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NONCONVENTIONAL RESOURCES FOR MONOGASTRIC FEEDING

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Abstract

Non-conventional feed resources (NCFR) as potential alternative feed ingredients for animal production continue to be a topic of great interest in recent years. As a promising solution for livestock feeding to reduce feed costs and ensure productivity and environmental sustainability with maximum efficiency, some of the potentially available NCFR are useful oilseed by-products. Some of them have a high nutritional value and contain several bioactive compounds (dietary fiber, essential oils, vitamins, minerals, polyphenols, etc.) which can promote the health and well-being of animals. However, the protein content, low energy level or the presence of some anti-nutritional factors can compromise its quality and restrict its use in animal feeding. Therefore, this paper reviews the nutritional value of three NCFR cold-pressed cakes, i.e., flax, hemp, and pumpkin) and the effects of their inclusion in monogastric diets (poultry and pigs), to provide a theoretical reference for their usefulness in the nutrition field.

Key words*: animal nutrition, cakes, flax, hemp, pumpkin.*

INTRODUCTION

The development of animal breeding by scientific progress and the increasing demands of the national economy is primarily based on finding some nutritional strategies to make animal feed more efficient. In general, the lack of animal feed resources has mobilized animal nutrition researchers to find promising solutions to ensure cheap and environmentally sustainable feedstuffs (Rakita et al., 2022). For this reason, it is important, to focus on circular economy, where the by-products from food industries have involved much more attention (Berwanger et al., 2014). Moreover, increasing the availability of non-conventional feed resources (NCFR*)* for animal livestock is an essential nutritional solution. Generally, NCFR refers to all those feeds that have not been traditionally used for feeding livestock and are not commercially used in the production of livestock feed (Areaya, 2018). Thus, in our paper, the NCFR term has been used to describe different sources such as oil seeds by-products with applicability in animal consumption (Amata, 2014). In this sense, one alternative solution is based on reducing food waste and trying to extract the maximum values from their by-products (Rakita et al., 2022). Instead, NCFR contains high amounts of nutrients and bioactive compounds, such as polyphenols, carbohydrates, lipids, organic acids, proteins, antioxidants (Švarc-Gajić et al., 2020), dietary fiber, minerals, oils, essential vitamins (Malenica et al., 2022), which could provide numerous benefits on animal welfare, performance, and health status (Manju Wadhwa et al., 2015). Nowadays, more and more attention has been paid to the by-products as a result of oilseeds extraction from oleaginous plants. Oil can be extracted by applying pressure and shear forces with mechanical expeller presses in a process called "*pressing*" (Zheng et al., 2003; Shim et al., 2015; Vidal et al., 2022). Cold pressed do not alter the crude oils (Berwanger et al., 2014). Compared with solvent extraction treatments (i.e., hexane, xylene, and toluene), the cold pressing produces a solid meal-defined *cake* with a range of oil contents, higher level of fat (6-7% *vs*. < 1%), crude protein and crude fiber (Shim et al., 2015). Due to the applied extraction conditions that cause a decrease in the efficiency of oil extraction from seeds

(Petraru & Amariei, 2020; Vidal et al., 2022), cold pressing is seen as an alternative to conventional pressing. Instead, following the Codex Alimentarius, the cold pressing is led at a temperature not exceeding 50°C (Petraru & Amariei, 2020; Sumara et al., 2023) and the oxidation stability is lower than extraction with organic solvents (Kostić et al., 2013). Further, cold pressing is cheap, rapid, and easy technique to obtain cakes even if it is used in small quantities of raw materials (Cakaloglu et al., 2018). The oilseed cakes are very rich in proteins and represent an alternative nutritional solution to cover the necessary proteins for food production, animal feed or biotechnological processes (Teh & Bekhit, 2015). Instead, that remains after oil seed extraction permits effective utilization and successful realization of the circular economy concept (Petraru & Amariei, 2020), especially in the field of animal nutrition (Petraru et al., 2021). The term oilcake is synonymous with press cake, meal, or oil meal (Petraru & Amariei, 2020), which can be used successfully in livestock production. In addition, Serrapica et al. (2019) affirmed that oilseed cakes are an excellent alternative source rich in proteins providing an increase of biomass in animal diets.

This review is aimed at providing an overview of the (i) current knowledge about the chemical composition and nutritional value of three NCFR cold-pressed cakes, such as flax, hemp, and pumpkin; and (ii) the inclusion of cold-pressed oilseed cakes in monogastric animal (poultry and pigs) diets and the effects on growth, productive performance, and products quality.

MATERIALS AND METHODS

A systematic literature search and selection methodology of the relevant research articles in international databases (PubMed, Science Direct, Google Scholar, Scopus) were accessed, explored, compared, and evaluated. The literature search was based on articles with keywords such as flax, hemp, pumpkin, cakes, animal nutrition, nutritional value, bioactive compounds, and circular economy. The aim of writing this bibliographic study is mainly to focus on the nutritional value of three NCFR cold-pressed cakes (flax, hemp, and pumpkin) and to discuss their bioactive contents as well as to present the principal effects of use in animal nutrition (poultry and pigs), respectively the results after processing it in diets.

RESULTS AND DISCUSSIONS

Oilseed cakes, general aspects

In recent years, oilseed cakes have been used as ingredients feedstuff for animals as it was an excellent and economical source of benefits (Singh et al., 2022). Source of protein, energy, carbohydrates, and minerals, oilseed cakes were found to provide benefits and to have a potent role in animal growth and production of energy (Teh et al., 2013). Due to their potential, oilseed cakes (Shim et al., 2014; Turner et al., 2014; Singh et al., 2022) contribute to better use of resources for economic growth and to meet food demand worldwide for an increasing human population (Teh et al., 2013). They can be used as substrates or can be successfully incorporated into diets to develop new products rich in nutrients (amino acids, bioactive compounds, pigments, enzymes, vitamins). Founded on variety, conditions of growth, and extraction process, the oilseed cakes involve different physiochemical and functional properties which make them unique (Rani & Badwaik, 2021). Further, oilseed cakes are recognized as low-processed materials, but safe (Petraru & Amariei, 2020). Particular attention must be paid to the storage conditions because improper preservation can cause rancidity (unpleasant smell and taste). Based on literature data, there are two types of oilseed cakes, i.e., edible, and non-edible (Cozea et al., 2016; Singh et al., 2022). The edible categories can be included in animal consumption as feed ingredients compared with non-edible cakes that consist of toxic compounds or anti-nutritional factors (Gupta et al., 2018).

Nutrient composition of oilseed cakes

Based on the nutritional value view, the by-products resulting from the production of oils from vegetable oleaginous seeds named cakes, are successfully used with significant results in animal feed (Kolláthová et al., 2019). This review begins by summarizing and characterizing the chemical composition and nutritional value of flax, hemp, and pumpkin seed cakes, presenting the health benefits and growth performance through *in vivo* studies to maximize their potential in new feed structures for animal nutrition.

Flaxseed or **linseed** (*Linum usitatissimum* L.) is an annual herb plant, a member of the *Linaceae* family. The species is native to the eastern Mediterranean, western Asia and the Middle East, up to India. Regarding the varieties, the flax plant prefers deep moist soils rich in silt, sand, and clay (Bernacchia et al., 2014). The seeds of flax are brown to yellow and golden. The composition of flax can vary with, the growing environment, genetics, seed processing and method of analysis. Flaxseed contains various phenolic compounds such as lignans, flavonoids, phenolic acids, and tannins with high antioxidant potential (Kasote, 2013). Regarding the by-product resulting from cold press extraction, flaxseed cakes (**FSC**) still have good nutritional values. However, the research on FSC is relatively limited. FSC involves excellent functions and can be used like other ingredients as NCFR in animal livestock (Xu et al., 2022). According to the literature reports, FSC has higher nutritional content after cold press of protein (from 14-41%), fats (6-22%), ash (between 4.0-7.0), and energy (Table 1). Further, the nutritional composition of FSC differs due to the factors that are closely related to the technological process of oil extraction and environmental conditions (Cozea et al., 2016).

Hemp (*Cannabis sativa* L.) is an ancient Asian crop that has been cultivated and grown for about 10,000 years (Leonard et al., 2019). As an herbaceous plant, hemp can grow from about 1 to 6 meters tall, depending on factors such as cultivation, and environmental and agronomic conditions (Fike, 2017).

Cannabis sativa can be classified into drug type (marijuana) and nondrug type (hemp). Hemp is included in the *Cannabaceae* family with four subspecies: *sativa, indica, ruderalis* and *afghanica* (McPartland et al., 2018). Industrially, there are two different types of hemp plants, namely fiber hemp and oil hemp, which is a variety of *Cannabis sativa* distinct from the marijuana used for seeds production. A major importance of hemp is rendered by the extraction of oil from its seeds using the cold pressing process (without the involvement of the oilseed conditioning step) with a screw or a hydraulic press, respectively the solvent extraction. Instead, cold pressing is the most used because it does not involve the use of organic solvents or heat (Teh et al., 2013). Also, the cold pressing process involves the step of cleaning the seeds, grinding them into a paste and finally applying high pressure to extract the oil. After oil extraction, it results in the defatted cake, this being a by-product rich in fibers and proteins. According to literature reports, hempseed cakes (**HSC**) have a nutritional value equal to rapeseed and can be effectively used as a feed ingredient in animal feed. At the same time, the demand for the use of cold-pressed oil cakes is increasingly sought after, thanks to the simple equipment, which can be used both on a farm and in rural areas (Roy & Deshmukh, 2019), offering extraction yields of 27-31.5% (Anwar et al., 2016).

Pumpkin (*Cucurbita* spp.) belongs to the genus *Cucurbita*, family C*ucurbitaceae* and is one of the most significant vegetable crops in Mexico, being widely cultivated in South Asia, Africa, Latin America, and the United States. Depending on the variety and climate, the pumpkin is available in many shapes, sizes, and colours. The most popular pumpkin varieties worldwide are *C. pepo, C. moschata, C. mixta,* and *C. maxima*. At the same time, pumpkin is one of the most important vegetable crops, being widely consumed on agricultural land and in certain urban regions. The pumpkin has gained special attention due to its composition and the protection generated on health, all these benefits being due to the nutritional value of its seeds (Kaur & Sharma, 2018). It is known that pumpkin seeds are the most important part, but unfortunately, they are mostly thrown away as waste. Currently, pumpkin seeds are subjected to industrial processing for the extraction of oil, being also marketed as a salty snack (Kaur & Sharma, 2018). Pumpkin is characterized by low caloric content, high concentrations of β-carotene (precursor of vitamin A) and antioxidant properties (El-Adawy & Taha, 2001). The effective use of these pumpkin by-products involves the extraction of bioactive compounds (PUFAs, antioxidants, vitamins such as carotenoids and tocopherol, minerals) and their addition in the food industry chain, but especially as feed ingredients in animal nutrition, improved the nutritional value of diets (Aziz et al., 2023). Furthermore, pumpkin seeds are known for their special issues like anti-fungal, anti-inflammatory, and anti-bacterial effects (Wang & Ng, 2003; Caili et al., 2006; Kaur & Sharma, 2018).

Chemical composition

Flaxseed is a low-cost, unconventional feed resource with a unique phytochemical composition and diverse utilization. Flaxseed oil, which is mostly obtained by pressing the seeds, is an important source of omega-3 PUFA (Shim et al., 2015). Following the extraction of the beneficial component (the oil), the secondary product known as cakes has a high nutritional value. Instead, the oilseed cakes contain a balanced ratio between protein and fat content (Table 1).

Hempseed are fruits of *C. sativa* composed of white seed and brown skin. It has a round shape, dark red-brown colour, with a diameter between 3.0 to 5.0 mm (Leonard et al., 2020). Table 1 reports data on the chemical composition of HSC as rich sources of fat and protein, the differences being generated by the variety or hybrid studied, pedoclimatic conditions, agronomic practices, and processing methods (Vastolo et al., 2021). Whole seed of *Cannabis sativa* L. is a valuable source rich in protein (25-30%), polyunsaturated fatty acids (PUFA, 75-80%), dietary fiber (approximately 4%) and phenolic compounds (House et al., 2010).

Table 1. The proximate nutritional composition of oilseed cakes

Items						
DM	CP	EE	CF	Ash	GE	References
air dry basis, %					MJ/kg DM	
Flax						
90.30	31.60	22.10	8.40	5.40	n.d.	Ogunronbi et al. (2010)
89.70	32.20	11.50	8.60	4.90	10.78	Halle & Schöne (2013)
93.11	35.36	18.18	8.56	4.92	n.d.	The et al. (2014)
89.70	32.83	21.40	9.50	5.30	n.d.	Budžaki et al. (2018)
90.73-93.10	14.40-41.97	6.11-21.40	6.29-12.90	4.70-6.27	n.d.	Petraru & Amariei (2020)
90.60	34.10	10.20	10.50	6.30	20.70	Feedipedia.org
91.20	35.40	10.70	9.70	6.30	20.90	Feedtables.com
90.20	33.90	7.02	9.88	5.45	n.d.	Xu et al. (2022)
94.50	n.d.	n.d.	n.d.	6.19	n.d.	Kolláthová et al. (2019)
Hemp						
91.30	31.90	11.50	30.30	7.20	21.60	Feedipedia
89.20	24.80	8.90	25.10	5.80	1.80	Callaway (2004)
88.00	31.00	8.50	17.90	8.10	-	Hessle et al. (2008)
93.70	34.40	12.40	n.d.	6.70	9.50	Karlsson et al. (2010)
92.00	29.80	9.69	32.55	7.24	20.40	Šťastník et al. (2019)
92.47	32.06	9.02	32.21	5.38	n.d.	Kasula et al. (2021)
94.40	37.70	16.40	26.10	7.90	2.30	Rakita et al. (2023)
Pumpkin						
93.20	52.20	12.30	6.40	8.10	n.d.	Baia et al. (1965)
93.90	52.90	16.30	39.40	8.51	13.10	Klir et al. (2017)
94.48	28.53	37.18	21.58	6.71	20.88	Wafar et al. (2017)
92.10	61.00	13.70	2.90	8.00	22.70	Greiling et al. (2018)
92.50	38.30-62.30	9.00-36.20	23.10	7.50-8.10	20.70	Keller et al. (2021)
90.77	42.96	11.23	23.08	7.51	n.d.	Boldea et al. (2021)
88.00	63.20	13.00	5.70	9.00	22.60	Feedipedia.org

Where: DM = Dry matter; CP = crude protein; CL = crude lipid; EE = ether extract; CF = crude fiber; GE=gross energy; n.d. = non defined.

Unshelled hemp seeds contain 25-34% fat, and shelled seeds contain 42-47% fat. Interestingly, hempseeds have been identified with 181 proteins with two major storage proteins being the legumin-type globulin edestine (67% to 75%) and globular-type albumin (25% to 37%; Callaway, 2004; Aiello et al., 2016). These two proteins have different AA compositions and functional properties. Structurally, edestine is a hexamer with identical subunits that belongs to the globulin family (Docimo et al., 2014), being less soluble in water or buffer with neutral or low pH, but soluble in a basic buffer (Malomo & Aluko, 2015). Despite its low solubility, edestine is known for its high digestibility (Banskota et al., 2022). *Albumin* has fewer disulfide bonds compared to edestine (globulin), with a flexible structure with higher protein solubility and foaming capacity (Malomo & Aluko, 2015). In addition to these essential nutrients, hemp contains compounds such as plant sterols and Phyto cannabinoids, including the most abundant delta-9-tetrahydrocannabinol (THC), which is a powerful fat-soluble antioxidant with a role in appetite stimulation (Potter et al., 2008).

Pumpkin seed cakes (PSC) are a high-quality by-product rich in proteins, resulting from pumpkin oil production (Steiner et al., 2020). The chemical composition of PSC is presented in Table 1. According to the literature, the CP content recorded in PSC was between the range of 28-63% more highly than FSC (14-35%) and HSC (24-38%) confirming that it is a rich source. The ether extract (EE) from PSC ranged from 11-37%, comparatively with FSC where the level was found from 7-22%, respectively 17-33% in HSC. Overall, the nutritional composition results were within expected levels and consistent with literature data. Special attention has been paid to hemp cakes as a result of the cold pressing process, which is very rich in proteins, fibers, minerals, and biologically active compounds (Majchrzak et al., 2020).

Minerals

In terms of low mineral content, oilseeds are considered deficient, meaning they are nutritional sources of a small range of minerals (Kolláthová et al., 2019). Based on literature studies, Table 2 lists the content of relevant minerals in analysed oil seed cake sources.

Table 2. The minerals content of oilseed cakes

Items									References
Macroelements					Microelements				
Ca	P	K	Na	Mg	Mn	Zn	Cu	Iron	
g/kg DM					mg/kg DM				
Flax									
3.32-3.82	6.43-8.24	8.99-10.07	0.38-0.60	4.91-5.82	32.80-49.91	64.72-69.33	16.49-20.86	-	Ogunronbi et al. (2010)
3.61	9.52	12.41	0.34	4.41	13.72	48.60	17.75	78.60	Kolláthová et al. (2019)
4.30	9.00	11.80	0.80	5.50	40.00	68.00	19.00	175.00	Feedipedia.org
4.30	9.30	11.30	0.69	5.20	39.00	66.00	18.00	164.00	Feedtables.com
Hemp									
2.90	10.50	-	-	-	-	-	-	-	Feedipedia.org
0.12	-	0.43	0.015	0.17	7.80	2.40	0.10	-	Radočaj et al. (2014)
0.17	0.71	0.95	0.01	0.48	133	133.67	77.83	18.83	Kasula et al. (2021)
Pumpkin									
1.60	17.80	13.70	0.30	5.70	80	190	16.00	211	Feedipedia.org
0.73	10.40	7.90	0.20	4.60	38.50	49.50	11.50	73.50	Frida.fooddata.dk
0.34	15.70	5.79	0.006	5.69	49.30	113	15.40	106	Glew et al. (2006)
0.60	-	<0.005	-	6.70	-	155.10	6.37	134.60	Sobczak et al. (2020)

Where: Ca = calcium; P = phosphorus; P = potassium; Na = sodium; Mg = magnesium; Mn = manganese; Zn = zinc; Cu = copper; Fe = iron.

Oilseeds are an important source of many nutrients and minerals in animal nutrition (Das et al., 2017). In recent years, Kolláthová et al. (2019) reported that there has been an increasing interest in the utilization of organic by-products of industrial processing as feed ingredients for animal nutrition. Regarding the presence of macro elements from our oilseed cakes, the flax is mostly rich in calcium, potassium, and magnesium, followed by pumpkin where the phosphorus content is higher than flax. Radočaj et al. (2014) found a low percentage of HSP (2.40 mg/kg of DM). Further, as related to Gálik et al. (2011), Zn is very important in nutrition mainly to immunize animals. The Iron (Fe) presence, in FSC and PSC, was detected the higher content. In cuprum content a wide range from 0.10-77.83 was found in HSC *vs*. FSC where values were between 16.49-20.86, respectively 6.37-15.40 in PSC.

Amino acids contents

Amino acid (AAs) composition is an essential factor in evaluating the nutritional quality of a feed resource, along with its chemical composition and degree of digestibility. The profile of AAs, especially essential AAs (EAAs), determines the biological value of proteins. The absence of an EAAs automatically inhibits the synthesis of protein, and its deficiency diminishes it. At the same time, when it makes the feed structure, synthetic AAs such as L-lysine and DL-methionine are used to cover the requirement. According to the reports data presented in Table 3, FSCs have a good EAAs profile and can constitute a great protein source for animal feed (Panaite et al., 2017). The most abundant AAs found in FSC were glutamic acid (6.18-20.40 g 100 g^{-1}), followed by arginine (3.03-9.60), and aspartic acid (3.05-9.40), while the limiting was tryptophan, methionine, cystine, tyrosine, valine, and lysine. Regarding the abundance of AA found in HSC, glutamic acid, arginine, and aspartic acid are among them (Table 4). HSC protein contains all 21 known amino acids (AAs), including the 9 EAAs that the animal body cannot synthesize (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine). Because lysine is only present in small amounts of hemp protein, it is considered a limiting AA. Thus, to cover the level of lysine, nutritionists recommend that, for example, hemp protein can be combined with pea or rice protein powder.

Table 3. Amino acids profile in flaxseed cakes (g 100 g^{-1})

Essential						
LYS	4.00	3.90	3.93-4.18	3.90	1.29	3.93-5.80
THR	3.90	3.80	4.19	3.60	1.20	3.40-3.87
MET	1.90	1.90	2.20	1.40	0.58	-
ILE	4.40	4.30	4.36-5.21	4.00	1.46	2.80-4.36
LEU	6.00	6.00	6.07	5.80	1.95	6.07-6.50
PHE	4.80	4.90	5.33	4.60	1.50	-
VAL	5.20	5.10	5.17-5.42	4.60	1.73	3.50-5.42
ARG	9.60	9.40	10.63	9.20	3.03	-
HIS	2.50	2.70	2.45	2.20	0.79	-
TRP	1.60	1.50	1.38-3.87	1.80	-	-
Total sulfated AA (MET + CYS)	-	-	-	-	-	2.50-3.80
Total aromatic AA (PHE + TYR)	-	-	-	-	-	6.30-7.95
Non-essential						-
ALA	4.70	4.70	4.59	4.40	1.46	
ASP	9.40	9.70	9.78	9.30	3.05	-
CYS	1.80	1.90	2.20	1.10	0.65	-
GLU	20.40	20.10	26.92	9.30	6.18	-
GLY	6.00	5.90	6.14	5.80	1.89	-
PRO	4.20	3.70	5.24	3.50	1.23	-
SER	4.80	4.70	5.88	4.50	1.49	-
TYR	2.50	2.40	2.94	2.30	0.93	-

References: Feedipedia.org; Feedtables.com; Prestoet al. (2011); Singh et al. (2011); Stodolak et al. (2013); Guimarães et al. (2017); Bekhit et al. (2018)

Where: LYS = lysine; THR = threonine; MET = methionine; ILE = isoleucine; LEU = leucine; PHE= phenylalanine; VAL= valine; ARG = arginine; HIS= histidine; TRP = tryptophan; ALA = alanine; ASP = aspartic acid; CYS = cystine; GLU = glutamic acid; GLY =glycine; PRO = proline; SER = serine; TYR = tyrosine.

Hydrolysis of hemp seed proteins by enzymes such as pepsin, pancreatin, trypsin and proteases leads to the release of bioactive peptides with antihypertensive, antioxidant, antiproliferative and anti-inflammatory properties (Kotecka-Majchrza et al., 2021). The percentage distribution of EAAs is like that of soybean, with the mention that they have a higher methionine content (Wang & Xiong, 2019). PSC are rich in AAs like glutamic and aspartic acid, arginine, leucine, and lysine. As can be observed, the rest of AAs are presented in low quantities (Table 5). Based on protein content, reports indicate that pumpkin seed is like soybean cake protein due to the rich content of EAA (Vinayashree & Vasu, 2021).

Table 4. Amino acids profile in hempseed cakes (g 100 g^{-1})

Essential						
LYS	3.30	1.13	2.91	3.86	1.39	5.50
THR	3.20	1.18	2.6	3.94	1.42	-
MET	2.10	0.51	2.01	2.57	0.93	1.80
ILE	3.80	0.91	3.14	4.23	1.52	-
LEU	6.10	1.93	5.11	6.86	2.47	-
PHE	4.30	1.24	3.60	4.73	1.70	-
VAL	4.60	1.13	3.84	5.58	2.01	-
ARG	10.70	4.00	3.01	11.42	4.11	-
HIS	2.50	0.73	2.56	2.72	0.98	2.50
TRP	1.50	0.27	-	1.14	0.41	-
Non-essential						
ALA	4.00	1.19	3.01	4.70	-	-
ASP	9.50	1.37	7.55	10.69	-	-
CYS	1.70	0.34	1.36	2.04	0.74	2.00
GLU	16.00	1.45	13.07	17.61	-	-
GLY	4.20	1.18	2.60	4.85	-	-
PRO	3.70	4.94	3.01	4.64	--	-
SER	4.70	3.55	3.21	5.05	-	-
TYR	3.20	0.89	2.42	3.36	-	-

References: Feedipedia.org; Eriksson (2007); Karlsoon et al. (2012); Wang & Xiong (2019); Semwogerere et al. (2020); Kasula et al. (2021)

Where: LYS = lysine; THR = threonine; MET = methionine; ILE = isoleucine; LEU = leucine; PHE= phenylalanine; VAL= valine; ARG = arginine; HIS= histidine; TRP = tryptophan; ALA = alanine; ASP = aspartic acid; CYS = cystine; GLU = glutamic acid; GLY =glycine; PRO = proline; SER = serine; TYR = tyrosine.

Table 5. Amino acids profile in pumpkin seed cakes (g 100 g^{-1})

Essential				
LYS	0.50	3.80	4.66	1.36
THR	0.30	3.10	1.39	1.04
MET	0.10	2.10	-	0.73
ILE	0.30	3.90	4.05	1.29
LEU	0.60	6.90	6.60	2.49
PHE	0.40	5.50	-	1.81
VAL	0.30	4.70	4.69	1.71
ARG	1.70	16.40	14.00	5.28
HIS	0.40	2.40	1.48	0.81
TRP	0.20	2.70	-	0.61
Total sulfated AA (MET + CYS)	-	-	1.30	-
Total aromatic AA (PHE + TYR)	-	-	10.09	-
Non-essential				
ALA	0.40	3.70	3.63	1.55
ASP	1.00	9.00	11.94	3.23
CYS	0.20	1.10	-	0.39
GLU	1.80	17.90	20.40	6.32
GLY	0.60	4.20	7.30	1.88
PRO	0.40	3.40	3.65	1.39
SER	0.50	5.20	4.90	1.79
TYR	0.30	3.90	-	1.19

References: Feedipedia.org; Glew et al. (2006); Sá et al. (2021); Frida.fooddata.dk

Where: LYS = lysine; THR = threonine; MET = methionine; ILE = isoleucine; LEU = leucine; PHE= phenylalanine; VAL= valine; ARG = arginine; HIS= histidine; TRP = tryptophan; ALA = alanine; ASP = aspartic acid; CYS = cystine; GLU = glutamic acid; GLY =glycine; PRO = proline; SER = serine; TYR = tyrosine.

Further, PSC are rich in nutrients such proteins, starch, soluble sugars, crude fibers, and bioactive compounds carotenoids) which can provide sufficient energy and antioxidants for animal feed (Chen et al., 2019; Lyu et al., 2021). Li et al. (2022) stated that pumpkin has a series of benefits generated by their seeds, through the lens of nutritional characteristics, thus representing a valuable resource for animals.

Fatty acids contents

The fat acids (FA) content of pressed oilseed cakes determines their quality, ecological and economic efficacy, functional, technological, and special properties, respectively the principal value for consumers (Nikberg et al., 2011). Based on the analytical review of scientific and technical information, oilseed cakes can be used as feed ingredients with high nutritional value in animal nutrition (Stodolak et al., 2013). As shown in Table 6, FSC had between 7.73-16.88% saturated fatty acids (SFA), 5.67-41.72% monounsaturated fatty acids (MUFA), and a maximum of 71.85% polyunsaturated fatty acids (PUFA).

Table 6. Fatty acids composition of oilseed cakes

FA %							References
C14:0	C16:0	C16:1	C18:0	C18:1n-9cis	C18:2n-6	C18:3n-3	
Flax							
0.00	6.10	0.00	3.60	18.40	15.80	55.70	Feedipedia.org
0.03	5.60	0.08	4.40	20.20	14.70	53.80	Feedtables.com
n.d.	4.21-8.71	n.d.	3.52-8.17	22.10-41.72	19.13-44.82	33.22-54.79	Singh et al. (2011)
n.d.	9.54	n.d.	2.76	23.33	19.78	43.07	Aziza et al. (2013)
0.06	6.44	0.02	2.57	16.82	14.50	57.35	Stodolak et al. (2013)
0.07	5.99	0.07	2.25	15.71	12.66	42.81	Mannucci et al. (2019)
Hemp							
n.d.	6.70	n.d.	2.20	11.40	55.30	21.60	Feedipedia.org
n.d.	9.30	n.d.	3.80	13.10	52.50	19.10	Mierlita (2019)
0.07	4.46	0.15	1.76	8.27	59.52	15.85	Juodka et al. (2018)
0.17	8.77	0.14	2.51	13.83	56.98	14.62	Arango et al. (2021); Bailoni et al. (2021)
n.d.	8.60	n.d.	2.80	13.10	53.10	12.30	Tufarelli et al. (2023)
n.d.	6.00-9.30	n.d.	0.60-1.60	51.60-59.60	52.50-56.00	14.40-24.70	Halle & Schőne (2013); Mierliță (2018, 2019); Rakita et al. (2023)
Pumpkin							
n.d.	13.29	n.d.	6.74	27.06	51.04	n.d.	Radočaj et al. (2012)
0.23	14.83	0.015	6.68	25.81	50.88	0.18	Bardaa et al. (2016)
0.15	12.90	0.17	4.48	34.40	44.40	1.80	Klir et al. (2017)
0.12	13.20	0.15	4.95	29.60	49.00	0.63	Keller et al. (2021)
0.12	12.30	0.16	5.16	28.75	51.18	0.49	Boldea et al. (2021)

Where: C14:0 = myristic; C16:0 = palmitic; C16:1 = palmitoleic; C18:0 = stearic; C18:1n-9cis = oleic; C18:2n-6 = linoleic; C18:3n-3 = linolenic; nd = not detected.

The predominant SFA was palmitic acid (C16:0), while the predominant unsaturated FA was linolenic (C18:3n-3), followed by oleic (C18:1n-9cis) and linoleic acid (C18:2n-6). According to the literature, the SFA level found in HSC was between 6.00-11.45%, *vs.* MUFA where the percentage was noted from 8.00 to 59.60%. Instead, the PUFA of HSC were between 65.40-80.70% with linoleic as the predominant acid. Regarding the SFA from PSC, the level was higher (17.58-21.74%), while MUFA was between 25.82-35.70% and the PUFA was representative (46.20-51.67%). As had been was linoleic, respectively oleic acid from the MUFA profile. The results from Table 6, show that the oilseed cakes are characterized by a low quantity of SFA, of which palmitic acid is the most abundant. HSC, FSC and PSC are a major source of MUFA, where oleic acid is considered necessary. Instead, as a source of PUFA, the FSC are major, followed by PSC and HSC, where linoleic (LA) and α-linolenic acid (ALA) are considered essential. Further, these FAs are essential for health and are vital for inclusion in the animal diet due to the body incapacity of synthesising them (Rakita et al., 2023).

Benefits of oilseed cakes in monogastric feed

Alternative fodders intended for monogastric animals' production are divided into those rich in crude proteins, and respectively rich in energy (Steiner et al., 2020). In the field of animal nutrition, oilseed cakes would give potential benefits when it is utilized as a substrate converting the feed into a new beneficial product (Sarkar et al., 2021). The present report realised to compress the principal properties of oilseed cakes and the capacity of their valorisation in monogastric feed due to bioactive compounds (Figure 1).

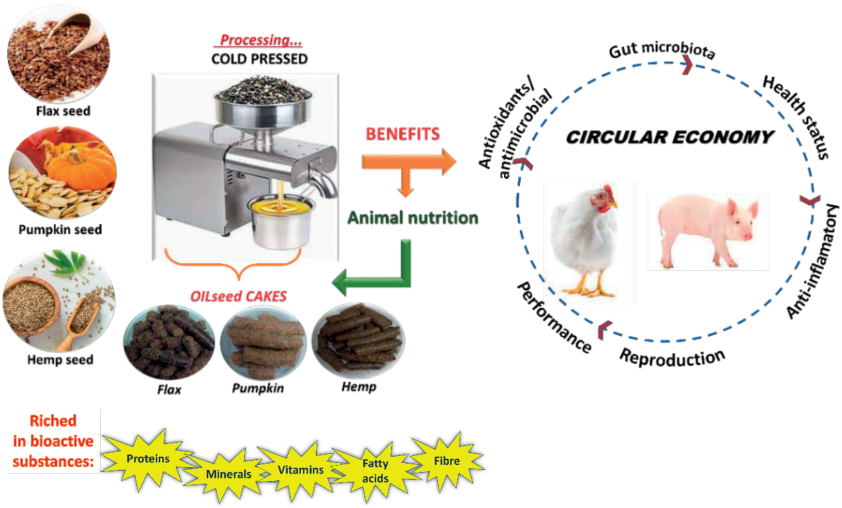

Figure 1. The schematic diagram shows various resources of NCFR rich in bioactive compounds used as monogastric animal feed (Original)

Studies on the use of FSC, HSC and PSC in the feed are relatively limited. Table 7 summarizes available reports and the main effects when cold-pressed oilseed cakes are included in poultry and pig diets.

Table 7. Effect of cold-pressed cakes in monogastric diets

Cold pressed cake	Species	Trial duration	Level of inclusion (g/100 g feed)	Main effects	References
			Poultry		
FSC	Laying hens	6 months	10%	Enrichment of yolk fat with PUFA. The egg mass production was lower.	Halle & Schöne (2013)
FSC	Broiler	42 days	5%; 10%; 15%; 20%	Improvement of carcass weight. Non-significant differences in the weights of giblets (liver, gizzard, spleen, and heart).	Leghari et al. (2017)
FSC	Layer birds	4 weeks	2% FSC +pyridoxine	Improved the omega-3 from eggs. A positive effect on egg cholesterol and health status.	Khan et al. (2019)
FSC	Duckling	3 weeks	5%; 10%; 15%	Decreased the relative weight of the left breast.	Zhai et al. (2019)
FSC	Laying hens	27 weeks	10%	Positive effect on nutrients of omega-6/omega-3 from eggs.	Perić et al. (2019)
FSC	Laying hens		Up to 26%	No effects on egg production, quality, and fertility of eggs.	Tamasgen et al. (2020)

FSC	Laying hens	6 weeks	5%	Beneficial effects on egg nutritional quality. Decrease in significant SFA content, as well as the ΣSFA/ΣUFA ratio and the PUFA ω6:ω3 ratio.	Panaite et al. (2020)
FSC	Laying hens	27 weeks	10%	Higher amounts of ALA, DHA, and PUFA in egg yolk.	Perić & Drinić (2021)
Pigs					
FSC	Growing pigs (31± kg)	12 weeks	5%; 10%; 15%	Feeding up to 15% FSC for 8 weeks had no impact on live animal performance. Feeding any level of flax for 12 weeks reduced average daily gain but feeding higher levels of flax improved feed efficiency.	Juárez et al. (2010)
FSC	Growing pigs (60 kg)	46 days	2.5%	Significantly impacts carcass FA profile.	Đorđević et al. (2016)
FSC	Growing pigs (25 kg)	28 days	12%	Reduced fat digestibility and serum cholesterol.	Ndou et al. (2017)
FSC	Pigs (60-100 kg)	40 days	5%	Muscle depth and the average meat yield was improved. PUFA and meat quality were improved.	Vlaicu et al. (2019)
			Poultry		
HSC	Laying hens	12 weeks	10%; 20%	Higher egg weights. Fatty acid profile of eggs was improved.	Gakhar et al. (2012)
HSC	Laying hens	6 months	5%; 10%; 15%	Registered lower performance. The level of SFA and MUFA decreased, while the content of LA and ALA increased with increasing dietary levels. HSC with linoleic acid oil resulted in the highest yolk fat content of this FA.	Halle & Schöne (2013)
HSC	Hens	30 days	25%	Rapport n-3 PUFA and the n-3/n-6 ratio were improved with decreasing SFA in the yolk of eggs stored at room temperature for 30 days.	Raza et al. (2016)
HSC	Laying hens	10 weeks	20.3%	No effect on growth performance. The atherogenicity index and cholesterol level were not affected. ALA, EPA, and DHA in eggs increased.	Mierlita (2019)
HSC	Growing broilers	48 days	5%; 10%	Positively influenced the lipid profile of meat. Improved the oxidative status and gut health of broilers.	Tufarelli et al. (2023)
HSC	Quails	42 days	10%	Increased n-3 PUFA content from meat. No effect was observed on performance.	Juodka et al. (2023)
HSC	Laying hens	4 weeks	5%; 10%; 20%	Egg production, feed consumption, feed efficiency, and body weight were not affected. A higher level of HSC determined a decrease in palmitic acid concentration.	Silversides & LefranÇois (2023)
			Pigs		
HSC	Growing pigs	14 days	28%	Dietary treatment affected the ileal apparent of essential AA and non-essential AA.	Presto et al. (2011)
HSC	Sows	21 days	5%	Increased n-3 FAs profile; Decreased n-6/n-3 in colostrum and milk; Increased milk yield.	Habeanu et al. (2018)

			Poultry		
PSC	Broiler chicken	49 days	10% as partial replacement of soya bean	The productive performance and meat sensorial quality were not affected.	Martínez et al. (2010)
PSC	Laying hens	49 days	3.3%; 6.6%; 10%	Increase the body weight and egg quality. Abdominal fat and serum levels of harmful lipids were reduced, while the serum levels of beneficial lipids increased.	Aguilar et al. (2011)
PSC	Chicks	56 days	5%; 10%; 15%; 20%	As the levels of PSC the growth, final body weight, total body weight gain and average daily weight gain significantly was improved.	Wafar et al. (2017)
PSC	Fattening chickens	135 days	7%; 14%	Positive effect on the production indicators and the mortality rate of chickens.	Klarić et al. (2018)
PSC	Broiler chickens	6 weeks	7%	Improve production and slaughter indicators (live, carcass, dressing percent, drumstick, breast, wings, back weight, neck)	Steiner et al. (2020)
Pigs					
PSC	Fattening pigs (60-100 kg)	40 days	5%	Improve the meat quality.	Vlaicu et al. (2019)
PSC	Fattening pigs (12-120 kg)	189 days	15% (100 g per animal)	The quality of the meat was similar but the animals were generally in good health; which also leads to the reduction of agricultural waste.	Stahn et al. (2023)

Where: FSC = flax seed cakes; HSC = hemp seed cakes; PSC = pumpkin seed cakes

Flaxseed cakes

The application of FSC in poultry diets is shown in Table 7. Particularly attention was focused on egg production. According to the literature, the addition of FSC to laying hens diets could improve n-3 PUFA content in eggs (Mattioli et al., 2017). Further, FSC is an important high-quality protein source (Xu et al., 2022), the reason for which it attracted special attention due to the presence of ALA as one of the omega-3 PUFA. Additionally, this flax by-product involves benefits in poultry due to their active compounds such as AAs, lipids, soluble fibres, and phenols. Depending on the oil extraction method, the FSC displays modifications on the chemical composition and value of the press cake. Therefore, published data on the inclusion of FSC on pigs comparatively with sow diets are more consistent. As previously reported, FSC is the richest oilseed source of n-3 PUFA and their utilisation in pig diets is necessary to increase n-3 PUFA levels from meat (Nguyen et al., 2003). Later, an inclusion of 15% FSC in finishing pig diets determined significant results on carcass FA profile (Eastwood et al., 2009). In conclusion, eggs and pork can be positively enriched with n-3 FA in a diet with a relatively low content of FSC, due to the presence of anti-nutritional factors that can affect the quality of the finished product.

Hemp seed cake

The use of HSC in diets of monogastric animals is attracting increasing interest. A peculiarity of hemp cakes is the content of narcotic substances, which is why their inclusion in nutrition diets must be done very carefully. In addition, the less dense structure of them confirms the degree of hygroscopicity; however, to date, there are limited studies in the literature (Lanzoni et al., 2024). As shown in Table 7, the use of HSC has been widely explored in poultry feed, especially in laying hen's sector. Aspects such as nutritional and functional properties of eggs by evaluating quantitative and qualitative characteristics together to zootechnical animal performance have been investigated. The inclusion of HSC in poultry feed implies several positive effects,

most likely, these results are associated with the presence of bioactive compounds (phytosterols and antioxidants) that are responsible for preventing lipid peroxidation of eggs during storage.
Regarding HSC inclusion in the swine sector, it is still in an early stage. The use of these by-products was carried out in growing pigs or lactating sows, less in piglets' diets due to the presence of stress factors generated by the weaning crisis period (Dumitru et al., 2020). Further studies are necessary to identify the best optimal level of HSC to ensure performance and animal health status.

Pumpkin seed cake
Interesting results were reported at PSC inclusion in poultry. As an alternative ingredient feed with a high potential content of protein, PSC is a good source with successful results in poultry diets (Wafar et al., 2017). Steiner et al. (2020) affirmed that PSC contains up to 500 g/kg of CP and 70 g/kg of raw fiber. As the level of PSC increased, the broiler performances significantly improved. These results can be attributed to the balance in nutrient composition and maybe to the metabolism process (Wafar et al., 2017). Instead, a dietary inclusion of 10% PSC in broiler diets determined a better feed conversion ratio (FCR) which was associated with absorption, digestion, and nutrient utilisation (Wafar et al., 2017). Research on PSC in pig nutrition has been very little studied, however, it has potential as animal feed not only for its nutritional value but also for its antioxidants, pigments, and polysaccharides content that could enhance the quality of meat, milk, and egg, as well animal health. Stahn et al. (2023) mention that PSC has a protein content of 52.1%, 6.3% fiber and 1.9% ADF. In the experiment carried out for 189 days on 3 groups of piglets (control group, BSG 1 or BSG 2) aged 42 days, they used brewer's spent grains (BSG)-raw matrix was technologically and functionally improved by adding natural active ingredient carriers (crushed wheat, rapeseed, and pumpkin seed press cake) and using planetary roller extrusion and used as feed additive for pigs. Two BSG-extrudates containing 30% BSG silage, 55% crushed wheat, and 15% rapeseed press cake (BSG 1), or 15% pumpkin seed press cake (BSG 2) were used. The quality of the meat was similar but the animals were of good health and marketable quality. BSG and agricultural residue-based feeds can be used in pig diet, which leads to the reduction of agricultural waste and reduced feed consumption that would also be suitable for human nutrition. Schwediauer et al. (2021) studied the feed intake behaviour of piglets during a 6-week suckling period. It is known that early contact with plant-based feed (creep feed) should stimulate the adaption of the gastrointestinal system and promote gut development, with the desired effect of less physiological stress at weaning, lower incidence of diarrhoea and higher growth rates due to better feed efficiency. It is also important to consider the food preferences of the piglets. In this sense, they mention the use of PSC, % in creep feed (pelleted) for piglets was 4.7%.

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CONCLUSIONS

This paper reviews the nutritional value of three NCFR cold-pressed cakes based on flax, hemp, and pumpkin and the effects of their inclusion in diets for monogastric animals (pigs and poultry), to provide a theoretical reference for their usefulness in the nutrition field.

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