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Review

Influence of Glycerol Supplementation to Dairy and Feedlot Cattle Diets on Performance and Health: A Review

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ABSTRACT

Increasing population and demand in nearly every sector led humankind to use energy efficiently in every production area. One of the recent "megatrends" worldwide is to supply energy from renewable sources. Rapid emerge of biodiesel industry in the world accompanied with increasing production of industry by-products. As a result of this, some of the industry by-products, such as glycerol, are started to become more available and feasible which is thought to have a promising potential for being a remarkable alternative to high-energy containing feed raw materials. Because of increasing prices of cereals all over the world and search for alternative feed materials by producers has encouraged animal nutrition scientist to determine the effects of this different commercially valued products on performance, metabolism and final product quality for cattle nutrition. Thus the aim of this review is to evaluate the potential of glycerol for feedlot and dairy cattle nutrition.

Keywords: Glycerol, Feedlot, Dairy Cattle, Performance

Besi ve Süt Sığırlarının Rasyonlarına Gliserol İlave Edilmesinin Performans ve Sağlık Parametreleri Üzerine Etkileri

ÖZ

Artan dünya nüfusu ve neredeyse her sektörde gözlenen talep artışı, insanoğlunun tüm üretim alanlarında enerjiyi etkin bir şekilde kullanmasına yol açmaktadır. Dünyadaki en yeni ve en önemli eğilimlerden birisi de enerjinin yenilenebilir kaynaklardan elde edilmesidir. Biyodizel endüstrisindeki dünya çapındaki hızlı gelişme endüstri yan ürünü üretimini de beraberinde getirmektedir. Bu durumun bir sonucu olarak gliserol gibi yüksek enerji içeren tahıllara alternatif olma potansiyeline sahip bazı endüstri yan ürünleri gün geçtikçe daha kullanılabilir ve ticari olarak mantıklı bir hale gelmektedir. Dünya çapında tahıl fiyatlarının artışı ve üreticilerin alternatif hammadde arayışı, hayvan besleme alanında çalışan bilim adamlarını sığırların beslenmesinde ticari değeri olan bu yan ürünlerin performans, metabolizma ve son ürün kalitesi üzerine çalışmalar yapmaya teşvik etmektedir. Bu derlemenin amacı, gliserolün besi ve süt sığırlarının beslenmesinde kullanım olanaklarının değerlendirilmesidir.

Anahtar Kelimeler: Gliserol, Besi, Süt sığırı, Performans

INTRODUCTION

Renewable energy is defined as energy supplied by natural resources which is constant, sustainable and less detrimental to the environment. Renewable energy sources are becoming crucial during recent years because non-renewable resources are finite that will be eventually consumed and also environmentally damaging. Increasing population and urbanization over the years has led to great demand in nearly every production area and as a result of this; concerns about using exhaustible resources eventuated in increasing interest for biodiesel production. One of the biggest advantages of biodiesel is being environment friendly compared to petro-fuels since high cost of production due to increased prices of feedstock counted as the most forcible challenge for biodiesel production (Demirbaş 2007).

Livestock and feedstock production is forecasted to be influenced dramatically by competition for natural resources, and challenged in a carbon-constrained economy (Thornton 2010). As a result of rising ethanol production, grains prices are raised considerably because of competition and demand driven reasons. Interest on "green energy" and alternative high energy feedstuffs that can be used in livestock production is increasing globally (Anderson *et al.* 2008). In addition to that, economically reasonable and feasible by-product feeds are mainly preferred and generally used by livestock producers (Başalan *et al.* 2011). Future projections show that

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using novel feedstuffs derived from ethanol industry may provide alternative sources of protein and energy for livestock diets (Thornton 2010).

Different by-products are obtained by different processing methods to produce main product. Nearly 4 to 5 kg of glycerol (glycerine, propane-1, 2, 3-triol) is obtained as a co-product for every 50 gallons of biodiesel produced (Thompson and He 2006). Glycerol is used in various industries apart from livestock nutrition and rapid increase in biofuel production led glycerol to become available and cheap feedstuff for livestock diets (Kass 2014). Thus, the objective of this review was to evaluate the use of glycerol in dairy and beef cattle nutrition.

BACKGROUND AND CHEMISTRY OF GLYCEROL

Glycerol is known to be the oldest organic molecule isolated by humankind and obtained during soap production since as early as 2800 BC. It was firstly discovered in 1783 by Carl Wilhelm Scheele while treating olive oil with alkali compounds. He noticed the formation of a syrupy which tasted sweet flavor (Behr *et al.* 2008). During World War I, glycerol became a strategic military product for manufacturing explosive materials such as dynamite (Ciriminna et al 2014). Glycerol, a simple alcohol, is recently used in large variety of industries including; automotive, cosmetic, paint, food, tobacco, pharmaceutical, leather and textile (Wang *et al.* 2001). Glycerol is one of the most valuable chemical compound known that can be used in more than thousand area of use (PAgliaro and Rossi 2010) and can be isolated as a co-product of fat and oil industry, synthesized from propylene by different processes or produced via fermentation (Taherzadeh *et al.* 2002). Approximately 20 Mt of fats and oils are processed by various industries and because of this glycerol has a large availability on the global market; in 2012 glycerol production was estimated at nearly 1.2 Mt, and it is forecasted to increase 1.54 Mt in 2015 and around 2.5 Mt in 2020. Thus, these trends influence remarkably the glycerol market and “glycerochemistry” seems to have a considerable potential for being an emerging sector in the future (Cespi *et al.* 2015).

Glycerol, also known as propane-1, 2, 3-triol or glycerin(e), is an organic compound and has functions as an alcohol and it is formed by three hydrophilic alcoholic hydroxyl groups. It was stated that glycerol is a highly flexible molecule and 126 conformers can be formed by glycerol (Pagliaro and Rossi 2010). Glycerol is liquid at room temperature, hygroscopic, colorless, odorless and sweet-tasting (Silva *et al.* 2014). Glycerol is soluble in water and short chain alcohols and shows limited solubility in extensively used organic solvents such as ether, ethyl acetate etc. and not soluble in hydrocarbons. Glycerol is highly stable, compatible with many chemical compounds, non-irritating in many areas of use and environment friendly (Pagliaro and Rossi 2010). Crystals are formed by glycerol under 17.8 °C, specific density and molecular weight of glycerol is 1.26 and 92.09, respectively (Gu and Jérôme 2010). In the terms of nutrition, glycerol can be considered as a simple carbohydrate. Glycerol derived from industry is not pure generally which contains different amounts of methanol. Methanol amounts of different glycerol sources and energy content of crude glycerol is given in Table 1 and Table 2, respectively (Dasari 2007). Glycerol is defined as safe feed material for animal feeds but methanol is the main toxic compound in glycerol where levels higher than 150 ppm could be considered unsafe for animal feed (Donkin 2008).

Table 1. Glycerol purity and methanol content in different crude glycerol sources (Dasari 2007).

Crude Glycerol Source	Glycerol (%)	Methanol (ppm)
1	86.3	<100
2	72.2	11500
3	88.3	<100
4	78.9	400
5	82.0	580
6	84.6	200
7	94.0	<100

Table 2. Range of energy content in crude glycerol obtained from 4 different sources (Dasari 2007).

Component	Range
Crude Glycerol, %	82-88
Total Digestible Nutrients (TDN), %	81-83.5
Net Energy Maintenance (NEm), Mcal/kg	1.92 - 2.00
Net Energy Gain (NEg), Mcal/kg	1.32 - 1.41
Net Energy Lactation (NEl), Mcal/kg	1.85 - 1.94
Digestible Energy (DE), Mcal/kg	3.53 - 3.64
Metabolizable Energy (ME), Mcal/kg	3.31 - 3.48

RUMEN METABOLISM OF GLYCEROL

Glycerol is rapidly fermented into volatile fatty acids (VFA) by microorganisms in rumen (Donkin 2008) due to its glycogenic property. Reports obtained from early studies showed that glycerol was fermented into propionic acid almost completely (Garton *et al.* 1961), but other researchers determined that after glycerol incubation in the rumen acetate and propionate (Wright 1969) or propionate and butyrate levels were increased (Czerkawski and Breckenridge 1972). Traube *et al.* (2007) stated that two ways existed for investigating glycerol's rumen metabolism; with *in vivo* experiments by glycerol administration either orally or by infusion through a cannula and by in vitro studies with ruminal fluid obtained from rumen cannulated cattle. Different results were obtained from studies focused on effects of glycerol supplementation on rumen VFA levels and summary of the various results are given in Table 3.

As seen on Table 3, different results were obtained from stated studies but one can be said that mainly propionate and butyrate seems to be increased with glycerol supplementation where acetate: propionate ratio shows a decreasing tendency according to stated results. Glycerol is rapidly fermented by microorganism in rumen. There are reports indicate that most of the supplemented glycerol to diet disappeared in rumen within 2 to 6 hours, other reports showed the glycerol disappeared in rumen with a range of 0.52 to 0.62 g/h or 1.2 to 2.4 g/h (Donkin 2008). Because of its high fermentable structure, ruminal pH and digestibility may be affected by glycerol supplementation depending on diet, supplementation level, physiologic status of animal etc.. Hales *et al.* (2004) conducted a study with ruminally cannulated steers where rumen pH was not effected by glycerol supplementation levels at 0, 3, 6 h after feeding since at 9 h, rumen pH was detected lowest in the highest supplementation group (10% of dietary DM). In this study (Hales *et al.* 2004), ruminal digestibility (%) of apparent organic matter (OM), true OM, apparent starch and true starch were increased linearly with glycerol supplementation since ruminal NDF digestibility was not affected by dietary glycerol supplementation levels. In contrast to these findings Shin *et al.* (2012) reported that NDF digestibility linearly decreased as glycerol increased from 0% to 10% in the lactating cow diets, possibly because of ruminal fiber digestibility depression with glycerol addition to diet. Wang *et al.* (2009) reported that rumen *pH* was decreased linearly with increasing glycerol inclusion levels (0, 100, 200, 300 g glycerol/ head/ day) in growing steer diets because of increased total VFA proportions. In addition to that, *in situ* effective ruminal degradability of DM, NDF for corn stover and DM, crude protein (CP) for concentrate mix used in this study were increased linearly with glycerol supplementation. Boyd *et al.* (2013) reported that *pH* of ruminal fluid was not changed due to glycerol addition at the doses of 0, 200 or 400 g/d to rumen cannulated lactating cows. Furthermore, no differences were observed in apparent digestibility of DM, CP, NDF and ADF in the stated experiment.

Table 3. Summary results of dietary glycerol supplementation on rumen environment.

Animals	Glycerol Supplementation Level	Method	VFA Status	Reference
Growing steers (n= 4)[1]	0, 2.5, 5 and 10% of diet DM*	Ruminal canulla	Acetate:Propionate ↓	Hales *et al.* 2004
Growing bulls (n=48)	0, 4, 8, 12% of concentrate feed[2]	*in vivo*	Propionate, acetate, butyrate ↔	Mach *et al.* 2009
			Total VFA concentration (only in 8% level) ↑	
Finishing steers (n=8)	0, 100, 200, 300 g/ head/ day	Ruminal canulla	Acetate ↔	Wang *et al.* 2009
			Acetate: Propionate ↓	
			Total VFA, propionate and butyrate ↑	
Fermenters (n= 8)[3]	0, 50,100, 150 g/kg of DM	RUSITEC[4]	Total VFA, butyrate and propionate ↑	Avila-Stagno *et al.* 2014
Fermenters (n=24)[5]	0, 5, 10, 20% of DM	Continuous fermentation system	Total VFA concentrations ↔	Ramos and Kerley 2012
			Propionate, valerate ↑	
			Acetate, iso-butyrate ↓	
Fermenters (n=4)[1]	0, 3, 5 and 8% of diet DM	Continious culture	Propionate and valerate at the expense of acetate ↑	Rico *et al.* 2012
Lactating cows (n=6)[6]	0, 200, 400 g/day		Propionate and butyrate ↑	Boyd *et al.* 2013
			Acetate, valerate and acetate:propionate ↓	
Lactating cows (n= 4)[1]	0 or 10% ofdiet DM	Rumen canulla	Propionate, butyrate, valerate ↑	Shin *et al.* 2012
			Acetate ↓	
Transition cows[7] (n=23)	0, 11.5-10.8% of diet DM	*in vivo*	Total VFA concentrations ↔	Carvalho *et al.* 2011
			Butyrate and propionate at the expense of acetate ↑	

[1]Experiment was conducted using 4x4 latin square design.
[2]Concentrate and straw was offered to bulls *ad libitum*.
[3]Experiment was conducted using 4x4 latin square design with duplicate fermenters in each treatment.
[4]RUSITEC: Rumen simulation technique; semi-continuous fermentation system
[5]Experiment was conducted using 4x4 latin square design with 6 replicate fermenters in each treatment.
[6]Experiment was conducted using 3x3 latin square design
[7]Study was carried out from −28 to +56 dsyd relative to calving. Glycerol supplementation levels were 11.5% and 10.8% for pre and postpartum, respectively.

In a study conducted with rumen simulation technique (24), increasing concentrations of glycerol resulted in a linear increase in DM, NDF and ADF disappearance from hay and maize silage. Crude protein disappearance was not affected in hay samples since linearly increased in silage samples. It was also stated that glycerol inclusion also linearly decreased culture *pH* (Avial-Stagno *et al.* 2014). Similarly Ramos and Kerley (2012) determined that *pH* decreased linearly as crude glycerol content increased (0, 5, 10, 20% replacement with corn) in study conducted with continuous culture experiment. In the stated experiment (Ramos and Kerley 2012), apparent and true DM digestibility reported to be decreased linearly when dietary crude glycerol increased from 0 to 20% with the higher inclusions of crude glycerol being less compared to low crude glycerol treatments. Rico *et al.* (2012) has conducted a study using single-flow continuous culture fermenters and results obtained as increased DM, OM and NDF digestibility with increasing doses of dietary glycerol (0, 3, 5, 8%) where CP digestibility was not affected by treatment.

ANIMAL TRIALS

Feedlot Cattle

Glycerin could be supplemented to feedlot cattle diets as a high energy feed ingredient and may replace other expensive feedstuffs in the ration such as grains with cost reducing potential. Mach *et al.* (2009) supplemented Holstein bull diets with doses of 0, 4, 8, 12% of concentrate DM, where concentrate and straw was offered to animals *ad libitum*, and evaluated the feedlot performance and carcass parameters. Study was carried out for 91 days, no difference was observed for concentrate intake, straw intake, total dry matter intake (DMI), average daily gain (ADG) and gain to feed ratio (G:F) between control and experiment groups. Furthermore different levels of glycerol was not affected the carcass and meat quality such as hot carcass weight (HCW; kg), dressing percentage (DP; %), Warner-Bratzler shear force (kg), back fat classification and conformation (%), *Longissimus* muscle (LM) area (cm^2) and fat content (%). Authors were reported that glycerol can be supplied to feedlot concentrate feeds at the level of 12.1% without affecting performance and carcass parameters adversely. One can be concluded that, in this study (Mach *et al.* 2009), animal were offered concentrate and straw *ad libitum* and average concentrate/ straw intake raito was nearly 83% in all groups so Holstein bull diets can be supplemented with glycerol at the level of 10% of diet DM without affecting performance and carcass parameters. In addition to that, ME content of glycerin can be calculated as 3.47 Mcal/kg of DM in Holstein bulls fed high concentrate diets (Mach *et al.* 2009). Ramos and Kerley (2012) conducted a study by 3 different *in vivo* experiments. In experiment 1, 72 crossbred steer calves (250±2 kg) were used and treatment groups included 0, 5, 10, and 20% of corn replacement with glycerol in diet. DMI was observed to decrease linearly with increasing doses of glycerol, ADG was affected by treatment where the highest ADG was observed 10% glycerol group compared to others (quadratic effect), G:F ratio was not affected by treatment in Exp. 1. In Exp. 2, 100 crossbred steers (300 ± 2.0 kg) were used to evaluate 5 different treatments: 0, 5, 10, 12.5, or 15% crude glycerol replacement with corn grain in diet. DMI, ADG and G:F was not different between experiment groups. Exp.3 was carried out with 100 heifer calves (270 ± 2.0 kg) and consisted of 4 treatments: 0, 5, 10, or 20% crude glycerol that replaced hay in diet. No differences were observed in performance parameters either such as DMI, ADG and G:F. As a result of 3 different in vivo experiments, authors have concluded that feedlot performance should remain equal or potentially improve when corn is replaced with crude glycerol up to 20% of the feedlot diets. Parsons *et al.* (2009) evaluated crude glycerol supplementation influence on performance and carcass parameters of finishing heifers in a 85 d study. Three hundred and seventy-three finishing heifers (421.6±28.9 kg) were fed finishing diets contained 0, 2, 8, 12 and 16% crude glycerol of dietary DM. Experimental groups' ADG were reported to be increased at the 2, 4, 8% inclusion levels but decreased when inclusion level raised to 12 or 16% to diet compared to control. Furthermore, DMI was not different between control and 2% inclusion group since DMI was negatively affected by higher inclusion levels and G:F ratio enhanced in 2, 4, 8 and 12% supplementation levels, 16% inclusion of crude glycerol reduced G:F by 2.8% compared to control. In the stated experiment HCW was increased in 2, 4, 8% glycerol inclusion levels correspondingly to ADG, likewise, reduced in 12 and 16% treatment groups. *Longissimus* muscle area, subcutaneous fat over the 12th rib and marbling scores were determined to be linearly decreased with increasing levels of glycerol inclusion. Percentage of cattle grading USDA Choice was reported to show a decreasing tendency with glycerol supplementation. Authors concluded that inclusion levels of 8% or less on DM basis enhanced body weight gain and G:F ratio. Elam et al (2008) carried out a study with 158 beef heifers fed 0, 7.5 or 15% glycerol replaced with steam flaked corn in diet. Reported results showed that DMI, G:F and ADG were not affected by treatment doses but a linear reduction tendency was observed with increasing glycerol inclusion levels in DMI resulted a negative effect in overall feedlot performance. Same authors (Elam *et al.* 2008) performed another experiment in the same study to evaluate effects of 10% (DM basis) glycerol replacement with flaked corn in Hereford x Charloais cross calves' finishing diets. Obtained results showed that 10% glycerol supplementation was not effected DMI, G:F, ADG and carcass parameters; HCW, DP, rib eye area, USDA quality grade, marbling score and internal fat. Supplemented glycerol's methanol content was considerably high (12.5%) in the stated study but no health problems were observed during the study. Elam *et al.* (2008) remarked high methanol glycerol was not effected feedlot performance but also stated that "*these findings should not be considered an endorsement for feeding glycerin containing high methanol levels*".

Dairy Cattle

Average milk yield of dairy cattle breeds has enhanced over the years as a result of genetic selections. Thus, feeding high yielding dairy cattle is becoming more and more challenging for nutritionists. Glycerol has a remarkable potential to be a convenient replacement for corn in dairy cattle diets which contains approximately 20% more NEl value compared to corn according to calculations of Linke et al (2004). Boyd *et al.* (2013) carried out a study in rumen cannulated high yielding dairy cows where treatments were 0, 200 and 400 g glycerol/head/day replaced with ground corn in diet and evaluated milk yield and composition. According to this experiment's results, DMI, milk yield and milk fat percentage was reduced compared to control group with glycerol supplementation, but milk protein percentage observed to be highest between groups in 400 g glycerol inclusion level. These findings caused to decreased energy-corrected milk yield and efficiency (milk/DMI) in diets with highest glycerol inclusion level compared to control group. In contrast to this study, Lomander et al (2012) compared top dress glycerol (450 g/day) and propylene glycol (300 g/day) addition to diets and stated that top-dress glycerol resulted with highest total and energy-corrected milk yield (kg) between experimental groups during the first 90 days of lactation. A similar study was conducted by Chung *et al.* (2007) in which glycerol product (minimal 65% of food grade glycerol, dry powder was added (top-dress) on total mix rations offered to Holstein cows during 0 to 21st days of parturition with a dose of 250 g/day (162.5 of glycerol/day) where control group did not receive the product. Top-dress dry glycerin product addition to diet reported to not affect average feed intake, milk yield and components such as milk fat, protein, lactose percentage, fat, protein and lactose yield (kg/d), %4 corrected milk yield and efficiency. In a study conducted by Shin *et al.* (2012), two different dietary roughage sources (corn silage and cottonseed hulls) and three different concentrations of glycerol (0, 5, 10% of diet DM) was evaluated with total of 24 Holstein cows. Results showed that the influence of glycerin on cow performance were the same for both dietary roughage sources where feed efficiency was affected by treatments. Five percent glycerol replacement in the diet led to increased DMI without increasing milk yield but milk yield and milk fat was reported to be reduced when glycerin was fed at 10% of dietary DM. Authors concluded that 5 or 10% of glycerol replacement in corn silage based diets improved 4% fat corrected milk production efficiency while negatively affected it when feeding animals with cottonseed hull based diets. Differently, a study was conducted by Carvalho *et al.* (2011) which is focused on dietary glycerol supplementation to transition cow diets. Total of 23 multiparous Holstein cows were assigned into two groups; control (without glycerol supplementation), glycerol (11.5% glycerol supplementation to diets from -28 days to parturition and 10.8% for parturition to +56 days). Results of this study indicated that feed intake before and after parturition was not affected by glycerol supplementation, likewise, milk yield, milk composition (milk fat, protein, lactose, solids and %4 fat corrected milk yield) parameters were same between experimental groups. Authors suggested that glycerol was a reasonable replacement for corn in diets offered to transition dairy cows. In a different study of the same authors (Carvalho *et al.* 2012), same amounts of glycerol replacement with corn in the transition cow diets and glycerol addition to diet altered the feed sorting behavior and intake pattern and reduced sorting against long particles. Consequently, it was stated that glycerol supplementation to transition cow diets had a potential to reduce fluctuations in rumen and to improve rumen health.

Effects on Metabolic Status

Transition period is the most critical period of a dairy cow's life cycle and high yielding dairy cows generally experience the state of negative energy balance (NEB) in this period which is related with many metabolic disorders such as milk fever, subclinical hypocalcemia, ketosis, fatty liver syndrome, retained placenta, metritis, mastitis and displaced abomasum (Kara 2013). As a consequence of these metabolic disorders dramatic yield loses can be occurred in dairy farms. Genetic selection performed on dairy cattle breeds to improve milk yield caused ketosis to become a very commonly observed metabolic disorder in modern dairy production since ketosis symptoms are generally unnoticed by producers in the field (Berge and Vertenten 2014). Ketosis is occurred as a result of NEB and characterized with increased blood ketone bodies (acetone, acetoacetate and ßhydroxybutyrate; BHBA) concentrations which are formed in the liver during oxidation of nonesterified fatty acids (NEFA). Furthermore ketosis has a strong relationship with fatty liver syndrome. Fatty liver syndrome is defined as triglyceride accumulation in the liver as a result of severe fatty acid infiltration to liver which is more than its oxidation capacity (Kara 2013).

Feeding dairy cows with high energy diets in early lactation with an adaptation in close-up period is a common nutritional strategy performed by nutritionists in the field to prevent NEB. Glycerol, as stated before, is a good even better alternative to grains with high energy density which encouraged scientist to evaluate glycerol supplementation strategies to transition and early lactation diets of dairy cattle. Lomander et al (Lomander *et al.* 2012) compared top dress inclusion of glycerol (450 g/d) and propylene glycol (300 g/day) to early post-partum diets (0 to 21 days in milk), and determined that no improvement were observed between control and treatment groups for body condition score (BCS), hearth girth (HG) and metabolic parameters such as plasma concentrations of glucose, BHBA, NEFA, or insulin-like growth factor (IGF-I) were found between the control group and any of the treatment groups. However, glycerol and propylene glycol numerically reduced the treated animal numbers for 0 to 90 days in milk period for ketosis, feed depression or displaced abomasum compared to control group where treated animal numbers were 8, 5 and 4 for control, glycerol and propylene glycol groups, respectively. Authors indicated that top-dress glycerol addition during the first 3 weeks in lactation could increase milk yield during the early lactation period without negatively affecting the metabolic may provide an advantage for laboring costs compared to oral drenches of these glycogenic products. Similar to this study, Pechová *et al.* (2014) also compared propylene glycol and glycerol addition to diets of early lactation cows with two different experiments. In experiment 1, right after parturition animals started to receive oral drenches of 300 ml/head/day propylene glycol or 500 ml/head/day glycerol which are calculated to be energetically equivalent and treatments have continued for first 3 weeks of lactation. Results showed that no differences were observed during study period for blood concentrations of glucose, NEFA, BHBA, triacylglycerol, oxidized and total ketone bodies where both experimental groups were determined to be in NEB status. In the second chapter of the study glycerol oral drench dose increased to 1000 ml/head/day where propylene glycol oral drench dose remained the same (300 ml/head/day) and same blood parameters were stated to not differ between experimental groups during the first 3 weeks of lactation. In addition to these results, milk yield, milk composition and rumen parameters such as *pH*, concentrations of total VFA, acetate, propionate, butyrate and valerate were not different between the experimental groups, thus, authors (Pechová *et al.* 2014) concluded that glycerol may have a potential for being a suitable alternative to prevent energy deficiency during early lactation but increasing oral drench dose from 500ml/head/day to 1000 ml/head/d had no beneficial effect on energy metabolism. In parallel to these results, there are other reports indicated that no significant differences observed for energy metabolism disturbance between propylene glycerol and glycerol supplemented lactation cows (Adamski *et al.* 2007; Osborne *et al.* 2009). Carvalho et al (2011) found that replacing corn with glycerol approximately 11% of transition diet (from -28 to +56 days of parturition) reduced the blood levels of glucose, increased BHBA levels and not affected NEFA concentrations during prepartum period. Nevertheless these metabolic changes did not affect DIM, milk yield and milk composition so glycerol was still defined by authors (Carvalho *et al.* 2011) as a suitable replacement for corn in transition diets. Similar to these results, in a study conducted by Chung et al (2007) to determine effects of a dry glycerin product (%65 glycerin content) addition to lactating cow diets and no differences were observed for blood metabolites and serum insulin concentrations. However author also stated higher concentrations of plasma glucose and lower concentrations of plasma BHBA and lower concentrations of urine ketones were determined for glycerine supplemented cows in the second week of lactation which has been considered as a more positive energy balance and improved energy availability. Osborne et al (2009) carried out a study differed from reviewed experiments in which glycerol (20 g/L) or soybean oil (10 g/L) administered to drinking water from -7 to +7 of parturition to dairy cow diets. Researchers found that treatment groups' DMI was reduced throughout the experiment and water intake influenced in the same pattern during prepartum period but not different between control and glycerol group during postpartum period. Results in this study has showed that energy intake, energy balance, serum glucose and NEFA levels were not affected by treatments but glycerol supplementation reduced serum triacylglycerol concentration compared to control and soybean oil supplemented cows prepartum and was lower than for the soybean oil supplemented cows postpartum. In addition to that serum BHBA levels were determined to be highest in glycerol supplemented group during prepartum, however control group's BHBA levels were highest during postpartum period. Performance was not affected by treatment thus, authors concluded that the dose (20g/L) of glycerol supplementation the drinking water seemed not sufficient to alter the milk yield response but stated dose succeed to reduce BHBA levels in glycerol supplemented group.

CONCLUSIONS

Based on reviewed studies, glycerol can be accounted as a reasonable replacement for grains of feedlot and dairy cattle diets. Depending on its price, glycerol can be supplemented to feedlot and dairy cattle diets approximately 10 to 15% or up to 500ml/head/day, without adversely affecting performance and final product quality. One can be clearly indicated that glycerol supplementation to feedlot either dairy cattle rations alter rumen conditions depending on diet composition, dose of glycerol inclusion, quality of glycerol or glycerol product and physiologic properties of the animal. Glycerol has long been thought to be an efficient antiketogenic agent since 1950s. Even some studies showed no effect of glycerol on negative energy balance and energy metabolism, further studies are need to be conducted to reveal antiketogenic properties of glycerol in the field conditions. Some questions are remained to be asked if the glycerol has any influence on reproductive parameters of dairy cattle. Also effects of glycerol on dairy and feedlot calves' nutrition are not clear. Further studies on dairy and feedlot cattle and calves with different doses and delivery methods of glycerol should be established to reveal the actual effects on performance, final product quality and metabolism.

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