Chapter

Nutritional Potential of *Erythrina edulis* as a Forage Alternative for Supplementation in Feeding Ruminants

Oscar Giovanny Fuentes Quisaguano
and Santiago Alexander Guamán Rivera

Abstract

The main limiting factor in livestock production is fluctuation in the quantity and quality of forage resources. Therefore, it is necessary to determine the chemical composition and degradation kinetics of the feed that is used for ruminant feeding regime. *Erythrina edulis* (*Euphorbia edulis*) is a multipurpose legume plant with high nutritional quality and possibly the capacity to meet dairy ruminant requirements. The study showed that the two phenological stages leaves (SV) and sheath without seed (SF) had greater CP contents than other sources than are typically used for feeding ruminants. Nevertheless, the SF had lower fiber contents, so the highest DM and CP degradation parameters than SV, it was obtained. Consequently, *E. edulis* might be considered as a forage alternative for inclusion in ruminant feeding.

Keywords: shrubs, phenological stages, chemical composition, degradability, *Erythrina edulis*

1. Introduction

The sustainability of livestock farming systems plays a central role in addressing policies aimed at sustained and planned rural development [1]. In Latin America, the dairy sector has been more dynamic in the past 20 years than in the rest of the world with an average growth of 12.5% for its 3.15 million milk producers [2]. Dairy production in Ecuador is concentrated mostly in the Andean highlands, the Sierra Region [3]. In addition, FAO [4] stated that in Ecuador the cattle breeding systems tend to be extensive (5 million hectares dedicated to livestock with 4.1 million cattle) with low productivity (5.38 liters of milk per cow) and with poor use of pastures.

The crude protein (CP) and energy requirements for ruminants are the most important limitans in the livestock industry worldwide [5–8]. Soybean products are commonly fed concentrates in highly productive ruminants because of their high content of protein and good profile in essential amino acids [9–11], although the high

global demand has resulted in price increases. In the Ecuadorian Highland Region approximately 57% of livestock farms are less than 10 hectares, and they are managed as smallholder production with low intensification levels and economic incomes [4], so in these production systems the use of soybean meal is too expensive. According to Camero et al. [12], feeding leguminous fodder that is high in protein, can improve rumen fermentation parameters leading to increased digestibility and intake of low-quality feeds, and hence improved animal production. For this reason, for the Ecuadorian Andean Region is necessary to research new forage alternatives to use in ruminant feeding. In this sense, trees and shrubs have had an increasing interest due to their high potential for supplying fodder which provides greater nutritive value and environmental services [1, 13–15].

Erythrina edulis is a leguminous plant with a wide range of uses from human (mainly seeds) to animal (forage) diets, as well as in the recovery of the soil nitrogen content [16–18]. Furthermore, this species has a higher protein content (ranging from 18 to 25%) than other legumes and is similar in terms of quality to egg protein [19–21]. South America countries such as Colombia, Peru, and Venezuela have already studied this species and its potential for use in animal production [12, 18, 22–24]. However, little available information on this multipurpose plant in the context of Ecuadorian conditions is available, despite that, *E. edulis* can be found as a wild plant, the lack of knowledge on its properties and potential for livestock nutrition, this species has gone unnoticed with a latent danger of extinction.

2. Materials and methods

The study was performed in (INIAP), Pichincha, Ecuador and all experimental procedures were approved by them.

2.1 Study area

The study was carried out in Valle de los Chillos, Pichincha province, located in the northern Highland region of Ecuador. The soil type in the area of study is Molisols, at 45.88%, followed by Andisols at 17.88% [25]. The climatic conditions predominant in this zone are, on average temperature (22.9°C), rainfall (1200 mm/year), relative humidity (78%), and an altitude of 2200 m.a.s.l.

2.2 Experimental design, collection, and preparation of samples

For the experimental procedure, 150 vegetative stakes of *E. edulis* were planted with a 6 × 6 m distance between them. After 2 years of establishment, the trees of *E. edulis* were randomly divided into two equilibrate groups to assess the vegetative stage (SV = leaf) and fructification stage (SV = previously seed was removed). The leaf samples were cut 50–60 cm from the tip of the second youngest branch at the top of each tree. Thereafter, the 60 samples of each phenological stage were pooled, according to SV and SF, giving 9 samples, and then frozen at −20°C for further analysis. Before analyses, samples were conditioned at 60°C for 48 h, and then milled and homogenized through a cyclone mill (Model 4 Wiley Mill, Thomas Scientific, Swedesboro, NJ, EUA) with a 1 mm mesh, and for *in situ* rumen incubation, samples were milled with a 2 mm mesh.

2.3 Chemical analysis

All determinations were performed, according to official reference methods [26]. Thus, Dry matter (DM) was determined at 103°C for 24 h, and ashes burnt at 550°C for 5 h. Whereas wall cell components such as crude fiber (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) using the Ankom200 Fiber Analyzer (Ankom Technology, Fairport, NY, USA). Furthermore, Crude protein (CP) was calculated as a percentage of N × 6.25 using the Kjeldahl method. Besides this, phenols and total tannins were determined using the Folin–Ciocalteu method, before and after the treatment of extracts with polyvinylpolypyrrolidone [27].

2.4 In situ rumen incubation

For this study, two 4-year-old Holstein non-lactating cows, (650 ± 5.0 kg BW) equipped with permanent rumen fistula were used. The cows, were subjected to a 15-d adaptation period, being fed (2% of BW) with only *Pennisetum clandestinum* (chemical composition, as % DM; ash, 7%; CP, 13.2; NDF, 38%; ADF, 26%; CF, 25.0%; and EE, 1.53). Throughout the experiment, the cows had free access to mineral and vitamin block (Na, 12 g; Ca, 20 g; P,10 g; Mg, 0.10 g; S, 0.29 g; Zn, 0.16 g; Mn, 0.12 g; Fe, 0.12 g; I, 0.020 g; Co, 0.002 g; Se, 0.003 g; Zinc, 0.16 g; and Cu, 0.002 g; Favetex, Favesal, Ecuador, milk production).

The DM and CP *in situ* degradability were carried out by incubating nylon bags (Ankom Technology Corporation, Fairport, NY, USA) in the rumen, which was 10 × 20 cm, 47 μm, pore size, containing 10 g of samples. Previously, zero-hour disappearance was estimated by washing duplicate bags containing feed samples in cold water (without passing through the rumen). After that, the samples were incubated in duplicate in the rumen for 3, 6, 12, 24, 36, 48, and 72, h, according to Aufrère [28] and NRC [29], before feeding at 0830 h. Once the bags were removed from rumen incubation, were immediately washed with clean water several times (three washing cycles of 5 min). They were also frozen at −20°C for 24 h to halt fermentative activity. After all this, the bags were dried at 60°C for 48 h, weighed, and so the residues were mixed for chemical analysis. Finally, using the equation of Orskov and Mcdonald [30], DM and CP degradation parameters were calculated:

$$D = \alpha + b(1 - e - \mathrm{ct}). \tag{1}$$

where D is the fraction corresponding to the disappearance of either DM or CP at time t; α is an intercept representing the DM or CP soluble fraction; b is the fraction of insoluble but potentially degradable DM or CP; c is the rate of disappearance of fraction b; t is incubation time. The non-linear parameters α, b, and c were estimated using an interactive least-squares procedure of SAS (v. 9.4; SAS Institute Inc., Cary, NC). Therefore, the effective degradability (ED) of DM and CP was calculated using Equation:

$$\mathrm{ED} = \alpha + [\mathrm{bc}/(c + k)], \tag{2}$$

where α, b, and c are the same parameters as described earlier, and k is the estimated solid passage rate. In this study, we reported a k 6%/h for most lactation feeding conditions INRA [31], and according to low–middle–high level of intake (2, 5, and 8%/h, respectively).

2.5 Statistical analyses

Firstly, all data were checked with a normality test and then analyzed under a general linear model, using the GLM procedure of SAS v. 9.4 (SAS Institute Inc., Cary, NC). The means were determined using the PDIFF option of SAS, and Tukey's multiple range tests were used to compare means between SV and SF. Statistical differences were declared at $p < 0.05$, and tendencies at $p < 0.10$.

3. Chemical composition of leaves and sheath from *Erythrina edulis*

The chemical determinations of leaves (SV) or sheath without seed (SF) from *E. edulis*, are shown in **Table 1**. The SV had 61% greater DM content than SF (31.4 vs. 12.2 ± 5.0%; $p = 0.009$), but its ash content was 27% higher compared to SF (10.5 vs. 7.7 ± 1.40%; $p < 0.001$; **Table 1**). Besides this, the SV showed a greater CP content than the obtained in SF (28.7 vs. 20.3 ± 2.59; $p = 0.022$; **Table 1**), but no differences in CF (24 ± 3.15%, on average; $p = 0.50$) and E.E (1.3 ± 0.21%, on average, $p = 0.50$) contents between them, were observed (**Table 1**).

On the other hand, lower NDF (42.1 vs. 62.4 ± 8.60%; $p = 0.021$) and ADL (6.4 vs. 13.8 ± 2.07%; $p = 0.007$) contents in SF than SV were observed, with a trend in the ADL content (36.2 vs. 51.2 ± 7.98%; $p = 0.080$; **Table 1**). As for nutritive values, differences were observed in NE_L values between both studied stages (1.43 vs. 1.47 ± 0.06 Mcal kg/DM; $p = 0.010$; **Table 1**), while that MP content showed a tendency (1050 vs. 1227 ± 109 g/d; $p = 0.070$; **Table 1**).

Regarding antinutritional factors, the different metabolites did not differ between both studied stages ($p = 0.80$–0.21; **Table 1**), being their averages, for phenols (0.7 ± 0.11%), steroids (0.5 ± 0.10%), alkaloids (0.6 ± 0.11%) or saponins (0.7 ± 0.13%). The mineral contents observed in *E. edulis* differed according to the phenological stage, as shown in **Table 1**. Although the Na content did not vary between both studied stages (0.02 ± 0.01%, on average; $p = 0.62$), however, SF had greater P (0.31 vs. 0.19 ± 0.07%; $p = 0.04$) and K (3.0 vs. 1.3 ± 0.39%; $p = 0.05$) contents than SV, but with a 93% lower Ca content (0.1 vs. 1.4 ± 0.39%; $p = 0.05$; **Table 1**).

According to McDonald et al. [32], the chemical composition is highly correlated with feed digestibility. For this reason, in the grazing livestock systems, the forages should meet nutritional requirements for milk and meat production at a cheaper cost [33, 34]. This study showed that the vegetative stage (SV) had greater DM content than the fructification stage (SF), which was similar to the one found by Naranjo [35]. Consequently, the leaves of *E. edulis* will have greater DM content than the reported for *P. clandestinum* (12.0%), *Dactylis glomerata L.* (23.8%), and *Lolium perenne* (26.1.0%) which are the most important grasses in feeding ruminants in the livestock systems in the Andean region [36], although these values differ when compared for SF (12.2%). Despite huge differences in DM contents between both phenological stages, the SF showed a lower mean ash value than SV with clear differences in OM content. Additionally, as was expected, the EE values were low, as is typical for temperate climate forages [34, 37].

According to Schwab and Broderick [38] and Pfeffer and Hristov [39], CP content is essential for multiple organic functions and also serves as a substrate for rumen bacteria [40]. Additionality, McDonald et al. [32] and Gosselink et al. [41], revealed that there is a positive relationship between protein intake and the digestibility of

Item	*Erythrina edulis*		SEM	*p*-value
	SV[1]	SF[2]		SV vs. SF
DM at 60°C	31.4	12.2	5.0	0.009
Composition, % DM				
OM	89.5	92.3	0.89	0.020
Ash	10.5	7.7	1.40	0.001
CP	28.7	20.3	2.59	0.022
CF	24.9	23.1	3.15	0.50
NFE[3]	35.8	48.9	5.81	0.003
NDF	62.4	42.1	8.60	0.021
ADF	51.2	36.2	7.98	0.080
ADL	13.8	6.4	2.07	0.007
EE	1.5	1.1	0.21	0.50
NE⊠, Mcal kg/DM	1.43	1.47	0.06	0.010
MP[4], g/d	1053	1227	109	0.070
Antinutritional factors, % in DM				
Phenols	0.7	0.6	0.11	0.80
Steroids	0.5	0.5	0.10	0.53
Alkaloids	0.7	0.5	0.11	0.50
Saponins	0.7	0.7	0.13	0.21
Minerals, % in DM				
Ca	1.4	0.1	0.39	0.05
P	0.19	0.31	0.07	0.04
K	1.3	3.0	0.39	0.05
Na	0.02	0.02	0.01	0.62

[1]*SV, leaves.*
[2]*SF, sheath without seeds.*
[3]*NFE, N-free extract (or non-fiber carbohydrates) = OM − CP − CF.*
[4]*MP, was calculated based on 13 kg of DMI, according to NRC (2001); SEM, standard error of the mean.*

Table 1.
Chemical composition of Erythrina edulis *(leaves and sheath without seed).*

feed. Overall, the two studied phenological stages showed high CP contents (>20% on DM basis) in comparison to the common grasses used in the Andes region (*P. clandestinum*, 13.2%; *D. glomerata L.*, 18.4%; and *L. perenne*, 17%, respectively). In the same way, our CP contents obtained in *E. edulis* are similar to the reported for other legume plants *Medicago sativa* (22%) and *Trifolium pratense* (23%), respectively [36]. Additionality, our results were similar to those reported by Rosales (CP, 25%) [13], Bedoya et al. (CP, 18%) [16], Intiquilla et al. (CP, 22%) Perez et al. (CP, 20%) [22], and Pérez et al. (CP, 23%) [42], when they determined CP contents in leaves of *E. edulis.* Some studies have showed that, CP contents less than 7% in DM basis, are not adequate for feeding ruminants [43–45]. Based on our results, the *E. edulis* had enough CP contents to supply the requirements of protein and ammonia need by rumen

microbial [40, 45, 46]. Possibly, this could explain the no correlations detected between CP contents and DM degradability for SV (p = 0.97) and SF (p = 0.95), as shown in **Table 2**.

With regard to the fiber contents, a study with leaves of *E. edulis* reported similar NDF contents (61 vs. 62%) to our work [13], and greater compared to those obtained by Naranjo [35] (62 vs. 50%). Whereas other researchers have reported in other varieties of *Erythrina (indica, subumbrans, and variegata)* lower NDF contents (54%, on average, on DM basis) than *E. edulis* [12, 18]. Positive correlations were detected between CP and NDF contents (r = 0.99; $p < 0.001$; **Table 2**), such as it has been seen in studies with pastures.

In the same way, Rosales [13] and Naranjo [35] reported lower ADF contents than our study (ranged from 45 to 26%), but this last author worked with other varieties, so cannot be comparable. Anyhow, in this work, SF showed lower ADF contents that above mentioned studies. The NDF stimulates the rumination and salivation, being important for remaining the normal rumen function [47, 48]. Nevertheless, negative correlations have been observed on DMI when NDF contents is above the limit require for ruminants (35–28%, in DM basis) [49, 50]. For this reason, the NDF content of forages is a good predictor to know its gut fill capacity, reflecting its nutritional value [51].

Differences on chemical composition between studied phenological stages, were reflected in the nutritive value, as shown in **Table 1**. The NE_L contents were greater in SF than SV (NE_L, 1.47 vs. 1.43 ± 0.06 Mcal kg/DM; p = 0.010) with a tendency in the MP contents (1227 vs. 1053 g/d; p = 0.070). Analyzing the correlations, the NE_L contents in SV were positively correlated with OM, CP, NFE and NDF (r = 0.99; $p < 0.001$) contents, but no correlated for SF (r =–0.99; $p < 0.001$). On the contrary, MP contents showed be positively correlated with CP, NFE and NDF contents in both phenological stages (r = 0.99; $p < 0.001$), as shown in **Table 2**.

Effects of condensed tannins on feeding efficiency, N losses and animal health are highly relevant, and a greater understanding of how grazing management might be refined to enable these potential benefits to be realized is critical [15, 52]. Several studies [43, 52–54] stated that temperate legumes contain moderate levels of secondary compounds, such as condensed tannins and flavonoid which could reduce environmental problems by increasing nitrogen use efficiency in protein utilization. In this sense, several studies have showed that antinutritional factors at low concentrations (20–40 g kg/DM) are nutritionally beneficial through decreased degradation of dietary protein in the rumen, and increase protein availability for digestion and absorption leading to good animal performance [15, 44]. Based on these evidence, *E. edulis* in both phenological stages showed lower antinutritional levels (<2% in DM basis) which was similar to the reported by Rosales [13]. Therefore, theoretically, the studied phenological stages (SV and SF, respectively) should not represent a nutritional problem in feeding ruminants according with Moore et al. [34] and Mehrez and Keely [55]. Although, we hypothesized that the latex or resins presents in the plant could inhibit the initial colonization of rumen microbes. Anyway, it must be confirmed with more studies.

4. Ruminal degradability data of DM and CP from *Erythrina edulis* according to different incubation times

Ruminal degradability data of DM and CP of *Erythrina edulis*, are shown in **Table 3**. Statistical differences in the DM degradability at 24/h between SV vs. SF

Stages		DM	OM	Ash	CP	CF	NFE	NDF	ADF	ADL	EE	NE	MP
SV	DMd	0.017 0.94	–0.008 0.97	–0.008 0.97	–0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97	– 0.008 0.97
	CPd	– 0.05 0.81	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64	0.11 0.64
	DM		– 0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02	–0.50 0.02
	OM	– 0.50 0.02		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	Ash	–0.50 0.02	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	CP	–0.50 0.02	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	CF	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	NFE	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	NDF	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	ADF	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001
	ADL	–0.50	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001
	EE	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001
	NE	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001
	MP	–0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	

Stages		DM	OM	Ash	CP	CF	NFE	NDF	ADF	ADL	EE	NE	MP
SF	DMd	− 0.024 0.91	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	− 0.012 0.95	0.012 0.95	− 0.012 0.95
	CPd	0.056 0.80	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	0.11 0.62	− 0.11 0.63	0.11 0.62
	DM		0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	0.50 0.02	–0.50 0.02	0.50 0.02
	OM	0.50 0.02		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	Ash	0.50 0.02	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	CP	0.50 0.02	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	CF	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	NFE	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	NDF	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	ADF	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	0.99 0.001	–0.99 0.001	0.99 0.001
	ADL	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		0.99 0.001	–0.99 0.001	0.99 0.001
	EE	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001		–0.99 0.001	0.99 0.001
	NE	–0.50 0.02	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001	–0.99 0.001		0.99 0.001
	MP	0.50 0.02	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	0.99 0.001	–0.99 0.001	–0.99 0.001

Table 2.
Correlation matrix amongst chemical composition and digestibility of dry matter and crude protein from Erythrina edulis.

were observed (47.9 vs. 75.4 ± 0.68%/h; $p < 0.001$; **Table 3**). Whereas at 72/h rumen incubation the SF had 38% higher DM degradability than to the observed in SF (86.1 vs. 53.1 ± 0.68%/h, $p < 0.001$; **Table 3**). With regard to CP degradability, at 24/h incubation time the SV showed lower data than SF (53.4 vs. 61.3 ± 2.50%/h; $p < 0.001$), with marked differences at 72 h rumen incubation (53.4 vs. 77.9 ± 2.50%/h; $p < 0.001$; **Table 3**).

In situ procedures of the artificial synthetic fiber bag which have evolved since the earlier part of the 20th century, there is a standard means of estimating the extent of feed degradation [30, 56]. Consequently, degradation kinetics in the reticulorumen are one key tool for evaluating ruminant feedstuffs [5, 57, 58]. Naranjo [35] found a lower DM degradability value than our study (40 vs. 53%/h), although our value was similar to the obtained by Rosales [13]. In contrast, other reports have shown high degradability values at a 48 h incubation time (81.45%/h, on average) by Pedraza et al. [59] and Camero et al. [12] (68%/h, on average) although with other *Erythrina* varieties (*berteroana*, *variegate and poeppiginia*). Anyway, the SF showed high DM degradability at 48 h incubation time (84.1%/h). Unfortunately, there were not more reports on the rumen degradability kinetics with sheath of *E. edulis*, and our data are proposed as referential values. In summary, our work showed acceptable values compared with other forage used for livestock feeding [33, 60–62].

According to Jian et al. [63] and Buxton et al. [64] DM intake is essential for dairy ruminants to maintain and production performance [65]. However, the contents of NDF and ADF in forage are also considered the major factors affecting feed intake and feed conversion efficiency of ruminants, influencing animal performance [49, 66, 67]. Therefore, in this study, the lower DM and CP degradability observed in SV could be explained due to higher hemicellulose and the degree of lignification, which reflects the difficulty of degradation [68]. Despite that, no correlation was observed between ADL contents and DM degradability ($p = 0.95$; **Table 2**).

	Incubation time (h)								SEM	*p*-value
Item	**0**	**3**	**6**	**12**	**24**	**36**	**48**	**72**		
Dry matter										
SV[1]	28.6^{bF}	32.8^{aE}	36.4^{bD}	41.7^{bC}	47.9^{bB}	50.8^{bA}	52.2^{bA}	53.1^{bA}	0.36	0.001
SF[2]	35.6^{aH}	44.5^{aG}	51.8^{aF}	62.8^{aE}	75.4^{aD}	81.6^{aBC}	84.1^{aA}	86.1^{aA}	0.49	0.001
SEM	0.68	0.68	0.68	0.68	0.68	0.77	0.68	0.68	-	-
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
Crude protein										
SV	35.0^{C}	48.7^{AB}	50.7^{A}	52.9^{A}	53.4^{A}	53.4^{bA}	53.4^{bA}	53.4^{bA}	2.5	0.001
SF	34.8^{B}	39.6^{B}	43.7^{B}	50.8^{B}	61.3^{AB}	68.2^{aA}	72.9^{aA}	77.9^{aA}	2.5	0.001
SEM	2.55	2.60	2.57	2.60	2.50	2.60	2.40	2.50	-	-
p-value	1.00	0.527	0.867	1.00	0.737	0.025	0.001	0.001	-	-

[1]*SV, leaves.*
[2]*SF, sheath without seeds.*
$^{a-b}$*Mean values with different letter in the same column differ* ($p < 0.05$).
$^{A-G}$*Mean values with different letter in the same row differ* ($p < 0.05$); *SEM, standard error of the mean.*

Table 3.
Average of DM and CP degradability (%) after 0, 3, 6, 12, 24, 48, and 72 h incubation in situ technique.

5. Degradability parameters of *Erythrina edulis* obtained *in situ*

In situ degradability parameters of *E. edulis,* are shown in **Table 4**. The SF had highest disappearance of fast and slow fractions compared to SV (α, 35.6 vs. 28.6 ± 0.57%/h; p = 0.003; b, 51.1 vs. 24.8 ± 0.57%/h; $p < 0.001$, **Table 4**). But, the "c" degradation rate in SF was lower when compared to SV (0.55 vs. 0.62 ± 0.57%/h; $p < 0.001$; **Table 4**). Despite this, SF had greater effective degradability values in all passage rates than SV 2%/h (73.1 vs. 47.4 ± 0.57%/h; $p < 0.001$), 5%/h (62.4 vs. 42.3 ± 0.57/h; $p < 0.001$), 6%/h (60.0 vs. 41.2 ± 0.54%/h; $p < 0.001$) and 8%/h (56.4 vs. 39.4 ± 0.57%/h; $p < 0.001$), respectively, as shown in **Table 4**.

In contrast, no differences in the soluble fraction "α" for CP between both phenological stages (35 ± 2.03%, on average) were observed (**Table 4**). Nevertheless, the SF showed a highest insoluble but potentially "b" degradable fraction than SV (50.0 vs. 18.4 ± 2.03%/h; $p < 0.001$; **Table 4**). Whereas the ED only varied at passage rate of 2% between SF vs. SV (66.4 vs. 52.3 ± 2.0%/h; p = 0.011; **Table 4**).

The rumen degradability in SF was highest for all degradation parameters "α," "b," $\alpha + b$, and ED. These differences might be related with lower fiber contents, which increase of total degradable fraction ($\alpha + b$) [9]. Furthermore, with regard the lower ED for SV, we hypothesized that greater cell wall components especially lignin will be implicated. Naranjo [35] in leaves of *E. edulis* reported lower degradation parameter α (21.1 vs. 28.6%) than the obtained in this study, although with higher b (35.2 vs. 24.8%) and c (0.09 vs. 0.06/h) fractions. Differences that might be as a consequence of our greater ADF contents (51.2 vs. 32.2%). In this sense, forages with high wall cell components, have showed lower digestibly data, due to decreases the colonization of

Item	Degradation parameter[1]				Effective degradability			
					INRA	Passage rates[2]		
	α	b	$\alpha + b$	c	6%	2%	5%	8%
Dry matter								
SV[3]	28.6[b]	24.8[b]	53.4[b]	0.062[a]	41.2[b]	47.4[b]	42.3[b]	39.4[b]
SF[4]	35.6[a]	51.1[a]	86.7[a]	0.055[b]	60.0[a]	73.1[a]	62.4[a]	56.4[a]
SEM	0.57	0.57	0.57	0.57	0.54	0.57	0.57	0.57
p-value	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Crude protein								
SV	35.0	18.4	53.4	0.038	51.0	52.3[b]	51.0	49.7
SF	35.0	50.0[a]	82.0[a]	0.034	53.0	66.4[a]	55.2	50.0
SEM	2.03	2.03	2.03	2.03	2.10	2.0	2.0	2.0
p-value	1.00	0.001	0.001	1.00	1.00	0.011	0.20	1.00

[1]α: *Soluble fraction;* b: *Insoluble but degradable fraction; kd: The rate (%/h) of disappearance of* b *fraction.*
[2]*Passage rates, according to Bhargava and Ørskov [69] for different intake level. INRA [31] with a fixed transit rate of 6%/h.*
[3]*SV, leaves.*
[4]*SF, sheath.*
[a–b]*Mean value with different letter in the same columns differ* (p < *0.05).*

Table 4.
Disappearance of fast and slow fractions and effective degradability values of DM an CP from Erythrina edulis.

rumen microbiota reducing its degradation [49, 66, 70]. Despite all differences above mentioned, the SF had higher DM degradability than SV and other forage sources [35, 71], which might be related to its lower NDF, ADF and ADL contents. To the best of our knowledge, there are no more reports with sheath of *E. edulis*, so our data could be proposed as referential.

In ruminants, the quantity of amino acids that reach the small intestine depends on the microbial protein synthesis and feed proteins which escape ruminal degradation. Therefore, the feed protein degradation can be affected by its nature [72–75]. Consequently, the CP content degraded in the rumen is determined by their fractional degradation and passage rates [38, 45, 76]. At present, the model of Ørskov et al. [30, 77] for describing protein degradation and escape, it is widely accepted and applied. How in other studies, the CP degradability increased with incubation time. According to Ibrahim et al. [47], the CP from lush pasture is highly soluble and rapidly and extensively degraded in the rumen. Possibly, this could explain our no differences in the α fraction rate between both studied stages (35%, on average). Nevertheless, the SF showed a higher insoluble but potentially degradable fraction "*b*" (50 vs. 18 ± 2.03%/h), although with a slower CP disappearance rate than to the observed in SV, as shown in **Table 4**. Regarding the lower "*b*" fraction observed for SV, it could be explained by its chemical composition: greater fiber contents, resulting in a lower CP degradability than SF. Additionality, Bhargava and Ørskov [50] and Camero et al. [12] stated that when protein degradability is high, the release rate of microbial substrates is high, as well as the period after feeding, during which the microbial substrates are released over a short period of time. Therefore, the CP content in the rumen of both phenological stages was mainly affected by the retention time agree with Ørskov and McDonald [30]. In this study, at 24 h, the CP degradability in SF was 13% higher than SV (61 vs. 53 ± 2.50%/h), which is opposite to the mentioned by Ma [63] that higher contents of CP had beneficial for CP degrading in the rumen. Similar trend was observed at 72 h incubation time, with clear differences between both studied stages (78 vs. 53 ± 2.50%/h). Despite this, the passage rate of 5%, 6% and 8% per hour did not vary between leaves or sheath, because of similar degradation rate (0.36%/h, on average), with exception for at 2% passage rate (66 vs. 52 ± 2.0%/h; **Table 4**). Based on these results, the "*b*" degradability rates should be taken in account for the ration in feeding ruminant programs. Referential values in leaves of *E. edulis* reported by Rosales [35] have shown a slight greater α fraction than our study (41 vs. 35%/h) but with a lower "*b*" potentially degradable fraction (38 vs. 50%) and no differences in disappearance rate (0.03%/h). Contrary to this, higher degradation parameters for "α," "*b*," and ED in other *Erythrina* varieties *(indica, subumbrans, variegata and berteroana)* than the obtained in *E. edulis* have been reported by Kongmanila et al. [18] and Pedraza et al. [59]. Anyhow, the chemical composition as well as degradability parameters obtained in this study, could be similar to the other multipurpose fodder trees and shrubs (e.g., *Leucaena leucocephala, Gliricidia sepium*, *T. tetraptera*, *L. diversifolia*, and *L. sericeus*) widely used in ruminant nutrition [13, 78, 79].

6. Conclusions

The *E. edulis* showed similar CP contents to other widely sources used in diets for livestock nutrition, but the leaves showed greater wall cell contents than the sheath. As a consequence, at 72 h incubation time the leaves had lower DM and CP disappearance than the sheath. For this reason, the ED of DM in SF was higher than SV, and

only differences at outflow rate of 2%/h for CP was observed. Based on these findings, it necessary to perform an *in vivo* study to determine adequate levels of inclusion in ruminant feeding. Anyhow, *E. edulis* is an interesting feed to include as a supplementation to improve low quality forages in livestock systems.

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Conflict of interest

The authors declare no conflict of interest.

Abbreviations

Acid detergent fiber (ADF), Acid detergent lignin (ADL), Crude fiber (CF), Crude protein (CP), Dry matter (DM), Dry matter intake (DMI), Effective degradability (ED), *Erythrina edulis* (*Euphorbia edulis*), Ether extract (E.E), Fructification stage (SF), Microbial protein (MP), Neutral detergent fiber (NDF), N-free extract (NFE), Next energy for lactation (NE_L), Organic matter (OM), Standard error of the mean (SEM), vegetative stage (SV)

Author details

Oscar Giovanny Fuentes Quisaguano[1] and Santiago Alexander Guamán Rivera[2*]

1 Veterinary Medicine, Central University of Ecuador, Quito, Ecuador

2 Research Group Causana Yachay (GICAY), Escuela Superior Politècnica de Chimborazo, Sede Orellana, El Coca, Ecuador

*Address all correspondence to: santiagoa.guaman@espoch.edu.ec

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