{a}	40.8^{ab}	49.0^{a}	51.6^{ab}	51.0^{a}	0.069	7.28^{ab}
	8	26.5^{ab}	37.4^{bc}	47.2^{ab}	51.0^{ab}	49.9^{a}	0.056	6.79^{bc}
	10	25.6^{b}	36.1^{c}	44.9^{b}	48.1^{b}	46.5^{b}	0.058	6.60^{c}

$^{a-c}$ Means in a column and within the plant part with different letters vary significantly (P<0.05); *b* - potential gas production; *c* – rate of gas production; ME – metabolizable energy calculated as *ME = 1.242 + 0.146 GP + 0.007 CP + 0.0224 EE*, where GP is the gas production ml 200^{-1}mg DM in 24 hrs of incubation, CP-crude protein content and EE the ether extract (Menke and Steingass, 1988)

Tagasaste is among the forage legumes that produced the highest *in vitro* gas in comparison to 39 tropical browse trees (Getachew *et al*., 2002). Other experiments had also indicated that incubation of tagasaste resulted in higher or similar gas production in comparison to the widely grown browse trees in Ethiopia including *Sesbania* and *Leucaena* (Bonsi *et al*., 1995; El Hassan *et al*., 2000). The reduction of the gas volume produced with increasing re-growth harvesting stage of tagasaste forage might be due to the availability of immediately fermentable carbohydrates in the young tagasaste forage, which might decline with maturity. In addition, other inhibiting factors or anti-nutritional compounds such as tannins might have increased with plant maturity and seasonal changes (Getnet*et al*., 2006). Generally, there is a positive indicative potentials of tagasaste to be used as a supplement for ruminants. However intake, *in vivo* digestibility and performance responses with tagasaste feeding are usually comparatively lower than other browse trees with relatively lower *in vitro* gas production (Osuji and Odenyo, 1997; El Hassan *et al*., 2000). The reasons are not clearly understood and need further investigations.

Conclusions

Tagasaste forage had a high CP content maintained for prolonged re-growth stages, while the fibre and lignin contents increased with re-growth maturity Tagasaste forage is high with the essential amino acids lysine and leucine. Tagasaste forage is deficient with phosphorus, sulphur and sodium and had adequate amount of potassium, calcium, iron and zinc. The forage has high *in situ* degradability and *in vitro* gas productivity. The chemical composition, *in situ* degradability and *in vitro* gas production parameters demonstrated tagasaste to be a potential protein source with high degradability for ruminants. The result of this study should be further verified using animal performance trials.

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