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Review article

THE POTENTIAL OF USING CORN DRIED DISTILLERS GRAINS WITH SOLUBLES (DDGS) IN ORDER TO IMPROVE THE FERMENTATION PROFILE IN SHEEP

POTENCJAŁ ZASTOSOWANIA SUSZONEGO WYWARU Z KUKURYDZY (DDGS) W CELU POPRAWIENIA PROFILU FERMENTACYJNEGO U OWIEC

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Streszczenie. Globalny wzrost popytu na żywność oraz rosnące koszty jej produkcji sprawiają, że przemysł rolniczy poszukuje tańszych i bardziej wydajnych metod wytwarzania żywności. Częściowym rozwiązaniem tego problemu może być wykorzystanie w żywieniu zwierząt gospodarskich wysokobiałkowych pasz pochodzenia przemysłowego, takich jak suszony wywar z kukurydzy (z ang. *corn dried distillers grains with solubles*, DDGS). Ponieważ DDGS jest produktem ubocznym, powstającym w wyniku produkcji bioetanolu z kukurydzy, włącznie go do dawki pokarmowej stanowiłoby doskonały sposób jego naturalnej utylizacji. Istnieją przesłanki stwierdzenia, że DDGS może korzystnie wpływać na profil fermentacji, między innymi poprzez zwiększanie całkowitej produkcji lotnych kwasów tłuszczowych i dzięki zmianie proporcji między nimi. Inne doniesienia dotyczą ograniczenia emisji gazów przez zwierzęta przeżuwające. W związku z wysoką kalorycznością metanu redukcja metanogenezy jest zjawiskiem niezwykle korzystnym dla hodowców, ponieważ pozwala ograniczyć straty energii związane z emisją gazów fermentacyjnych. Ze względu na dużą pojemność cieplną uważa się, że metan ma duży wpływ na globalne ocieplenie. Kolejną korzyścią inhibowania produkcji metanu jest więc zmniejszenie ilości tego gazu w atmosferze. Efekt, jaki wywiera suszony wywar na fermentację, nie jest jednak dokładnie zbadany, szczególnie w odniesieniu do owiec, przy czym wyniki badań są często rozbieżne. Dlatego też istnieje potrzeba prowadzenia kolejnych badań, gromadzenia dostępnej wiedzy i weryfikowania, czy wykorzystanie DDGS w dawce pokarmowej owiec jest rzeczywiście celem zbieżnym z ekologicznego i produkcyjnego punktu widzenia.

Key words: corn dried distillers grains with solubles, DDGS, methane, sheep, volatile fatty acids.
Słowa kluczowe: DDGS, lotne kwasy tłuszczowe, metan, owce, suszony wywar z kukurydzy.

INTRODUCTION

With the growing need for replacing the conventional energy sources with renewable sources, increases the interest in the production of fuels obtained from plant biomass, such as bioethanol. This fuel can be derived from plants such as wheat, rye, potatoes and beets,

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but its production is most effective in the case of maize (Kuś 2002). One ton of corn allows to obtain 400 liters of ethanol, simultaneously generating 320 kg CO2 and the same amount of corn dried distillers grains (Shurson and Noll 2005). In the period of 2007–20012 worldwide production of biofuels has increased about a 17% (Prugh 2014). A considerable amount of derived by-product is problematic due to the high costs of economical disposal. A perfect solution to this problem is including generated decoctions into the livestock ratio (Schmit et al. 2009). Physico-chemical properties of DDGS indicate the potential brought by inclusion DDGS into the ruminants nutrition. The high content of ingredients such as protected protein (Zachwieja et al. 2013) and neutral detergent fiber (Anderson et al. 2006) suggest that the use of DDGS may favorably affect the fermentation profile in ruminants. There are indications that a dried distillers grains with solubles has an impact on reducing the production of fermentation gases, including methane (Benchaar et al. 2013), which coincides with the currently prevailing trend of reducing greenhouse gas emissions in agriculture (McGinn et al. 2009). Only few studies concerns the impact of DDGS application on fermentation profile in sheep, but research conducted on cows show that distillers grains can be safely included into the ruminants diet (Urdl et al. 2006; Mpaphoi et al. 2007). Janicek et al. (2008) showed that nearly 20% of DDGS in the diet of cows, increases milk yield as well as milk protein and fat production, which was confirmed in subsequent studies (Szulc et al. 2011). Since creating a balanced diet may be difficult due to combining DDGS with individual dietary components (Pezzanite et al. 2010) in order to exploit the potential of dried distillers grains with solubles, there is a need to analyze the available literature and conduct further studies verifying the impact of DDGS on fermentation profile.

CHARACTERISTICS OF CORN DRIED DISTILLERS GRAINS WITH SOLUBLES

The decoction obtained from bioethanol production may occur in various forms depending on the applied technology:

1. DDG (Dried distillers grain) – dried corn residue after distilling off the ethanol derived from yeast fermentation
2. 2. DDGS (Dried distillers grain with solubles) – wet corn residues (DG) mixed with condensed liquid phase in the form of syrup (CDS) – most commonly used in a dried form.
3. HPDDG (High-protein distillers dried grains) – before the distillation, parts rich in fiber and fat such as bran and germ are removed from the kernels, which allows obtaining decoction with increased protein content after drying.

Decoction can also occur in undried from, containing 5 to 8% of dry matter (WDG, WDGS and HPWDG) that have a much lower price, but are inconvenient to store and to transport. (Zachwieja et al. 2013). Dried distillers grains with solubles can be stored for a year with virtually no losses, while the wet decoction storage period is approximately 3 to 7 days. As a result, WDGS must be delivered almost every day, which is highly uneconomical solution, especially for small-sized breeding (Pezzanite et al. 2010).

The largest part of the DDGS dry matter, constituting 89.3% of the total weight, have a crude protein (30.9%), fat (10.7%), fiber (7.2%) and ash (6%) (US Grains Council 2012). This means that DDGS contains almost three times more nutrients than corn which is a raw material. A characteristic feature of dried distillers grains is also a high concentration of neutral detergent fiber (NDF) with high content of lignin, cellulose and hemicellulose (Anderson et al. 2006). The only raw material, in which the DDGS is much poorer than corn is starch which is converted to ethanol in the fermentation process. The starch content in DDGS dry matter reaches 4.7% to 5.9%, whereas starch in corn grains varies between 70.6% and 71.8% (Belyea et al. 2004). For this reason, the energy value of dried distillers grains with solubles is slightly lower than the value of the corn kernels (Koreleski and Świątkiewicz 2006).

Consequently, DDGS derived from corn contains little starch and a lot more protein, fat and biologically available phosphorus than corn (Stallings 2009), which makes it a valuable substitute of feed concentrates in the diet of ruminants (Schingoethe et al. 2009; Zhang et al. 2010). Included in DDGS protein is characterized by a relatively high proportion of so called "by-pass" protein, which constitutes 47–63% of total protein. The protein is resistant to the rumen juice action so virtually unchanged gets into the intestines, where it is digested by ruminant own enzymes into amino acids and in that form it is absorbed (Bodarski et al. 2012; Zachwieja et al. 2013). In a period of intense lactation, only feed rich in "by-pass" protein can meet the animals demand for amino acids. For this reason, in the production more and more popular is the use of so-called “protected proteins”, which are obtained inter alia by the action of 0.15% formalin, protein denaturation, xylose cover or by extrusion. Yet another method of efficient delivery of amino acids to the sections of gastrointestinal tract where they are absorbed is to apply amino acids protected with a special coating (Preś et al. 2004). A great advantage of dried broth is favorable amino acid profile, thanks to the fermentation process similar to the amino acid profile of yeast (Table 1).

Table 1. Comparison of essential amino acid content [g · 100 g^{-1} of dry matter] contained in the DDGS, yeast and corn (Belyea 2004)
Tabela 1. Porównanie zawartości niezbędnych aminokwasów [g · 100 g^{-1} suchej masy] zawartych w DDGS, drożdżach i kukurydzy (Belyea 2004)

Amino acid Aminokwas	DDGS	Yeast Drożdże	Corn Kukurydza
Leucine Leucyna	2.43	3.45	1.12
Phenylalanine Fenyloalanina	1.64	1.96	0.49
Valine Walina	1.63	2.52	0.51
Isoleucine Izoleucyna	1.52	2.37	0.39
Arginine Arginina	1.05	2.35	0.54
Threonine Treonina	1.01	2.27	0.39
Lysine Lizyna	0.77	3.32	0.24
Tyrosine Tyrozyna	0.76	1.6	0.43
Histidine Histydyna	0.7	1.17	0.25
Methionine Metionina	0.54	0.79	0.21
Tryptophan Tryptofan	0.19	0.55	0.09

Contained in DDGS dried yeast cells remaining after the fermentation process may be for ruminants also a source of minerals, vitamins of group B (thiamin and riboflavin) and biologically active substances such as nucleotides, inositol, nucleic acids or beta-glucans (Cromwell et al. 1993). Although from the assumption DDGS does not contain anti-nutritional substances, the consequences of inadequate drying and storage need to be considered (Podkówka 2009). Heating decoction at too high temperature can lead to the formation of Maillard reaction products, which are characterized by low bioavailability or even show evidences of toxicity (De Almeida 2013). Complications associated with the use of DDGS may also be associated with variable content of each nutrient or physical properties which affect the transport and storage (Pezzanite et al. 2010). Therefore, it is important to care for the high quality of the resulting decoction, which translates into a more economic use of DDGS as a feed (Liu 2008).

APPLICATION OF DDGS IN THE NUTRITION OF SHEEP

The increased production of bioethanol in recent years has significantly increased the quantity of dried decoction allocated for animal feed, especially cattle (Schmit et al. 2009; Nuez-Ortin and Yu 2010). In sheep this solution is introduced much slower for which it is responsible, inter alia, insufficient data concerning the impact on the fermentation profile in these animals. The results obtained so far show that the inclusion of DDGS in the ration may offer economic advantages for both breeding the ewes (Wertz-Lutz et al. 2007) and lambs (Held 2006). Tests carried out on 3-month-old lambs (Şahin et al. 2013) showed no effect of the use of DDGS in the ration on parameters such as feed intake, growth rate of lambs and rumen parameters. It has been shown, however, that only a mix containing in composition 20% of DDGS may be a source of protein in the lamb diet, while 10% DDGS inclusion resulted in significant reduction in digestibility rates. The high share of long-chain unsaturated fatty acids (over 80%) of fat contained in the DDGS creates the potential for positive changes in fatty acid composition and quality of milk and meat fat in sheep and lambs (Borys 2011). Extensive research on the effect exerted by DDGS inclusion on slaughter indicators in lambs were conducted by Schauer et al. (2008). Randomly selected group of 240 Rambouillet sheep was divided into 16 test groups, each using one of the four variants diet: conventional feed composition based on barley and soybean (control), and a dose which feed was replaced with a 20%, 40% and 60% of corn dried distillers grains with solubles. The results obtained after 111 days have shown that it is possible to safely include DDGS to ration in the amount not exceeding 60% of the dry weight of the mixture, without adversely affecting the performance and the basic slaughter rates in lambs.

In addition to a small amount of available data another limitation for including DDGS into small ruminants diet is low calcium/high phosphorus concentration characteristic for corn co-products (Warren 2011). While the calcium/phosphorus ratio in small ruminant diet can vary from 2 : 1 to 7 : 1 (Schauer and Held 2008), it is important to retain approximately the optimal ratio of 2 : 1, which helps to maintain the health of urinary tract, especially in bucks and rams (Warren 2011). Another challenge is to monitor and manage the sulfur concentration which is realtively high in corn co-products and therefore using a high dose of DDGS with high sulfur content may lead to polioencephalomalacia (Warren 2011). Since the mycotoxins are not degraded during the fermentation process of mycotoxins contained in corn co-products should be constantly monitored (Pezzanite 2010). Another aspect of the DDGS application that needs to be considered is a high level of fat. In the ruminants nutrition the total dietary fat should not exceed 8%, otherwise it may affect the fiber digestion and decrease performance of ruminal fermentation. (Pezzanite 2010).

INFLUENCE ON METHANOGENESIS

Methane is the second most common greenhouse gas in the atmosphere and its emission is closely related to human activity. It is estimated that within the European Union methane emission from agriculture averaged 10.2 million tons per year. Nearly two-thirds of that comes from the enteric fermentation, and one-third from livestock manure (Moss et al. 2000). The value of the indicator of global warming (Global Warming Potential -GPW) for methane reaches 25, which means that methane gas is 25 times more effective at capturing heat than CO_2 (Podkówka and Podkówka 2011). Daily a sheep produces 20.3 L of methane (Lockyer and Champion 2001), which is equal to 0.0134 kg, assuming that the density of methane is 0.66 $m^{-3}\cdot kg$. According to the report of Central Statistical Office from December 2014 sheep flock in Poland counted about 201.3 thousand animals (including 129.7 thousand of ewes) (GUS 2014). This allows to estimate that the entire sheep population in Poland produces approximately a total of 2697.42 kg of methane per day and 984.4558 tons per year. The emission of methane is negative phenomenon also from a productive point of view (Johnson and Johnson 1995). Methane production rate depends on many factors - primarily on the amount and quality of feed, the animal species, the body weight, age and condition. Differences exist not only between species, but also between individuals of the same species (Zhou et al. 2007). The calorific value of methane amounts 9.45 kcal/l, in terms 39.56 kJ/l of the energy. The high structural carbohydrate content in the feed can generate up to 16% loss of energy taken from digestible nutrients as a result of intense methanogenesis (Zawadzki 1993). Attempts to limit the energy losses associated with the elimination of methane and its emission into the atmosphere are based on the inclusion of the feed ration some additives such as tannins (Woodward et al. 2001; Frutos et al. 2004; Puchala et al. 2005) or saponin (Lila et al. 2003; Hu et al. 2005; Patra and Saxena 2010).

Since the restriction of calorie intake in feed may lead to a reduction in the amount of emitted methane , the use of high-protein feed, such as DDGS, meet environmental and production needs for reduction of this gas emissions. Very little research has been conducted on sheep, but the results obtained in terms of *in vitro* and *in vivo* studies, in the rumen of cows show the potential use of corn dried distillers grains with solubles as an additive positively affecting the fermentation profile. Benchaar et al. (2013) reported a linear decrease of methane emission in proportion to the increased participation of DDGS in the diet in case of in vivo. This result corresponds to the studies carried out in *in vitro* conditions (Zachwieja et al. 2013) in the rumen of cows. Research conducted by Behlke (2007) on heifers have shown that using DDGS in ration may lead to a reduction of methane emission when the DDGS is used as a substitute for forage based diets. Replacement of corn and corn oil by products derived from industrial ethanol resulted in a significant increase in the amount of gas produced in the process of *in vitro* fermentation. As a potential cause the author considers first and foremost an increase in the number of methanogenic microorganisms. Subsequent studies confirmed the lack of impact of DDGS application on methanogenesis reduction: both *in vitro* and *in vivo* studies have demonstrated an increase in methane emissions after including DDGS into sheep and cows ratio (Behlke et al. 2008; Hünerberg et al. 2013; Li et al. 2014). The divergence obtained in different studies results may be due to a considerable amount of the factors influencing the formation of fermentation gases. The divergence obtained in different studies results may arise from a considerable amount of the factors influencing the formation of fermentation gases. Such factors include, among others, the quantity and quality of feed as well as the frequency of the supply, quality of applied supplements, age and performance of animals, conditions for maintenance, interactions between internal processes and fermentation strains and the interaction between all these factors (Hristov et al. 2013).

IMPACT ON THE LEVEL AND PROFILE OF VFA

Volatile fatty acids (VFA), as a primary source of energy for ruminants, are regarded to be the most important product of fermentation that occurs with the participation of microorganisms in the gastrointestinal tract (Morvay et al. 2011). Acetic acid, covering up to 50% of energy demand, propionic acid and butyric acid occur in the highest concentration. Zhou et al. (2012) found that in the process of in vivo fermentation ideal ratio of acetic, propionic and butyric acids should be 78: 15: 7. The amount of acid produced by the fermentation is determined by the diet of the animal (Adjiri et al. 1992).

The VFA production is increased as a consequence of the development of the cellulolytic microflora and is closely linked to the production of methane – with the inhibition of methanogenesis process the amount of propionic acid in the total volume VFA increases (Zawadzki et al. 2001; Zawadzki et al. 2002). The high share of neutral detergent fiber in the diet results in the increase in the share of acetic acid, at the expense of butyric acid, by contrast the supply of the feed poor in nonstructural carbohydrates can lead to a reduction in the total production of VFA (Villalba et al. 2006; Grochowska et al. 2012).

In case of the VFA studies a very important is the non-glucogenic/glucogenic ratio (NGR). It is true that the indicator itself does not change depending upon the diet (Abrahams 2009; Miśta et al. 2014), however, the energy balance, the amount of methane emitted and the level of milk production have a significant impact on its value (Morvay et al. 2011). Non--glucogenic acids, like acetic and butyric acids are the source for the synthesis of long chain fatty acids, and glucogenic acids, which include propionic acid, favor the accumulation of fat in the tissues. Since the production of gases, including methane, is closely related to the profile and concentration of VFA, the high value of NGR may indicate high energy costs in the form of emitted gases (Pedreira et al. 2013) or correspond to the high fat content in milk (Abrahams 2009).

Results following examination the effect of using DDGS in the ration, in the *in vivo* and *in vitro*, are inconclusive. Some authors have found an increase in the total concentration of VFA (Lia et al. 2012), while others have observed its decline (Miśta et al. 2014), or did not report any significant influence on the concentration of these acids (Kleinschmit et al. 2006; Zhang et al. 2010).

Also unclear is the effect exerted by the inclusion of DDGS in the diet of ruminants on the percentage of individual fatty acids. Loy et al.(2007) reported that with a growing share of DDGS the value of propionic and butyric acids is increasing at the expense of reduction of the value of acetic acid. These results have been confirmed by other authors (Leupp et al 2009; Zhang et al. 2010). In a recent study (Miśta et al. 2014) there was no change in the proportion of acetic, propionic and butyric acids, while a decrease was observed in percentage of isobutyric and isovaleric acids. Although fluctuations in the concentration of volatile fatty acids, there were no significant differences in the pH of the rumen (Zhang et al. 2010; Lia et al. 2010; Miśta et al. 2014).

Also the impact of the inclusion of DDGS to the ratio on the NGR is ambiguous. The results obtained by Zawadzki (1993) shows that DDGS inclusion may provide a slight decrease in the NGR ratio which proves that dried distillers grains with solubles may reduce energy losses associated with gas emission. On the other hand subsequent studies did not confirmed a significant influence of incorporating DDGS into the diet on the non-glucogenic/glucogenic ratio in the *in vitro* study (Miśta et al. 2014). Studies conducted by Hippen et al. (2010) has shown great potential for DDGS incorporation into the diet of ruminants, by inducing favorable changes in the proportions of saturated fatty acids to unsaturated fatty acids in cow's milk.

Thus using a DDGS in the daily ratio may result in lower total fat content but simultaneously increase the quality of milk fat. Inclusion of DDGS into ruminant diet may also provide improvement in the quality of meat due to the increased content of polyunsaturated fatty acids (PUFA) in the fat (Borys 2011). Szulc et al. (2010) reported that including a corn dried distillers grains with solubles into the diet results in the increase in linoleic acid content, and the total content of PUFA in the beef fat. The same relationship was observed by other authors in pork (Moreno et al. 2008) and veal (Strzetelski 2006). Discussed results indicate that the use of DDGS into ruminants diet may be economically beneficial because it allows to obtain products of high quality while reducing energy losses associated with methanogenesis.

RECAPITULATION

The limitation of methanogenesis is a very desirable process, both for economic reasons and the need to counter the greenhouse effect. Because some fatty acids contribute to the reduction of emissions of methane, DDGS characterized by a high fat content, could potentially affect the inhibition of rumen methanogenesis (Dohme et al. 2001; Miśta et al. 2014). Therefore, the use of DDGS in the ration of sheep, provide a double benefit. On the one hand, represents a natural way of managing waste from the synthesis of bioethanol side, on the other it can be a source of cheap and highly available protein.

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Abstract. The global increase in food demand and rising costs of production forces the agricultural industry to search for cheaper and more efficient methods of food provision. A partial solution to this problem could be the use of a high-protein feed of an industrial origin in livestock nutrition, such as corn dried distillers grains with solubles (DDGS). Since DDGS is a byproduct, arising as a result of bioethanol production from corn, including it to ratio could be an excellent way of its natural utilization. There are indications that DDGS may favorably affect the rumen fermentation profile, inter alia, by increasing the total production of volatile fatty acids and changing the ratio between some of acids. Other reports relate to the reduction of greenhouse gases emitted by ruminants. Regarding the high calorific value of methane, the reduction of methanogenesis is an extremely beneficial phenomenon for grazers, because it allows to reduce energy losses associated with emission of fermentation gases. Due to the large heat capacity, it is believed that methane has a great influence on global warming. Therefore, another advantage of inhibiting methane production is reduced amount of gas in the atmosphere. However, the effect exerted on the fermentation following DDGS insertion into diet is not carefully examined, particularly in relation to the sheep, and the results are often conflicting. For that reason, there is a need for further research, gathering knowledge and verify whether the use of DDGS in the ratio of sheep is actually the convergent goal from ecological and productive point of view.