

Perspective

Seeds of n-GM Soybean Varieties Cultivated in Poland and Their Processing Products as High-Protein Feeds in Cattle Nutrition

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Abstract: Soybean (*Glycine max* (L.) Merr) is a source of high-quality edible protein and oil for humans, but also a high-quality feed in livestock feeding. In Poland, imported genetically modified soybean meal covers 65%, and leguminous seeds that are cultivated locally cover 11% of the protein requirement in livestock nutrition. The implementation of the Polish national program and the European strategy supporting the growth of the leguminous area resulted in adaptation to local agro-climatic conditions of 36 varieties of non-genetically modified soybean (n-GM), which achieved an average seed yield of about 3.7 t·ha⁻¹ with a content of about 38% protein and 23% fat in dry matter. The 27-fold increase in n-GM soybean cultivation area observed over the past eight years resulted in the opportunities in the use of this high-protein feed in feeding cattle, the section providing 26% of gross agricultural production. In cattle feeding, soybean seeds are utilized as whole, cracked, roasted, and extruded full-fat seed; after oil pressing as cold press cakes and extruded oil cakes; and moreover, late-ripening soybean plants with late maturity are used as fodder plants. The presented review is based on literature and analysis of data on the use of each of these forms in cattle nutrition, including the limitation of their use as components of feed rations, which is caused by the high rate of nitrogen release in the rumen and the effects of fat and saponin on microbial fermentation in the rumen due to the role of endogenous seminal enzymes.

Keywords: soya; cattle nutrition; protein-rich feed; pre-treatment soybean

1. Introduction

Soybean (*Glycine max* (L.) Merr) is grown primarily for the production of grains due to the high content of protein (40%) and oil (20%) [1]. Soybean is an economically important leguminous plant used in feed industrial sectors as a source of the high-protein, defatted, and toasted soybean meal used in livestock feeding [2]. Most of the soybean meal imported into the EU is from genetically modified (GM) cultivars, and this product supplies 64% of the protein-rich feed materials [1,3]. In animal protein production, feeds account for 50% to 70% of costs, and the protein is the most expensive dietary component [4]. In Poland, imported GM soybean meal covered 65% of protein requirements in livestock nutrition in 2016 [5]. The cattle production (milk and slaughter animals) is an important section of agricultural production that provides 26% of gross agricultural production and during the last 15 years observed a threefold rise in the demand for protein feed which is related to 55% growth in milk production [6,7].

In recent years, agriculture is considered to be the main driver of losses of biodiversity and a major contributor to negative climate change and pollution [8]. The significant challenge in current livestock production is to minimize the threat of environmental pollution [9,10]. The most appropriate way to reduce the negative impact on the environment is to increase the area of legumes with high nitrogen binding efficiency and the abilities to improve the soil structure and enrich soil fertility [11]. Currently, legumes grown in Poland cover only 11% of the demand for feed protein in livestock nutrition [5]. With regard to sustainable development, the animal production sector, and ensuring farm profitability, the area of cultivation of new locally adapted legumes is growing. The most promising are soybean varieties, characterized by the high content in protein grains with a high nutritional value in animal nutrition [1]. On other hand, consumer concerns about genetically modified food production [12]. Public opinion poll results showed that about 57% of Polish citizens prefer food products of animal origin without the content or participation of genetically modified organisms (GMOs), and 65% do not qualify them as safe once containing or produced with GMOs [13,14]. As a consequence of social acceptance for limiting the negative impact of animal production on the environment and improving the health safety of food of animal origin, during last 10 years, a 27-fold increase in the cropping area of varieties of non-genetically modified soybean (n-GM) was observed despite the cool growing conditions in Poland, belonging to the central climatic region of Europe [15]. In the structure of agricultural land in Poland, the percentage of farms qualified as small sections of arable land is 97.6% [16]. Small farms play an important role in supporting the employment of the rural community. They also play many key functions in the rural economy. Currently, there is a demand for the use of soybean obtained from own crops in feeding livestock. In order to be able to use soybean protein in animal nutrition, farmers need to know the appropriate agrotechnical procedures to produce high-quality soybeans [17].

Society accepts the implementation of agricultural practices that will limit climate change and pollution, increase the safety of food of animal origin, and also increase the usefulness of feeds derived from n-GM soybean varieties. In this review, we provide an update compiled from recent publications on the use soybean feed as: full-fat grain; cracked, roasted, or extruded full-fat grains; extruded oil cakes; and whole plant silage. Each of these products has unique nutritional properties, making them suitable for feeding specific categories of cattle.

2. N-GM Soybean Varieties Cultivating in Poland

Soybeans, faba beans, lupins, and peas are included in the group of arable crops with the agricultural name "legumes". All listed plant species belong to the family Fabaceae, and the basis for including them in the group is the ability to produce large seeds, rich in nutrients. Seeds of soybean are characterized by the highest content of protein with a high nutritional value in animal nutrition compared to others [1]. The protein is characterized by the nutritionally valuable amino acid composition, with a high content of the essential amino acid for animal feed and human food [18]. In addition, soybean plants are valuable from an agricultural point of view due to their ability to live symbiosis with rhizobial strain bacteria processing atmospheric nitrogen into organic compounds supplying both the plant and soil [19]. Moreover, an important agricultural feature of soybean plants is leaving rich crop residues that improve the physical and chemical properties of the soil [20].

The Center for Varietal Research in Poland, in accordance with the European Strategy in response to the growing interest in soybean cultivation, focused scientific work and applied research on the analysis of the possibilities of increasing the yield of this plant in agro-climatic conditions in Poland [21,22]. The implementation of the nationwide program "Center for Research on Protein Varieties Research Initiative" showed that the average seed yield of 36 n-GM soybean varieties was $3.7 \text{ t}\cdot\text{ha}^{-1}$, the protein yield was close to $1200 \text{ kg}\cdot\text{ha}^{-1}$, and seeds contained an average of 38.3% protein and 22.8% fat in dry matter [23]. The area of soybean cultivation increased; in 2010, it was 0.2 thousand ha; eight years later, soybean was cultivated on 5.4 thousand ha, and seed harvest reached 10.4 thousand tons [15]. The best-yielding varieties are presented in Table 1.

Table 1. Seeds chemical composition of non-genetically modified (n-GM) soybean varieties with the highest seed crude protein yield (≥ 1.0 ton/hectare), achieving harvest maturity in agro-climatic conditions of Poland in 2018 [23].

Soybean Variety	Content (% in Dry Matter)			Yield (ton/ha)		Maturity Groups Qualification	Vegetation Length (Days)
	Crude Protein	Crude Fat	Crude Fiber	Seed	Crude Protein		
ES ¹ Comandor	39.2	22.0	7.1	4.3	1.3	Late	133
Coraline	38.3	23.3	8.2	4.2	1.3	Very late	141
Abelina	38.1	23.6	9.0	4.1	1.2	Medium late	129
Aligator	37.2	23.7	7.5	4.1	1.2	Late	134
Erica	38.4	23.1	7.7	3.9	1.1	Early	123
Augusta	38.5	21.9	7.2	3.1	1.0	Very early	121
Maja	39.8	23.6	7.8	3.0	1.0	Medium early	131

¹ Owned by Euralis Semences Seeds Company (Euralis Holding SA, Avenue Gaston Phoebus, 64231 Lescar, France).

The differences between varieties and between raw or processed products of soybean in terms of quantity and quality of nutrients affect their usefulness in their usefulness in meeting livestock nutritional requirements [24,25]. In the context of environment protection and reducing the negative impact of modern agriculture on the food security and effective replacement of well-calibrated and chemically stable imported GM soybean meal, the inclusion of n-GM soybean varieties and processing products in cattle nutrition requires information on the possibilities of their proper use.

3. The Factors Affecting Soybean Utilization in Cattle Nutrition

Due to the high content of protein and fat, soybean seeds are a valuable high-protein and high-energy feed in cattle feeding. In ruminants, the nutritional value of protein is measured by the amount of amino acids absorbed in the small intestine from two fractions: the microbial protein synthesized in the rumen from the available nitrogen and energy (fraction estimated by the rumen microbial digestion coefficient) and the dietary protein which escaped digestion in the rumen (fraction determined by the intestinal digestion coefficient) [26]. The efficiency of microbial protein synthesis in the rumen depends on the precise and adequately selection of feed ration components, ensuring synchronization of the rate of nitrogen and energy release in the rumen fermentation processes [27]. The coefficient of rumen microbial protein digestion of raw soybean seeds reaching a high value of 0.72 indicated a high rate of nitrogen release [28]. The intense digestion of feed protein in the rumen could result in nitrogen losses in the form of urea in urine and ammonia in gases.

The estimation of the feed energy value included the fat content [26]. In the rumen environment, two major processes occur during the feed fat metabolism: the hydrolysis of ester linkages in lipids liberated free fatty acids and the biohydrogenation of unsaturated fatty acids [29]. Unsaturated fatty acids constitute nearly 88% of the soybeans oil [30]. The fat increases the energy density of diets to meet requirements of high producing dairy cows, but a large amount in the ration of soybean fat negatively affects the rumen fermentation due to the toxic nature of unsaturated fatty acids to many rumen bacteria [29]. The fat content in the ration for adult cattle should not exceed 7% of the dry matter and will usually be adequate at 6% or less [31].

The use of soybean seeds in feed ration composition is limited by the constituents modifying digestion in animal alimentary tract. Soybean plants contain trypsin and chymotrypsin inhibitors, lectins, antigenic proteins, estrogens, saponins, phytic acid, and non-starch polysaccharides which are referred to as anti-nutritional factors exerting negative impacts on monogastric and immature ruminant animal feeding [32,33]. In adult ruminants, most of the harmful anti-nutrient substances are

effectively inactivated by bacteria, fungi, and protozoa inhabiting the mature rumen, but saponins are not detoxified [34]. Saponins are a diverse group of glycosides, and their content in the seed hypocotyl of soybean seeds ranges from 0.6–6.2% [35]. The primary effect of saponins is the removal of protozoa from the microbial ecosystem in the rumen (defaunation), followed by a significant increase in the number of cellulolytic and total bacterial numbers in the rumen, which on the one hand causes intensive degradation of protein feed, but also increases the efficiency of microbial protein synthesis and the supply of protein to the duodenum [34]. Depending on the dose of saponins, a reduction in methane emissions was observed as an effect of decreasing the activities and numbers of methanogens [36]. In calves younger than 3 months, soybean seed protein is qualified as immunoreactive and escapes digestion [32]. The 70% of storage are classified as β -conglycinin (7S) and glycinin (11S) proteins [37–39]. The immunoreactive proteins in the functional rumen are inactivate [32].

Additional factors limiting the use of soybean seeds as a component of feed ration for cattle are endogenous seed enzymes, lipases, lipoxygenases, and urease. Lipases catalyze the hydrolysis of ester-carboxylic bonds of oil triacylglycerols and release fatty acids, while lipoxygenases catalyze the oxidation of unsaturated bonds to form hydroperoxides of the corresponding fatty acids [40,41]. The urease enzyme in the presence of urea in the ration achieves high hydrolytic activity leading to rapid ammonia production [42].

The high rate of nitrogen release in the rumen, the modification effect of fat and saponins on rumen fermentation, and the activity of endogenous seed enzymes are factors that require attention in the proper use of soybean in cattle nutrition.

4. The Application of Raw Seeds and Their Processing Products in Cattle Feeding

In the structure of agricultural land in Poland, the percentage of farms qualified as small with an area of ≤ 50 ha of arable land is 97.6%; the total number of agricultural holdings and farms with an area of ≤ 5 ha is 53.3% [16]. The structure of arable land in Poland does not provide the homogeneous material for companies producing high-protein feed. At present, the owners of small farms are interested in increasing the cultivation area of soybean varieties adapted to Polish agro-climate conditions both to reduce climate change and pollution and increase the safety of food of animal origin, as well as because of the increase in economic profitability. In the years 2014–2015, the percentage of revenues in total soybean cultivation costs reached 98% [43]. Economic efficiency is supported by EU subsidies, which covered 60% of the costs incurred by farmers for the cultivation of legumes [44].

Currently, an essential factor in the efficient use of n-GM soybean is the information on the proper use of raw seeds and the application of technological processes extending their utilization in feeding various technological groups of cattle. Processing of soybean seeds and whole soy plants in small farms into soybean products for feeding cattle are presented on Figure 1.

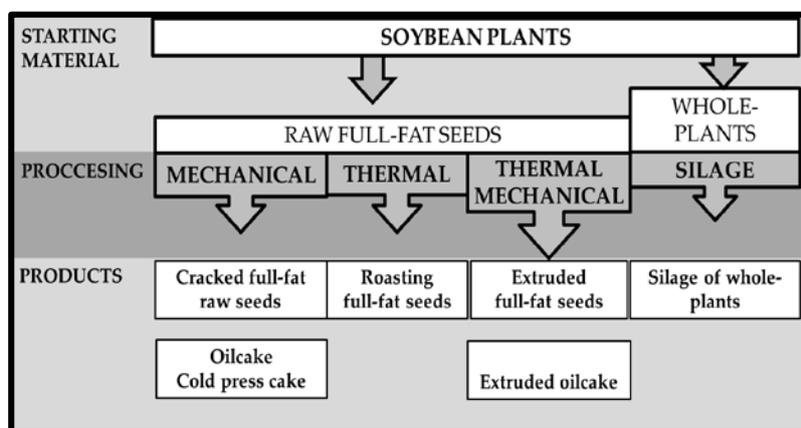


Figure 1. Processing of soybean seeds and whole soy plants into soybean products for feeding cattle on small farms.

The supply of protein to increase the protein content of rations is one of the most important feeding costs on high yielding cattle farms. The high rate of protein microbial digestion in the rumen indicates the need for use the processing technologies to reduce this susceptibility. The effects of processing methods on the digestibility of protein in cattle digestive tract is presented on Table 2.

Table 2. The effects of processing methods of soybean on the digestibility of protein in cattle alimentary tract.

Item		Chemical Composition, (g·kg ⁻¹ Dry Matter)		Coefficients of Crude Protein Digestibility			References
		Crude Protein	Ether Extract	Total Alimentarytract	Microbial in Rumen	Intestinal	
Whole raw seeds		368	175	0.82	0.72	0.65	[28]
		386	195	0.99	0.62	0.96	[45]
		369		0.57			[46]
Mechanical	Cold press cake	474	55				[47]
Thermal	Roasting full-fat seeds	381	185	0.80	0.56	0.72	[28]
		386	230	0.99	0.51	0.99	[45]
Processing	Thermal and mechanical	Raw soybeans heated at 146 °C, mean particle size 1.59 mm		389		0.63	[46]
		Extruded full-fat seeds	149 °C	468	100	0.60	0.40
	171 °C		469	109	0.41	0.60	
	Extruded oil cake		digestibility of protein in cattle alimentary tract of extruded oil cakes is similar to this characterized soybean meal				
Whole plants silage		164–199	18–53		0.39		[49]

Numerous scientific reports confirm the usefulness of the application of raw seeds and their processing products in cattle feeding. The effects of inclusion of raw soybean seeds, their processing products, and soybean forage in ration on performance in dairy cows are presented in Table 3.

Below, a brief overview of science reports of the use raw soybean seeds, their processing products, and soybean forage in cattle nutrition is presented.

Table 3. Effects of raw soybean seeds, their processing products, and soybean forage inclusion in ration on performance in dairy cows.

Item		Feeding Period	Milk Yield (kg/d)	Inclusion Level (% in Ration Dry Matter)	Productive Performance Effects	References	
Whole raw seeds		90, 60, 30, 0 d relative to the calving—84 d of lactation	30.1	12	no effects on: milk yield, milk composition compared with control fed without raw soybean	[50]	
		mid- to late lactation		0, 9, 18, or 27	milk yield, lactose, and protein yield decreased, fat and unsaturated fatty acids increased	[51]	
		188–201 d of lactation	18.9 ± 3.2	16	no effects on: milk yield, milk composition compare with control fed without raw soybean	[52]	
		121–145 d	30.2	20	milk yield and milk composition not differ compare with control fed without raw soybean	[53]	
Mechanical	Cracked, particle size 2 or 4 mm			20	no effects treatment on: milk yield milk composition	[53]	
	Cold press cake	15–71 d of lactation	32–35	0, 6, 12, or 18	no effects of treatment on: milk protein, milk fat, energy-corrected milk yield	[47]	
Processing	Thermal	Roasting full-fat seeds			no data available		
	Thermal and mechanical	Extruded full-fat seeds	141 169 d of lactation	41	13	substituting soybean meal with extruded full-fat seeds improved feed intake and milk yield	[48]
		Extruded oil cake	nutritional value of extruded oil cakes and the range of use in feeding cattle are similar to those of soybean meal				[48]
Whole plants silage		early to mid-lactation	35–37	35	no effects on energy-corrected milk yield, milk composition relative to alfalfa silage	[54]	

4.1. Whole Full-Fat Raw Soybean Seeds

The whole full-fat raw soybean seeds are used as a component of the daily ration for heifers and beef cattle. The heifers achieved a $900 \text{ g}\cdot\text{d}^{-1}$ weight gain at 12 months of age when fed rations with 20% raw whole soybeans [55]. The Angus steers received $1.26 \text{ kg DM}\cdot\text{d}^{-1}$ of raw whole soybeans supplementing low-to-medium quality roughages as the basal diet, achieving the expected $700 \text{ g}\cdot\text{d}^{-1}$ weight gain [56].

Research results indicate that the amount of whole raw full-fat soybean seeds in the feed ration for high producing dairy cows depended of the stage of lactation. A 12% content in the feed ration given to cows from the 90th day preceding the expected date of calving to the 81st day of lactation had no effects on their energy-corrected milk yield and composition and positively affected the immunity of cows compared with those fed without raw soybean [50]. The whole full-fat raw bean content reaches 16% of the feed ration when used in feeding cows during days 188–201 of lactation (the ration contained 5.7% fat) without negative effects on the dry matter intake and production and composition of milk [52]. The content of this feed in the ration for adult cattle is limited by the amount of fat contained in the feed ration [31]. Venturelli et al. [51] added increasing levels of whole raw soybean (0%, 9%, 18%, and 27%) in the diet of mid- to late-lactating cows and reported a linear decrease of milk yield and linear increase of fat and unsaturated fatty acids content. The current research results indicate, that feeding cows with soybean seeds in the form of whole seeds ensures protection of unsaturated fatty acids against rumen biohydrogenation; this protection is more effective than the administration of fatty acids in the form of calcium salts [52,57]. The results presented above suggest that the inclusion of 12% of whole full-fat raw soybean seeds in daily ration during the first period of lactation and 16% during the late period did not adversely affect the production performance of dairy cows, while higher levels during mid-lactation reduced milk yield.

4.2. Mechanical Processing Products

Mechanical processing increases the intensity of microbial degradation of the total protein as well as the rate of fat release and biohydrogenation in the rumen environment. The prepared feed has a short shelf life because during storage, fat is susceptible to fat-modifying processes resulting from the activity of endogenous enzymes, storage duration, and temperature which influenced the content and composition of fatty acids in raw soybean [58].

4.2.1. Cracked Full-Fat Raw Seeds

Cracked full-fat raw soybeans are applied in cattle nutrition. Cracking soybean in small particles causes the protein content to be more rapidly degraded than the protein in larger particles because small particles have a larger surface area [46]. The latest research from 2015 showed that inclusion of 200 g per kg ration (dry matter) of whole full-fat raw seeds and seeds cracked to particle size 2 or 4 mm stated that milk yield and milk composition were not influenced by experimental diets [53].

4.2.2. Cold Press Cake

The mechanical process, which is a crusher, is a commonly used method of oil and cake production. This process is mainly used in the feed industry. Mechanical pressing of oil is often combined with extrusion to increase productivity [59]. The process itself is the physical pressure that the soybeans undergo for oil extraction. If the temperature does not exceed $49 \text{ }^{\circ}\text{C}$, the process is referred to as “cold pressing”, and the oil has a high nutritional value in human nutrition. The resulting oil cake has a lower fat content and higher protein content compared to raw seeds, while the activity of endogenous enzymes does not change. Cold press cake in the feeding of dairy cows during the first period of lactation ($32\text{--}35 \text{ kg}\cdot\text{d}^{-1}$ mean milk production) was introduced at the level of 6%, 12%, and 18% of ration (dry matter) for cows [47]. The author observed that milk protein, milk fat, energy-corrected milk yield, and feed efficiency did not differ between treatments and the control group fed soybean meal.

4.3. Thermal Treatment Processing Products

Heat treatment (steam explosion) can increase the degradation of lignin, cellulose, and hemicellulose in by-products from the milling industry. This will make the by-products more suitable for ruminants [60]. However, the most important effect of thermal treatment is limitation of protein solubility in the rumen and increasing the pool of available protein in the small intestine. The decrease in soybean protein susceptibility to rumen microbial degradation results from heat-initiated chemical reactions between free amino acid groups of the peptide chain and sugar aldehyde groups of carbohydrates [45,46]. It was investigated that seeds heated to a temperature of 140–145 °C increased the proportion of the non-degradable protein fraction in the rumen in relation to raw seeds by 26%, the proportion of this fraction in heated seeds was 56%; heating increased the amount of digestible protein in the small intestine by 18% from the non-degradable fraction in the rumen [28]. Additionally, an inactivation of endogenous seed enzymes is a beneficial effect of thermal treatments. It has been shown that temperature above 50 °C inactivates lipoxidase and above 80 °C denatures urease [61,62]. Roasting and extrusion are the most commonly used types of thermal heating.

Roasted Full-Fat Soybean Seeds

Positive roasting effects are characterized by limitation of protein solubility in the rumen and inactivation of endogenous grain enzymes. The limitation of the product's share in the composition of feed ration results from the high fat content and possible fragmentation of seeds. The results presented by Rafiee-Yarandi et al. [63] showed that roasting at 115 °C for 10 min of full-fat soybeans crushed to a particle size of 1.15 mm preferably stabilizes the ratio of non-degradable protein content in the rumen to digestible protein in the small intestine, ensuring optimal protein nutritional values of such processed full-fat soybeans in cattle feeding. According to Tice [64], roasting of raw soybean seeds resulted in an increase of unsaturated fatty acids content in milk fat; additionally, the content of polyunsaturated fatty acids in milk increased compared to milk from cows fed with raw soybeans. These results are in line with Salles et al. [65] who indicated that the inclusion of unsaturated vegetable oils in the diet of lactating dairy cows significantly increased the content of unsaturated fatty acids in milk.

4.4. Thermal and Mechanical Processing Products

The extrusion parameters are high temperature and pressure which have a large influence on the properties of the extrudate. The process involves exposure to fluctuations of these factors. Positive effects are the limitation of protein solubility in the rumen and inactivation of endogenous seeds enzymes. Negative effects are fragmentation of seeds and rupture of fatty micelles during a rapid pressure drop when the product leaves the extruder. Disruption of fatty micelles causes a rapid release of oil directly into the rumen after administering feed with the presence of extruded full-fat soybeans [66].

4.4.1. Extruded Full-Fat Soybean Seeds

Extruded full-fat soybeans are characterized by high protein and energy values. The product is used in feeding dairy cows, especially in the early lactation period. The introduction of 7.2% of extruded full-fat soy (about 1.5 kg) in the composition of the feeding ration during the first 4 weeks of lactation had a positive effect on cows metabolic indicators and milk production in the first 8 weeks of lactation [67]. Moreover, iso-protein replacement of 13% soybean meal with extruded full-fat soybeans in the composition of a completely mixed ration with a fat content of 4.35% had a positive effect on feed intake and milk yield of cows without affecting milk composition [48]. Similar effects were obtained by introducing full-fat extruded soybeans in place of soybean meal to the feed ration administered up to 60 days of lactation period [68]. Extruded full-fat soybeans are also used in calf nutrition. It was investigated that replacing 50% of the soybean meal by the Extruded full-fat soybean seeds in the starter mix composition did not reduce weight gain and efficiency of feed utilization on the obtained growth [69,70].

4.4.2. Extruded Oil Cake

The nutritional value of extruded oil cakes and the range of use in feeding cattle are similar to those characterized soybean meal [48].

4.5. Whole-Plant Soybean

Soybean was introduced to Western countries as a forage crop, and some forage soybean cultivars have been released [71]. A narrow margin is the use of whole plants of varieties with late maturity, the seeds of which may not reach maturity in unfavorable weather conditions. In Eastern Canada and the Northern United States, soybean cultivars have been developed specifically for use as a forage crop. Dry matter yields of forage cultivars range between 4.5 and 14 t·ha⁻¹ [72]. The nutritional value of silage is affected by the vegetative development phase of the plant, drying time, chemical composition of the silage and the composition of the feed ration modifying digestion in the rumen [49]. Advancing plant maturity increased the crude protein and ether content from 164 to 199 and from 18 to 53 g·kg⁻¹ DM [72]. As Vargas-Bello-Pérez et al. [54] stated, the energy-corrected milk yield and milk chemical composition was the same in dairy cows fed with alfalfa silage and those fed with whole-plant soybean silage. In Poland, no research has been carried out on the cultivation of soybean plants of late-ripening varieties intended for the production of forage crop.

5. Conclusions

Society in Poland expects the implementation of agricultural practices that will limit climate change and pollution and increase the safety of food of animal origin. An increase in acreage of non-genetically modified soybean (*Glycine max* (L.) Merr), included in legumes, was observed during the last years to meet these expectations. The Polish national program and the European strategy supporting the growth of the leguminous area resulted in adaptation to local agro-climatic conditions of varieties, characterized by high yield of seeds, protein, and fat.

A review of the literature showed that soybean crops can be used in feeding cattle in many forms as raw seeds and their thermally and/or mechanically processed products, each of which has unique nutritional properties and limitations. The raw soybean seeds protein is characterized by a high rate of nitrogen release in the rumen as indicated by the 0.72 value of efficiency of the rumen microbial digestion coefficient, and inadequate feed ration composition could result in nitrogen losses. The decrease in protein susceptibility to rumen microbial degradation results from thermal processing, as roasting and extrusion decrease the rumen microbial digestion coefficient to 0.51 and 0.41 (respectively). The fat is characterized by a high content of unsaturated fatty acids toxic to many rumen bacteria, and a high fat content in the ration negatively affects the rumen fermentation. The decrease in fat content results from mechanical processing. The mechanical processing increasing fragmentation of seeds with a larger surface area causes the more rapid protein microbial digestion in the rumen. On the other hand, mechanical processing in which physical pressure is associated with growth of temperature leads to the lowering of the rate of rumen microbial digestion. The combination of thermal and mechanical processing is extrusion, with high temperature and pressure changes. In extruded oil cake, protein solubility in the rumen is limited, but in extruded full-fat soybean products, disruption of fatty micelles causes a rapid release of oil directly into the rumen.

The successful implementation of locally cultivated varieties of soybean, whole plants, their raw seeds, and their processing products in feeding cattle depends on the precise and adequate selection of feed ration components, ensuring synchronization of the rate of nitrogen and energy release in the rumen fermentation processes.

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