Abanico Veterinario. January-December 2020; 10:1-10. http://dx.doi.org/10.21929/abavet2020.32
Original Article. Received: 31/07/2020. Accepted: 28/11/2020. Published: 05/12/2020. Code:2020-63.

Effect of extrusion temperature, moisture and sunflower oil content on the functional properties and digestibility of bovine cattle feeds

Efecto de la temperatura de extrusión, humedad y contenido del aceite de girasol sobre las propiedades funcionales y digestibilidad de alimentos para ganado bovino

Delgado Efren*[1] ID, Alvarado-González Óscar[2] ID, Medrano-Roldán Hiram[2] ID, Rodríguez-Miranda Jesús[3] ID, Carrete-Carreón Francisco[4] ID, Reyes-Jáquez Damián[2] ID**

[1]College of Agricultural, Consumer and Environmental Sciences, Department of Family and Consumer Sciences, Food Science and Technology, New Mexico State University, USA. [2]Departmento de Ingeniería Química y Bioquímica, Posgrado en Ingeniería Bioquímica, Tecnológico Nacional de México/ Instituto Tecnológico de Durango, México. [3]Tecnológico Nacional de México/ Instituto Tecnológico de Tuxtepec, México. [4]Facultad de Medicina Veterinaria y Zootecnia, Universidad Juárez del Estado de Durango, México. *Responsible author: Efren Delgado **Correspondence author: Damián Reyes-Jáquez. Departamento de Ingeniería Química y Bioquímica, Posgrado en Ingeniería Bioquímica, Tecnológico Nacional de México/ Instituto Tecnológico de Durango, Blvd. Felipe Pescador 1830 Ote., Col. Nueva Vizcaya, C.P. 34080, Durango, Durango, México. Tel. + 52 (618) 829-0900. edelgad@nmsu.edu, ingoscaralvarado@gmail.com, hiramdurango@yahoo.com, jesus.rm@ittux.edu.mx, focc1928mx@yahoo.com, damian.reyes@itdurango.edu.mx

ABSTRACT

Preparation of extruded products with high oil content, presents a technological challenge, due oil decreases specific mechanic force but also acts as a lubricant, and forms starch-lipid complexes; thus, decreasing starch gelatinization. This research aimed to evaluate the effect of temperature, moisture, and sunflower oil content, on the extrusion process of bovine cattle feed. Two main ingredients were used for each diet: alfalfa (*Medicago sativa* L.), and bean (*Phaseolus vulgaris* L.). The obtained results showed that high temperature, moisture, and oil content, decreased bulk density, and hardness ($P < 0.05$). Oil content-temperature interaction increased both bulk density and hardness, while moisture-oil content interaction increased ($P < 0.05$) hardness. Optimization was performed based on the physicochemical characteristics of commercial feeds, showing that the best bean diets were obtained at 121ºC, 14% moisture content with 0% sunflower oil; 120ºC and 16% moisture content with 3.5% sunflower oil; and, 142ºC and 15% moisture content with 7% sunflower oil. Effective degradability ranged from 87.4 - 90.4% for all extruded diets; and none of them showed significant differences between bean and alfalfa ($P < 0.05$), which opens a high potential opportunity of producing high concentrations of CLA from sunflower oil at a ruminal level.
Keywords: Bovine cattle feed, extruded, digestibility, sunflower oil.

RESUMEN

La preparación de productos extruidos con alto contenido de aceite presenta un desafío tecnológico, debido a que el aceite disminuye la fuerza mecánica específica pero también actúa como lubricante y forma complejos de almidón y lípidos; disminuyendo así la gelatinización del almidón. El objetivo de esta investigación fue evaluar el efecto de la temperatura, la humedad y el contenido de aceite de girasol en el proceso de extrusión de alimento para ganado bovino. Se usaron dos ingredientes principales para cada dieta: alfalfa (*Medicago sativa* L.) y frijol (*Phaseolus vulgaris* L.). Los resultados obtenidos mostraron que la alta temperatura, la humedad y el contenido de aceite, disminuyeron la densidad aparente y la dureza ($P < 0.05$). La interacción entre el contenido de aceite y la temperatura

aumentó tanto la densidad aparente como la dureza, mientras que la interacción entre el contenido de humedad y aceite aumentó la dureza (P < 0.05). La optimización se realizó con base en las características fisicoquímicas de alimentos comerciales, mostrando que las mejores dietas de frijol se obtuvieron a 121ºC, 14% de contenido de humedad con 0% de aceite de girasol; 120ºC y 16% de contenido de humedad con 3.5% de aceite de girasol; y, 142ºC y 15% de contenido de humedad con 7% de aceite de girasol. La degradabilidad efectiva varió de 87.4 a 90.4% para todas las dietas extruidas; y ninguno de ellos mostró diferencias significativas entre el frijol y la alfalfa (P < 0.05), lo que abre una gran oportunidad potencial de producir altas concentraciones de CLA a partir del aceite de girasol a nivel ruminal.
Palabras clave: alimento para ganado bovino, digestibilidad, aceite de girasol.

INTRODUCTION

Cattle's breeding is one of the main cornerstones of the global economy, being usually sustained from grassland, which lately has been affected by many problems, particularly, dry seasons (Petherick, 2005). A feasible option to help to solve this problem is to use pinto beans (*Phaseolus vulgaris* L.) as an ingredient for animals' feed. Small, cracked, or split beans are considered an agro-industrial by-product, not suitable for human consumption. Bean has a good protein (18 - 24%) and energetic (60 - 65%) content, but it also has the disadvantage of anti-nutritional factors (phytic acid, condensed tannins, polyphenols, trypsin inhibitors, chymotrypsin, α-amylase inhibitors, and haemagglutinating activity) presence (Iniestra-González *et al.*, 2005). However, these factors can be inhibited by thermal processing, such as extrusion (González-Valadez *et al.*, 2008). Sunflower oil is rich in linoleic acid content (El-Saidy *et al.*, 2011), which is transformed by ruminants into conjugated linoleic acid (CLA); a common term referring to all isomers of an octadecanoic carboxylic acid with unsaturation in different positions. CLA presents several health benefits: it helps to decrease weight-loss promoting muscle mass growth, and also, it is anti-carcinogenic (Pariza *et al.*, 2001). CLA content in bovine milk ranges from 6 to 16 mg/ g lipids, being lower in meat (Chillard *et al.*, 2007).

Recommended daily CLA consumption is 3 g/d for a 70 kg person, having the highest consumption rates in Australia (1.5 g/d) and Germany (0.5 g/d) (Poulson *et al.*, 2004). Studies showed an increase of 1.5 g/100 lipids g in milk obtained from cattle fed with 11.2% of sunflower seeds and an increase of 0.8 g/100 lipids g from cattle fed with 5% of a mixture of sunflower oil and fish oil (3:1) (Abu-Ghazaleh and Holmes, 2006). Extrusion has a wide range of food applications (Singh *et al.*, 2007), representing a good processing alternative, due to its economic feasibility since crop residues are underutilized in many developing countries. This research aimed to study the effect of temperature (T), moisture content (MC), and sunflower oil content (OC) on the extrusion process to elaborate bovine cattle feed, which could be reflected in milk and meat CLA content for human consumption.

MATERIALS AND METHODS

Experimental diets

Two diets were elaborated with 10% of bean flour (BD) or 10% of alfalfa flour (AD). Agroindustrial Saltillo bean (*Phaseolus vulgaris*) residue (small and cracked beans) was used, as well as alfalfa (*Medicago sativa*), cornflour (*Zea mays*), cane molasses, Mine-Gan, Química Industrial Agropecuaria S.A. de C.V., México), soybean meal flour (47.7% crude protein), sunflower oil and $CaCO_3$. All ingredients were milled and sieved (< 2 mm). Three OC/corn flour percentages ratios were used: 0:55, 3.5:51.5 or 7:48. All other ingredients were kept constant for AD and BD: cane molasses: 5%; soymeal: 5%; $CaCO_3$: 2%; and, glandless cottonseed meal: 23%.

Chemical composition

The chemical composition of raw materials, extrudates, and two commercial diets were determined following (AOAC, 2019) standards.

Extrusion

Samples were processed with a Brabender laboratory simple-screw extruder (Model 2523, 3/4” L/D - 25:1 ratio, C. W., Disburg, Germany), with four heating zones. The first three heating zones had a constant T; 90, 100, and 110°C, respectively. The fourth heating zone varied (120, 135, and 150°C), according to experimental design. The screw compression force was 1:1 and the internal diameter of the exit die was 6 mm. Before extrusion, all ingredients were mixed and conditioned to MC of 14, 16, or 18%, following experimental design. After processing, extruded samples were cooled at room T for 4 h and stored in sealed polyurethane bags at 4ºC for further analysis.

Experimental design and data analysis

A factorial design with three independent variables was performed for both diets: OC (X_1) [0, 3.5 and 7%], T (X_2) [120, 135 and 150°C] and MC (X_3) [14, 16 and 18%] before extrusion. Response variables were: expansion index (EI), bulk density (D), water absorption index (WAI), water solubility index (WSI), and hardness (H). Surface response methodology was applied to the experimental data using Design Expert 7.0® software and results were analyzed by multiple quadratic regressions. Statistical analysis and variance analyzes (ANOVA) for each response were performed using Statistica 7.0®.

Optimization

Optimization was performed for each OC using a central composite design with three independent variables. Priority responses used for the optimization were: H 25 - 50 N, EI 1.0 - 1.1, minimum WSI, and maximum D.

Functional Properties

EI and D were measured according to (Gujska and Khan, 1990 and Wang *et al.*, 1993), respectively. WAI and WSI were determined as outlined by (Ding *et al.*, 2005). H was evaluated using a texture profile analyzer model TA–XT2 (Texture

Technologies Corp., Scarsdale, NY/Stable MicroSystems, Haslemere, Surrey, UK). In each trial, fifteen samples were sheared using a Warner Brazler blade probe (sensitivity of 1 kg_f and 5 cm min^{-1}) to evaluate breaking strength.

In vitro digestibility and effective degradability

In vitro digestibility (IVD) was calculated using the Daisy II procedure (ANKOM, 2017); inoculum was prepared by diluting ruminal liquid obtained from a 459 kg rumen fistulated cow (criollo race) fed at free grazing, with a buffer solution 1:4 (v/v). Mean comparison was obtained using the Tukey test ($P < 0.05$). Effective degradability (ED) was calculated following (Solanas *et al.*, 2004) method. Means differences (Duncan, 95%), correlations (Pearson), and t-tests (Student) were performed using Statistica 7.0®.

RESULTS AND DISCUSSION

Chemical composition

The chemical content of all ingredients (Table 1) is comparable to other reports (Reyes-Jáquez *et al.*, 2011), except for alfalfa's ash content, which is 2% above reported values, possibly due to a higher presence of fertilizers. Also, alfalfa's crude protein content was slightly higher than other reports (Coblentz and Hoffman, 2009). THE highest NFE was shown in pinto beans, thus increasing the extrusion capacity of the diets (Reyes-Jáquez *et al.*, 2012).

Table 1. Chemical composition of ingredients before extrusion (g/ 100g DM).

Ingredient	Ash	Crude protein	Crude fat	Crude fiber	NFE*
Alfalfa flour	10.6 ± 0.15	25.2 ± 1.68	0.6 ± 0.06	23.1 ± 1.29	40.3 ± 0.06
Pinto Saltillo Bean flour	3.9 ± 0.11	24.2 ± 0.38	0.9 ± 0.11	2.3 ± 0.19	68.6 ± 0.56
Soybean meal flour	6.9 ± 0.03	58.5 ± 0.53	1.8 ± 0.13	0.0 ± 0.00	32.8 ± 0.43
Corn	1.5 ± 0.04	9.2 ± 0.56	1.9 ± 0.00	2.9 ± 0.02	84.3 ± 0.64
Cottonseed meal	7.2 ± 0.72	52.5 ± 1.13	1.9 ± 0.14	7.6 ± 0.09	30.6 ± 1.80
Molasses	7.1 ± 0.78	5.8 ± 0.89	0.1 ± 0.02	0.5 ± 0.05	86.9 ± 3.96
Calcium carbonate	39.7 ± 1.86	0.1 ± 0.02	0.0 ± 0.00	0.0 ± 0.00	60.2 ± 2.97

NFE= Nitrogen free extract

Functional Properties

All regression coefficients of EI are low (Table 2), possibly because NFE (Table 1) is not high enough to expand, and, process conditions did not yield a significant pressure differential, thus influencing only shaping, not expansion. These results are similar to others (Reyes-Jáquez *et al.*, 2011), where similar diets were extruded at the same T but with higher MC (18 - 22%) and without oil. Oil adding in extrudates decreases starch gelatinization due to lower shear stress applied upon the mixture since it acts as a lubricant; it also promotes lipid-starch complexes' formation, restraining water-starch interaction, resulting in lower EI (Liu *et al.*, 2006). D and H of AD and BD presented significant negative coefficients in all lineal terms (Table 2). High OC percentages generate a less structured and more fragile matrix, because of lipid-starch complexes' formation (Abu-Hardan *et al.*, 2011); also, high crude fiber content contributes to the fragility of the extruded matrixes (Reyes-Jáquez *et al.*, 2012). High lipid content in extrudates decelerates starch retrogradation and reduces H, adding the fact that high T further degrades starch granules, even leading to dextrinization and creating a less dense and easier to disrupt matrix (Rodríguez-Miranda *et al.*, 2012). High MC generates a higher amount of steam, producing an expanded volume when the mixture is exposed to a pressure differential, resulting in the rupture of matrixes' cellular walls and creating a more porous product with low D and H ($P < 0.05$) (Reyes-Jáquez *et al.*, 2012). OC-T interaction presented a significant positive effect ($P < 0.05$) on D and H, due high concentrations of oil generate more lipid-starch complexes, although high T could lead to break such complexes, allowing starch gelatinization and retrogradation (De Pilli *et al.*, 2011). OC-MC interaction had a positive effect ($P < 0.05$) on H; (Hernández-Hernández *et al.,* 2011) proposed a model of starch and α-lysophosphatidylcholine (LPC) complexes, indicating a strong competition among lipids and water to bond with starch, and inferring that high MC and OC, are likely to bond starch and water, gelatinizing it and obtaining denser and harder matrixes.

Table 2. Regression coefficients obtained from quadratic response surface models for bean and alfalfa diets. X_1 = oil content, X_2 = temperature, X_3 = moisture content.

Responses	Intercept	Lineal			Quadratic			Interactions			R^2
	b_0	X_1	X_2	X_3	X^2_1	X^2_2	X^2_3	X_1X_2	X_1X_3	X_2X_3	
EI-AD	1.088	-0.023*	-0.047*	-0.018*	-0.02*	-0.046*	-0.009*	-0.019+	0.014*	-0.009*	0.537
EI-BD	1.058	-0.02*	-0.044*	0.005	0.004	-0.03*	0.004*	-0.008	0.004*	0.022	0.384
D-AD	988.805	-47.65*	-32.52*	-12.06*	3.999	48.497*	8.27	57.404*	-16.93*	34.478*	0.457
D-BD	1100.499	-53.71*	-42.53*	-17.54*	5.711*	17.027*	-34.43*	13.287*	-10.09*	2.722	0.439
H-AD	34.232	-20.65*	-4.932*	-7.829*	16.34*	3.006*	0.804	8.319*	3.542*	1.237	0.697
H-BD	34.636	-19.41*	-2.922*	-5.873*	15.54*	1.389	3.54*	6.134*	2.242*	1.224	0.706
WAI-AD	2.688	-0.072*	0.19*	-0.006	-0.003	0.076	-0.08	0.051	0	0.054	0.549
WAI-BD	2.273	-0.133*	0.065*	-0.013	0.012	0.006	0.007	0.028	-0.011	0.033	0.422
WSI-AD	12.024	-0.375	-0.868	0.224*	-0.05	-0.882*	0.586*	0.17	0.076	0.099	0.547
WSI-BD	11.54	0.489*	-0.234*	-0.214*	0.096	-0.11	0.339*	-0.247*	-0.191	0.194	0.452

*Indicates significant difference ($P < 0.05$). DA = alfalfa diet, DB = bean diet, EI = expansion index, H = hardness, D = bulk density, WSI = water solubility index and WAI = water absorption index

WAI is firstly related to the amount of absorbed water by the starch granules after swallowing in water excess and can be used as a gelatinization grade index (González-Valadez *et al.*, 2008); and, secondly, to the proteins hydrophilic balance in the mixture, which changes according to the denaturalization grade of proteins, where the extrusion process changes solubility profiles (Serrano *et al.*, 1998). Table 2 presents WAI regression analysis: OC and T linear terms affected ($P < 0.05$) on WAI of both diets. Increasing OC decreases WAI due to lower water availability for the starch granule. As for T, at high values, amylose and amylopectin chains form an expandable matrix that translates into higher water retention capacity. WSI is directly related to starch degradation happening inside the extruder (Gujska and Khan, 1990). Table 2 presents WSI regression analysis: MC linear term, T, and MC quadratic terms of AD; and T, MC, and OC linear terms, MC quadratic term, T, and OC interaction term of BD, had a significant effect (P < 0.05) on WSI. BD's T negative linear term and T and OC interaction indicate that with high T, proteins denaturalization exposes hydrophobic groups located in the interior, contributing to solubility diminish (Ikpeme *et al.*, 2010).

Optimization

Optimal extrusion conditions were obtained at three different oil concentrations for each diet; AD (0% OC): 142°C, 18% MC; EI: 1.04, D: 1042.7 kg/m^3, H: 50 N, WAI: 2.67 g/g, and, WSI: 10.5%; AD (3.5% OC): 131°C, 18% MC; EI: 1.04, D: 1021.7 kg/m^3, H: 50 N, WAI: 2.67 g/g, and, WSI: 10.9%; AD (7% OC): 120°C, 18% MC; EI: 1.04, D: 1004.6 kg/m^3, H: 25 N, WAI: 2.67 g/g, and, WSI: 10.4%; BD (0% OC): 121°C, 14% MC; EI: 1.09, D: 1125 kg/m^3, H: 50 N, WAI: 2.34 g/g, and, WSI: 12.2%; BD (3.5% OC): 120°C, 16% MC; EI: 1.07, D: 1121.3 kg/m^3, H: 50 N, WAI: 2.26 g/g, and, WSI: 12%; and, BD (7% OC): 142°C, 15% MC; EI: 1.02, D: 1101 kg/m^3, H: 50 N, WAI: 2.27 g/g, and WSI: 11.6%. AD with 7% of OC had the lowest H, while this was not observed with BD. On the other hand, low T for BD with high OC was required compared to AD with low OC. BD needed high T to obtain optimal extrusion characteristics, specifically extrudates with 7% of OC compared to diets with 3 or 0% of OC. Optimization results have the required values to be commercialized due their similar characteristics compared to commercial products as shown in earlier publications (Reyes-Jáquez *et al.*, 2011). Chemical analysis was performed on BD optimal treatment with 7% of OC: MC: 10.7±0.22, protein: 17.6±0.63, fat: 10.7±0.11, fiber: 2.5±0.63 and ash: 8.7±0.18 g/100 g.

In vitro digestibility and effective degradability

IVD of 60.7% or higher is a well-accepted digestibility (Coblentz and Hoffman, 2009), placing AD and BD above such values (Table 3). Excluding both commercial diets, all diets had IVD ranging from 85 to 89% without significant differences (P > 0.05) among them. AD containing 0 or 3.5% of OC has a lower (P < 0.05) IVD than both commercial diets. BD with 3.5 and 7% of OC had comparable IVD to both commercial diets, concluding that incorporating sunflower oil in the extruded diets, increases (P < 0.05) IVD of BD. Table 3 shows the potential degradability (PD) and ED of all diets. PD describes the sum of soluble (A) and insoluble (B) fractions, being B, the maximum degradability peak achieved during 120 h. Table 3 showed that all EDs' values oscillated between 87.4 and 90.4% with no significant difference (P > 0.05), which are acceptable values compared to other reports (Reyes-Jáquez *et al.*, 2011). It can be concluded that OC and anti-nutritional factors presence did not have a significant difference in IVD nor ED since they were inactivated by high T and shear stress during processing. Also, OC is inside permissible ranges for ruminants' consumption (Byers and Schelling, 1993). Extrusion T, MC, and OC affected negatively (P < 0.05) D and H of both diets. However, increasing T and OC, and MC and OC, increases (P < 0.05) H. Obtained IVD was 89.1 and 86.4% for BD and AD with 7% of OC, respectively. Obtained optimal extrusion conditions for BD with 7% of OC were 142°C and 15% of MC; while for AD with 7% of OC were 120°C and 18% of MC. ED was 87.5 and 87.4% for BD and AD with 7% of OC, respectively. Results showed that incorporating sunflower oil in the diets, increases (P < 0.05) IVD, thus opening a high potential opportunity of producing high concentrations of CLA at the ruminal level.

Table 3. Nonlinear regression coefficients of In Situ Degradability (ISD) and Effective degradability (ED) of bean and alfalfa extruded diets at three different oil concentrations: 0, 3.5, and 7%.

Diet	Oil (%)	Coefficient			PD (%)	ED (%)	R^2	IVD (%)
		A	B	C				
Alfalfa	0	0.54	0.41	0.07	95.2	88.2[a]	0.99	85.2
Alfalfa	3.5	0.5	0.45	0.07	95.2	87.5[a]	0.98	84.7
Alfalfa	7	0.51	0.44	0.07	94.7	87.4[a]	0.96	86.4
Bean	0	0.6	0.36	0.07	96	89.7[a]	0.98	86.3
Bean	3.5	0.6	0.36	0.06	96.2	90.4[a]	0.98	89.4
Bean	7	0.49	0.47	0.08	95.9	87.5[a]	0.97	89.1
Commercial 1	-	-	-	-	-	-	-	93.8
Commercial 2	-	-	-	-	-	-	-	91.5

Different letters indicate significant difference (P < 0.05); Degradability times: 0 - 120 h. A = soluble fraction or quickly degradable, B = insoluble fraction but potentially degradable, C = degradation rate, t = feed residence time, considered 5% per hour, PD = potential degradability (A+B), ED = effective degradability rate at a constant feed's residence time in the animal (kp) $0.05*h^{-1}$

CONCLUSION

Extrusion temperature and moisture content affected negatively (P < 0.05) D and H of extruded cattle feed. Likewise, D and H decreased (P < 0.05) in extrudates, as oil content increased. However, increasing extrusion temperature and oil content, makes it possible to increase (P < 0.05) hardness of extrudates, as well as increasing moisture and oil content. Obtained In Vitro Digestibility was 89.1% and 86.4% for bean and alfalfa diets, respectively. Obtained optimal extrusion conditions for a bovine cattle feed using pinto bean residues with 7% of sunflower oil were 142°C and 15% of moisture content. While for extrudates containing alfalfa with 7% of sunflower oil were 120°C and 18% of moisture content. Effective In Situ Degradability was 87.5% and 87.4% for bean and alfalfa diets, respectively. Results showed that the incorporation of sunflower oil in extruded diets, increases (P < 0.05) In vitro digestibility of extruded alfalfa and pinto bean diets, opening a high potential opportunity to increase the production of organic CLA at ruminal level.

REFERENCES

ABU-GHAZALEH AA and Holmes LD. 2006. Diet Supplementation with Fish Oil and Sunflower Oils to increase Conjugated Linoleic Acid Levels in Milk Fat of Partially Grazing Dairy Cows. *J.Dairy Sci*. 90:2897-2904. https://doi.org/10.3168/jds.2006-684

ABU-HARDAN M, Hill EH and Farhat I. 2011. Starch conversion and expansion behavior of wheat starch cooked with either palm, soybean or sunflower oils in a co-rating intermeshing twin-screw extruder. *International Journal of Food Science and Technology.* 46:268-274. https://doi.org/10.1111/j.1365-2621.2010.02473.x

ANKOM. 2017. "In vitro true digestibility using the DAISY incubator". https://www.ankom.com/sites/default/files/document-files/Method_3_Invitro_D200_D200I.pdf

AOAC. 2019. Official Methods of Analysis. Association of Official Analytical Chemists International. Gaithersburg, Maryland. 21st ed. Vol. I. 700 p.

BYERS FM and Schelling GT. 1993. Lipids in ruminant nutrition. In: Church DC, editor. The ruminant animal: digestive, physiology and nutrition. 2nd ed. New Jersey, U.S.A: Waveland Press Inc. Pp. 298-312. ISBN 10: 0-88133-740-4. ISBN 13: 978-0-88133-740-2.

CHILLARD Y, Glasser F, Ferlay A, Bernard L, Rouel J and Doreau M. 2007. Diet, rumen biohydrogenation and nutritional quality of cow and goat milk fat. *Eur. J. Lipid Sci. Technol*. 109:828-855. https://doi.org/10.1002/ejlt.200700080

COBLENTZ WK and Hoffman PC. 2009. Effects of bale moisture and bale diameter on spontaneous heating, dry matter recovery, in vitro true digestibility, and in situ disappearance kinetics of alfalfa-orchardgrass hays. *J. Dairy Sci.* 92:2853- 2874. https://doi.org/10.3168/jds.2008-1921

DE PILLI T, Derossi A, Talja RA, Jouppila K and Secerini C. 2011. Study of starch-lipid complexes in model system and real food produced using extrusion-cooking technology. *Innovate Food Science and Engineering Tech*. 12:610-616. https://doi.org/10.1016/j.ifset.2011.07.011

DING QB, Ainsworth P, Tucker P, Marson H. 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *Journal of Food Engineering*. 66:283-289. https://doi.org/10.1016/j.jfoodeng.2004.03.019

EL-SAIDY EA, Faraouk S and Adb El-Ghany HM. 2011. Evaluation of different seed priming on seeding growth, yield and quality components in two sunflower (*Helianthus annus* L.) cultivars. *Trends in Applied Sciences Research.* 6:977-991. https://doi.org/10.3923/tasr.2011.977.991

GONZÁLEZ-Valadez M, Munoz-Hernández G and Sánchez-López R. 2008. Design and evaluation of an extruder to convert crop residues to animal feed. *Biosystems Engineering.* 100:66-78. https://doi.org/10.1016/j.biosystemseng.2008.02.002

GUJSKA E and Khan K. 1990. Effect of temperature on properties of extrudates from high starch fractions of navy, pinto and garbanzo beans. *J. Food Sci*. 55:466-469. https://doi.org/10.1111/j.1365-2621.1990.tb06788.x

HERNÁNDEZ-Hernández E, Ávila-Orta CA, Hsiao BS, Castro-Rosas J, Gallegos-Infante JA, Morales-Castro J, Ochoa-Martínez LA, Gómez-Aldapa CA. 2011. Synchrotron X-ray scattering analysis of the interaction between corn starch and an exogenous lipid during hydrothermal treatment. *Journal of Cereal Science*. 54:69-75. https://doi.org/10.1016/j.jcs.2011.03.001

IKPEME ECA, Osuchukwu NC and Oshiele L. 2010. Functional and sensory properties of wheat (*Aestium triticium*) and taro flour (*Colocasia esculenta*) composite bread. *Afr. J. Food Sci*. 4:248-253. https://academicjournals.org/journal/AJFS/article-full-text-pdf/4AAAB0C23570

INIESTRA González, José J., Ibarra Pérez, Francisco J., Gallegos Infante, José A., Rocha Guzmán, Nuria E. y González Laredo, Rubén F. Factores antinutricios y actividad antioxidante en variedades mejoradas de frijol común (*Phaseolus vulgaris*). Agrociencia. 2005;39(6):603-610. [fecha de Consulta 21 de Julio de 2020]. ISSN: 1405-3195. Disponible en: https://www.redalyc.org/pdf/302/30239603.pdf

LIU L, Kerry JF and Kerry JP. 2006. Effect of food ingredients and selected lipids on the physical properties of extruded edible films casings. International Journal of Food Science and Technology. 41:295-302. https://doi.org/10.1111/j.1365-2621.2005.01063.x

PARIZA MW, Park Y and Cook ME. 2001. The biologically active isomers of conjugated linoleic acid. *Progress in Lipid Research*. 40:283-298. https://doi.org/10.1016/S0163-7827(01)00008-X

PETHERICK JC. 2005. Animal welfare issues associated with extensive livestock production; the northern Australian beef cattle industry. *Applied Animal Behavior Science*. 92:211-234. https://doi.org/10.1016/j.applanim.2005.05.009

POULSON CS, Shiman TR, Ure AL, Cornforth D and Olson KC. 2004. Conjugated linolenic acid content of beef from cattle fed diets containing high grain, CLA, or raised on forages. *Livestock Production Science*. 91:117-128. https://doi.org/10.1016/j.livprodsci.2004.07.012

REYES-Jáquez D, Casillas F, Flores N, Andrade-González I, Solís-Soto A, Medrano-Roldan H, Carrete F, Delgado E. 2012. The effect of Glandless Cottonseed Meal Content and Process Parameters on the Functional Properties of Snack during Extrusion Cooking. *Food and Nutrition Sciences*. 3:1716-1725. https://doi.org/10.4236/fns.2012.312225

REYES-Jáquez D, Vargas-Rodríguez J, Delgado-Licón E, Rodríguez-Miranda J, Araiza-Rosales E, Andrade-González I, Solís-Soto A And Medrano-Roldan H. 2011. Optimization of the Extrusion Process Temperature and moisture Content on the Functional Properties and in vitro Digestibility of Bovine Cattle Feed Made out of Waste Bean Flour. *Journal of Animal Science Advances*. 1:100-110. ISSN: 2251-7219 https://www.researchgate.net/publication/245536642_Optimization_of_the_Extrusion_Process_Temperature_and_Moisture_Content_on_the_Functional_Properties_and_in_vitro_Digestibility_of_Bovine_Cattle_Feed_Made_out_of_Waste_Bean_Flour

RODRÍGUEZ-Miranda J, Delgado-Licón E, Ramírez-Wong B, Solís-Soto A, Vera MA, Gómez-Aldapa C, Medrano-Roldán H. 2012. Effect of Moisture, Extrusion Temperature and Screw Speed on Residence Time, Specific Mechanical Energy and Psychochemical Properties of Bean Four and Soy Protein Aquaculture Feeds. *Journal of Animal Production Advances*. 2:65-73. ISSN: 2251-7677. https://www.researchgate.net/publication/246044402_Effect_of_Moisture_Extrusion_Temperature_and_Screw_Speed_on_Residence_Time_Specific_Mechanical_Energy_and_Psychochemical_Properties_of_Bean_Four_and_Soy_Protein_Aquaculture_Feeds

SERRANO X, Baucells MD, Barroeta AC and Puchal F. 1998. Effects of extruded diet on the productive performance of weaning and post-weaned calves. *Animal Feed Science and Technology*. 70:275–279. https://doi.org/10.1016/S0377-8401(97)00082-5

SINGH S, Gamlath S and Walkeling L. 2007. Nutritional aspects of food extrusion: a review. *J. Food Sci. and Technol*. 42:916-929. https://doi.org/10.1111/j.1365-2621.2006.01309.x

SOLANAS E, Castrillo C, Balcells J and Guada JA. 2004. In situ ruminal degradability and intestinal digestion of raw and extruded legume seeds and soya bean meal protein. *Journal of Animal Physiology and Animal Nutrition*. 89:166-171. https://doi.org/10.1111/j.1439-0396.2005.00555.x

WANG WM, Klopfenstein CF and Ponte JG. 1993. Effects of twin-screw extrusion on the physical properties of dietary fiber and other components of whole wheat and wheat bran and on the baking quality of the wheat bran. *Cereal Chem*. 70:707-711. https://agris.fao.org/agris-search/search.do?recordID=US9434019