A Study on the Use of Glycerol, a Byproduct of Biodiesel Production, as a Feed Ingredient for Fattening Pigs

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Abstract: A large quantity of glycerol as byproduct of biodiesel production process is produced world widely every year. Glycerol, one of renewable energy resource, has been used for industrial purposes including cosmetic and soap material, and recently glycerol is regarded as feed ingredient for animal feed. In this paper, we have tested the worth of glycerol as feed additive for pig feed. For the test we prepared three different feeds depending on the glycerol content, weight basis, of 0%, 5% and 8.5%, and measured weight gains and pork meat quality, stability of feed of three different groups of pig, 250 pigs each, for seven weeks. The data collected from this investigation proved that glycerol as feed additive can be a feed resource for pig feed.

Key words: Glycerol, byproduct, biodiesel production, fattening pigs, feed.

1. Introduction

The world's continuously growing population creates an increasing demand for food (meat, milk, eggs, etc.). To meet this growing demand, it is necessary to develop sustainable feeding solutions that allow the optimization of the basic costs and the improvement of quality.

Biodiesel has recently become more attractive because of its environmental benefits and the fact that it is obtained from renewable resources [1]. The availability of fossil fuel resources is decreasing day by day, while the use of biodiesel fuels is on the increase worldwide (Fig. 1) as blending components or direct replacements for diesel fuel in vehicle engines [2].

Biodiesel production is acknowledged as an important and efficient tool in combating climate changes [3]. It is very important to improve the energy efficiency of fuels and to produce a range of main and byproducts for the practice [4]. Glycerol is one of the most important byproducts of biodiesel manufacturing.

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Fig. 1 Biodiesel production of the world (based upon data from the Earth Policy Institute). Source: Earth Trends (2007).

Glycerol as a glycogenic substance is known to supply energy in feed formulations for ruminants. It alleviates ketosis and improves the lactation performance. The additional energy provided by glycerol is 8.7-9.5 MJ/kg, and glycerol provides protection against ketosis, especially in cows of high milk yield [5].

Pure glycerol is a clean, sweet liquid that is labeled as E-422 in the EU as a food additive. It has wetting, dissolving, sweetening and preservation properties. There are 1,500 different known applications of glycerol in the pharmaceutical, cosmetics, food and paper industries. Ninety-five percent of these

applications require the clean grade (technical or pharmaceutical purity) [6, 7]. Before the advent of biodiesel, synthetic and natural glycerol products had competed on the market. By now the overproduction of natural (biodiesel) products has resulted in price erosion and decreased the production of synthetic glycerol.

Researchers at Iowa State University and at the Agricultural Research Service of the USDA have suggested that glycerol can be used at up to 10% in poultry and pig diets without any adverse effect. In these feeding systems they used pharmaceutical grade glycerol [8]. Researchers at the University of Arkansas concluded that the amount of glycerol that can be used in broiler chicken diets is limited by the degree of purity. This is the situation in the case of pig diets as well.

Bypass glycerol originating from the biodiesel production process is not clean. It contains several impurities such as methanol, different salts (sodium chloride or potassium phosphate) and phosphatides. After the cleaning process, the glycerol concentration of the product is approximately 85%, with 5% sodium chloride and water.

The aim of this trial was to examine the possibility of using glycerol in the feeding of fattening pigs. Glycerol was added to the diet of two groups of fattening pigs at an inclusion level of 5% and 8.5%, respectively.

2. Materials and Methods

The trial was conducted in the years 2009-2010 on a huge pig farm in Hungary (Dráva-Coop Ltd.). A total of 750 pigs, divided into three treatment groups (5% and 8.5% glycerol supplementation and control; n = 250 pigs each), were used.

In our previous study, the salt content of glycerol had been determined (5%), and this salt content limited the amount of glycerol added to the experimental feeds. Based on the data obtained, a maximum inclusion level of 8.5% was considered

suitable for use in feeds, and added salt had to be totally omitted. By this approach it could be guaranteed that the diets of all groups used in the trial were completely equal in terms of salt content.

During the first 3 weeks of life the feeding of the pigs was the same: they received a piglet feed produced by Vitafort Co. (Piglet II, Table 1), which did not contain glycerol.

Subsequently, the pigs received the Fattening I and II granulated feeds *ad libitum* throughout the trial.

The calculated nutritional value of the three feeds (Fattening I and II, control, 5%, 8.5%) was completely identical (Tables 2 and 3).

According to data of the literature, the real energy value of glycerol for swine (DE and ME) is very poor. These values were determined by Lammers et al. [9]

Table 1 Nutritional value of the piglet feed (Piglet II).

Contents	
Dry matter (%)	86
Crude protein (%)	18.2
DE (MJ/kg)	13.7
ME (MJ/kg)	13.35
Calcium (%)	0.83
Phosphorus (%)	0.59
Sodium (%)	0.17
Vitamin A (IU/kg)	12,160
Vitamin D ₃ (IU/kg)	1,600
Vitamin E (mg/kg)	120
Lysine (%)	1.10

Table 2 Nutritional value and glycerol content of the fattening feed (first fattening phase).

Contents	Fattening I (control)	Fattening I (5%)	Fattening I (8.5%)
Dry matter (%)	87.0	84.9	83.4
Crude prot. (%)	16.1	16.1	16.1
DE (MJ/kg)	13.6	13.6	13.7
ME (MJ/kg)	13.2	13.2	13.2
Calcium (%)	0.88	0.89	0.88
Phosphorus (%)	0.58	0.56	0.57
Sodium (%)	0.2	0.2	0.25
Vitamin A (IU/kg)	6,840	6,840	6,840
Vitamin D ₃ (IU/kg)	900	900	900
Vitamin E (mg/kg)	74	74	74
Lysine (%)	0.95	0.95	0.95
Glycerol (%)	0	5.09	8.59

Table 3 Nutritional value and glycerol content of the fattening feed (second fattening phase).

Contents	Fattening II (cont.)	Fattening II (5%)	Fattening II (8.5%)
Dry matter (%)	87	84.9	83.4
Crude prot. (%)	15.1	15.1	15.1
DE (MJ/kg)	13.6	13.6	13.6
ME (MJ/kg)	13.0	13.0	13.0
Calcium (%)	0.89	0.89	0.89
Phosphorus (%)	0.58	0.58	0.56
Sodium (%)	0.19	0.2	0.25
Vitamin A (NE/kg)	6,840	6,840	6,840
Vitamin D-3 (NE/kg)	900	900	900
Vitamin E (mg/kg)	74	74	74
Lysine (%)	0.86	0.86	0.86
Glycerol (%)	0	5.09	8.59

and confirmed by Professor Schmidt et al. [10], who worked with us in the project. In the trial we used this value (ME = 13.47 MJ/kg) for the calculations, and all nutritional values were equivalent in the feeds. In order to ensure this, some corn was taken out from the trial feed, but it was necessary to complete the protein and amino acid values by additional extracted soybean meal in the trial group as well. On the other hand, it was necessary to take into consideration the price differences between the control and the trial feeds.

The most important production figures were recorded in all three groups throughout the trial period. All technological parameters, such as the principal nutritional values and the extra glycerol content, were monitored to ensure the objectivity of the trial. To exclude the potential impact of a possible mycotoxin contamination on the production of the three groups, a systematic mycotoxin analysis was also carried out.

The effect of this type of feed (having a glycerol content of 5% and 8.5%, respectively) on the quality of pig meat was examined at the end of the trial by assessing the following parameters: dripping losses [11], total losses, baking losses, shearing stress, and pH value of the pig meat. If the pH value of the meat 45 minutes after slaughtering (pH_{45}) is lower than 5.7 and at 24 hours after slaughtering (pH_{24}) it is lower than 5.6, the prevalence of PSE (pale, soft, exudative) meat will be higher. In contrast, the occurrence of

DFD (dark, firm, dry) meat will be more likely if the pH_{45} is > 6.3 and the pH_{24} is > 6.2 . The quality of the meat was measured according to the EUROP standard test sequences as well.

It was questionable also whether glycerol had any effect on the (chemical and microbiological) stability of feeds, mainly because of its hygroscopic character. During the trials the feeds were stored under normal warehouse conditions, in warehouse amounts (hundreds of kilograms). The moisture content, the mould counts, the vitamin A and vitamin E content were measured, and stability was evaluated on the basis of the acid and peroxide numbers serving as indicators of rancidity.

3. Results and Discussion

The production results obtained in trial are presented in Table 4. The feed conversion ratio and the meat quality (boneless meat %) showed practically the same values in the three groups (control, 5% and 8.5% of glycerol content). At the same time, the daily body weight gain was higher (by approximately 20 grams/animal) in the two groups fed the glycerol-supplemented diet than in the control group, although it is a fact that the average body weight of the control group was lower at the beginning of the trial (at the time of placement).

Our own observation was that the pigs preferred the glycerol-containing feed, since its palatability was probably better. This may be an explanation of the higher daily body weight gain. It seems to be a benefit that finishing pigs fed the glycerol-supplemented diet could achieve the slaughter weight 3-4 days earlier than pigs in the control group. Since the total body weight gain of the animals was determined by the collective weighing of the entire groups, it was not possible to perform individual statistical analysis, even though the number of feeding days was calculated very precisely. It can be concluded that there were no remarkable differences between the control and the experimental groups in the production results.

Table 4 Results of the fattening pig trial.

Parameter	Cont.	Group 1 (5%)	Group 2 (8.5%)
Number of animals (n)	245	252	252
Average weight at the time of placement (kg)	23.67	24.98	25.19
Total weight at the time of placement (kg)	5,800	6,295	6,350
Deaths (n)	8	9	9
Deaths (kg)	664	605	550
Emergency slaughter (kg)	350	60	235
Number of animals sold (n)	230	242	238
Total weight of animals sold (kg)	29,495	31,000	30,617
Average weight of animals sold (kg)	128.23	128.09	128.64
Total body weight gain (kg)	24,709	25,370	25,052
Feed consumption (kg)	76,780	78,610	79,000
Number of feeding days	29,540	29,755	29,188
Daily body weight gain (gram)	836	853	858
Feed conversion ratio (kg/kg)	3.11	3.1	3.15
Meat quality (boneless meat %)	57.56	57.22	57.56

Based on the facts and figures (Table 5), it can be declared that the quality of the feeds was adequate and completely equal in the different groups (including even the mycotoxin contamination), so this could not cause any differences in the body weight gain and other production results during the trial. Overall, it can be laid down as a fact the glycerol does not have any negative effect on feed quality; conversely, it even improved the physical properties of the feed as compared to that of the control group (less dust and more pliable granulates).

The effects of glycerol on meat quality are

summarized in Tables 6 and 7. The two pH values (the values measured 45 minutes and 24 hours after slaughtering) do not indicate any PSE or DFD quality problem, and there are no significant differences between the treated and the control groups. As regards the color changes of the meat, we measured a significant difference for the 5% glycerol group in the color abyssal parameter.

In this case the higher value means more intensive meat color which is preferable in terms of perception of customer since the meat color become more attractive.

Table 5 Analytical results of the fattening pig feeds—quality control*.

	Fattening I control	Fattening I (5% glycerol)	Fattening I (8.5% glycerol)	Fattening II control	Fattening II (5% glycerol)	Fattening II (8.5% glycerol)
Moisture (%)	10.00/14.00	9.95/14.00	10.55/14.00	8.60/14.00	8.00/14.00	8.00/14.00
Crude protein (%)	16.85/16.09	16.20/16.15	16.20/16.11	16.10/15.08	15.30/15.1	15.40/15.09
Crude fat (%)	2.46/2.70	2.30/2.40	2.13/2.30	2.66/2.60	2.20/2.40	2.10/2.20
Calcium (%)	0.86/0.88	0.95/0.89	0.87/0.88	0.90/0.89	0.92/0.89	0.92/0.89
Phosphorus (%)	0.62/0.58	0.58/0.56	0.62/0.57	0.66/0.58	0.61/0.58	0.61/0.56
Sodium (%)	0.17/0.20	0.15/0.20	0.24/0.25	0.20/0.19	0.21/0.20	0.26/0.25
F-2 toxin (mg/kg)	< 0.025, Below the limit of detection	< 0.03 Below the limit of detection	< 0.03 Below the limit of detection	< 0.025 Below the limit of detection	< 0.03 Below the limit of detection	< 0.03 Below the limit of detection
T-2 toxin (mg/kg)	0.04 Tolerable	0.04 Tolerable	0.04 Tolerable	0.04 Tolerable	0.05 Tolerable	0.06 Tolerable
DON toxin (mg/kg)	< 0.25 Below the limit of detection.	< 0.25 Below the limit of detection	< 0.25 Below the limit of detection	< 0.25 Below the limit of detection	< 0.25 Below the limit of detection	< 0.25 Below the limit of detection
Glycerol (%)		5.11/5.00	8.6/8.5		5.05/5.00	8.79/8.50

*measured/guaranteed values.

Table 6 The pH value and color of the meat examined.

Group	Control	Glyc. (5%)	Glyc. (8.5%)
pH ₄₅	6.55 ± 0.24 ^a	6.63 ± 0.18 ^{ab}	6.85 ± 0.32 ^b
pH ₂₄	6.08 ± 0.23	6.10 ± 0.25	5.75 ± –
L*	49.03 ± 5.64 ^a	55.30 ± 3.18 ^b	57.67 ± –
a*	16.91 ± 1.76	16.23 ± 0.59	15.43 ± –
b*	12.99 ± 3.30	12.93 ± 1.45	15.11 ± –

L*: color abyssal parameter measured in the 24th hour after slaughtering;

a*: redness parameter measured in the 24th hour after slaughtering;

b*: yellowness parameter measured in the 24th hour after slaughtering.

Table 7 Test parameters of meat quality.

Group	Control	Glyc. (5%)	Glyc. (8.5%)
Dripping loss (%)	5.97 ± 1.49	7.56 ± 1.54	3.36 ± –
Shearing stress (kg)	3.81 ± 1.05 ^b	2.35 ± 0.49 ^a	2.76 ± –
Baking loss (%)	13.32 ± 3.17	12.07 ± 2.19	16.48 ± –
Total loss (%)	25.54 ± 2.55	22.00 ± 3.04	24.18 ± –

The shearing stress value was significantly lower in the 5% glycerol group than in the control, indicating that glycerol supplementation of the feed improves the friability of the meat.

No relevant differences could be found in the other meat quality parameters (dripping loss, baking loss, total loss) except for the shearing stress, which was more favorable for the meat of glycerol-fed pigs (2.35 ± 0.49) than for the control meat (3.81 ± 1.05).

As regards the chemical and microbiological stability of feeds, it can be stated that the measured parameters did not show a notable decrease in vitamin A and vitamin E content, and thus feed quality was practically stable (Table 8).

Furthermore, the peroxide and acid numbers were not higher at the end of the trial than at the beginning of the storage period; thus, glycerol did not have any

Table 8 Results of the stability analysis of fattening pig feeds.*

Sample	Parameter/results					Storage time
	Glycerol (%)	Vitamin A (IU/kg)	Vitamin E (mg/kg)	Peroxide number	Acid number	
Fattening I control	-	10,630/6,840	83/74	18	21	Day 0
	-	9,520/6,840	84/74	23	29	Week 2
	-	9,150/6,840	83/74	8	27	Week 4
	-	10,460/6,840	79/74	25	31	Week 8
	-	9,980/6,840	93/74	11	28	Week 10
	-	8,920/6,840	90/74	14	32	Week 12
	-	10,760/6,840	83/74	18	35	Week 17
	-	10,600/6,840	91/74	39	52	Week 22
Fattening I (5% glycerol)	5.09/5.00	7,310/6,840	80/74	18	34	Day 0
	-	6,260/6,840	74/74	15	35	Week 2
	-	7,460/6,840	82/74	14	31	Week 4
	-	7,135/6,840	82/74	14	30	Week 8
	-	6,944/6,840	80/74	14	32	Week 10
	-	7,100/6,840	78/74	11	32	Week 12
	-	6,500/6,840	76/74	19	31	Week 17
	-	7,990/6,840	79/74	15	37	Week 22
Fattening II (8.5% glycerol)	8.99/8.5	7,260/6,840	84/74	23	34	Day 0
	-	7,640/6,840	84/74	16	50	Week 2
	-	8,680/6,840	81/74	11	40	Week 4
	-	7,740/6,840	82/74	14	36	Week 8
	-	8,690/6,840	83/74	16	36	Week 10
	-	8,400/6,840	84/74	17	34	Week 12
	-	8,015/6,840	80/74	12	34	Week 17
	-	8,600/6,840	86/74	15	42	Week 22

*measured/guaranteed values.

rancidity-promoting effect on the feeds during storage. Despite the hygroscopic property of glycerol, there was no undesirable change in the microbiological status either. According to the mould counts and germ counts measured, the quality of the stored feedstuffs was not exceptionable (Table 9).

It should be mentioned that the stability tests were carried out for five months, which exceeds the length of the normal storage period. However, we considered it important to determine whether the long storage period could cause any feed quality defects and, consequently, affect the health of the pigs fed with these diets.

Changes of the acid number and vitamin E concentration of the fattening pig feeds are shown in Figs. 2 and 3. Although a variance was observed in

the vitamin E concentrations, this is absolutely acceptable because of the inherent uncertainty of the laboratory measurement.

4. Conclusions

The results of the feed trial have demonstrated that glycerol, a byproduct of purified biodiesel origin, is an excellent feed ingredient for fattening pigs. At an inclusion rate of 5% and 8.5%, glycerol supplementation improved the quality of feeds and did not cause any negative effect during storage. The production results (i.e. feed conversion ratio, daily body weight gain, etc.) of the experimental groups were practically equivalent with those of the control animals. Meat quality was better in the experimental groups than in the control, so glycerol supplementation has multiple benefits.

Table 9 Microbiological results of the stability analysis of fattening pig feeds.*

Sample	Parameter/result		Time
	Total mould count/g	Total germ count/g	
Fattening I control	2.1×10^3 (<i>fusarium, rhisopus</i>)	1.5×10^4	Day 0
	2.4×10^3 (<i>mucor, fusarium, cladosporium, penicillium</i>)	1.0×10^4	Week 2
	1.2×10^3 (<i>fusarium, cephalosporium</i>)	1.0×10^4	Week 4
	1.2×10^3 (<i>fusarium, mucor</i>)	1.2×10^4	Week 8
	1.1×10^3 (<i>fusarium, mucor, cephalosporium, penicillium</i>)	5.0×10^4	Week 10
	1.4×10^3 (<i>mucor, penicillium, alternaria</i>)	3.0×10^3	Week 12
	1.7×10^3 (<i>mucor, fusarium</i>)	3.0×10^3	Week 17
	2.4×10^3 (<i>fusarium</i>)	3.0×10^4	Week 22
Fattening I (5% glyc.)	2.0×10^2 (<i>fusarium, penicillium</i>)	8.0×10^2	Day 0
	2.2×10^2 (<i>fusarium, aspergillus</i> sp.)	4.0×10^3	Week 2
	1.1×10^2 (<i>fusarium, cladosporium</i>)	7.0×10^2	Week 4
	1.0×10^2 (<i>Aspergillus flavus</i>)	1.0×10^3	Week 8
	1.0×10^2	7.0×10^2	Week 10
	1.0×10^2 (<i>Aspergillus amstelodami</i>)	1.5×10^3	Week 12
	1.0×10^2 (<i>cephalosporium</i>)	9.0×10^4	Week 17
	1.0×10^2 (<i>mucor</i>)	8.0×10^3	Week 22
Fattening II (8.5% glyc.)	1.0×10^2	1.0×10^3	Day 0
	1.3×10^2 (<i>mucor, fusarium, cladosporium, alternaria</i>)	1.0×10^3	Week 2
	4.0×10^1 (<i>fusarium, Aspergillus flavus</i>)	4.0×10^2	Week 4
	1.0×10^2	1.0×10^2	Week 8
	1.0×10^2	4.0×10^2	Week 10
	1.0×10^2	3.0×10^2	Week 12
	$<1.0 \times 10^2$	1.0×10^2	Week 17
	$<1.0 \times 10^2$	1.5×10^3	Week 22

* On the basis of the parameters measured, the quality of the feeds is not exceptionable.

Fig. 2 Change of the acid number of the fattening pig feeds during storage (Fattening II, 8.5% glycerol).

Fig. 3 Change of the vitamin E levels of the fattening pig feeds during storage (Fattening II, 8.5%).

It is true that the profitability of using glycerol depends on the current price of glycerol and of the feed ingredients to be replaced by it (e.g. corn, soybean). However, glycerol is a very promising substance in pig feeding, mainly because of its prospective price decreasing, in consequence of the increased biodiesel production.

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