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# The effects of minor oilseeds cakes on rumen metabolism and productive performances of ruminants

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ABSTRACT

The article focuses on the chemical composition, nutritional value and the effects of four minor oilseeds' cakes when used in ruminants' nutrition. Although less abundant than the well-known major oilseeds, mechanical extraction of oils from the minor oilseeds retrieves important quantities of cakes which, beside a high content of crude protein have variable, yet important proportions of residual fat, upon the efficiency of the extraction processes and retains some nutritional properties of the seeds, including the content in bioactive substances.

The browse of the literature on minor oilseeds cakes retrieved scattered and contradictory data, implying a need for systematic comparison, among them and against a reference feed. Although specific literature is scarce, a number of articles reported the chemical composition of the four cakes, allowing their hierarchization and their comparison with the rapeseed cake, considered as reference feed.

On the other hand, the review identified numerous knowledge gaps, concerning the effects of the four cakes on rumen metabolism and their effects on animals' productive performances. However, the literature review confirmed that the four cakes can be good substitutes of rapeseed cakes or similar feeds in ruminants' nutrition, as long as the potential effects of bioactive substances taken into consideration.

**Keywords**: linseed, safflower, sesame, crambe, cakes, ruminants.

INTRODUCTION

In terms of world production, soybeans are on the first position, with 337.9 mil. tonnes, the other major oil crops (rapeseed, cottonseed, groundnuts, sunflower seeds, palm kernels, copra) accounting all together for 234.6 mil tonnes (F.A.O, 2020). The by-products of oil crops are important protein sources for livestock industry, especially in areas where the needs exceed the production of protein feedstuffs. An example is the E.U., which is a major importer of protein meal, especially soybean meal (Colsell et al., 2018), which raise the need for alternative sources of protein for animal feeding, preferably locally produced.

Also, the increase of the human population in a world with limited resources lead to the need of efficiently valorise of all feed resources, especially those not implying a competition with the food industry. Some feedstuffs, e.g., the by-products or wastes generated from the processing of plants by the food or non-food industries may even be more cost-effective than the commonly used feeds. It is also, the case of the cakes resulted from the extraction of special oils from the so-called minor oilseeds.

The minor oilseeds industry is constantly evolving, leading to the production of a wide range of oil-based products for food, paint or biodiesel industries (Alves et al., 2018). The oil extraction process retrieves large quantities of by-products, with variable content of residual oil (upon extraction efficiency), which can be good sources of proteins but also energy for animal's nutrition. Such by-products can be successfully included in ruminant's diet with lower costs than soya imports (Yehudi et al., 2019; de Goes et al., 2018; Liu et al., 1994). Beside the protein and energy supply, some oilseeds by-products are rich in some bioactive compounds, such as fatty acids or polyphenol compounds that may have beneficial effects when fed to animals (Kenari et al., 2014; Böhme et al., 2005; Mukhopadhyay & Ray, 2001).

However, an important barrier against the valorisation of these cakes in animal's nutrition is the insufficient knowledge of their properties that are relevant from the nutritional point of view, especially when they are used in ruminants' diets. The literature referring to this subject is scarce and scattered, therefore, the objective of this work is to summarize the results of studies that used some less known minor oilseed cakes (linseed, safflower, sesame and crambe) in ruminants nutrition and to retrieve an overview on their potential to be valorised in ruminants' feeding.

## MATERIALS AND METHODS

This review included the articles published in the last three decades, which refers to the use of minor oilseed cakes in ruminant's nutrition. Two exceptions were made in case of safflower cakes in order to ensure data consistency. The literature research was done by retaining the articles that refer either to the chemical composition of the cakes, to their effects on ruminal metabolism or to their effects on ruminants' production performances when the cakes are included in their diets. PubMed and ScienceDirect were the main interrogated databases, completed by search on Google Academic and other sources.

Only the by-products resulted from the mechanical extraction of oils (without solvents) were retained for the study. Also, of the oilseed cakes, only the first four ranked in terms of knowledge gaps, data availability and data consistency were retained for the review: linseed, safflower, sesame and crambe cakes. Linseed and flaxseed cakes were considered the same by-product, from nutritional point of view, disregarding the name used by various authors.

Data collected from the literature browsing were presented as averages and standard deviations; these data were compared among the studied cakes and against a reference feed – the rapeseed cake. In order to ensure representativity, Feedipedia database (Feedipedia, 2020) was used as a reference, therefore the rapeseed data were extracted from this database.

## RESULTS AND DISCUSSION

Although various authors referred to soybean by-products when comparing the nutritive values and effects on animal performances of the minor oilseeds' cakes, we have chosen the rapeseeds cake as classical feed to compare with. Rapeseed is the second most abundant oil crop after the soybeans (FAO, 2020) and the chemical composition of the rapeseed cakes (especially protein and fat content) and its specifics are closer to the four studied oilseed cakes.

### *1. Primary chemical composition*

Values presented in Feedipedia, 2020, were used as reference for rapeseed cake (mechanically extracted) chemical composition: 33.7 % crude protein (CP); 12.8% ether extract (EE); 12.7 % crude fiber (CF); 19.5 % acid detergent fiber (ADF); 29.3 % neutral detergent fiber (NDF); 9 % acid detergent lignin (ADL) dry matter (DM) basis.

Ensuring sufficient and affordable supply of protein-rich feeds for the livestock industry is a challenge in many regions. For example, ensuring the European protein security is a high priority on the European Commission agenda (ATF Vision Paper, 2019). In this context, all four studied cakes have CP contents that makes them interesting alternatives to rapeseed protein-rich by-products: 33.1% the linseeds cake, 32.93% the safflower seeds cake, 31,42% the sesame seeds cake, 27.37% the crambe seeds cake (Tables 1, 2, 3, 4).

***Linseed cake*** *(Linum usitatissimum L.).* It was reported that the annual production of linseed is higher than 2.7 million tonnes, whereas the production of linseed oil and linseed meals is in range of 0.6 to 1 million tonnes (FAO, 2020).

Linseed it is considered to be one of the non-edible oilseeds, used in several industries such as paint and plastic, but can be used, in a limited extent, in animal nutrition, especially for ruminants (Oomah & Mazza, 1993). These authors also highlighted the high level of constituents such as linoleic acid and some active compounds such as phytochemicals, that can be important from the point of view of human and animal health. Its average CP content calculated from the reported values (Table 1) is very close to the CP content of rapeseed cakes. On the other hand, the residual oil content is slightly higher, which add to its energy value. However, it has to be noted that, similar to rapeseed cake, there is a large variability of the residual oil content (from 7 to 29.37%), which makes mandatory the chemical analyses of the batches of linseed cakes, especially when the producer is unknown.

**Table 1.** Linseed cake chemical composition, DM basis

| Item | Linseed cake | SD[1] | N[2] | Minimum | Maximum |
|---|---|---|---|---|---|
| Dry Matter % | 92.62 | 2.68 | 9 | 88.64 | 96.5 |
| Organic Matter % | 92.57 | 1.10 | 3 | 91.3 | 93.3 |
| Crude Protein % | 33.10 | 4.57 | 11 | 26.77 | 39.38 |
| Ether Extract % | 14.35 | 6.98 | 10 | 7 | 29.37 |
| Crude Fiber % | 11.31 | 5.78 | 7 | 5.5 | 22.7 |
| ADF[3] % | 14.83 | 2.08 | 6 | 12.8 | 18.52 |
| NDF[4] % | 27.76 | 8.13 | 7 | 19.4 | 39.9 |
| ADL[5] % | 5.14 | 0.69 | 4 | 4.27 | 5.9 |

Note:[1]Standard deviation, [2]Number of references, [3]Acid Detergent Fiber, [4]Neutral detergent fiber, [5]Acid Detergent Lignin, References: Alemu et al., 2010; Baltrukonienė et al., 2015; Chen et al., 2016; Teshome et al., 2016; Gutiérrez et al., 2010; Halle & Schöne, 2013; Jóźwik et al., 2016; Khorasani et al., 1994; Mukhopadhyay & Ray, 2001; Rinne et al., 1997; Tafa et al., 2010a; Uchockis et al., 2014

The chemical composition of the cake and of the whole seeds indicates that the average oil extraction efficiency (59%) is lower than that of rapeseed (71%). Although it is known that the mechanical extraction of oils from the linseed has a low efficiency (Willems, 2008), this extraction method is still used in many factories, as indicated by the high residual oil content of the cakes comparing to the oil content of seeds.

Linseed cake has less crude fiber than rapeseed cake; moreover, the digestible part of the fibre (NDF) is high, which suggests that inclusion of linseed cake in ruminants' diets contributes both to energy supply and to the stability of the rumen environment.

***Safflower cake*** (*Carthamus tinctorius L.).* Although the world production is not negligeable (0.3-0.5 mil. tonnes, according to FAO, 2020), the literature reporting the chemical composition of safflower cake is scarce.

The average chemical composition, based on the few authors who studied the safflower cake is presented in Table 2.

**Table 2.** Safflower cake chemical composition, DM basis

| Item | Safflower cake | SD[1] | N[2] | Minimum | Maximum |
|---|---|---|---|---|---|
| Dry Matter % | 93.10 | 2.71 | 3 | 89.60 | 95.80 |
| Crude Protein % | 32.93 | 10.41 | 4 | 25.00 | 45.00 |
| Ether Extract % | 10.14 | 7.20 | 4 | 5.02 | 21.54 |
| Crude Fiber % | 16.88 | 4.98 | 3 | 5.00 | 14.00 |

Note:[1]Standard deviation, [2]Number of references, Abrham et al., 2018; Chaudhary et al., 1989; Farran et al., 2010; Thomas et al., 1984

These data revealed an average protein content (32.93%) similar to that of the rapeseed cake. It is higher than the average presented by Feedipedia, 2020 (24.8%), but the references used in our studies are also more recent. As the number of references is rather low, it cannot be concluded that this trend is due to plant amelioration or rather to the evolution of the processing (oil extraction) technologies. On the other hand, the safflower cakes can be clustered upon the degrees of the hulls' removal, a processing decision that ensures a higher CP content, closer to the CP of soybean meal.

The average content of the residual oil is slightly lower than the reference value of rapeseeds cake (10.41 versus 12.8%) and it is the lowest of the four studied cakes. This is a result of the fact that safflower seeds had the lowest fat content of the four plants but also of the fact that the oil extraction efficiency was the poorest. It has to be noted that mechanical extraction can be also very efficient: Farran, et al, (2010), reported a content of residual oil of 3.76% only, with the mention that this was obtained by extrusion of dehulled seeds.

Although the safflower has the highest crude fiber content of the four oilseeds (31%), the cakes have a moderate content of crude fiber (16.8%), suggesting the existence of a dehulling stage during the oil extraction process (not always reported). This is important, as dehulling and its extent have a significant impact on the nutritive value of the cakes. Indeed, the fat removal alone cannot explain the high content of crude protein of the cakes.

***Sesame cake*** *(Sesamum indicum L.).* Sesame seeds is considered to be one of the oldest oilseed plants, cultivated for various purposes such as food or medicine. It is considered to be "queen of oilseeds" due to its rich content in active compounds that can exert antioxidant activities (the lignin and tocopherols) and anticancer activities (the sesamol). The world production of sesame seeds is important - e.g., 3.84 million metric tons in 2010 (Islam et al., 2016). Sesame cake is an important by-product obtained after oil extraction of the sesame seeds, due to its specific properties.

**Table 3.** Sesame cake chemical composition

| Item | Sesame cake | SD[1] | N[2] | Minimum | Maximum |
|---|---|---|---|---|---|
| Dry Matter % | 91.30 | 5.51 | 5 | 83.20 | 95.70 |
| Organic Matter % | 89.80 | - | 1 | - | - |
| Crude Protein % | 31.42 | 7.57 | 9 | 22.65 | 43.94 |
| Ether Extract % | 20.08 | 8.59 | 8 | 9.30 | 29.94 |
| Crude Fiber % | 8.69 | 1.77 | 8 | 6.22 | 26.52 |
| ADF % | 33 | - | 1 | - | - |
| NDF % | 45 | - | 1 | - | - |

Note: [1]Standard deviation, [2]Number of references, References: Babiker, el al, 2009.; Kenari et al., 2014; Hejazi & Omar, 2009; Hossain et al., 1997; Mahmoud & Ghoneem, 2014; Nadeem et al., 2014; Omar, 2002; Ramachandran et al., 2007; Shirzadegan & Jafari, 2014; Sunil et al., 2015

The protein content (Table 3) is also close to the protein content of rapeseed cake, similar to the safflower and linseed cakes.

Of the four reviewed cakes, it has the highest content of residual oil (20%), which significantly contributes to the energy value. The low average efficiency of the oil extraction (59.6%) is not the only explanation: the seeds have a very high content of fat: 49.7%, according to Feedipedia, 2020. The high content of residual oil makes the sesame cake important from the point of view of diet optimisation (being both protein and energy supplier) but also as a cheap source of dietary sesame oil. Also, it has to be noted the large variability of the cakes from the fat content perspective (from 9 to almost 30%), which underlines the necessity to perform chemical analyses for each batch of purchased safflower cake.

The crude fibre content is the lowest among the four cakes (8.69 % only) with a rather low variability comparing to other cakes, suggesting that dehulling is a usual step in sesame seeds processing.

***Crambe cake*** *(Crambe abyssinica).* Although cultivation of crambe for seeds is not new, the production is rather limited and unsystematic (Hebard, 2016). However, in the recent years this plant drew attention of the processors as a source of oils that have special properties which can be valorised by various industries. Thus, it is considered to be one of the major sources of erucic acid, counting up to 60% of its content, which can be used in various fields such as plastic, ink, food, pharma or biodiesel industries. It was reported that its high content of glucosinolates makes it toxic for some animals such as monogastric, but the crambe by-products were included in some ruminant's diets (cow, sheep) (Samarappuli et al., 2020).

**Table 4.** Crambe cake chemical composition

| Item | Crambe cake | SD[1] | N[2] | Minimum | Maximum |
|---|---|---|---|---|---|
| Dry Matter % | 91.86 | 3.51 | 8 | 86.37 | 98.10 |
| Organic Matter% | 93.28 | 1.43 | 5 | 91.80 | 95.20 |
| Crude Protein% | 27.37 | 3.61 | 8 | 20.70 | 32.61 |
| Ether Extract% | 18.80 | 5.15 | 8 | 13.90 | 29.60 |
| Crude Fiber% | 23.51 | 10.04 | 3 | 12.82 | 34.40 |
| ADF% | 25.37 | 9.51 | 6 | 19.44 | 44.50 |
| NDF% | 39.99 | 17.24 | 6 | 26.10 | 68.00 |
| ADL% | 5.90 | 4.02 | 2 | 3.06 | 8.74 |

Note: [1]Standard deviation, [2]Number of references, References: Böhme et al., 2005; Canova et al., 2015; Carrera et al., 2012; de Souza et al., 2015; Goes et al., 2019; Ítavo et al., 2015; Liu et al., 1994; Syperreck et al., 2016

From the point of view of protein and energy supply, crambe cake has, in average, the lowest protein: fat ratio of the four cakes (1.46); considering also the relatively high protein content (27.4%), this specific makes it interesting from the point of view of diet optimization. The collected data showed a relatively low variation of the protein content upon source.

The protein level is significantly lower than rapeseed and the other three reviewed cakes; however, crambe cake is considered a feedstuff that lowers the feeding costs when it's used instead of some conventional and more expensive protein sources like soybean meal (de Goes et al., 2018) while bringing also dietary energy supply.

Indeed, data in table 4 reveals a high content of the residual oil (18.8%) which can ensure, beside protein, an important supply of energy. As in the case of sesame cake, the high content of both protein and energy supply contribute to easier diet optimization in some feeding situations. On the other hand, caution should be taken to the overall fat content of the diets – a too high level it is known to impair rumen processes such as cellulolysis (Wanapat et al, 2011), and therefore may negatively impact productive performances of the animals.

The high content of residual oil is a result of both high fat content of the whole seeds (55%, according to Feedipedia, 2020) and relatively high efficiency of the extraction (close to that of rapeseed cakes).

Of the four reviewed cakes, the crude fibre content is the highest (23.5%). Crude fibre it's a very approximative parameter, but also the van Soest fractions of the fibres are high. Indeed, it was reported important amounts of some lignified fibres can remain in crambe cake, limiting the administration in the diet of some ruminant categories, such as lambs (Canova et al., 2015).

Beside the fact that protein value of the four studied cakes is similar to that of the rapeseed cake (Fig 1.), the average values of the crude fat and of the crude fiber content are particularities that can orient their use within certain feeding strategies, e.g., higher fat content of the sesame and crambe cakes, much higher fiber content of the crambe cake.

*2. Fine chemical composition*

***Amino acids profile.*** In general, due to the microbial protein synthesis in rumen, there are fewer situations where ruminants need supply of essential amino acids, comparing to monogastric animals: very high production levels, impairment of rumen metabolism, etc. According to Schwab & Broderick, 2017, of the essential amino acids, three are more susceptible to limit the production levels in ruminants: lysine, methionine and histidine.

In this context, it worth mentioning that according to Feedipedia, 2020, the four seeds have much lower contents of lysine (4.8% crambe seeds, 4.1% linseed, 3.2% safflower seeds and 2.5% sesame seeds) comparing to the rapeseed (6.3%). The contents of methionine are in the same range with rapeseed (1.5 - 2.7% versus 2.0%), while the contents of histidine are slightly lower (2.3-2.8% versus 2.9%). However, these data are relevant in particular situations only: high yielding animals, use of precision feeding, potential use of rumen-protected amino acids, etc.

Thus, the particularities of ruminants' digestive system make more complex the issue of individual amino acids supply, an important factor being the susceptibility of each amino acid to the protein degradation in rumen. The free amino acids are quickly degraded into ammonia; this led to the development of commercial products containing amino acids that are protected against rumen proteolysis, using various methods (coating, etc.).

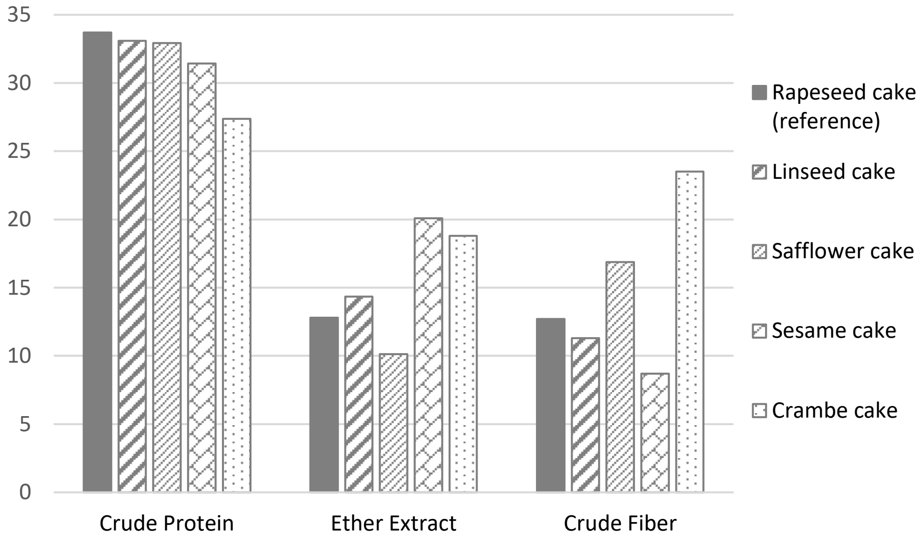


**Figure 1.** Overview of the main chemical composition of the studied cakes, compared with the reference feed

The amino acids that constitute the dietary proteins are degraded upon the nature of the source. For example, in case of the whole seeds the amino acids are less exposed to the rumen microorganisms and their enzymes, while in case of the untreated protein meals the exposure is higher. It is known that treatments with high temperatures or tannins induce a reduction of rumen degradability of the protein meals. An overall image is given by the protein degradability of each feedstuff (including cakes), a parameter that is usually shown in the feeding tables. This parameter may be used by assuming that, for a given feed, individual amino acids have similar degradability, which is not always true. On the other hand, for some less-known feeds, even this average value parameter is unknown or inconsistent – it is also the case of the cakes obtained from the minor oilseeds. In this context, the amino acids profile of the four cakes is relevant only for the part that escapes the rumen degradation (the so-called protein by-pass). Even so, the data concerning the amino acids composition of the four cakes is too scarce to allow quantitative comparisons. However, as the cakes are obtained through the mechanical removal of various quantities of oils, the profile of amino acids depends on the corresponding profile of the seeds, with a concentration effect that varies upon the efficiency of oil extraction.

***Fatty acids profile.*** In the absence of specific data, the fatty acids composition of cakes can be approximated from the composition of seeds or of the extracted oils, as there are no consistent data describing the influence of mechanical processing of seed on the fatty acids profile of the residual oil. The fatty acids profile is relevant when the cakes are included in diets in order to influence the fatty acids profile of the meat and milk. Although the cakes do not ensure the protection of the residual oils against rumen biohydrogenation, sufficient dietary supply may induce improvements of the quality of the animals' products.

In this context, it has to be highlighted that according to Feedipedia 2020, in case of linolenic acid, only the linseed has a higher value than rapeseed (55.7% versus 10.1%), the other three seeds have much lower values (5.6% crambe seed, 0.5% sesame seed, 0.4% safflower seed).

In contrast, in case of linoleic acid, sesame seed and safflower seed have much higher content comparing with rapeseed (81.5% safflower seed and 44.5 sesame seed versus 20.6% rapeseed), while linseed and crambe cake, as reported by Lalas et al., 2012, have lower values (15.8% linseed and 13.19% crambe cake).

All the four seeds present lower contents of oleic acid: 39.3% sesame seed, 18.4% linseed, 15.07% crambe seed, 11% safflower seed, versus 59.9% rapeseed).

The content of stearic acid is higher in cases of linseed and sesame seed (3.6% and 6.7%), comparing with rapeseed (1.7%), but lower for crambe seed (0.8%) (Chaudhary et al., 1989), while in case of safflower seed the content of stearic acid is in the same range as rapeseed content (1.62 %).

***Vitamins & minerals***. In ruminants, comparing to monogastric animals, it is easier to ensure the vitamins and minerals supplies according to the nutritional requirements, as a large part is brought through the basal diet (silages, hays, etc.) thus lowering the need to supplement them through the compound feeds. The supplementation may be further lowered when certain compound feed' ingredients are rich in minerals and vitamins, allowing formulation of cheaper feeding formulas. However, in order to benefit of the advantages of such ingredients, it is necessary to apply precision animal nutrition.

Considering these facts, it is noteworthy to mention that, according to Feedipedia 2020, the content of calcium and phosphorus in the linseed, safflower seed (as reported by Lee et al., 2009) and sesame seed are lower than their content in rapeseed. On the other hand, the contents of natrium and magnesium (0.5 g/kg DM and 4 g/kg DM) are much higher in case of linseed comparing with rapeseed (0.1 g/kg DM and 2.6 g/kg DM).

Concerning the vitamins, it is known that ruminants don't usually need supplementation with B and K vitamins; on the other hand, supplementation with vitamins D, A and E is beneficial. Plants are not known as sources of vitamin D; also, the specific literature is scarce. Considering the fact that, normally, it can be synthesized in the animal organism from sterols (upon direct action of sunlight) the animals with outdoor access would have lower needs for dietary supplementation.

Similarly, vitamin A is found only in animals' organism. However, various plants contain carotenes (pigments) that are the principal precursors of vitamin A in animal body. The content of total carotenoids of safflower oil ranged between 1.13 mg/kg and 1.34 mg/kg, with predominant forms as β-cryptoxanthin (0.31–0.37 mg/kg) and β-carotene (0.3–0.35 mg/kg) (ben Moumen et al., 2015). In case of sesame oil, Borchani et al., 2010 reported that raw sesame oil contains low levels of carotene (2.62 ± 0.10 μg/g). It is interesting to mention the attempts to increase the content of plants in precursors of vitamin A: de Aguiar et al., 2017 reported that crambe oil presented appreciable amounts of carotenoids 191.01 mg/kg after a high-dose treatment with phytosterols.

Concerning the E vitamins, El-Beltagi & Mohamed, 2010 reported that rapeseed contain tocopherols in amount of 73.02–138.3 mg/100 g oil (Schwartz et al., 2008) in a study comparing the composition of various oils found lower contents of tocopherols in various sources of rapeseed, 61-71 mg /100 g oil.

However, these values were higher than the content they found in linseed samples: 54 mg/100 g oil. Various reports showed that crambe oil contains high amounts of tocopherols (102.35–202.18 mg/100 g of oil), especially γ-tocopherol (74.5–94.4%) followed by α-tocopherol (3.7–23.4%) and δ-tocopherol (1.5–3.4%) (Santos et al., 2015). Matthaus et al., 2015 analysed various sources of safflower seed oil and found that the total content of tocopherols was in range of 47.29 – 73.09 mg/100g oil. The most abundant isomers form found in safflower oil was α-tocopherol (46.05-70.93 mg/100g safflower oil), followed by β-tocopherol 0.85-2.16 mg/100g safflower oil and γ-tocopherol 0.23-0.42 mg/100g safflower oil. According to Cooney et al., 2001 sesame seeds contain lower amounts tocopherols, mainly γ-tocopherol, (280.9 μg/g), followed by α-tocopherol (7.4 μg/g) and δ-tocopherol (202 μg/g).

There are also atypical values reported in the literature: Bernacchia et al., 2014 found much higher tocopherol contents in linseed, the most abundant being γ-tocopherol (522 mg/100g), followed by δ-tocopherol 10 mg/100g linseed and α-tocopherol 7 mg/100g linseed. But these variations can be valorised only in situations when precision nutrition approach is implemented.

The content of the studied feedstuffs in vitamin E is important not only from the dietary supply point of view (higher content meaning less need for supplementation), but also for its beneficial effects for the animal organism. They are known for their antioxidant activity, the highest being recorder for α-tocopherol isomer.

***Bioactive compounds.*** Many of the plants' compounds have properties that qualifies them to be considered as bioactive. In case of oilseeds and in the context of nowadays trend of focusing on consumer's health and preferences, a major source of bioactive compounds is their oil content. As already mentioned, some of the fatty acids, beside their energy supply, can exert important activities, with beneficial or detrimental effects from the point of view of animal's product quality and human nutrition, e.g., unsaturated versus saturated fatty acids. On the other hand, the non-oil constituents of the oilseeds may also contain substances having various activities – antioxidant, anti-inflammatory, etc.

The content of the studied cakes in fatty acids are of a major interest, due to the potential to partly by-pass the rumen environment and influence the lipids' profile of the animal products. Also, the content of antioxidants is important, as the unsaturated fats are more susceptible to oxidation.

Linseed is considered an interesting feedstuff from this point of view, as it is one of the richest sources of omega 3 fatty acid, a very important compound from the point of view of human nutrition. Also, linseed presented important amounts of phenolic compounds (especially ferulic acid, chlorogenic acid and gallic acid), flavonoids and lignans - all these compounds exerting antioxidant and anti-cancer activities. Moreover, linseed is a valuable source of carotenoids and tocopherols, that can protect cell proteins and fats against oxidative processes (Tavarini et al., 2019). It is noteworthy to mention that the mechanical oil extraction removes only part of the oil (from 34.6% to 14.5%, in average, Feedipedia, 2020) therefore the linseed cakes still contain important quantities of omega 3 fatty acids. On the other hand, removal of 20% of the seed weight led to a concentration of the other mentioned active compounds in the remaining biomass (the cake).

Safflower oil is one of the richest sources of essential fatty acids (which cannot be synthesized by the human body) and an important source of tocopherols and polyphenols, known for their antioxidant activity (Günç & Özbek, 2018).

Sesame cakes are rich in some phenolic compounds having antioxidant activity, such as sesaminol, pinoresinol, sesamin etc. Various studies reported that these compounds have the potential to diminish the polyunsaturated fatty acids (PUFA) oxidation process - a real concern in case of PUFA - rich animal products (Sunil et al., 2015; Kenari et al., 2014; Nadeem et al., 2014). On the other hand, presence of some antinutritional compounds (such as trypsin- and pepsin-inhibitors, tannins or hemagglutinins) was reported; however, their activity could be stopped through thermal treatments (Sunil et al., 2015; Kenari et al., 2014).

An important group of active substances that are present in the studied cakes has potential negative effects - on the ingestion, on the digestion of nutrients or even on animal health. Such substances are present both in the oily and non-oily parts of the seeds, therefore the partial removal of oil is not necessarily accompanied by the removal of the anti-nutritive compounds. Although ruminants are less susceptible than monogastric animals to the activities of the antinutritive substances, their potential negative effects shouldn't be underestimated. Like the reference feed, the studies cakes also contain a broad range of antinutritional substances, similarly to the corresponding whole seeds (Table 5).

**Table 5.** The main antinutritive substances susceptible to be found in the cakes

| Rapeseed* | Linseed | Safflower | Sesame | Crambe |
|---|---|---|---|---|
| erucic acid, glucosinolates, mucilage, phytates, sinapine, tannins | (cyanogenic) glycosides, antagonists of VitaminB6, mucilage, phytates | (phenolic) glucosides | oxalates, phytates tannins, saponins, | erucic acid glycosylates phytates |

* Includes all types of cultivars.
Sources: Hisano et al., 2022; Nazir et al., 2021; Sharma et al., 2021; Warner et al., 2019; Newkirk, 2015; Kajla et al., 2014; Bello et al., 2013; Khattab et al., 2012; Embaby et al., 2010; Bhinu et al., 2009; Matthaus, 1998.

The content of these substances largely varies upon the cultivar (e.g., the case of Canola; the case of high-erucic Crambe), upon the degree of oil extraction, the processing conditions that lead to the obtaining of cakes, etc.

In this context, the literature is not consistent enough to allow presentation of data as averages and a hierarchization of the studied cakes from this point of view. On the other hand, literature highlights the occurrence of certain antinutritive substances in proportions that are relevant from nutritional point of view, both in case of reference feed and of the studied cakes.

The content of erucic acid is so important that is known as a classifier criterion for rapeseed quality, leading to three categories of rapeseed: high erucic acid rapeseed (HEAR) with an erucic acid content of 45-60%, rapeseed with moderate content of erucic acid, 35-40%, but with high glucosinolates concentrations (more than 150 µmol/g seed) and low erucic acid rapeseed (LEAR) with a content of approximatively 0.03% erucic acid and lower concentration of glucosinolates (Warner et al., 2019). Also, rapeseed contains sinapine in proportions that range from 0.7 to 4%, mainly in the non-hull fraction (Bhinu et al., 2008), and phytic acid in a range between 3.6-5.1% (Embaby et al., 2010). It also contains tannins, in variable proportions, from 2.8-7.6 mg/g in whole seed, 1.1-2.7mg/g in dehulled seed and 0.2-1.2mg/g in hulls (Matthaus, 1998).

Linseed cakes is rich in cyanogenic glycosides, such as linustatin (213-352mg/100g seed), neolinustatin in amount of 91-203 mg/100g seed and linamarin counting approximatively 32 mg/100g seed; their proportion also varies largely, upon the cultivars (Shahidi and Wanasundara, 1997). Kajla et al., 2014 reported a proportion of phytic acid in the linseed meal (23-33g/kg) that is lower than the values specific to the rapeseed. Also, linseed can contain vitamin B6 inhibitors, in a range approximatively between 20-100 mg/kg seed (Newkirk, 2015) and mucilage, represented by water-soluble carbohydrates, counting approximatively 2-7% of its total weight (Przybylski, 2005). It has to be mentioned that heat treatment above 350°C can remove antinutritional factors without altering the major bioactive compounds (Khattab et al., 2012).

Safflower cake contains phenolic glycosides, including the 1-matairesinol-mono-β-D–glucose and 2-hydroxy-arctin, which is associated with its bitter taste (Kadam et al, 2021). The content ranges between 3800-5700μg/g (Nazir et al., 2021). It is known that diets that are rich in polyphenols may have both positive and negative effects (Beslo et al., 2022), therefore insights on the content and individual phenolic compounds are needed.

Sesame also presents several antinutritional factors in considerable concentrations such as phytic acid (5.18% in seeds), oxalic acid (2.2%), tannins (5.62 mg/100g seed) (Sharma et al., 2021), but it was reported that some heat treatment such as roasting, cooking and autoclaving can reduce these content (Bello et al., 2013).

Crambe seeds are known for the high content of some antinutritional components such as erucic acid or glycosylates: their content in meal is about 10.8g/kg and 41 μmol/g, respectively. The presence of glycosylates in crambe cake composition may decrease the nutritional value of feed and represent a risk for ruminant health; in this context there are a number of studies presenting various methods of glycosylates extraction in order to improve crambe cake nutritional quality (Böhme et al., 2005; Liu et al., 1994; Carlson & Tookey, 1983). Also, crambe can contain other antinutritive factors such as phytates, approximately 20.84 g/kg in seed meal (Hisano et al., 2022).

*3. Digestibility, rumen degradability and the effects on rumen metabolism*

***Apparent digestibility***. Data on apparent digestibility of the four cakes are incomplete and inconsistent. According to Feedipedia 2020 and INRA 2018 databases, linseed and safflower cakes have lower digestibility, while sesame and crambe have higher digestibility than rapeseed cakes. However, the value reported for safflower cake digestibility is low (47.8%), which may suggest particular processing conditions.

The apparent digestibility of the reference feed (rapeseed) shows that the removal of oil leads to a decrease of apparent digestibility, from 82.4 the whole seeds to 78% the cakes and 75.8% the meal (Feedipedia, 2020) suggesting that the non-fat compounds have lower digestibility than fat.

This is also valid, in a lower extent, for linseed (77, 76 and 75.5%, for seeds, cakes and meals, respectively) but not for crambe, whose digestibility tend to increase along with oil removal (80, 80 and 83%, for seeds, cakes and meals, respectively). In case of safflower and sesame, there are not enough data to assess a tendency.

The overall apparent digestibility of a diet is strongly correlated with the nature of the dietary ingredients; therefore, it can be influenced by inclusion of linseed, safflower, sesame or crambe cake, especially when their content of anti-nutritive compounds is high.

It was reported that inclusion of linseed in sheep's and goats' diets (0.3 kg DM/head) led to a significant increase in crude protein digestibility (Alemu et al., 2010; Tafa et al., 2010). Also, Alemu et al., 2010 observed that linseed cake can improve the digestibility of DM, organic matter (OM) and CP, these data revealing a potential capacity of linseed to improve nutrients use in ruminant's diet.

In contrast, various authors observed that supplementing ruminants' diets with safflower seeds did not influence apparent ruminal digestibility of OM, NDF, CP, and DM (Alizadeh et al., 2010; Atkinson et al., 2006; Dschaak et al., 2011).

In case of sesame, Omar, 2002 observed that the inclusion of cakes in lambs' diet (20%) was associated with a better digestibility of CP. On the other hand, other authors reported that inclusion of sesame meal did not influence digestibility of OM, DM, CP or EE (Obeidat et al., 2009, 2019).

In case of crambe cake, Canova et al., 2015 found that supplementation on lambs' diet with increasing proportions (22%, 44% and 64% replacement of the soybean meal protein) led to decreases of the apparent digestibility coefficients of DM, OM, EE, ADF, NDF, cellulose (CEL), but there were no differences for CP, hemicellulose (HEM) and NF. Similar effects were also observed after including crushed crambe in ewes' diet (5, 10 and 15% in the compound feed, DM basis): it led to decreases of the digestibility of DM, OM and CP (Goes et al., 2019).

There are also authors (Caton et al., 1994; Ítavo et al., 2016) who found no influence of crambe meal on the overall digestibility of steers and lambs' diets.

***Ruminal Degradability.*** Data on rumen degradability of the four cakes are even more incomplete and less consistent that digestibility data. According to Feedipedia, 2020 and INRA, 2018 databases, rumen degradability of the four plants is similar or lower than the rumen degradability of rapeseed, disregarding of the processing (whole seeds, cakes or meals). While rumen degradability of the whole rapeseeds is 77% (INRA, 2018), whole linseeds degradability is 75% (INRA, 2018), but the whole crambe seeds degradability is much lower, 42% (Feedipedia, 2020). The latter is partly supported by de Goes et al., 2019, who observed that crambe seeds have similar effective degradability of DM and CP comparing with soybean cakes, a protein source that less degradable than rapeseed. There are also contrasting results: according to Liu et al., 1994 the rumen degradability of crambe meal is higher than the rumen degradability of rapeseed meal. Such divergent results are probably caused by the diversity of the processing technology of the oilseeds (e.g., degree of the hulls removal).

Similar with the whole tract digestibility, the data from the two databases (Feedipedia, 2020 and INRA, 2018) suggest that the removal of oils leads to a decrease of the degradability (from 77% to 69% in case of rapeseed, from 75% to 57% in case of linseed), with the notable exception of crambe, where the rumen degradability increases (from 42% to 69%). Also, Liu et al., 1994 observed that potential in vitro rumen degradability of OM is higher for crambe meal than for crambe cake. This imply that the substances that decrease the crambe rumen degradability are constituents of the oil. The relation between the rumen degradability and the presence of some plant secondary metabolites (e.g., polyphenols) either in oils or in the non-oily parts of the seeds is well known.

However, there is not enough data to substantiate this in case of the four studies cakes. As mentioned, degradability data are inconsistent; the inconsistencies are even higher in case of the parameters describing the rumen degradability dynamics, e.g., hourly degradability rate. Rinne et al., 1997, observed that linseed proteins are more rapidly degraded in rumen than rapeseed proteins. In case of safflower, Alves et al., 2018, observed that inclusion of increasing levels of safflower seeds (0, 7.5 and 15%) in sheep's diet led to reductions of the degradation rate and of the soluble fraction. In an in vitro study (Khan, et al., 1998), it was observed that after 48 h of incubation, the CP degradability of sesame cake was 91.2%, lower than the CP degradability of soybean meal (99.1%). This implies that sesame cakes are even more slowly degradable than soybean meal, which is known to be less degradable than rapeseed. However, these high values suggests that in vitro conditions were not representative for rumen environment and therefore offer limited info on the effective rumen degradability. In another study comparing degradability of various unconventional sources of proteins, sesame seeds had a higher CP degradability at 48 h incubation than hemp seeds, poppy seeds or canola meal (Şehu et al., 2010). In case of crambe, the meal was reported to be more soluble and having a rate of degradation of the slowly degradable fraction which was higher than that of the rapeseed meal (Liu et al., 1994).

***The influence on the main rumen parameters.*** The minor seeds are known for their content in active substances (Tavarini et al., 2019, Kenari et al., 2014; Nadeem et al., 2014). The presence of some of these substances, at such relevant doses, presumably leads to noticeable effects at rumen level, which may be relevant from nutritional point of view. In this context, the results describing the effects of the minor oilseeds on rumen parameters may serve as a base for applying rumen manipulation strategies.

Linseed inclusion in ewes' diets (220g/head/day) led to a higher rumen ammonia and a decrease in butyrate content in ruminal liquid, with no influence on the total volatile fatty acid profile, molar proportion of acetate and propionate, ration between acetate and propionate and pH level (Correddu et al., 2015). Li et al., 2020 reported that proportion of propionate was decreased. Moreover, Martin et al., 2016 reported that linseed can led to a decrease of the total number of protozoa at ruminal level.

In case of safflower Atkinson et al., 2006, reported a linear decrease of the molar proportion of acetate after duodenal supplementation of lambs with increasing levels of high-linoleate safflower oil (0, 3, 6, 9%). Similar trend was reported by Mirzaei-Aghsaghali & Maheri-Sis, 2008, who found a significantly decrease of the acetate: propionate ratio and a linear increased of the molar proportion of propionate after supplementing ewes' diet with safflower oil (20 g/kg of DM intake).

On the other hand, it was observed a decreased in propionate proportion and an increased in acetate/propionate ratio in supplemented diets with sesame oil (2.5% and 5%) (Ghafari et al., 2015).

Upon inclusion of crushed crambe in ewes' diet (0, 5, 10 and 15% in the compound feed, DM basis), Goes et al., 2019 observed that it led to a higher pH level, an increase of propionate and isovalerate proportions and a decrease of butyrate and valerate proportions.

*4. The effects on ruminants' productive performances*

The first concern when using alternative, less known feedstuffs are **the upper limits of their inclusion in the diets**, without leading to significant negative effects. In the case of the studied cakes, beside their protein feeding value, their content in digestible essential amino acids and other parameters that may be used in diet optimisations, there are two other concerns: their content in antinutritional substances and their content in residual fat. While the literature is scarce in studies focusing on the effects of increasing dietary participation of the studied cakes on the productive parameters of ruminants, some indications can be derived from studies where cakes were used in high proportions without leading to significant decrease of the diet's nutritive supplies and animals' productive parameters.

Thus, linseed cakes were safely used in proportions varying from 6 to 19% of the total DM intake (DMI), upon ruminants' species and categories (Gilbery et al., 2010; Jóźwik et al., 2010; Dixon et al., 2003). The references are scarcer in case of safflower cakes; reports suggests that they can be included up to 20% of the total DMI in diets for goat kids (Ragni et al., 2015; Pinto et al., 2011). In case of sesame cakes, the proportions reported in the literature, mainly for small ruminants, usually accounts for 10-12% of the diets, DM basis (Gebremariam, 2019; Hassan et al., 2013).

Crambe cakes were used in proportions up to 21% in lambs' diets (Canova et al., 2015); however, this level was associated with reduction of DMI. On the other hand, a moderate inclusion level, of 14%, let to similar performances as the control group. Bohme et al., 2005, recommend an upper limit of 1 kg/head/day in case of dairy cows, based on the problems induced by its supply of erucic acid and glucosinolates.

Of course, for the batches of cakes having high levels of residual oils, or included in diets together with other sources of fat, caution should be taken to the overall fat content of the diets: it is well-known that high levels of fat impair various rumen processes (Harvatine & Allen, 2006). Less know are the effects of the broad range of antinutritive substances contained by the studied cakes.

There was insufficient data on negative effects of erucic acid in ruminants to declare an overall limit, but it was reported that intake of 0.4 g of erucic acid/kg of body weigh resulted in reduction of feed intake and milk yield (Knutsen et al., 2016). However, according to the same authors, ruminants usually consume between 1.8 to 2.6 mg/kg body weight of erucic acid from dietary ingredients, less than the level which can cause side-effects

Even if the ruminants can by more tolerant to glucosinolates intake, due to the action of microorganism in digestive tract, the long-term exposure can lead to higher level of thiocyanates and can reduce the level of thyroxin in plasma. Diets contain glucosinolates in levels more than 11.7 to 24.3 µmol/g may reduce the milk production and feed intake in dairy cows. Notably, some studies reported that sheep fed diets containing glucosinolates at concentrations of 1.2-2.2 µmol/g DM even lost body weight (Tripathi et al., 2007), suggesting that sheep are more sensitive than dairy cows to these antinutritive substances.

The second concern of replacing classical with alternative feedstuffs are **the effects induced by the replacement on production performances**: milk yield, average daily gain, specific consumption, etc. Although bibliographic references are more numerous than in the case of the effects on rumen metabolism, the accumulated data are too scarce, considering the diversity of ruminants' species and categories, each of them having their own specifics from the nutritional point of view. Therefore, data volume that is available for each species and categories didn't allow aggregation of data (e.g., as averages), when considering the effects on the two main ruminants productions: milk (yield and quality) and meat (weigh gain and quality). Still, some effects of the four oilseeds could be extracted from the literature.

***Linseed cake***. It was reported that inclusion of linseed cake in dairy goats' diet (19.9 %, of diets' total DM) led to higher milk production, to the increase of the milk monounsaturated fatty acids (MUFA) proportion and decrease of the saturated fatty acids (SFA) proportion in the total FA. Also, the content of short chain fatty acids (SCFA), which are responsible for milk taste and flavour intensity, has increased (Jóźwik et al., 2010).

In other studies that involved dairy cows, Jóźwik et al., 2016 observed that the inclusion of linseed cake in proportion of 21.31% in concentrate mixture significantly has increased the content of milk linoleic acid and MUFA content and has decreased the omega 6/omega 3 ratio, which has beneficial implication in consumers health. Nudda et al., 2015 reported that the content of C18:3 n-3 (linolenic alpha fatty acid), which can be a potential factor that prevent the atherosclerosis in human, was increased by supplementation of goats' diet with 160 g/day extruded linseed.

In term of meat quality, it was reported that inclusion of 284 g linseed cake in goats' diet led to a higher performance in daily body weight gain and better carcass parameters (Alemu et al., 2010). Same trends, of inducing higher body weight gain and better carcass parameters were also observed by Tafa et al., 2010 after supplementation of sheep's diet with 300 g/kg DM linseed cake. Also, Baltrukonienė et al., 2015 reported that linseed cakes have potential effects of increasing MUFA and n-3 fatty acids content in *M. longissimus dorsi* of bulls.

***Safflower cake.*** In case of safflower, Kott et al., 2003 observed that supplementation of lamb's diets with 6% safflower oil improved conjugated linoleic acid (CLA) content in muscle tissue. Partial replacing of soybean meal with safflower cake in lambs led to a decrease in SFA content in meat and an improvement in concentration of MUFA; also, the ratio between omega 6/omega 3 PUFA was decreased by the safflower cake diet (Tufarelli et al., 2013).

***Sesame cake.*** The effects of the sesame cake on milk quality parameters are not well documented in literature, but it was reported that inclusion of sesame oil cake in dairy goats' diet (5, 10, 15% of the compound feed) resulted in a higher milk yield and milk fat content. The results of the sensory analysis of cheese revealed that the higher dose of sesame oil cake supplementation led to better cheese flavour (Hejazi et al., 2019).

The inclusion of sesame cake in ruminants' diet can also influence the meat quality. It was reported that inclusion of sesame seed cake in growing sheep's diet (300g DM/day) lead to a higher body weight gain (Fitwi & Tadesse, 2013). The same trend was observed by Gebru, 2014 after supplementing goat's diets with 63, 84 and 105 g/day sesame cake.

***Crambe cake.*** In literature there are very few studies that presents the effects of supplementation with crambe cake in ruminant's diet on milk composition. Böhme et al., 2005 reported that inclusion of crambe cake in cows' diet (30%) has decreased milk yield and milk fat content, which is consistent with crambe cake particularities.

The same type of effects was observed in case of meat quality: it was reported that inclusion of crambe cake (0, 22, 44 and 66% replacement of the soybean meal protein) in lambs' diet led to a decrease of the fat content of *Longissimus lumborum* muscle and a reduction in its tenderness and luminosity, which are correlated with fat content reduction. Moreover, it was observed a significantly reduction in concentration of SFA, MUFA and PUFA in intramuscular fat (Issakowicz et al., 2017). It is relevant that they also observed that the erucic acid concentration in meat was drastically higher in animals fed crambe cake diets. This may have negative influence on consumers' health, considering the fact that erucic acid can contribute to several cardiovascular diseases (Knutsen et al., 2016).

For all the studied cakes, it can be observed that of the effects on the productive performances, many are related to the influence of the residual oils on the FA profile of animal products, either milk or meat. These findings are important from consumers point of view, considering the fact that SFA are associated with a higher risk of developing cardiovascular disease (Siri-Tarino et al., 2010). In contrast, its well known that food matrix rich in PUFA can help with the prevention against cardiovascular diseases (Tapiero et al., 2002).

On the other hand, it is well known that a higher proportion of PUFA is associated with higher potential of oxidation, shorter storage time which leads to the need for feeding strategies, such as ensuring the presence of antioxidants in the diets.

## CONCLUSION

Compared with the more known rapeseed cake, the four studied cakes had **lower crude protein content**: slightly lower in case of linseed cake and safflower seeds cake, more pronounced in case of sesame seeds cake (-7%) and crambe seeds cake (-19%). This imply lower protein value and it may be partly related to the extent of oils extraction, as the studied cakes had higher residual fat than rapeseed cake, with the exception of safflower seeds cake.

Also, for each of the four cakes, the chemical composition presented a **large variability**, especially in the case of fat and crude fiber content, which suggests a large diversity of the processing techniques, e. g. with or without dehulling stage prior to the oil extraction.

Data on fine constituents (amino acids, fatty acids, minerals and vitamins) were scarce not only in case of cakes, but also for the whole seeds. Of these, the fatty acids were more frequently assessed, in the context of the general interest for feeding strategies aiming to obtain animal products having a fatty acids profile that is beneficial for the consumers health. **Each cake has particularities from this perspective**, such as the high content of the linolenic acid in linseed.

Of the fine constituents it is important that **all of the studied cakes contain substances that exert bioactivity**, e.g., at rumen level: phenolic compounds, tocopherols, erucic acid, glycosylates. Some of them exert positive activities (antioxidant, anti-inflammatory) but some are anti-nutritive factors. Therefore, their inclusion in ruminants' diets is expected to influence apparent digestibility or to changes rumen parameters such as acetate: propionate ratio.

Overall, the studied cakes are good alternatives to more classical protein sources, such as rapeseed cakes, while also benefiting of some positive properties (favourable active substances, content of polyunsaturated fatty acids). Their use in ruminants' diets implies several cautions, such as the low content of some amino acids, not exceeding the safe level of dietary fat intake and keeping the intake of anti-nutritive factors as low as possible.

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