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Digestible and metabolizable energy of crude glycerin for finishing pigs

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ABSTRACT. The aim of this study was to determine the values of apparent digestible energy (DE) and metabolizable energy (ME) for crude glycerin derived of biodiesel based on pork fat for finishing pigs. The diets consisted of a basal diet and four levels of crude glycerin (0, 5, 10 and 15%). Twelve pigs were housed individually in metabolic cages and after seven days of adaptation, total collections of urine and feces for four consecutive days were performed. Gross energy (GE) of crude glycerin, diets, urine and fecal samples from each animal was determined. The crude glycerin used in this experiment presented 74.74% glycerin and 6,500 kcal kg^{-1} gross energy. The values of digestible energy (DE) and metabolizable energy (ME) were estimated by difference in the DE, and content of the basal diet was subtracted from the test diets containing the ingredient. The amount of GE, DE and ME for finishing pigs was 6,500, 5,839 and 5,509 kcal kg^{-1}, respectively, with a coefficient of 91.0% of DE and 94.0% of ME. The energy of crude glycerin is based on the levels of fatty acids and GE depends on the concentration of fatty acids and glycerin, ME being a percentage of GE averaging is 84.75%.

Keywords: biodiesel, by-product, lard, swine.

Energia digestível e metabolizável de glicerina bruta para suínos em terminação

RESUMO. O objetivo do estudo foi determinar os valores de energia digestível (ED) e metabolizável (EM) aparente da glicerina bruta de biodiesel à base de gordura suína para suínos em terminação. Os tratamentos experimentais consistiram de quatro níveis de glicerina bruta (0, 5, 10 e 15%) a partir de uma dieta basal. Doze suínos foram alojados individualmente em gaiolas metabólicas e foram realizadas coletas de urina e fezes durante quatro dias. Foi determinada a energia bruta (EB) da glicerina bruta, das dietas, da urina e das amostras de fezes de cada animal. A glicerina bruta apresentou 74,74% de glicerina e 6.500 kcal de energia bruta kg^{-1}. Os valores de energia digestível (ED) e metabolizável (EM) foram estimados por diferença, em que o conteúdo ED e EM da dieta basal foram subtraídos das dietas contendo o ingrediente teste. A quantidade de EB, ED e EM para suínos em terminação foi de 6.500, 5.839 e 5.509 kcal kg^{-1}, respectivamente, com um coeficiente de 91,0% de ED e 94,0% de EM. A energia da glicerina bruta é baseada nos níveis de ácidos graxos e a EB depende da concentração de ácidos graxos e glicerina, sendo a EM um percentual da EB variando na média de 84,75%.

Palavras-chave: biodiesel, coproduto, banha suína, suíno.

Introduction

Throughout the world, biodiesel has been one of the most widely used alternative energy source. Most of the countries recommend that diesel must contain some amount of biodiesel, and Brazil has abundant raw material, technological resources and framework with high capacity to develop its production (Ferreira-Leitão et al., 2010). According to the Brazilian National Program for Production and Use of Biodiesel (Law 11,097), the addition of 5% biodiesel to the fossil diesel proposed for 2013 was already achieved in 2010, reaching 2.9 billion of litters in 2013. However, the main limitation to the high production of biodiesel in the country is the destination of the crude glycerin, a by-product of biodiesel, that represents approximately 10% of the biodiesel produced (Bowker et al., 2009). The traditional destination of purified glycerin are drug, cosmetics and food industry, which are already saturated. Besides, purification of crude glycerin is a costly process (Rivaldi et al., 2007). An effective alternative may be it use in animal production (Eiras et al., 2014; Françozo et al., 2013). Pure glycerin is a colorless, odorless, and a sweet-tasting viscous liquid, containing approximately 4.3 Mcal of gross energy (GE) kg^{-1} as basis (Kerr et al., 2009).

However, crude glycerin can range from 3 to 6 Mcal GE kg^{-1}, depending upon its composition (Kerr et al., 2009; Lammers et al., 2008b; Mendoza et al., 2010). Biodiesel can be produce by a variety of esterification technologies from vegetable oil, animal fat, or yellow grease as the initial feedstock (Thompson & He, 2006; Van Gerpen, 2005). Considering that, there is a wide difference between the several sources of crude glycerin. Establishing the difference between the available energy of the crude glycerin in Brazil became very important to ensure the use of this by-product in the animal production. If swine and poultry production use 10% of crude glycerin in the diet, these markets would be able to consume the entire surplus of crude glycerin generated in Brazil. Thus, the aim of this study was to determine the digestible and metabolizable energy of crude glycerin, originated from biodiesel production, from pig fat through the energy balance of finishing pigs.

Material and methods

Source of crude glycerin

Crude glycerin was obtained from the pig farm 'Pork Terra', located in Caconde, São Paulo State. It was originated from biodiesel production derived from pork fat of fried bacon. This farm works in such a way that all the systems are integrated, a pig farm, a slaughterhouse, a butchery, and a biodiesel plant. The farm uses the pig fat originated from the fried skin, bacon and visceral fat to produce its own biodiesel. Crude glycerin from the biodiesel production is used in swine feed. The analyses of water, fatty acids, protein, sodium, potassium and total glycerin were performed at the Laboratory of Animal Science of the Federal University of Lavras (Table 1).

Table 1. Composition of crude glycerin.

Characteristics	Value (%)
Glycerin	74.740 %
Moisture	10.320 %
Fatty acids	14.000 %
Protein	0.880 %
Sodium	0.065 %
Potassium	0.000%
Gross energy	6,500 kcal kg^{-1}

Evaluation of crude glycerin originated of pork fat

Twelve barrows (Topigs C40 females x TOPPI sires), with average initial body weight (BW) of 74.17 ± 2.05 kg, were randomly assigned to individual metabolism cages (0.53 × 0.71 m) equipped with screens and trays that allowed total but separate collection of feces and urine. The rooms were equipped with air conditioning to control the temperature (21.2 ± 3.0°C). Four different levels of glycerin were evaluated from twelve animals used in the experiment, following Matterson et al. (1965) methodology, where the basal diet is replaced with crude glycerin levels (5; 10; and 15%). Dietary treatments consisted of a common basal diet, which met or exceeded the NRC (2012) requirements based on corn and soybean meal supplemented with vitamins and minerals (Tables 2 and 3).

Table 2. Composition of the diets.

Ingredients (kg)	Amount
Corn	0.7548
Soybean meal (46.5%)	0.2155
Dicalcium phosphate	0.0109
Limestone	0.0081
Sodium chloride	0.0033
Mineral-vitamin mix[a]	0.0040
Tylan[b] (250G)	0.0002
Kaolin[c]	0.0032
Total	100.00

[a]Composition kg^{-1} of the product: Ca (98,800 mg); Co (185 mg); Cu (15,750 mg); Se (105 mg); Fe (26,250 mg); I (1,470 mg); Mn (41,850 mg); Zn (77,999 mg); niacin (5,600 mg); folic acid (116.55 mg); pantothenic acid (2,333.5 mg); biotin (5.28 mg); pyridoxine (175 mg); riboflavin (933.30 mg); thiamine (175 mg), Vit. A (1,225,000 IU); Vit. D3 (315,000 IU); Vit. E (1,400 mg); Vit. K3 (700 mg); Vit. B12 (6,825 mg), antioxidant (1,500 mg). [b]Antibiotic based on granulated tylosin. [c]Inert compound.

Table 3. Calculated and evaluated composition of dietary treatments.

Variable*	Crude glycerin levels			
	0%	5%	10%	15%
GE[a]	3934.36	4081.08	4163.43	4257.72
CP[a]	12.70	12.11	11.50	10.85
DM[a]	89.02	89.73	88.86	87.56
TLys[b]	0.83	0.79	0.75	0.63
DLys[b]	0.70	0.66	0.63	0.59
DMet[b]	0.24	0.23	0.22	0.20
DThr[b]	0.54	0.51	0.48	0.46
AP[b]	0.30	0.28	0.27	0.25
Calcium[b]	0.65	0.61	0.58	0.55

*GE: Gross Energy (kcal kg^{-1}); CP: Crude Protein (%); DM: Dry Matter (%); TLys: Total Lysine (%); DLys: Digestible Lysine (%); DMet: Digestible Methionine (%); DThr: Digestible Threonine (%); AP: Available Phosphorus (%); [a]Values determined in the Laboratory of Animal Science (UFLA); [b]Values calculated according to the levels of basal diet and crude glycerin.

Experimental procedures

The experiment was conducted at the Experimental Station of Swine in the Department of Animal Science of the Federal University of Lavras. The experiment lasted eleven days: seven days for the adaptation of the animals to the cages, experimental diets and adjustment of the voluntary feed intake, and four days for the collection of feces and urine. The gross energy (GE) of crude glycerin, diets, urine, and fecal samples from each pig were determined by calorimeter. Ferric oxide (Fe_2O_3), at 1%, was used as fecal marker to determine the beginning and the end of feces collection. The animals were fed at 7:00 am and 4:00 pm. The total daily feed intake was established based on metabolic weight (body $weight^{0.75}$). The amount of feed intake was adjusted by the lower intake of the animal in each block observed during the adaptation period, allowing that all animals consumed equal amounts of nutrients in relation to the metabolic weight. Feces were collected daily, stored in plastic bags and kept in a freezer (-20ºC). Subsequently, they were placed at room temperature until thawed, then weighed and mixed. Around 20% of the sample was dried in a forced air oven (65°C) and exposed to air for one hour to equalize with room temperature. Then samples were ground to carry out the laboratory analyzes. Likewise, daily urine was collected in a plastic bucket with filter, containing 20 mL of hydrochloric acid (HCl) 1:1 to prevent bacterial growth, fermentation, and possible losses of nitrogen. From the total daily urine, 10% was collected and frozen at -20°C for analysis. All analyzes were performed at the Laboratory of Animal Research of the Federal University of Lavras.

Equations

Based on the data of feed intake, excretion of feces and urine, and analysis of dry matter (DM) and gross energy (GE) of feces and urine, the digestible energy (DE) and metabolizable energy (ME), was determined using the following equations by Matterson et al. (1965).

For comparative purposes, the feed DE was calculated through the following equation:

$$\text{DE feed} = \frac{\text{GE intake} - \text{GE feces}}{\text{DM intake}}$$

where:

DE feed: Digestible energy of the feed;

GE intake: Gross energy ingested by the animals;

GE feces: Gross energy of animal feces;

DM intake: Dry matter ingested by the animals.

After determining the value of feed DE, crude glycerin DE was calculated through the following equation for all the experimental diets:

$$\text{Crude glycerin DE} = \text{DE basal feed} + \left[\frac{(\text{DE experimental feed} - \text{DE basal feed})}{\text{g of crude glycerin / g of feed}}\right]$$

Feed ME was calculated through the following equation:

$$\text{ME} = \frac{\text{GE intake} - \text{feces GE} - \text{urine GE}}{\text{DM intake}}$$

After determining the value of feed ME, crude glycerin ME was calculated using the following equation for all the experimental diets:

$$\text{Crude glycerin ME} = \text{ME basal feed} + \left[\frac{(\text{ME experimental feed} - \text{ME basal feed})}{\text{g of crude glycerin / g of feed}}\right]$$

Estimating the energy value according to Matterson et al. (1965) did not demand the use of particular calculations. The method suggests the use different food levels and the use of the level with lower standard deviation to determine the energy value.

Results and discussion

Crude glycerin, in its composition, has about 85% glycerol, a high energy nutrient that has potential as a partial replacement of cereal grains (Lammers et al., 2008a; Mendoza et al., 2010). The crude glycerin used in this experiment contained - glycerin, moisture, fatty acids, protein, sodium (74.74, 10.32, 14.0, 0.88, 0.065%, respectively) and 6,500 kcal kg^{-1} of gross energy. Crude glycerin can range from three to six Mcal GE kg^{-1}, depending upon its composition (Carvalho et al., 2012; Kerr et al., 2009; Lammers et al., 2008b).The gross energy value of crude glycerin in this study does not resemble to any crude glycerin in the literature. This value may have been influenced by the high level of fatty acids (14%) and lower level of sodium (0.065%) when compared with other crude glycerin. Considering the economic value of the crude glycerin used in this trial compared with oils or fats, is important to consider it as a source of energy and fatty acids in the diet due to its low costs.

Low concentrations of methanol can be found in crude glycerin; acute methanol intoxication can lead to formic acid accumulation causing metabolic acidosis (Medinsky & Dorman, 1995; Skrzydlewska, 2003). Crude glycerin originated of pig fat had a solid aspect, so to be used it in the diet of the animals in the present study it had to be liquefied. The liquefying process lowered the level of methanol to 0.00% in the crude glycerin used in this study, since it is vaporized at 65.5ºC. There were no negative effects on performance and histological parameters swine fed different methanol levels (Lammers et al., 2008a).

The amounts of digestible energy and metabolizable energy increases with the substitution of the basal diet by a percentage of crude glycerin. This is due to the high-energy value and high digestibility of the crude glycerin used in this experiment (6,500 kcal kg^{-1}). The high digestibility can be observed in the amount of digestible dry matter, which increased as the level of glycerin in the diet was raised (Table 4).

Table 4. Digestible and metabolizable energy in the feed.

Variable*	Crude glycerin levels			
	0%	5%	10%	15%
DDM	86.5	86.9	87.2	89.1
DE	3,452 ± 67	3,577 ± 55	3,652 ± 118	3,741 ± 41
DEC	87.3	87.4	88.2	90.2
ME	3,279 ± 120	3,386 ± 63	3,445 ± 119	3,540 ± 106
MEC	94.8	94.7	94.3	94.3

*DDM: Digestible Dry Matter (%); DE: Digestible Energy (kcal kg^{-1}); DEC: Digestible Energy Coefficient (%); ME: Metabolizable Energy (kcal kg^{-1}); MEC: Metabolizable Energy Coefficient (%);

As presented in Table 5, estimated values of DE and ME for levels 5 and 10% of glycerol showed high deviations. This occurs because energy values are calculated taking into account low inclusion levels of crude glycerin. As presented by the equation proposed by Matterson et al. (1965), the difference of 100 kcal in the test diet evaluated in calorimetric bomb will generate a high variation in the prediction of energy values of food. Therefore, higher levels of inclusion should be considered when using this methodology in order to have a better energy estimation of feed and low variation.

Table 5. Digestible and metabolizable energy of crude glycerine.

Variable*	Estimated values of crude glycerin		
	5%	10%	15%
DE	5,442 ± 1,095	5,558 ± 1,180	5,839 ± 270
DEC	85.0	87.0	91.0
ME	5,153 ± 1,049	5,232 ± ‘1,122	5,509 ± 341
MEC	94.7	94.3	94.3

*DE: Digestible Energy (kcal kg^{-1}); DEC: Digestible Energy Coefficient (%); ME: Metabolizable Energy (kcal kg^{-1}); MEC: Metabolizable Energy Coefficient (%);

The digestible energy coefficient increased with the addition of crude glycerin, and it was due to the fact that glycerin is very digestible compared with regular feed. The glycerol is directly absorbed into the portal system and goes straight to the liver. After that, the glycerin is converted into glycerol-3-phosphate by glycerol kinase, and then it is oxidized to dihydroxyacetone phosphate on the outer face of the inner mitochondrial membrane and goes to the glycolytic pathway for energy production (Robergs & Griffin, 1998). In this study, fatty acids concentration aided the increased digestibility of the crude glycerin. According to Kerr et al. (2009), the amount of fatty acids appeared to be a major factor determining the ME in crude glycerin. These authors had to eliminate two crude glycerin types with an elevated content of fatty acids to improve the ability to estimate ME from the composition of crude glycerin, due to a higher interference in the fatty acids, to create an equation to estimate the energy of crude glycerin. For this, new models have to be created to estimate the values of DE and ME of crude glycerin with a high level of fatty acids. GE concentration is dependent on the concentration of glycerin and fatty acids, and the ME can be estimated as a percentage of GE averaging 84.75%. Kerr et al. (2009) show similar results. The authors evaluated twelve samples of crude glycerin and found that the GE concentration is dependent on the concentration of glycerin, methanol, and fatty acids, being ME as a percentage of GE, averaging 85.4%.

Thus, the estimated value of digestible energy and metabolizable energy of glycerin was 5,839 and 5,509 kcal kg^{-1}, respectively. A higher level of inclusion was used to estimate due to the low variation between the results, as suggested by Matterson et al. (1965). The higher EM values presented in literature to date for crude glycerin was 5,206 kcal kg^{-1} (Kerr et al., 2009). The other values ranged from 2.5 to 4.6 Mcal kg^{-1} (Kerr et al., 2009; Lammers et al., 2008b; Mendoza et al., 2010). Digestibility and metabolism of glycerol were 91 and 94%, respectively, and these results are similar to those found by Lammers et al. (2008b), who found values of 92% for DEC and 96% for MEC. Crude glycerin is a valuable energy source to swine and the levels of fatty acids are the most important to increase these values, in this way, if the suppliers of crude glycerin are able to produce a product rich in fatty acids, it will be a valuable ingredient for monogastric animals. GE concentration depended on the concentration of glycerin and fatty acids, and ME as a percentage of GE averaging is 84.75%.

Conclusion

The apparent digestible energy and metabolizable energy for crude glycerin derived from biodiesel based on pork fat for finishing pigs were 5.839 and 5.509 kcal kg^{-1}. The level of fatty acids in crude glycerin has a great impact on energy values. Thus, crude glycerin can be used in diets for finishing pigs, both as energy or fatty acids source. More studies are necessary to understand the differences between crude glycerin that are commercialized.

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