GLOBAL EFFECTS OF MAXIMIZING THE FORAGE IN PRODUCTION AND QUALITY OF BOVINE MILK AND MEAT. A META-ANALYSIS

Gustavo Tirado-Estrada, Deli Nazmín Tirado-González, Sergio Ernesto Medina-Cuéllar, Luis Alberto Miranda-Romero, Mónica González-Reyes, Luis Antonio Sánchez-Olmos and Iván Castillo-Zúñiga

SUMMARY

The potential effects of the type of forage (TF) and forage proportion (FP) in bovine diets, regarding nutrient digestibility and productive behaviour, were quantified from previously published data. Variance and orthogonal polynomial analysis were performed on a sample of 44 in vivo *and 40* in situ *experiments from randomly selected articles. The model included: 1) FT (legumes and grasses), 2) FP, and 3) random effect experiments within articles [Exp(Art)]. The* in situ *dry matter and neutral detergent fiber disappearance (ISDMD and ISNDFD) and ruminant productive behavior variables were analyzed. The dry matter intake (DMI), milk production, and milk protein and fat were similar or greater in legume-based diets with FP≥50% than in grass-based diets with FP<50%. In contrast, negative effects in animal performance were observed in both legume-based diets with FP<50% and grass-based diets with FP≥50%. Cubic trends were observed in milk and milk fat production; the optimal FP was 50% and 37% for legume- and grass-based diets, respectively. Increasing FP from 42 to 50% in grass-based diets negatively and linearly affected the average daily gain (ADG) and feed conversion (FC) of beef cattle. In certain legume-based diets, decreasing the proportion of concentrate and/or grains could improve the DMI, and the production and quality of bovine milk.*

Introduction

The content of cell walls has been quantified through neutral detergent fiber (NDF; Van Soest *et al*., 1991). Although the ruminal degradability of NDF (NDFD) can be affected by the availability of non-structural carbohydrates as the starch content (Demirel *et al*., 2006; Hassant *et al*., 2013; Hart *et al*., 2015; Khan *et al*., 2015), the structure and composition of NDF is closely related with the potential degradability (Grabber, 2005; Hatfield and Fukushima, 2005; Jung and Casler, 2006a, b), and the rate of average daily gain, the feeling of fullness in the rumen, the dry matter intake (DMI), milk production, as well as milk fat content (Oba and Allen, 1999; 2005; Jung *et al*., 2004).

It is difficult to predict the changes of rumen ecosystem due to the components of diets, but reducing the proportion of NDF in the diet does not always increase production, particularly when NDF of forages is highly digestible (Oba and Allen, 2003, 2005; Bradford and Allen, 2004, 2005; De Souza *et al*., 2017) The excess of grain can negatively affect ruminal ecosystem diversity, and reduce the potential and the degradability of NDF proportions (Saleem *et al*., 2012, 2013; Petri *et al*., 2013; Zhao *et al*., 2014).

Regardless, reducing the grains and concentrates in the diets of animal feed could reduce environmental costs such as deforestation, land preparation, and fertilizer applications that contribute with greenhouse gas emissions (Beauchemin *et al*., 2008; Knapp *et al*., 2014). Using correct amounts of forage in the diet can improve the fiber digestibility and might reduce the feed costs (Sanh *et al*., 2001; Shaver, 2006; Mertens, 2009).

In this study, the dietary effects of the balance and type of forage on the nutrient digestibility and productive behavior of bovines were quantified and discussed.

KEYWORDS / Bovine / Forage Proportion / Legume and Grass / Milk and Meat Quality / Neutral Detergent Fiber /

Received: 09/11/2019. Modified: 10/26/2020. Accepted: 10/28/2020.

Gustavo Tirado-Estrada. Agronomical Engineer, Universidad Autónoma Chapingo, Mexico. M.Sc. in Agrarian Biotechnology, Instituto Tecnológico Agropecuario No. 20/ Tecnológico Nacional de México (TecNM). Doctor in Biological Sciences, Universidad Autónoma de Aguascalientes, Mexico. Researcher, Instituto Tecnológico EL Llano Aguascalientes (ITEL/ TecNM), Mexico. e-mail: gtiradoes@hotmail.com

Deli Nazmín Tirado-González (Corresponding author). Agronomical Engineer and M.Sc. in Biotechnology, TecNM, Mexico. Doctor in Sciences, Universidad Autónoma Chapingo, Mexico. Researcher, Centro Nacional de Investigación Disciplinaria en Agricultura Familiar/Instituto Nacional de Investigaciones Agrícolas Forestales y Pecuarias (CENID AF/INIFAP), Mexico, and Professor, ITEL/TecNM, Mexico. Address: Agricultura Familiar, INIFAP/CENID. Km. 8.5 Carr. Ojuelos-Lagos de Moreno, Jalisco, MÉXICO. C.P. 45570. e-mail: tirado.deli@inifap.gob.mx.

Sergio Ernesto Medina-Cuéllar. M.Sc. in Agricultural and Natural Resources Economics, and Doctor in Sciences in Agricultural Economics, Universidad Autónoma Chapingo, Mexico. Professor-Researcher, Universidad de Guanajuato, Mexico.

Luis Alberto Miranda-Romero. Chemist, Instituto Politécnico Nacional, Mexico. M.Sc. in Animal Nutrition and Doctor in Sciences in Cattle Raising, Colegio de Postgraduados, Mexico. Professor-Researcher, Universidad Autónoma Chapingo, Mexico.

Mónica González-Reyes. Agronomical Engineer and M.Sc. in Animal Production, Mexico. Doctor in Sciences in Cattle Raising, Colegio de Postgraduados, Mexico. Professor-Researcher, ITEL/TecNM, Mexico.

Luis Antonio Sánchez-Olmos. Chemical Engineer, M.Sc. in Chemical Engineering and Doctor in Sciences in Chemistry, ITEL/TecNM, Mexico. Professor-Researcher, Universidad Politécnica de Aguascalientes, Mexico.

Iván Castillo-Zúñiga. Systems Engineer, Instituto Tecnológico de Zacatecas/TecNM, Mexico. M.Sc. in Computational Sciences, Centro Nacional de Investigación y Desarrollo Tecnológico, Mexico. Doctor in Sciences in Computational Engineering, ITEL/TecNM, Mexico. Professor-Researcher, ITEL/TecNM, Mexico.

EFECTO GENERAL DE LA MAXIMIZACIÓN DE FORRAJE EN LA PRODUCCIÓN Y CALIDAD DE LA LECHE Y CARNE DE BOVINOS. METAANÁLISIS

Gustavo Tirado-Estrada, Deli Nazmín Tirado-González, Sergio Ernesto Medina-Cuéllar, Luis Alberto Miranda-Romero, Mónica González-Reyes, Luis Antonio Sánchez-Olmos e Iván Castillo-Zúñiga

RESUMEN

Los efectos potenciales del tipo de forraje (TF) y proporción de forraje (PF) fueron cuantificados en la digestibilidad y el comportamiento productivo de bovinos. Los datos de desaparición in situ *de la materia seca (DISMS) y fibra detergente neutro (DISFDN), ingesta de la materia seca (IMS), producción de leche y sus contenidos de grasa y proteína, ganancia diaria de peso (GDP) y conversión alimenticia (CA), fueron tomados de 44 experimentos* in vivo *y 40* in situ*, obtenidos de una muestra aleatoria de artículos publicados. Análisis de varianza (ANOVA) y polinomios ortogonales fueron utilizados para el análisis del modelo que incluyó: 1) TF (leguminosas o gramíneas), 2) PF, y 3) los efectos aleatorios de los experimentos dentro de los artículos [Exp (Art)]. La IMS, producción de leche y sus contenidos de proteína y grasa fueron similares o mayores en las dietas que incluyeron forrajes de leguminosas y PF≥50%. Las dietas de leguminosas y FP<50%, y de gramíneas con FP≥50% provocaron efectos negativos en la producción de leche. La producción y grasa de la leche tuvieron tendencias cúbicas, donde la PF óptima fue 50% para las dietas de leguminosas y 37% para las de gramíneas. El incremento de la PF de 42 a 50% afectó lineal y negativamente la GDP y la CA en ganado de carne. Dependiendo del tipo de forraje, disminuir la proporción de concentrado y/o granos podría mejorar IMS, y la producción y la calidad de la leche bovina.*

EFEITO GERAL DA MAXIMIZAÇÃO DE FORRAGEM NA PRODUÇÃO E QUALIDADE DO LEITE E CARNE BOVINOS. META-ANÁLISE

Gustavo Tirado-Estrada, Deli Nazmín Tirado-González, Sergio Ernesto Medina-Cuéllar, Luis Alberto Miranda-Romero, Mónica González-Reyes, Luis Antonio Sánchez-Olmos e Iván Castillo-Zúñiga

RESUMO

Os efeitos potenciais do tipo de forragem (TF) e proporção de forragem (PF) foram quantificados na digestibilidade e no comportamento produtivo de bovinos. Os dados de desaparecimento in situ de matéria seca (DISMS) e fibra em detergente neutro (DISFDN), ingestão de matéria seca (IMS), produção de leite e o respectivo teor de gordura e proteína, ganho de peso diário (GPD) e conversão alimentar (CA), foram tomados de 44 experimentos in vivo e 40 in situ, obtidos de uma amostra aleatória de artigos publicados. Análise de variância (ANOVA) e polinômios ortogonais foram utilizados para a análise do modelo que incluiu: 1) TF (leguminosas ou gramíneas), 2) PF, e 3) os efeitos aleatórios dos experimentos dentro dos artigos [Exp (Art)]. A IMS, produção de leite e seus teores de proteína e gordura foram similares ou maiores nas dietas que incluíram forragens leguminosas e PF≥50%. As dietas de leguminosas e PF<50%, e de gramíneas com PF≥50% provocaram efeitos negativos na produção de leite. A produção e a gordura do leite tiveram tendências cúbicas, onde a PF ótima foi 50% para as dietas de leguminosas e 37% para as de gramíneas. O incremento da PF de 42 a 50% afetou de maneira linear e negativamente o GPD e a CA em bovinos de corte. Dependendo do tipo de forragem, reduzir a proporção de concentrado e/ou grãos poderia melhorar a IMS, e a produção e a qualidade do leite bovino.

Materials and Methods

Database

Data from 47 articles randomly selected since 2000 were recorded and analyzed (Table I). The articles included experiments which evaluated ruminal degradability, digestibility, and fermentation patterns as animal productive performance variables in dairy and beef cattle.

Experiment definition

The articles that presented several means of treatments (diet compositions and handling methods) were separated into discrete experiments. Each experiment was codified in an independent way. From the selected articles, 84 experiments were codified: 44 *in vivo* and 40 *in situ* (Table I).

Main factors reported in the studies

All the data was transformed into similar measurement units to allow for the direct analysis of factors. The most frequent variables in the experiments were considered and categorized by using multiple regression (stepwise). Data was classified into subgroups depending on a) type of experiment: 44 experiments were *in vivo* and 40 *in situ*. The subgroups were further classified according to 1) primary FT in diets (grasses and legumes); 2) FP in the diet, firstly FP was calculated for each experiment according the reported ingredients of the diets in the experiments in the articles and, secondly, FP was categorized in FP≥50% or <50% (in order to maintain the highest number of repetitions in each level of FP); 3) the random effect of the article in which the experiments were published [Exp(Art)]; and 4) the effects of covariates, including initial body weight (BW) and days in milk (DIM).

Evaluated variables

The following data was collected: milk production, protein and fat content in milk, DMI, average daily gain (ADG), feed conversion (FC= DMI/ADG), ISDMD and ISNDFD (evaluated at 24h for dairy cows and 48h for beef cattle).

Statistical analysis

Statistical analysis was performed using the Statistical

TABLE I

REFERENCES OF TREATMENT MEANS INCLUDED IN META-ANALYSIS

Dairy cows	
In vivo	Arriola *et al*., 2011; Bilik *et al*., 2009; Bowman *et al*., 2002; Carreón *et al*., 2010; Chung *et al*., 2012; Elwakeel *et al*., 2007; Hristov *et al*., 2000; Hristov *et al*., 2008; Holtshausen *et al*., 2011; Knowlton *et al*., 2007; Lopuzsanka-Rusek and Bilik, 2011; Miller *et al*., 2008b; Sutton *et al*., 2002; Titi, 2003; Wang *et al*., 2004.
In situ	Bahh *et al*., 2005; Bassiouni *et al*., 2011; Dean *et al*., 2008; Hristov *et al*., 2008; Holtshausen *et al*., 2011.
Beef cattle	
In vivo	Balci *et al*., 2007; Cano *et al*., 2003; De Souza *et al*., 2006b; Gómez-Vázquez *et al*., 2011; Hwang *et al*., 2008; Malik *et al*., 2010; Miller *et al*., 2008a; Morgavi *et al*., 2000; Santana *et al*., 2005; Wang *et al*., 2003; Ware *et al*., 2005.
In situ	Álvarez *et al*., 2009; De Souza *et al*., 2006a; Franco *et al*., 2008; Gallardo *et al*., 2010; Guerra *et al*., 2007; Wang *et al*., 2004; Ware *et al*., 2005.

Analysis System program (SAS, 2013). The distribution of the data in all the variables was verified by using the Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling tests (Proc Univariate).

Variance analysis

The lineal model was analyzed by ANOVA. The probability values, coefficients of determination (R^2) and variation (VC) of fixed effects of the model, were obtained by using Proc GLM (Model 1). The significances were corrected using Proc GLIMMIX (Eugene *et al*., 2004, 2008), considering the random effects of the experiment (treatment means) within the article based on where it was published [Exp(Art)], taking the number of experiments minus one from each article (Exp-1) as a weight factor. The adjusted means and standard errors (S.E.) were estimated by using the LsMeans/pDiff instruction.

$$Y = \mu+[Exp(Art)]_{i(j)} +FT_k+FP_l + (FT*FP)_{kl} + \beta x_n + E_{ijkl} \quad (1)$$

where Y: answer, μ: mean, $[Exp(Art)]_{i(j)}$: random effect of the i^{th} experiment within the jth article, FT_k: k^t type of plant, FP_l: l^{th} forage proportion, $(FT\times FP)_{kl}$: interaction between factors, βx_n: n^{th} effect of the covariates (initial BW and/or DIM), and E_{ijkl}: random error.

Media comparison

Adjusted means were compared using the minimum significant differences (MSD) which were calculated through number of error degrees of freedom and adjusted standard errors, considering the probability P<0.05.

Trend analysis

The statistical package from the Universidad de Nuevo León, version 1995 (Softaware, 2011) was used to perform orthogonal polynomial trend analysis to test the lineal, quadratic and cubic effects associated with the FP for the animal behaviour variables (milk production, milk fat content, ADG and FC).

Results

The legume-based diets primarily included alfalfa hay and different type of clovers, while grass-based diets were primarily composed by different types of grasses, corn or rice stovers, and corn, sugar cane, barley or oats silages. High-forage diets (FP>80%) were mostly evaluated in experiments performed *in vitro*, but the effect of FP between 60 and 80% were tested *in situ*. *In vivo* experiments included diets with FP ranging between 15 to 40%, 45 to 50% and 65 to 80% for dairy cows, but from 15 to 50% for beef cattle (Figure 1).

Effect of type and proportion of forage on productive behavior

Dairy cows

There were no effects of the covariate DIM (Table II), the mean values of productive animal behavior variables were adjusted by the initial BW covariate (P<0.001). There was an interaction between the FP and the FT included in diets (P<0.01).

Adding at least 50% of legume forages improved the milk quality and production (P<0.001). For the grass-based diets, the DMI, milk production, milk protein, milk fat and ISDMD had better responses when FP<50% than FP≥50% (22.37 vs 14.72kg DM/d, 34.81 *vs* 27.50kg/d, 1125.71 *vs* 869.81g/d, 1459.73 *vs* 1020.54g/d, and 72.67 *vs* 56.89%, respectively; P<0.0001), but FP≥50% improved the DMI, milk production, milk protein and milk fat in legume-based diets (27.09 *vs* 19.64kg DM/d, 40.69 *vs* 25.26kg/d, 1243.15 *vs* 882.24g/d, and 1447.47 *vs* 881.41g/d, FP≥50% *vs* FP<50%, respectively; P<0.0001). Moreover, milk production and

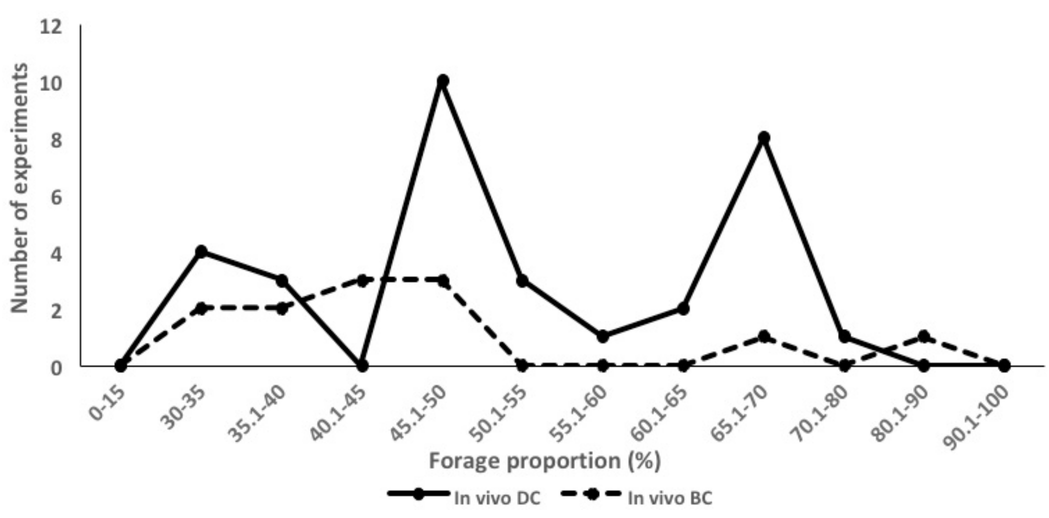

Figure 1. Number of experiments performed *in vivo* with dairy cows (DC), and beef cattle (BC) including different forage proportions in diets.

TABLE II
GLOBAL EFFECTS OF FORAGE PROPORTION AND TYPE OF FORAGES ON BOVINE PRODUCTIVE BEHAVIOR

Variable	Type of Forage (TF) Legumes		Grasses		N§	CV	R^2	S.E.	*P*-value			Covariate	
	Forage proportion (FP)								FT	FP	FT*FP	BW	DIM
	F<50%	F≥50%	F<50%	F≥50%		(%)				(%)	(%)	(kg)	(d)
			Dairy Cows										
Initial BW (kg)	508.05 c	632.65 a	559.73 b	646.59 a	52	6.64	0.63	28.13	***	***	NS	-	-
DIM (d)	144.19 a	107.42 b	59.22 c	53.32 c	52	41.16	0.69	23.56	***	NS	NS	-	-
DMI (kg/d)	19.64 b	27.09 a	24.37 a	14.72 c	52	12.3	0.82	2.48	***	***	***	***	NS
Milk production (kg/d)	25.26 c	40.69 a	34.81 b	27.50 c	52	9.8	0.84	2.68	***	***	***	**	NS
Milk protein (g/d)	882.24 b	1243.15 a	1125.71 a	869.81 b	49	11.67	0.78	101.43	***	***	***	***	NS
Milk fat (g/d)	881.41 c	1447.47 a	1459.73 a	1020.54 b	49	9.86	0.85	95.26	*	†	***	***	NS
ISDMD (g/kg MS)	-	-	726.72 a	568.87 b	46	4.9	0.97	21.55	-	***	-	-	-
			Beef cattle										
Initial BW (kg)	-	-	423 a	324 b	45	6.84	0.82	0.22		***		-	
DMI (kg/d)	-	-	8.67 b	10.12 a	45	6.84	0.82	0.77		***		***	
ADG (g/d)	-	-	1547.24 a	971.13 b	45	5.81	0.93	115.32		***		***	
FC (DMI/ADG)	-	-	8.38 a	12.51 b	45	16.44	0.92	1.46		***		***	
ISDMD (g/kg)	-	-	677.25 a	607.55 b	25	4.24	0.99	48.59		**		-	
ISNDFD (g/kg)	-	-	561.75	586.25	25	5.51	0.91	88.65		NS		-	

BW: body weight, DIM: days in milk, DMI: dry matter intake, ADG: average daily gain, FC: feed conversion, ISDMD: *in situ* dry matter disappearance, ISNDFD: *in situ* neutral detergent fiber disappearance. * P<0.05, ** P<0.01, *** P<0.0001, † P<0.1, NS: P>0.01.

composition were similar or greater in diets containing FP≥50% of legume forages compared to grass-based diets that included more than 50% of grains (differential of 2.72kg DM/d, 5.83kg/d, 117.44g/d and -12.26g/d, respectively).

Although grass-fed diets (primarily grasses as hay, corn and rice stovers, and corn, sugar cane, barley or oats silages) with FP<50% had greater ISDMD than diets with FP≥50% (67.73 *vs* 60.76%; P<0.002), there were no differences in the ISNDFD.

Beef cattle

The covariate initial BW was significant in all variables (P<0.0004). Beef cattle had a higher DMI when FP≥50% (10.12 *vs* 8,67kg DM/d, FP≥50% *vs* FP<50%; P<0.0008). In addition, the ADG and, consequently, the FC, were enhanced in diets containing more than 50% concentrate (1547.24 *vs* 971.13g/d, and 8.38 *vs* 12.51, FP≥50% vs FP<50%, respectively; P<0.0001).

Trend of forage proportion on dairy cows and beef cattle's production

The fat-corrected milk and milk productions were mainly explained by their cubic effects (P<0.01; Table III). The greatest milk fat content (ranging from 3.54-3.70% for FP 50-67%) and milk production were observed when dairy cows were fed legume-based diets with FP≥50% (P<0.01), however, the best milk fat content and milk production was observed in grass-based diets when the FP was 37% (P<0.0001).

In beef cattle, grass-based diets affected the ADG and FC of beef cattle (P<0.0001; Table IV), although the greatest ADG and FC were observed when FP was 42%, the optimum balance of the FP might be less than 42%.

Discussion

Effects of forage proportion in the milk and meat quality and production

Metabolites and microorganisms differ among the FP (Lee *et al*., 2012; Saleem *et al*., 2012). Cell walls and non-structural carbohydrates of diets interact with the ruminal ecosystem changing the proportion of major ruminal phyla (*Bacteroidetes*, *Firmicutes* and *Proteobacteria*) and *archaeas* (Saleem *et al*., 2012, 2013).

The correct balance of legumes and grasses, and/or forage proportions in diets, aids to improve the potential degradability of forages (Saleem *et al*., 2012; Hassant *et al*., 2013; Petri *et al*., 2013; Machado *et al*., 2014; Zhao *et al*., 2014). The excess of rapidly fermentable ingredients may decrease the diversity of rumen microorganisms and the potential digestibility of the fiber (Petri *et al*., 2013); in addition,

TABLE III
FORAGE-TO-CONCENTRATE RATIO EFFECTS ON BOVINE MILK PRODUCTION AND MILK FAT CONTENT

	Forage proportion (FP)							*P*-value		
	33	37	50	52	60	63	67	Lineal	Quadratic	Cubic
			Legume-based diets							
Milk fat (g/d)		629	1543.8	1269.7			1191.7	***	***	***
Milk (kg/d)		19.98	42.27	35.90			32.2	**	*	**
Milk fat (%)		3.15	3.65	3.54			3.70	NE	NE	NE
			Grass-based diets							
Milk fat (g/d)	1332.7	1525	1162.7		990.33	986.83		***	*	***
Milk (kg/d)	31.02	38.3	29.66		29.43	25.63		***	***	***
Milk fat (%)	4.30	3.98	3.92		3.37	3.85		NE	NE	NE

P-value, probability value for the lineal, quadratic, and cubic effects. * P<0.05; ** P<0.01, *** P<0.0001, NE: non-estimated P-values.

TABLE IV
FORAGE-TO-CONCENTRATE RATIO EFFECTS ON THE AVERAGE DAILY GAIN OF BEEF CATTLE

	Forage proportion (FP)			*P* – values		
	42	45	50	Lineal	Quadratic	Cubic
Grass-based diets						
ADG (g/d)	1640.90	1178.20	1128.00	***	***	NS
FC (DMI/ADG)	5.31	7.65	10.18	***	NS	NS

P-values: probability value for the lineal, quadratic and cubic effects, ADG: average daily gain, FC: feed conversion, DMI: dry matter intake, NS: not significant (P>0.10), *** P<0.0001.

the rapid rate of propionate flux to the liver, reduces the voluntary feed intake: the oxidation of excess propionate and its fast flow that lead to the feeling of fullness and satiety causing a decrease in the animals intake (Oba and Allen, 2003; Bradford and Allen, 2004, 2005, 2007). However, the excess of low-degradable NDF can reduce the passage rate and DM intake (Warner *et al*., 2013; De Souza *et al*., 2017), limit the DMD (R^2= -0.71 and -0.90, respectively; Coleman and Moore, 2002), forage nutrients availability and therefore, negatively impact the ruminal fermentation patterns (Na *et al*. 2013; Chen *et al*. 2015).

Since NDF and non-structural carbohydrates proportions affect the passage rate, DMI, degradability, fermentation patterns and animal productive behavior (Schwab *et al*., 2003; Shaver, 2006; Stendal *et al*., 2006), individual rates of degradability of diet components should be considered when ruminant diets are being balanced (Bradford and Allen 2004, 2005, 2007; Danielsson *et al*., 2017). Similarly, some proportions, like starch:NDF, could be more precise to predict the diet's components on DMI, animal productive behavior, and to explain some trends between FP and milk quality and yield (Kolver *et al*., 2001; Khan *et al*., 2012, 2015).

Machado *et al*. (2014) compared three diets with FP of 65%, 55% and 45%, respectively, in Holstein cows (575 ±70kg BW, 18.4 ±3.0kg/d of milk/d, 121 ±21d DIM) and found that increasing the concentrate linearly improved the milk production (from 22 to 23.6kg/d), but the milk fat content decreased (from 3.9 to 3.6%). Sanh *et al*. (2001) reported lineal effects for milk yield, protein and fat contents when two groups of dairy cows were fed with diets that included grass-based; milk production linearly increased when grain proportion increased from 30 to 70%, however the milk fat content decreased (0.21 and 0.16%, for groups 1 and 2). Oba and Allen (1999) and Jung *et al*. (2004) found that for each unit of increase in the NDFD, the DMI could be improved by 0.168kg/d, and the fat-corrected milk from 0.14 to 0.25kg/d. Furthermore, grain costs can be reduced without abating the milk and quality production by including corn hybrids with higher *in vitro* NDF degradability (Oba and Allen, 2000a, b).

Substituting stovers with silage, or with any legume, also can improve the N retention, the N-ammonia concentration, and the A:P ratio (Cantalapiedra-Hijar *et al*., 2008; Na *et al*., 2013). For example, substitution of corn silage with alfalfa silage improved the DMI, milk production and milk protein content (Sterk *et al*., 2011; Hassant *et al*., 2013; Khan *et al*., 2015).

Milk and meat composition can benefit human health (Ip *et al*., 1999; Parodi, 1999; Belury, 2002; Martínez-Borraz *et al*. 2010) since the human body cannot synthesise α-linoleic acid (α-LA), a precursor for the synthesis of longer chain n-3 polyunsaturated fatty acids. The n-3:n-6 fatty acids ratio in diets should be 1:4. Optimal intake of n-3 fatty acids can reduce the incidence of depression and Alzheimer's, and increasing conjugated linoleic acid (CLA, C18:2) ingestion has been related to a lower incidence of breast cancer (Daley *et al*., 2010).

Khan *et al*. (2015) found that substituting grass silage with corn silage changed the quantity and composition of the unsaturated fatty acids, negatively affecting the nutritional quantity and quality of milk fat content. This was attributed to an increase in the unsaturated trans-10 C18:1 and C18:2n-6 fatty acids proportion with the increase in corn silage and a concurrent decrease in the trans-11, cis-15 C18:2 and C18:3n-3 fatty acids. Increasing the amount of low-quality forages (poor NDF degradability) but high concentrate levels may not improve the DMI, or the milk production, but may improve the unsaturated fatty acid profile. In general, reducing the concentrate in these types of diets decreases the C18:3n-3 content, which reduces the n-3 and increases the n-6 fatty acids (Khan *et al*., 2012).

Besides the ADG, the color of the animal meat can change as they are fed concentrate (Nuernberg *et al*., 2008; Daley *et al*., 2010). Increasing the forage proportion can improve the meat fat quality by enhancing the precursors of A and E vitamins (β-carotene and α-tocopherol), glutathione antioxidants, superoxide dismutase and α-LA synthesis, and by promoting the CLA, trans vaccenic fatty acid (C18:1 trans-11) and n-3 fatty acid synthesis (increasing the n-6:n-3 fatty acid ratio) in the tissues of meat (Loor *et al*., 2004; Demirel *et al*., 2006; Nuernberg *et al*., 2008; Daley *et al*., 2010).

The potential environmental impact to maximize the forage proportion in ruminant diets

The environmental costs of increasing FP and reduce grains and concentrates has been widely discussed. Balance of forages and grains suggests human and animal welfare, since reducing the amount of grains in the diet would allow a decrease in feed costs and increase the quality and production of milk (Shaver, 2006; Petri *et al*. 2013; Zhao *et al*. 2014).

Including a relatively high content of grains/concentrates as a high source of non-structural carbohydrates could decrease the emission of greenhouse gasses since their rapid fermentation produces more propionic acid and less H_2 available to produce methane (CH_4) (Aguerre *et al*., 2011; Na *et al*., 2013; Knapp *et al*., 2014). Warner *et al*. (2013) models related the passage rate of NDF and DM with propionic acid (r= 0.59), showing that more than the amount of NDF, the NDF degradability can be related to fermentation patterns and CH_4 emissions. The grains proportion increases the passage rates and DM intake, potentially reducing the release of CH_4 per unit intake (Danielsson *et al*., 2017). The excess of starch limits the NDF degradability and reverses the effect on greenhouse gas emissions (Cattani *et al*., 2014, Danielsson *et al*., 2017).

The excess of grain demands is related to the increase of greenhouse gas emissions, because of the deforestation process and the high usage of fuels during agricultural grain production, in contrast to the forage production process (Beauchemin and McGinn, 2005; Beauchemin *et al*., 2008, 2009; Knapp *et al*., 2014). On the other hand, maximizing the FP in ruminant diets can reduce the environmental costs of ruminant production.

Since fermentation patterns are directly related with the productive behavior of ruminants (Krause *et al*., 2003), both the excess of high-NDF (like forages) as well as high-starch (like grains) in ruminant diets would impact the costs *per* unit of products, but costs of the excess of grains would be higher than the excess of forages. The interchange of stovers with silage or better-quality forage, as well as the use of supplements, which increase the fiber digestibility, can be alternatives to decrease environmental contamination and improve feed utilization, in addition to the productive performance of the animal (Beauchemin *et al*., 2008; Na *et al*., 2013).

Conclusions

The optimum balance of the FP depends on the FT that is included in the diet. *In vitro*, legumes and grasses have different degradability depending on the incubation time and the source of ruminal fluid, and was shown to be greater to that of grasses. Milk production and milk fat contents presented cubic trends, and the optimal FP balance was 50% in legume-based diets but 37% in the diets based on grasses. The ADG and FC of beef cattle were negatively and linearly affected by an increase in the forage amount in grass-based diets from 40 to 50%. The present quantitative analysis suggests that increasing the forage amount in legume-based diets could improve the DMI, the milk quality and production, and reduce environmental and production costs. Nonetheless, the balance of the FP must be carefully considered, according to the FT that is included as the main ingredient in ruminant diets.

ACKNOWLEDGEMENTS

The authors are grateful to The Instituto Tecnológico El Llano Aguascalientes (ITEL)/Tecnológico Nacional de México and the Universidad Autónoma Chapingo. The funding sources had no role in the design of the study, the collection, analysis, or interpretation of data, nor in the writing of the manuscript and its submission for publication.

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