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Institute of Genetics and Animal Biotechnology
of the Polish Academy of Sciences, Jastrzębiec, Poland

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Apple pomace in feeding of dairy cattle as an element of sustainable agriculture strategy - a review

Monika Szymańska-Czerwińska, Krzysztof Niemczuk*, Agnieszka Wierzbicka, Nina Strzałkowska, Artur Jóźwik

Institute of Genetics and Animal Biotechnology, Polish Academy of Sciences, Jastrzębiec, Postępu 36A, 05-552 Magdalenka, Poland

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This work provides an overview of the knowledge about using apple pomace as milk cattle feed. Utilization of apple pomace as livestock feed is one of the possible alternatives to reduce environmental pollution and overcome the feed deficit. Apple pomace, rich in e.g. polyphenolic compounds, holds potential to be a valuable feed additive for enhancing the antioxidative capacity and overall quality of milk. The research on apple pomace as feed additive for livestock are important due to abundance of apples in Poland, the world's second-largest apple producer. To promote sustainability in animal feed production the use of agro-food-by products as apple pomace as animal feed component should be considered.

KEY WORDS: apple pomace / milk cattle / feed additives

Milk and dairy products occupy a special place in the human diet, and feeding of cattle has a fundamental impact on their chemical composition and health-promoting properties [Jóźwik *et al*. 2010, Strzałkowska *et al.* 2009, 2010]. In recent years, there has been an increasing interest in feed components that can improve the

*Corresponding author: k.niemczuk@igbzpan.pl

nutritional properties of animal products, especially milk. Simultaneously, rising costs of animal keeping, particularly feeding, are the reason for the search innovative feed components. Sustainable agriculture trends, which promote avoiding of waste of raw materials, motivate their use. By-products from the food industry, such as plant pomace, which are residues of seeds, fruits, vegetables after squeezing juice or oil, can be cost-effective, valuable, and environmentally friendly ingredients in animal feed, such as for cattle [Lashkari *et al.* 2013]. Lack of proper actions aimed at rationally managing fruit processing residues leads to broad losses. The emission of such large quantities of waste poses an obvious environmental threat. On the other hand, limiting the ability to spread pomace on fields creates a problem for processors related to the costly disposal and encourages the search for alternative solutions that would allow rational waste management without generating additional costs for the enterprise. Therefore, in the last decade, there has been increasing interest in research on the possibilities of using agricultural by-products [Lashkari *et al.* 2013]. Poland is the world's second-largest producer of apples and a significant producer of fruit and vegetable juices, resulting in thousands of tons of pomace annually, which can become a valuable feed component for animals [NHB. Indian Horticulture Database, National Horticulture Board, Ministry of Agriculture, Government of India 2023, Bartel *et al*. 2022]. Due to the common prevalence of apple production in Poland, cattle breeders and milk producers willingly include apple pomace in animal feed. The last few years have been particularly difficult for cattle breeders, especially dairy ones. Fines for exceeding milk quotas, falling milk prices, and the drought and the associated additional costs of purchasing feed have caused producers to increasingly look for alternative solutions related to reducing animal feed costs and improving milk production profitability. One such alternative could be fruit pomace.

Properties of apple pomace

Fruit and vegetable pomace, including apple pomace, are rich in protein (5.5-8.5%), carbohydrates (7%) such as pectin (2%), organic acids (1%), and minerals (20%) [Lyu *et al*., 2020]. Moreover, they also contain significant amounts of biologically active substances, including vitamins and polyphenolic compounds, which have health-promoting properties, as well as anti-inflammatory, antiviral, and anticancer effects [McCann *et al*. 2007, Strzałkowska *et al*. 2009, 2010, Jóźwik *et al*. 2010, Tewari *et al*. 2017, Mozos *et al*. 2018, 2021, Wang *et al*. 2018, 2020, Yeung *et al*. 2018, 2019, 2020abc, 2021abc, 2022, 2023, Pieczyńska *et al*. 2020, Chao *et al.* 2021, Chopra *et al* 2022]. However, certain properties make their regular use in animal feeding impossible. Firstly, they are seasonally available and have high moisture content (70-80%), and due to their high sugar content, fresh pomace undergoes rapid, uncontrolled degradation processes (fermentation) and physicochemical changes (e.g., freezing). Therefore, their collection from processing plants in the form of high-moisture pulp complicates storage and preservation, especially in autumn, winter, and early spring.

Thus, ensiling or dehydration is required for longer storage. These problems can be eliminated by using an innovative drying system. Dried and crushed apple pomace has low moisture content, making it easier to store and preserve, ensuring microbiological safety and maintaining health-promoting properties for a longer period. Only pomace that undergoes appropriate raw material processing will retain its health-promoting properties. Feed companies offer dried apple pomace added directly to basic feeds and in the form: flakes, powder, or granules sold separately. However, the price per ton is relatively high. Therefore, to secure fruit pomace, ensiling or drying is used. Existing drying methods often involve high-temperature processes (220-300°C) using belt or drum dryers. However, this completely degrades health-promoting compounds such as polyphenols. The final product thus becomes entirely worthless and is used as a material for producing fuel pellets. Conversely, technologies based on microwave drying in rotating drums allow maintaining all health-promoting properties of the product, but the efficiency of such solutions is very low, making them economically unviable. Therefore, the future for the effective use of fruit pomace is to create production lines enabling efficient drying at low temperatures. Dried or ensiled apple pomace is known as a sustainable and inexpensive substitute for energy feeds, with crude protein content from 19 to 65 g/kg, metabolizable energy from 7.7 to 9.1 MJ/kg, NDF (neutral detergent fiber) ranging from 300 to 482 g/kg, and ADF (acid detergent fiber) content from 250 to 420 g/kg on a dry matter basis [Pirmohammadi *et al*., 2006, Singh *et al*. 1992]. Its use in ruminant feeding improves feed palatability, leading to increased intake and thus higher milk yield with a simultaneous increase in the percentage of fat in milk. This is particularly important in terms of production profitability and milk technological suitability. Crushed and dried apple pomace can be an excellent source of energy, valuable protein, and fat. It can also be used as a concentrate feed equivalent and a component of a balanced TMR (total mixed ration). This product can successfully replace high-energy, costly feed additives (e.g., propylene glycol, calcium, or sodium propionate) used in feeding dairy cows during the peripartum period.

Impact of pomace on homeostasis

It is well known that metabolic processes are naturally linked to the production of reactive compounds in the body. However, a disproportion between the pool of free radicals and their derivatives and the antioxidant defense capacity leads to oxidative stress. This, in turn, plays a key role in many diseases, reproductive disorders, and reduced milk yield [Marwicka *et al*. 2021, Safa *et al*. 2019]. Cows are particularly vulnerable to homeostasis disturbances, and one of the causes has been the intensification of milk yield in recent years [Bava *et al*. 2014]. Dried apple pomace is rich in naturally occurring plant antioxidants (polyphenols, vitamins A, E, and C), which are also significant in terms of absorption by the animal body, as their synthetic counterparts do not have the same absorption level. Polyphenols, by neutralizing free radicals responsible for cellular damage, play a crucial role in maintaining the

body's antioxidant-oxidative homeostasis. Inflammation of the mammary gland in cows (*mastitis*) is currently one of the most common diseases that generate the highest costs in dairy cattle production. Economic losses from this disease result not only from treatment and veterinary care costs but also from milk losses, which, due inflammatory states, should not and cannot be delivered to collection points. Besides traditional treatment using antibiotics and anti-inflammatory drugs, feed additives are recommended for dairy cows to increase their blood's antioxidant capacity. Apple pomace could be an effective feed additive. Scientific studies show that dried apple pomace, as an additive to ruminant feed, stimulates redox potential, which is related to increased levels of glutathione reductase (GR) and vitamin C. Glutathione (GSH) plays an exceptional role as an intracellular antioxidant, participating in detoxification, eliminating carcinogens and toxins, synthesizing tissue hormones, DNA, and proteins, regulating gene expression and the immune system, and cell growth and death. DPPH (2,2-diphenyl-1-picrylhydrazyl) concentration in the rumen does not change during feeding. Vitamin C and glutathione reductase are sufficient factors to maintain the redox process. GSH and vitamin C also exhibit synergistic action in protecting against oxidative damage. Vitamin C, as a low molecular weight compound found abundantly in apple pomace, defends against oxidative processes in the rumen, preventing the activation of the enzymatic defense line, as indicated by the lower catalase activity, which is involved in detoxifying free radicals [Bartel *et al*. 2022].

Impact of pomace on rumen functional status

Feeding cows dried apple pomace increases fiber digestibility. It also positively affects the fatty acid profile, increasing the amount of polyunsaturated fatty acids (PUFAs). It significantly limits the biohydrogenation of acids carried out by rumen microorganisms, resulting in higher unsaturated fatty acids and lower saturated fatty acids (SFAs). Adding dried apple pomace reduces rumen acid (C18:2 cis-9, trans-11) concentration and no changes in vaccenic acid (C18:1 trans-11) concentration. This can be explained by lower *B. fibrisolvens* activity responsible for synthesizing these two isomers [De Paula *et al*. 2016]. Studies by Singh et al. [1992] showed decrease number of B. *fibrisolvens* population. Therefore, the lack of changes in C18:1 trans-11 concentration may result from decreased C18:0 concentration. This can be attributed to reduced activity of *B. proteocl*asticus, one of the bacteria responsible for converting C18:1 trans-11 to C18:0 [Rodríguez-Muela *et al*. 2015]. The linear increase in C18:2 cis-9, cis-12, and C18:3 n-3 also confirms the limiting effect of DAP on biohydrogenation, resulting in higher PUFA and n-3 fatty acids in the rumen. Previous studies have shown that the fatty acid profile (especially PUFAs, linoleic acid isomers, and n-3 FAs) in rumen fluid correlates with increased levels in milk. However, it is also worth noting the lower concentration of C18:2 cis-9 trans-11, beneficial to human health, in rumen fluid, which may result in lower levels in milk [Rodríguez-Muela *et al*. 2015].

Impact of apple pomace on cattle health

There is extensive research on using ensiled apple pomace in animal feeding [Rodríguez-Muela *et al*. 2015, Gharehbagh *et al*. 2020]. However, data on the impact of biologically active substances present in dried apple pomace is limited. Institute of Genetics and Animal Biotechnology of the Polish Academy of Sciences in Jastrzębiec is conducting research on the effects of dried apple pomace on animal organisms. So far, positive results have been obtained regarding its impact on processes occurring within the rumen and oxidative capacity [Bartel *et al*. 2022, Gadulrab *et al*. 2023, Yeung *et al*. 2024]. Cows are particularly vulnerable to metabolic disorders three weeks before and up to five weeks after calving. They are more likely to suffer from diseases such as ketosis, mastitis, milk fever, and, for example, abomasal displacement. They are also at risk of developing fatty liver syndrome. Therefore, a high content of easily accessible energy from the addition of ground and dried apple pomace can help reduce the negative energy balance and prevent liver steatosis during the transition period. The use of supplements containing polyphenols found in fruit pomace can help avoid these negative effects of metabolic disorders. Scientific studies show that incorporating apple pomace into ruminant diets positively affects animal growth and lactation [Beigh *et al*. 2015]. All these properties can be utilized in animal nutrition, including dairy cattle. Feeding dairy cows with fermented apple pomace alongside a basic diet results in an increase in average milk yield (1.89-1.90 kg/cow/day), milk fat, protein, and dry matter content, and reduces the incidence of diseases in dairy cows [Diao *et al*. 2003]. In the milk of cows fed with 30% apple pomace, an increase in fat and protein content is noted. Research shows that including ensiled apple pomace in the effective feeding of dairy cows during early lactation affects the dry matter content (DM), causing an increase of 9% for standardized and 5.9% for non-standardized milk. Regardless of the level of apple pomace intake, beta-hydroxybutyrate and blood urea levels significantly decrease; however, they remain within the reference values defined for cows [Anrique *et al*. 2003] The pectins present in apple pomace have gelling properties, so they can counteract diarrhea in calves. It is recommended to monitor cows' response to the introduction of apple pomace and adjust the dose based on production results and the animals' health status.

Reducing methane production

According to a report from the United Nations Food and Agriculture Organization (FAO), global livestock production accounts for approximately 18% of total anthropogenic greenhouse gas emissions, including 9% of carbon dioxide (CO_2). The level of methane emitted by the livestock sector is 37% of global production, most of which is produced by ruminants from the breakdown products of carbohydrates in the rumen. Methane contributes much more to global warming than carbon dioxide. Therefore, modern farming systems are seeking solutions to reduce methane emissions.

Current knowledge indicates that the nutritional values and functional features of dried and ground apple pomace could be used to lower the level of methane produced by ruminants. Scientists have proven that the inclusion of dried apple pomace (150 g/kg DM) subjected to low-temperature treatment in the modified diet of dairy cows positively affects the state of rumen microflora, thereby reducing methane emissions. In the rumen of cows fed with apple pomace, a significant decrease in the number of protozoa in the rumen fluid was observed, accompanied by a simultaneous increase in the number of bacteria, including fibrolytic bacteria, which can somewhat increase fiber digestibility. As a result, there is an increase in acetate concentration, which is a product of fiber fermentation. The reduction of methane production in the rumen due to the action of polyphenols could improve the energy balance in cows' bodies, as methane production in the cow's rumen is, as is known, an energy loss that could be used to meet the demand for milk production [Bartel *et al*. 2022].

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