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ENHANCING THE NUTRITIONAL VALUE OF POULTRY FEEDSTUFFS USING THE EXAMPLE OF RAPESEED PRODUCTS – A REVIEW

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Abstract

This paper outlines the main goals and methods for improving the nutritional value of poultry diets. The benefits of various processing techniques are demonstrated using the example of rapeseed and rapeseed by-products, i.e. rapeseed cake and rapeseed meal. The progress made in plant breeding in the past decades led to a significant reduction in the content of anti-nutritional factors and ingredients which reduce the nutritional value of feed. Rapeseed by-products have become a valuable source of protein for feedstuffs, and they can be safely used in poultry rations at high inclusion rates. Mechanical treatments, such as rapeseed hulling, and enzyme supplementation (phytases, carbohydrases) also significantly increase the nutritional value of feed ingredients. Further research is needed to tap into the new opportunities for improving the nutritional value of feedstuffs.

Key words: rapeseed meal, rapeseed cake, nutritional value, poultry

Commercial brown-egg layers have the genetic potential to produce 26.5 kg egg mass per hen (405 eggs with average weight of 65.5 g) in a prolonged laying period of 16 months, with a feed conversion ratio of 2.1 kg feed/kg egg mass (Lohmann Tierzucht, 2011). Fast-growing broilers reach marketable live weight of 2.1 kg in 5 weeks, with a feed conversion ratio of 1.58 kg per kg body weight gain (Aviagen, 2012). The genetic potential of birds to efficiently convert feed nutrients into eggs and poultry (broiler, turkey, duck) meat for human consumption can be fully exploited when birds are well managed, remain healthy and receive highly digestible, concentrated and well-balanced feed rations (Jeroch et al., 2013 b). The challenges for commercial poultry diets formulation are to optimize feed composition based on a limited choice of raw materials and limited inclusion rates, and to eliminate anti-nutritional factors.

Table 1 shows the annual use of ingredients currently used in poultry rations in Germany. The majority of raw materials are cereals (mainly wheat and maize) and soybean meal, which are also used for human consumption and the production of bioethanol (cereals).

Table 1. Annual use of raw materials in poultry rations in Germany (DVT, 2013)

Raw materials	Layer diets, million tons (%)	Broiler diets, million tons (%)	Source
Cereals (legumes)	1.4 (61)	1.6 (62)	Germany, EU
Soybean meal	0.3 (13)	0.5 (19)	South America, USA, EU
Other by-products of oil manufacture (rapeseed meal, sunflower meal)	0.15 (6.5)	0.1 (4)	Germany, EU
Food processing by-products	0.15 (6.5)	0.15 (5.5)	Germany, EU
Oils and fats	0.1 (4.3)	0.15 (5.5)	Germany, EU, other
Minerals (phosphates)	0.2 (8.7)	0.1 (4)	Germany, EU, other
Total	2.3 (100)	2.6 (100)	

The available resources are limited and have to be utilized efficiently in animal feed. The aim of poultry nutrition is to convert feed protein to egg and poultry meat proteins. According to our own calculations, the conversion ratios of dietary protein to edible protein are 33% in eggs, 26% in broiler meat, 24% in turkey meat and 20% in duck meat (Jeroch et al., 2013 b). This paper examines the possibilities for further improvement in feed conversion ratios and the incorporation of other ingredients in poultry nutrition.

Main goals and methods for improving the nutritional value of feedstuffs in poultry

The main goals are:

– to formulate species-specific feeds, increase feed intake and decrease mortality,

– to increase the content of valuable nutrients and decrease the content of indigestible components,

– to reduce the content of anti-nutritional compounds and undesirable components,

– to optimize digestion and intestinal health,

– to improve nutrient resorption and enhance the nutritional value of feed,

– to improve hygiene standards in feedstuffs and feed mixtures.

In the past decades, classical methods have been used to improve the nutritional value of feed. A variety of improvements and modifications have been introduced in recent years, including:

– conventional plant breeding/genetic modification,

– biological treatments (e.g. fermentation),

– use of feed additives (feed enzymes, probiotics, organic acids, phytobiotics),

– chemical treatments (decontamination),

– mechanical treatments (cleaning, milling, shelling, pelleting, toasting, decontamination, extrusion, expansion etc.).

Rapeseeds and rapeseed by-products as an example for enhancing the nutritional value

Genetic improvement of rapeseed

The quality of rapeseed intended for human and animal consumption has been significantly improved by European and Canadian breeders in the past decades (Table 2). Industrial rapeseed oil containing around 50% erucic acid (C22:1), which is deposited in body fat and may cause heart problems, has been transformed into a valuable product for human and animal consumption. The glucosinolate (GSL) content of oil extraction by-products has been significantly reduced to make them safe for monogastric animals. Traditional rapeseed varieties had negative effects on thyroid function and performance in poultry fed rations with 2–3% rapeseed meal (RSM). Ruminants were the only animals that could be safely fed the discussed by-products.

Table 2. Achievements and goals of genetic improvement of rapeseed[1]

Variety, breeding goal	Qualitative assessment
Traditional varieties	high content of erucic acid in oil, high concentrations of anti-nutritional compounds in fat-free dry matter, in particular glucosinolates, sinapine and other
One-zero varieties (improvement of one qualitative trait) – first stage in quality breeding; a one-zero winter rapeseed variety has been grown in Germany since 1973 and in Poland since 1976	varieties (winter rapeseed in Europe, spring rapeseed in Canada (canola) and Northern Europe) with reduced content of erucic acid (from 50% to <1% of total fatty acids)
Double-zero varieties (improvement of two qualitative traits) – second stage in quality breeding; a double-zero winter rapeseed variety has been grown in Germany since 1981 and in Poland since 1985; a double-zero spring rapeseed variety had been introduced earlier to Canada and Northern Europe	varieties containing <1% erucic acid with significantly reduced glucosinolate content (from 100 to <18 $\mu mol \cdot g^{-1}$ seeds)
New 00 types (improved double-zero varieties) of winter and spring rapeseed	glucosinolate content <10 $\mu mol \cdot g^{-1}$ seeds
Yellow-seeded varieties (improvement of three qualitative traits) – currently introduced in Canada (canola)	thinner seed coat, about 20–30% lower content of fibre, mostly lignin (about 50%), in by-products, higher energy value, improved amino acid digestibility
Varieties with improved qualitative traits for industrial processing, human and animal consumption	modified fatty acid profile, reduced glucosinolate content
Future varieties	partial or complete elimination of antimetabolites, including phenolic compounds (sinapine) and phytic acid derivatives, enhancement of phytase activity

[1]Becker et al., 1999; Röbbelen, 1997 and 2001; Li et al., 2007; Bartkowiak-Broda et al., 2011.

As shown in Table 2, glucosinolate content has been further reduced in the new double-zero rapeseed varieties. This achievement, combined with toasting in modern oil mills, contributed to a significant reduction in the glucosinolate content of RSM. In a 4-year study (2005–2008) of rapeseed meal quality in Germany, glucosinolate levels were determined in the range of 6.9 and 9.4 µmol/g RSM (Weber, 2010). Rapeseed meal containing 4.9 µmol/g glucosinolate was analysed in Poland (Mikulski et al., 2012). Plant breeders in Poland and Canada are aiming for a further reduction in the glucosinolate content of rapeseed and rapeseed meal. RSM containing less glucosinolate can be safely included in poultry rations without delivering negative effects (Table 3).

Table 3. The use of RSM with low GSL content in diets for growing turkeys and laying hens

Source	Poultry category	RSM content of diets in %	GSL content in µmol/g RSM (88% DM)	Evaluation
Mikulski et al. (2012)	male turkeys	0/6/12/18	4.4	no significant effect on growth parameters or carcass value, footpad lesions were not intensified
Campbell et al. (1999)	white layers	0/10/20	1.8	identical performance in all groups, no effect on bodily organs
Rodehutscord et al. (2012)	brown layers[1]	0/5/10/15	6	no adverse effects on performance or egg quality

[1]Without the tainter gene.

Table 4. Qualitative parameters of rapeseed meal from black- and yellow-seeded (canola) rapeseed varieties

Parameter	Poultry category	RSM from	
		Black variety	Yellow variety
Fibre/lignin content (g/kg DM)		301/71	241/37
Oligosaccharide content (g/kg DM)		36	21
Crude protein content (g/kg DM)		438	498
Average prececal AA-digestibility (%)	broilers	83	89
Metabolizable energy (MJ AME/kg DM)	broilers	7.98 (100)	9.18 (115)
	turkeys	8.40 (100)	9.08 (108)

Słomiński et al. (2007, 2011); Jia et al. (2013).

The development of rapeseed varieties with a reduced content of total fibre and lignin (triple-zero varieties, Table 2) poses a new challenge for plant breeders. The new varieties will allow improving the digestibility of crude protein and amino acids and increasing the energy value of feed. Experimental yellow-seeded rapeseed varieties with a reduced hull content are currently being tested in Canada. In comparison with the conventional black varieties, yellow-seeded varieties contain less fibre and oligosaccharides and more crude protein and amino acids. Preliminary results suggest that yellow-seeded rapeseed is characterized by improved amino acid digestibility and a higher content of AME_N (Table 4).

Attempts are also made to eliminate other antinutrients, including phenolic compounds (sinapine), tannins and phytic acid, and to achieve a further reduction in the glucosinolate content of rapeseed meal.

Positive effects of mechanical treatments

Several mechanical treatment methods have also been developed to reduce the fibre content of rapeseed cake (RSC) and RSM. Hulling the seeds before processing (Kracht et al., 1998; Huang et al., 2007) improves the nutrient composition and energy value of feed (Table 5). The applied treatments reduce the content of fibre, in particular lignin (by 50%), and increase the content of crude protein, amino acids and other nutrients. The AME_N content is increased mainly by the reduction in fibre levels achieved by seed hulling, and it varies with the age of birds (Table 6).

Table 5. Chemical composition ($g \cdot kg^{-1}$ DM) of rapeseed meal from unhulled (uh) and hulled (h) seeds

Source		Crude ash	Crude protein	Crude fat	Crude fibre	NDF	Lignin	Lysine
Kracht et al. (2004)	uh	77	396	21	117	268	88	19
	h	82	424	21	72	193	44	22
Huang et al. (2007)	uh	79	386	14	118	ND	ND	13
	h	78	468	9.5	56	ND	ND	21

ND – not determined.

Table 6. The effect of rapeseed hulling on the energy value of rapeseed meal and rapeseed cake (Jeroch et al., 2001 b)

Feed source	Poultry category	Unhulled seeds		Hulled seeds		% increase in AME_N due to hulling
		crude fibre g/kg DM	AME_N MJ/kg DM	crude fibre g/kg DM	AME_N MJ/kg DM	
Rapeseed meal	broilers	117	6.94	72	8.27	19
	layers	117	8.08	72	9.91	23
Rapeseed cake	broilers	102	11.42	61	13.05	14

Seed hulling before processing also improves amino acid digestibility in by-products of rapeseed oil production included in diets for fattening pigs and broilers (Kracht et al., 2004; Zuprizal et al., 1992). The results for broilers are shown in Table 7. The digestibility of RSM from hulled rapeseed approximates that of soybean meal.

Other mechanical treatments of rapeseed (hydrothermal conditioning, micronization, infrared heating) and RSM (expansion, extrusion) did not improve the energy value of feed for broilers (rapeseed, RSM) and laying hens (rapeseed), whereas hot air treatment (Jet-sploding) at 125°C gave positive results (Dänicke et al., 1998 b). Chemical and hydrothermal treatment of rapeseed (Jeroch et al., 2009) reduced glucosinolate concentrations more effectively than toasting in oil mills. The above technique lowered the glucosinolate content of rapeseed from 13.8 µmol/g (91% DM) to 1.5 µmol/g. It should be noted that very high inclusion rates of expanded rapeseed in layer diets can have negative effects on thyroid function (Jeroch et al., 2008 a), which can probably be attributed to glucosinolate degradation.

Table 7. The effect of rapeseed hulling on the digestibility of amino acids in broiler diets (Zuprizal et al., 1992)

Amino acid	Rapeseed meal		Soybean meal
	unhulled	hulled	
Lysine	76	82	84
Methionine	84	90	89
Cysteine	76	80	80
Threonine	78	82	84

Sinapine is responsible for the fishy taint of eggs from brown layers with low endogenous trimethylamine oxidase activity. The undesirable effects of sinapine have been successfully mitigated by a combination of chemical (10% sodium bicarbonate solution) and hydrothermal treatment (expansion) (Jeroch et al., 1999). Originally, rations for brown-egg layers classified as tainters had included up to 7.5% rapeseed products (Dänicke et al., 1998 b). Continued breeding progress led to the elimination of the tainting gene and, consequently, the need for feed treatment.

The potential of enzyme supplementation

Rapeseed is characterized by a nearly complete absence of phytase, which is the primary cause of low phytic phosphorus utilization in oil extraction by-products. In a study by Oloffs et al. (2000), P utilization was estimated at 28% in RSM and 22% in RSC fed to laying hens as compared with 46–49% in phytase-rich wheat. Phytase supplementation significantly improved P utilization in broilers and laying hens, as shown in Table 8 (Dänicke et al., 1998 a). The above results indicate that poultry diets containing rapeseed by-products should be supplemented with phytase.

Table 8. The effect of microbial phytase supplementation of rapeseed by-products on P utilization in meat-type and egg-type chickens (Dänicke et al., 1998 a)

Poultry category	Rapeseed by-products	Phytase	P utilization (%)
Broilers	meal	without	43
		with	62
	cake	without	35
		with	52
Layers	meal	without	6
		with	32
	cake	without	22
		with	40

Due to high content of cell wall carbohydrates (non-starch polysaccharides, NSP) and indigestible oligosaccharides, poultry diets containing rapeseed products were supplemented with NSP degrading enzymes. The findings of different authors (Kocher et al., 2000, 2001; Słomiński et al., 2003, 2007; Fang et al., 2009; Zduńczyk et al., 2011) vary, and they do not support the formulation of recommendations for supplementing rapeseed-containing diets with enzymes. The absence of enzymatic effects reported by some researchers could be attributed to the fact that the tested preparations were developed for NSP contained in cereal grains rather than in rapeseed products. Inconclusive results could also be explained by short testing periods (Table 9).

Table 9. The effect of carbohydrases in turkey diets containing 30% rapeseed meal from yellow seeds[1]

Parameter	Enzyme addition[2]		P value
	without	with	
Digesta viscosity (mPa·s)	1.73	1.66	0.079
Body weight at 8 weeks (kg)	3.68 b	3.77 a	0.013
FCR (kg feed/kg weight gain)	2.19	2.08	0.091

[1]Zduńczyk et al. (2013).
[2]Enzyme mix of pectinase, cellulase, xylanase, glucanase, mannanase and galactanase.
a, b – values in rows with different letters differ significantly (P≤0.05).

The effect of rapeseed oil on poultry products

Protein-rich by-products of oil extraction are among the main components of poultry diets. Rapeseed oil from modern rapeseed genotypes (F_1, F_2 and F_3 generations, 0-, 00- and 000-rapeseed) is a valuable diet ingredient (Jahreis, 2003; Jahreis and Schöne, 2006; Jeroch et al., 2013 a) that is also commonly used in animal feeds, including poultry diets. Due to its high calorific value (35.55 AME_N MJ/kg DM; WPSA, 1989), rapeseed oil can increase the energy content of poultry diets. Rapeseed oil has desirable fatty acid composition (Table 10) and its inclusion in broiler and layer diets can modify the fatty acid profile of poultry products (eggs, meat).

Table 10. Comparison of the fatty acid content (g/100 g total fatty acids) of rapeseed oil and other vegetable fats and oils (Barth, 2007; Schöne et al., 1998)

Oil/fat type	Saturated fatty acids	Monosaturated fatty acids	Linoleic acid (*n-6*)	Linolenic acid (*n-3*)
Rape	5	54	23	10
Coconut	90	7	2	0
Maize	17	30	50	2
Flax	9	18	16	57
Olive	14	72	11	1
Palm	47	43	8	trace
Soybean	14	25	52	7
Sunflower	12	33	52	trace

Table 11. Effect of rapeseed oil on the fatty acid profile (% of total fatty acids) of hen egg lipids

Rapeseed oil, % in diet	Saturated fatty acids (C14:0, C16:0, C18:0)	Oleic acid (C18:1)	*n-6* fatty acids		*n-3* fatty acids		*n-6*:*n-3* ratio	References
			total	C18:2	total	C18:3		
0	28.0	44.5	9.6	9.3	1.2	0.8	8:1	Brettschneider et al. (2006)
6.5[1]	23.9	44.6	13.0	12.7	2.4	1.8	5.4:1	
0	33.1	46.2	13.0	11.3	1.3	0.3	10:1	Hämmal et al. (2000)
4	30.4	42.3	18.6	17.2	4.0	2.2	4.6:1	
0	29.6	44.3	9.8	9.0	0.7	0.4	14:1	Jeroch et al. (2001 a)
4	24.2	47.3	12.7	11.8	2.7	1.8	4.7:1	
8	21.2	48.1	14.0	13.1	3.4	2.5	4.1:1	
0	29.6	44.3	9.8	9.0	0.7	0.4	14:1	Jeroch et al. (2002)
6 + 2% linseed	20.6	44.6	15.4	14.6	5.7	4.8	2.7 :1	
0	46.5	33.7	12.4	11.5	2.1	0.6	5.9:1	Ezhil Valavan et al. (2006)
3	38.1	35.4	14.8	14.8	4.5	1.1	3.3:1	

[1]15% rapeseed in the feed mixture.

Numerous experiments with laying hens concerning the effects of dietary rapeseed products on the fatty acid profile of egg yolk lipids have been conducted in recent years. Apart from rapeseed oil, rapeseeds and RSC have also been evaluated. Selected results of those studies are presented in Table 11.

The inclusion of rapeseed oil in low-fat diets beneficially changed the fatty acid profile of egg yolk lipids. In comparison with eggs laid by hens fed diets without rapeseed oil, eggs produced by hens fed rapeseed oil-supplemented diets had considerably lower concentrations of saturated fatty acids and higher levels of *n-6* and *n-3* polyunsaturated fatty acids. The effect of rapeseed oil on the oleic acid content of eggs varied. Since the proportion of *n-3* PUFAs increased significantly relative to *n-6* PUFAs, the *n-6/n-3* PUFA ratio in the egg yolk narrowed down.

Additional linseed oil in layer diets (Jeroch et al., 2002) and the inclusion of high-fat linseed feedstuffs in the ration (Eder et al., 1998) can modify the fatty acid profile of eggs with regard to α-linolenic acid (*n-3* fatty acid) content. Dietary supplementation with rapeseed oil did ensure egg enrichment with *n-3* fatty acids comparable with that provided by linseed oil, fish oil or seaweed extract (Leskanich and Noble, 1997), but it improved the nutritional value of eggs (DGE, 2000). An egg (50 g total weight, at least 10% lipids) whose fatty acid profile has been modified by the addition of rapeseed oil can provide 10% of the recommended daily intake of *n-3* PUFAs (DGE, 2000) if it contains > 2% *n-3* PUFAs (i.e. 0.1 g) in total fat (Table 11).

A higher percentage of PUFAs in yolk lipids after layer diet supplementation with rapeseed oil did not affect the sensory properties and processing characteristics of eggs (Brettschneider et al., 1997, Jeroch et al., 2008 b). Modifications of the fatty acid profile of the lipid fraction of poultry meat and adipose tissue (e.g. abdominal fat) in the carcass through feeding have been described in detail by Leskanich and Noble (1997) in their review article. Similarly to egg lipids, also body lipids are affected by the fatty acid profile of dietary fats.

Conclusions

Rapeseed oil extraction by-products, i.e. rapeseed meal and rapeseed cake, are good examples illustrating the importance and benefits of improving the nutritional value of feed materials for poultry diets. Forty years ago, diets containing even small amounts of rapeseed products from traditional rapeseed varieties compromised thyroid function and reduced productivity. Today, the inclusion rates of rapeseed products from double-zero and triple-zero varieties can be safely increased to 25%. The differences in the nutritional value of rapeseed meal and soybean meal have been significantly minimized or almost eliminated (Table 12). For this reason, soybean meal, the predominant ingredient in poultry rations, can be safely replaced, in part, with rapeseed products.

The progress in plant breeding and feed technology also contributed to an improvement in the nutritional value of other feedstuffs. Recent advances in science should support the optimal formulation of animal feeds (Jeroch et al., 2013 a). The following possibilities have been suggested:

– reducing the content of anti-nutritional compounds through the use of conventional and molecular genetic methods in plant breeding and the use of new feed additives,

– developing a new generation of carbohydrases for effective degradation of the NSP-fraction in protein feedstuffs,

– modifying the properties of phytase for improved efficacy and consistency,

– utilizing the NSP-fraction as a source of energy in raw materials through enzymatic disintegration inside and outside the intestinal tract to release additional nutrients for poultry.

Table 12. A comparison of the nutritional value of rapeseed and soybean meal

Parameter	Rapeseed meal		Soybean meal
	yellow variety	hulled double-zero variety	
Crude protein (g/kg DM)	498	450	510
Crude fibre (g/kg DM)	–[*]	65	67
Lignin (g/kg DM)	37	44	
Lys digestibility (%)	88 (chicks)	82 (chicks)	84 (chicks)
AME_N (MJ/kg DM)	9.18 (chicks)	9.91 (hens)	11.55 (cocks)

[*]Not analysed.

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