



# Soluble dietary fiber, insoluble dietary fiber, and total dietary fiber in feed ingredients used in diets for pigs

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## Abstract

Dietary fiber is defined as the undigestible carbohydrates and lignin fractions of plant-feed ingredients. The most complete and representative analysis of fiber is the total dietary fiber (TDF) analysis, which includes the soluble dietary fiber (SDF) and the insoluble dietary fiber (IDF). There is, however, a lack of data for concentrations of SDF, IDF, and TDF in feed ingredients commonly used in diets for pigs. Therefore, work was conducted to quantify fiber fractions of plant feed ingredients to establish a database for SDF, IDF, and TDF in feed ingredients commonly used in animal nutrition. A total of 846 samples were analyzed for dry matter (DM) and for IDF and SDF, and TDF was calculated as the sum of IDF and SDF. Analyzed values for SDF, IDF, and TDF were corrected to 88% DM. For each feed ingredient, means and standard deviation were calculated. Results indicated that values for TDF were in the range of 3% to 35% for cereal grains, from 1% to 68% for cereal grain coproducts, from 3% to 68% for oilseeds and oilseed co-products, and in the range of 3% to 82% for other plant-based feed ingredients. In conclusion, the present work resulted in generation of a database for SDF, IDF, and TDF in feed ingredients often included in diets for pigs and other animals.

## Lay Summary

Understanding feed ingredient composition requires measuring all nutrients and energy accurately. Some fiber analysis procedures underestimate the fiber concentration in feed ingredients, but analyzing for total dietary fiber (TDF) usually results in an accurate account for most fiber components in feed ingredients. The total dietary fiber is determined by adding the soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) fractions. However, there is no summary of data for concentrations of SDF, IDF, and TDF in ingredients commonly included in diets for pigs. Therefore, the present work provides information about the concentration of SDF, IDF, and TDF in cereal grains, cereal grain coproducts, oilseeds, oilseed coproducts, and other feed ingredients. The current database is particularly relevant, as the use of coproducts with high fiber concentration has increased in diets for pigs and other animals.

**Keywords** dietary fiber, feed ingredients, insoluble dietary fiber, pigs, soluble dietary fiber, total dietary fiber

**Abbreviations:** ADF, acid detergent fiber; DDGS, distillers dried grains with solubles; DM, dry matter; IDF, insoluble dietary fiber; MSC, maximized stillage co-products; NDF, neutral detergent fiber; SD, standard deviation; SDF, soluble dietary fiber; TDF, total dietary fiber

## Introduction

Complete and representative chemical composition of feed ingredients is crucial for determining the nutritional value that can be used in diet formulation to support optimal digestion, nutrient absorption, and gut health in animals (NRC 2012; Navarro et al. 2018). Traditionally, swine diets have been formulated based on grains that mainly contribute energy and oilseed meals that provide amino acids in the diets (Stein et al. 2016). However, these ingredients may be replaced with co-products to provide similar nutrient profiles, which may reduce diet costs

(Zijlstra and Beltranena 2013). Most co-products are generated as a result of production of ingredients for the food industry, which results in a part of the original ingredient being left after production of the primary ingredient. Examples include wheat middlings that consist of the part of the wheat kernel that was not used for production of wheat flour (Stas et al. 2024) and rice bran that consists of the part of the dehulled paddy rice that was not used in production of polished white rice (Stein et al. 2015). Some co-products are generated as a result of production of industrial products rather than food ingredients; this is the case for distillers dried grains with solubles (DDGS), which

**Received:** December 22, 2025. **Accepted:** April 13, 2026

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consist of the part of the corn kernel that was not turned into ethanol (Stein and Shurson 2009). Because it is most often the starch part of cereal grains that is used in the food- or agro-industrial industry, the fiber in the grain is usually left in the co-product, and most co-products, therefore, contain more dietary fiber than cereal grains and oilseed meals, which makes these ingredients less expensive (Anguita et al. 2006). High-fiber co-products may be fed to pigs without affecting growth performance (Widmer et al. 2007; Yu et al. 2016; Casas et al. 2018; Acosta et al. 2021), although that is not always the case (Woyengo et al. 2014). Dietary fiber is defined by the Institute of Medicine, Food and Nutrition Board, National Academy of Sciences (2001), as “non-digestible carbohydrates and lignin that are intrinsic and intact in plants.” Non-digestible carbohydrates, by definition, include oligosaccharides, resistant starch, and non-starch polysaccharides (Bindelle et al. 2008). Fiber can be quantified and characterized as crude fiber, neutral detergent fiber (NDF), acid detergent fiber (ADF), total dietary fiber (TDF), or non-starch polysaccharides plus lignin (Figure 1). Among the methods available, the most representative, robust, and reproducible method is determining TDF by adding the values of the soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) fractions (Mertens 2003; Fahey et al. 2019). Data for crude fiber and detergent fiber in most feed ingredients have been published (Sauvant et al. 2004; NRC 2012; Stein et al. 2016), but there is no comparable database for concentrations of SDF, IDF, and TDF in ingredients commonly included in diets for pigs. Therefore, the present work was conducted to establish a database for SDF, IDF, and TDF in feed ingredients commonly used in animal nutrition and to provide information about the quantities of different fiber fractions that each ingredient provides.

## Materials and methods

### Description of samples

A total of 846 ingredient samples were collected from commercial feed mills around the world. Suppliers provided approximately 1 kg of each ingredient. From the samples, 554 samples were analyzed at the Monogastric Nutrition Laboratory at the University of Illinois at Urbana Champaign, IL, USA, whereas 292 samples were analyzed at Trouw Nutrition (Boxmeer, The Netherlands). Identical procedures were used to analyze the

samples in the two laboratories, and variability between the two laboratories has been demonstrated to not be different from within-laboratory variability (Nguyen et al. 2019).

Ingredient samples were classified in four groups: cereal grains, cereal grain co-products, oilseeds and oilseed co-products, and other feed ingredients. Cereal grains included barley, corn, extruded corn, high-oil corn, oats, rice, rye, hybrid rye, sorghum, and wheat. Cereal grain co-products included bakery meal, barley rootlets, corn co-products (ie corn bran, DDGS, corn fermented protein, corn germ meal, corn gluten feed, and corn gluten meal), oat hulls, rice co-products (ie full fat rice bran, defatted rice bran, broken rice, rice flour, rice mill feed, and rice protein), sorghum DDGS, and wheat co-products (ie wheat bran, wheat DDGS, wheat flour, wheat gluten feed, and wheat middlings). Oilseeds and oilseed co-products such as 00-rapeseed expellers, 00-rapeseed meal; canola expellers, canola meal, copra expellers, copra meal, cottonseed meal, palm kernel expellers, palm kernel meal, full-fat soybeans, soy protein concentrate, soy protein isolate, soybean expellers, soybean meal, fermented soybean meal, enzyme-treated soybean meal, soybean hulls, sunflower expellers, sunflower meal, and sunflower protein concentrate were also included. Other ingredients included alfalfa meal, chicory pulp, faba beans, field peas, flaxseed meal, lupins, pea flakes, pea protein concentrate, pea starch, pectin, pistachio, pistachio blanks, pistachio shell powder, potato protein concentrate, and sugar beet pulp.

### Chemical analysis

Samples were finely ground through a 0.5 mm screen and analyzed for dry matter (DM) determined by oven drying at 135 °C for 2 h (method 930.15, AOAC Int., 2019). Samples were also analyzed for IDF and SDF using the Ankom<sup>TDF</sup> Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA) as established by method 991.43 (AOAC Int., 2019). Briefly, 0.5 g of each sample was weighed in duplicate and placed into filter bags designed to hold the sample during enzymatic digestion with  $\alpha$ -amylase (150 Ceralpha U/mL from *B. licheniformis*, Ankom Technology, Macedon, NY, USA), protease (35 Tyrosine U/mL from *B. licheniformis*, Ankom Technology, Macedon, NY, USA), and amyloglucosidase (652 Glucose U/mL from *A. niger*, Ankom Technology, Macedon, NY, USA). After digestion, the mixture was filtered. The insoluble residue remained in the filter bags, whereas the soluble residue was in the filtrate. The soluble residue in the filtrate

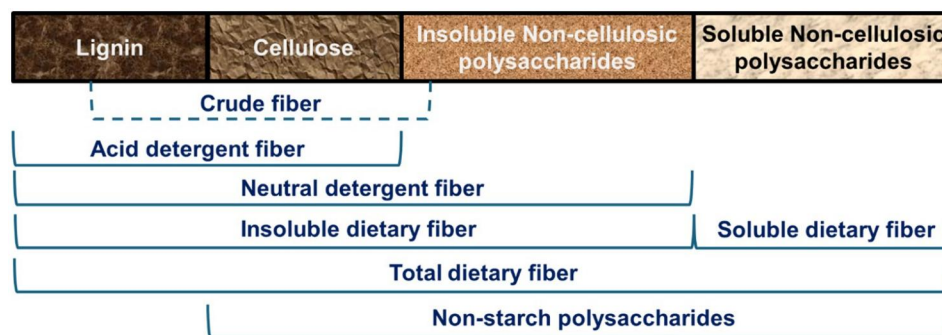


Figure 1 Fiber components included in each analysis for dietary fiber<sup>1</sup>.

<sup>1</sup>Adapted from Lancheros et al. (2022).

**Table 1** Insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) in cereal grains, 88% dry matter (DM) basis.

Feed ingredient	N <sup>1</sup>	DM, %	SD <sup>1</sup>	IDF, %	SD <sup>1</sup>	SDF, %	SD <sup>1</sup>	TDF, %	SD <sup>1</sup>	IDF/SDF
Barley	33	90.2	4.3	16.1	2.0	3.6	0.8	19.7	2.2	4.5
Barley, dehulled	1	89.1	–	9.4	–	3.3	–	12.6	–	2.8
Corn	115	89.1	4.0	10.5	2.2	1.3	2.4	11.8	3.8	8.1
Corn, extruded	7	89.9	1.6	8.6	0.5	1.4	1.2	10.0	1.2	6.1
Corn, high oil	1	89.5	–	15.0	–	0.0	–	15.0	–	–
Oats	6	89.2	1.5	32.0	4.3	3.1	0.5	35.1	3.9	10.3
Oats, dehulled	3	88.5	0.5	8.1	2.3	4.3	0.3	12.4	2.3	1.9
Oats, extruded	1	91.2	–	24.8	–	3.9	–	28.7	–	6.4
Rice, brown	2	87.0	0.8	3.3	0.0	0.2	0.1	3.5	0.1	16.5
Rye	4	87.2	2.2	14.2	1.0	4.7	3.2	18.9	4.0	3.0
Rye, hybrid	9	88.2	1.2	13.8	0.8	2.8	0.8	16.6	1.2	4.9
Sorghum	3	88.5	0.6	8.5	1.1	0.2	0.2	8.7	1.1	42.5
Sorghum, high lysine	2	89.3	0.0	10.0	2.4	0.3	0.3	10.3	2.2	33.3
Sorghum, red	3	88.7	0.0	9.3	1.2	0.3	0.2	9.5	1.4	31.0
Sorghum, red extruded	1	88.7	–	7.6	–	0.3	–	7.9	–	25.3
Sorghum, white	3	88.6	0.1	8.6	1.9	0.2	0.3	8.8	1.9	43.0
Sorghum, white extruded	1	89.1	–	6.4	–	0.6	–	7.0	–	10.7
Wheat	35	89.8	5.0	10.9	1.5	1.2	0.6	12.1	1.8	9.1

<sup>1</sup>N = number of samples analyzed; SD = standard deviation.

was precipitated using 78% ethanol and remained in the filter bags. Both the insoluble and soluble fiber residues were dried and weighed. One replicate of the insoluble and soluble residue were analyzed for nitrogen by the Kjeldahl method (Method 2001.11; AOAC Int., 2019) using a Kjeltac™ 8400 apparatus (FOSS, Eden Prairie, MN, USA). Crude protein was calculated as 6.25 × nitrogen. The second replicate of the residue was analyzed for ash (method 942.05; AOAC Int., 2019).

## Calculations and statistical analysis

The IDF and SDF in each sample was calculated using the following equations (AOAC Int., 2019):

$$\text{IDF (\%)} = \frac{\text{residue}_{\text{insoluble}} - (\text{protein}_{\text{insoluble}} + \text{ash}_{\text{insoluble}})}{\text{initial sample weight}} \times 100$$

where residue<sub>insoluble</sub> is the average weight of the dried insoluble residue after the first filtration of the replicates for each sample (g), protein<sub>insoluble</sub> is the crude protein content in the insoluble residue (g), and ash<sub>insoluble</sub> is the ash content in the insoluble residue (g), and initial sample weight is the average of the initial weight of the replicates for each sample.

$$\text{SDF (\%)} = \frac{\text{residue}_{\text{soluble}} - (\text{protein}_{\text{soluble}} + \text{ash}_{\text{soluble}})}{\text{initial sample weight}} \times 100$$

where residue<sub>soluble</sub> is the average weight of the dried soluble residue after the second filtration of the replicates for each sample (g), protein<sub>soluble</sub> is the crude protein content in the soluble residue (g), and ash<sub>soluble</sub> is the ash content in the soluble residue (g), and initial sample weight is the average of the initial weight of the replicates for each sample. Total dietary fiber was calculated as the sum of IDF and SDF. Analyzed IDF, SDF, and TDF were adjusted to an 88% DM basis to reflect the typical moisture content

of practical feed ingredients and to reduce error propagation associated with correction to dry matter basis. If two or more samples from an ingredient were analyzed, the average of samples within each feed ingredient and the standard deviation were calculated using Microsoft Excel functions AVERAGE and STDEV.S. The IDF to SDF ratio was calculated by dividing analyzed IDF in each ingredient by the corresponding analyzed SDF.

## Results

### Fiber in cereal grains

In cereal grains, values for TDF were in the range of 3% to 35% (Table 1). Barley contained 19.7 ± 2.2% TDF with 16.1 ± 2.0% IDF and 3.6 ± 0.8% SDF, whereas dehulled barley contained 12.6% TDF, 9.4% IDF, and 3.3% SDF. Corn contained 11.8 ± 3.8% TDF with 10.5 ± 2.2% IDF and 1.3 ± 2.4% SDF; however, if extruded, the TDF in corn was 10.0 ± 1.2%, IDF was 8.6 ± 0.5%, and the SDF was 1.4 ± 1.2%. High-oil corn contained 15.0% TDF, which was all IDF. Oats contained 35.1 ± 3.9% TDF, which corresponded to 32.0 ± 4.3% IDF and 3.1 ± 0.5% SDF, whereas extruded oats contained 28.7% TDF, which corresponded to 24.8% IDF and 3.9% SDF. If dehulled, oats contained 12.4 ± 2.3% TDF, reducing IDF to 8.1 ± 2.3% and increasing SDF to 4.3 ± 0.3%. In contrast, brown rice contained only 3.5 ± 0.1% TDF with 3.3 ± 0.1% IDF and 0.2 ± 0.1% SDF. Rye contained 18.9 ± 4.0% TDF, 14.2 ± 1.0% IDF, and 4.7 ± 3.2% SDF, whereas hybrid rye contained 16.6 ± 1.2% TDF, 13.8 ± 0.8% IDF, and 2.8 ± 0.8% SDF. Among sorghum samples, IDF was in the range of 6.4% to 10.0%, and SDF was in the range of 0.2% to 0.6%, giving TDF in the range of 7.0% to 10.3%. Wheat contained 12.1 ± 1.8% TDF with 10.9 ± 1.5% IDF and 1.2 ± 0.6% SDF.

Barley, rye, and hybrid rye had an IDF to SDF ratio that was less than 5:1, whereas corn, brown rice, and wheat had an IDF to SDF ratio between 8:1 and 16:1. However, sorghum contained

**Table 2** Insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) in cereal grain co-products, 88% dry matter (DM) basis.

Feed ingredient	N <sup>1</sup>	DM, %	SD <sup>1</sup>	IDF, %	SD <sup>1</sup>	SDF, %	SD <sup>1</sup>	TDF, %	SD <sup>1</sup>	IDF/SDF
Bakery meal	72	90.7	2.1	15.1	3.4	1.6	1.6	16.7	3.7	9.4
Barley rootlets	5	96.6	0.7	29.2	2.2	1.6	0.6	30.8	1.9	18.3
Corn bran	3	90.1	0.6	38.5	9.0	2.4	2.4	40.8	9.4	16.0
Corn DDGS <sup>2</sup>	64	87.8	1.7	33.7	3.1	2.4	1.5	36.1	3.2	14.0
Corn DDGS, post-MS <sup>2</sup>	2	88.6	2.0	36.8	8.0	2.1	0.3	38.9	8.3	17.5
Corn DDGS, high protein	4	88.2	0.6	34.2	1.9	3.0	1.0	37.2	2.1	11.4
Corn fermented protein	5	93.6	0.9	28.5	1.2	1.6	0.9	30.1	1.7	17.8
Corn germ meal	6	90.3	1.0	33.5	5.4	3.1	1.8	36.6	4.7	10.8
Corn gluten feed	4	89.6	1.1	34.4	7.7	2.7	1.6	37.1	6.2	12.7
Corn gluten meal	4	92.9	5.0	6.8	3.8	0.7	0.4	7.5	3.8	9.7
Oat hulls	2	96.2	5.4	66.4	4.6	1.3	0.4	67.6	5.0	51.1
Rice bran, full fat	1	94.9	–	27.1	–	3.8	–	30.9	–	7.1
Rice bran, defatted	1	89.3	–	21.9	–	1.5	–	23.3	–	14.6
Rice, broken	4	87.7	0.3	2.0	0.5	0.2	0.2	2.3	0.6	10.0
Rice flour	2	87.9	0.2	1.3	0.2	–	–	1.3	0.5	–
Rice mill feed	1	90.0	–	51.7	–	1.8	–	53.5	–	28.7
Rice protein	1	98.4	–	6.5	–	0.2	–	6.7	–	32.5
Sorghum DDGS	2	90.1	0.0	32.1	4.8	4.1	1.0	36.2	5.8	7.8
Wheat bran	26	91.0	4.5	36.5	3.6	2.5	0.7	39.0	3.6	14.6
Wheat DDGS	3	90.9	1.7	24.9	0.6	3.4	1.4	28.3	1.9	7.3
Wheat flour	3	93.7	5.5	2.7	0.6	2.0	1.4	4.6	2.0	1.4
Wheat gluten feed	2	90.9	0.8	28.4	2.3	2.3	0.8	30.7	3.0	12.3
Wheat middlings	26	89.4	0.7	35.4	4.8	2.6	0.7	38.0	4.8	13.6

<sup>1</sup>N = number of samples analyzed; SD = standard deviation.

<sup>2</sup>DDGS = Distillers dried grains with solubles; MSC = Maximized stillage co-products system.

very little SDF, and the IDF to SDF ratio, therefore, was greater than 30:1 in all analyzed sources of sorghum. Dehulling of barley and oats resulted in a reduced IDF to SDF ratio compared with non-dehulled grains, and extrusion of corn, oats, and sorghum reduced the IDF to SDF ratio compared with non-extruded grains.

## Fiber in cereal grain co-products

Bakery meal contained 16.7±3.7% TDF, 15.1±3.4% IDF, and 1.6±1.6% SDF (Table 2). Barley rootlets contained 30.8±1.9% TDF, which corresponded to 29.2±2.2% IDF and 1.6±0.6% SDF. Corn co-products from the wet milling industry, such as corn bran and corn germ meal, contained 40.8±9.4% and 36.6±4.7% TDF, with 38.5±9.0% and 33.5±5.4% IDF, and 2.4±2.4% and 3.1±1.8 SDF, respectively. Corn gluten feed contained 37.1±6.2% TDF with 34.4±7.7% IDF and 2.7±1.6% SDF. Corn gluten meal contained only 7.5±3.8% TDF, 6.8±3.8% IDF and 0.7±0.4% SDF. Corn DDGS, obtained after ethanol production in the dry grind process, contained 36.1±3.2% TDF with 33.7±3.1% IDF and 2.4±1.5% SDF, but if the DDGS was further processed by the maximized stillage co-products (MSC) system, DDGS contained 38.9±8.3% TDF with 36.8±8.0% IDF and 2.1±0.3% SDF. High-protein DDGS contained 37.2±2.1% TDF with 34.2±1.9% IDF and 3.0±1.0% SDF; however, corn-fermented protein contained 30.1±1.7% TDF with 28.5±1.2% IDF and 1.6±0.9% SDF. Oat hulls contained 67.6±5.0% TDF, which corresponded to 66.4±4.6% IDF and 1.3±0.4% SDF. Co-products from rice processing, such as full-fat rice bran and defatted rice bran contained 30.9% and 23.3% TDF, with

27.1% and 21.9% IDF and 3.8% and 1.5% SDF, respectively. Broken rice contained 2.3±0.6% TDF with 2.0±0.5% IDF and 0.2±0.2% SDF. In contrast, rice mill feed contained 53.5% TDF, 51.7% IDF, and 1.8% SDF. Rice protein and rice flour contained 6.7% and 1.3±0.5% TDF, with 6.5% and 1.3% IDF, respectively, but these ingredients contained very little detectable SDF. Sorghum DDGS contained 36.2±5.8% TDF with 32.1±4.8% IDF and 4.1±1.0% SDF, whereas wheat DDGS contained 28.3±1.9% TDF, 24.9±0.6% IDF, and 3.4±1.4% SDF, and wheat gluten feed contained 30.7±3.0% TDF with 28.4±2.3% IDF and 2.3±0.8% SDF. Wheat flour contained 4.6±2.0% TDF with 2.7±0.6% IDF and 2.0±1.4% SDF. In contrast, wheat bran contained 39.0±3.6% TDF with 36.5±3.6% IDF and 2.5±0.7% SDF, whereas wheat middlings contained 38.0±4.8% TDF with 35.4±4.8% IDF and 2.6±0.7% SDF.

All co-products from corn, sorghum, and wheat had an IDF to SDF ratio between 7:1 and 18:1 and bakery meal and rice bran were also within this range. However, a much greater IDF to SDF ratio was observed for barley rootlets (18.3:1), rice mill feed (28.7:1), rice protein (32.5:1), and oat hulls (51.1:1).

## Fiber in oilseeds and oilseed co-products

The TDF in oilseeds and oilseed co-products ranged from 3% to 68% (Table 3). 00-rapeseed meal contained 32.1±2.3% TDF, 29.8±2.3% IDF, and 2.4±0.7% SDF, whereas 00-rapeseed expellers contained 35.8±1.4% TDF with 32.1±1.9% IDF and 3.7±0.8% SDF. However, if 00-rapeseed expellers were fermented, they contained 28.5% TDF, 26.1% IDF, and 2.4% SDF. Canola expellers contained 31.2±0.9% TDF, with 26.7±0.5% IDF and

**Table 3** Insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) in oilseed co-products, 88% dry matter (DM) basis.

Feed ingredient	N <sup>1</sup>	DM, %	SD <sup>1</sup>	IDF, %	SD <sup>1</sup>	SDF, %	SD <sup>1</sup>	TDF, %	SD <sup>1</sup>	IDF/SDF
00-Rapeseed expellers	3	89.3	0.4	32.1	1.9	3.7	0.8	35.8	1.4	8.7
00-Rapeseed expellers, fermented	1	89.0	–	26.1	–	2.4	–	28.5	–	10.9
00-Rapeseed meal	21	89.4	1.2	29.8	2.3	2.4	0.7	32.1	2.3	12.4
Canola expellers	2	91.4	0.1	26.7	0.5	4.5	1.3	31.2	0.9	5.9
Canola meal	8	90.6	1.9	27.7	3.0	3.1	1.8	30.8	3.3	8.9
Copra expellers	4	89.9	4.3	40.9	2.0	4.3	2.0	45.1	3.5	9.5
Copra meal	4	92.3	3.4	38.7	3.6	4.0	0.9	42.7	3.8	9.7
Cottonseed meal	1	91.0	–	26.8	–	3.0	–	29.8	–	8.9
Palm kernel expellers	1	91.9	–	60.9	–	2.6	–	63.5	–	23.4
Palm kernel meal	4	92.3	0.7	58.6	5.1	2.7	0.7	61.3	4.5	21.7
Soy protein concentrate	15	95.0	3.8	17.7	3.0	2.0	1.5	19.6	3.3	8.9
Soy protein isolate	2	94.2	0.6	2.3	1.7	0.5	0.3	2.8	1.4	4.6
Soybean hulls	14	90.5	1.7	62.2	2.3	5.6	1.8	67.8	2.0	11.1
Soybean hulls, extruded	2	92.6	0.4	60.2	0.2	7.3	0.0	67.5	0.3	8.2
Soybean meal	145	90.1	2.9	16.0	3.0	2.2	2.3	18.2	3.3	7.3
Soybean meal, enzyme-treated	7	93.2	1.4	15.2	1.0	2.1	1.3	17.2	1.5	7.2
Soybean meal, fermented	12	90.3	4.5	14.8	3.1	2.6	1.4	17.4	3.4	5.7
Soybeans, expellers	7	91.8	2.0	17.2	1.2	3.3	1.5	20.6	1.7	5.2
Soybeans, full-fat	23	95.9	2.8	20.4	3.5	2.5	1.4	22.9	4.0	8.2
Soybeans, full-fat fermented	2	88.7	0.4	16.3	0.1	4.5	0.0	20.7	0.1	3.6
Sunflower expellers	1	96.2	–	36.9	–	4.1	–	41.0	–	9.0
Sunflower meal	23	90.5	1.5	39.6	6.7	3.9	2.3	43.4	6.4	10.2
Sunflower protein concentrate	1	95.3	–	2.7	–	2.6	–	5.3	–	1.0

<sup>1</sup>N = number of samples analyzed; SD = standard deviation.

4.5 ± 1.3% SDF, whereas canola meal contained 30.8 ± 3.3% TDF with 27.7 ± 3.0% IDF and 3.1 ± 1.8% SDF. Copra expellers contained 45.1 ± 3.5% TDF, 40.9 ± 2.0% IDF, and 4.3 ± 2.0% SDF, whereas copra meal contained 42.7 ± 3.8% TDF, 38.7 ± 3.6% IDF, and 4.0 ± 0.9% SDF. Cottonseed meal contained 26.8% IDF and 3.0% SDF, giving a TDF of 29.8%. Palm kernel expellers contained 63.5% TDF, 60.9% IDF, and 2.6% SDF, whereas palm kernel meal contained 61.3 ± 4.5% TDF, 58.6 ± 5.1% IDF, and 2.7 ± 0.7% SDF. Full-fat soybeans contained 22.9 ± 4.0% TDF with 20.4 ± 3.5% IDF and 2.5 ± 1.4% SDF, but if fermented, they contained 20.7 ± 0.1% TDF with 16.3 ± 0.1% IDF and 4.5 ± 0.1% SDF. If oil is extracted from soybeans using mechanical pressing, soybean expellers are produced, and they contain 20.6 ± 1.7% TDF, 17.2 ± 1.2% IDF, and 3.3 ± 1.5% SDF, but if oil is extracted using solvents, soybean meal is produced, which contains 18.2 ± 3.3% TDF, 16.0 ± 3.0% IDF, and 2.2 ± 2.3% SDF. Enzyme-treated soybean meal contained 17.2 ± 1.5% TDF, 15.2 ± 1.0% IDF, and 2.1 ± 1.3% SDF, whereas fermented soybean meal contained 17.4 ± 3.4% TDF, 14.8 ± 3.1% IDF, and 2.6 ± 1.4% SDF. If soybean meal is processed by removing soluble carbohydrates, soy protein concentrate is produced, which contains 19.6 ± 3.3% TDF, 17.7 ± 3.0% IDF, and 2.0 ± 1.5% SDF, and if further processed to increase protein concentration, soy protein isolate is produced. This ingredient contains 2.8 ± 1.4% TDF, 2.3 ± 1.7% IDF, and 0.5 ± 0.3% SDF. Soybean hulls contained 67.8 ± 2.0% TDF, which corresponded to 62.2 ± 2.3% IDF and 5.6 ± 1.8% SDF, but if extruded, soybean hulls contained 67.5 ± 0.3% TDF with 60.2 ± 0.2% IDF and 7.3 ± 0.1% SDF. Sunflower expellers contained 41.0% TDF, with 36.9% IDF and 4.1% SDF, whereas sunflower meal contained 43.4 ± 6.4% TDF with 39.6 ± 6.7% IDF and 3.9 ± 2.3% SDF,

and sunflower protein concentrate contained 5.3%, with 2.7% IDF and 2.6% SDF.

The IDF to SDF ratio in co-products from 00-rapeseed, canola, soybeans, and sunflower meal were within a relatively narrow range of 5:1 to 11:1, and copra meal and copra expellers were also within this range. However, for most oilseeds, expellers had a slightly lower IDF to SDF ratio than solvent extracted meals. The greatest IDF to SDF ratio was observed for palm kernel co-products that had a ratio greater than 20:1. In contrast sunflower protein concentrate and soy protein isolate had a IDF to SDF ratio of less than 5:1.

## Fiber in other plant-based feed ingredients

The TDF in other plant-based feed ingredients was in the range of 3% to 82% (Table 4). Alfalfa meal contained 49.5% IDF and 2.9% SDF, giving a TDF of 52.4%. Flaxseed meal contained 53.5% TDF with 48.3% IDF and 5.2% SDF. Pulses, such as faba beans, field peas, and lupins, contained 16.3%, 15.7 ± 0.8%, and 43.5% IDF and 1.5%, 1.7 ± 0.4%, and 2.8% SDF, giving a TDF of 17.8%, 17.4 ± 1.1%, and 46.2%, respectively. If peas are processed, pea flakes may be produced, and pea flakes contained 17.3 ± 6.6% TDF, 15.1 ± 4.1% IDF, and 2.2 ± 2.5% SDF, whereas pea protein concentrate contained 8.7 ± 2.4% TDF, 7.6 ± 1.6% IDF, and 1.1 ± 0.8% SDF, and pea starch contained 2.4 ± 1.7% TDF, 2.2 ± 1.5% IDF, and 0.2 ± 0.3% SDF. Chicory pulp contained 47.0% IDF and 15.2% SDF, giving a TDF of 62.2%, whereas sugar beet pulp contained 64.0 ± 7.1% TDF, 49.1 ± 6.8% IDF, and 14.9 ± 5.2% SDF. Pectin contained 52.9 ± 5.6% SDF, and only 0.5 ± 0.6%

**Table 4** Insoluble dietary fiber (IDF), soluble dietary fiber (SDF), and total dietary fiber (TDF) in other feed ingredients, 88% dry matter (DM) basis.

Feed ingredient	N <sup>1</sup>	DM, %	SD <sup>1</sup>	IDF, %	SD <sup>1</sup>	SDF, %	SD <sup>1</sup>	TDF, %	SD <sup>1</sup>	IDF/SDF
Alfalfa meal	1	84.6	–	49.5	–	2.9	–	52.4	–	17.1
Chicory pulp	1	89.8	–	47.0	–	15.2	–	62.2	–	3.1
Faba beans	1	88.9	–	16.3	–	1.5	–	17.8	–	10.9
Field peas	12	89.4	1.1	15.7	0.8	1.7	0.4	17.4	1.1	9.2
Flaxseed meal	1	92.9	–	48.3	–	5.2	–	53.5	–	9.3
Lupins	1	88.8	–	43.5	–	2.8	–	46.2	–	15.5
Pea flakes	2	89.3	0.7	15.1	4.1	2.2	2.5	17.3	6.6	6.9
Pea protein concentrate	2	97.0	4.3	7.6	1.6	1.1	0.8	8.7	2.4	6.9
Pea starch	5	90.2	2.4	2.2	1.5	0.2	0.3	2.4	1.7	11.0
Pectin	2	85.3	7.7	0.5	0.6	52.9	5.6	53.5	5.0	–
Pistachio	2	96.7	0.9	13.5	1.5	1.0	0.3	14.4	1.9	13.5
Pistachio blanks	1	93.9	–	69.9	–	6.1	–	76.0	–	11.5
Pistachio shell powder	2	97.3	1.4	77.7	8.9	4.5	4.9	82.3	4.0	17.3
Potato protein concentrate	11	94.2	4.6	5.6	2.3	0.1	0.2	5.7	2.4	56.0
Sugar beet pulp	25	89.4	3.9	49.1	6.8	14.9	5.2	64.0	7.1	3.3

<sup>1</sup>N = number of samples analyzed; SD = standard deviation.

IDF, giving a TDF of 53.5 ± 5.0%. Pistachio contained 14.4 ± 1.9% TDF with 13.5 ± 1.5 IDF and 1.0 ± 0.3% SDF, whereas pistachio blanks contained 76.0% TDF with 69.9% IDF and 6.1% SDF, and pistachio shell powder contained 82.3 ± 4.0% TDF with 77.7 ± 8.9% IDF and 4.5 ± 4.9% SDF. Potato protein concentrate contained 5.6 ± 2.3% IDF and 0.1 ± 0.2% SDF, giving a TDF of 5.7 ± 2.4%.

The IDF to SDF ratio in almost all analyzed other plant ingredients was between 6:1 and 17:1 indicating relative consistency among ingredients despite large variations in TDF concentrations. However, chicory pulp and sugar beet pulp had an IDF to SDF ratio of less than 4:1, whereas potato protein concentrate had a ratio of 56:1.

## Discussion

Complete chemical composition analysis of feed ingredients requires accurate measurements of all nutrients and energy-contributing components (Shurson et al. 2021). However, there are no standardized methodologies to analyze feed ingredients, and the values presented in feed composition tables often do not add up to 100% (Sauvant et al. 2004; NRC 2012). One of the reasons for this discrepancy is that there are inaccuracies in analysis of fiber, because some of the available fiber analysis procedures underestimate the fiber concentration in feed ingredients. Indeed, to overcome these difficulties, the fiber in feed ingredients is sometimes calculated rather than analyzed (Blok et al. 2015; Aldenhoven et al. 2020). Among the several methods available to analyze fiber (ie crude fiber, detergent fiber, TDF, non-starch polysaccharides plus lignin), the TDF procedure by the enzymatic-gravimetric method is more time-consuming than the crude fiber and detergent methods, but this method accounts for most of the fiber in feed ingredients because it includes all high molecular weight soluble fiber, including the majority of the soluble dietary fiber, which are not accounted for in the crude fiber or the detergent fiber analyses (Mertens 2003; Fahey et al. 2019). Compared with calculating the TDF

after determining non-starch polysaccharides and lignin via the Uppsala or the Englyst methods, the TDF procedure by the enzymatic-gravimetric method is robust and rapidly reproducible (Mertens 2003; Shurson et al. 2021; Lancheros et al. 2022) and is particularly valued for its ability to provide consistent results across different laboratories (McCleary et al. 2012; Nguyen et al. 2019).

The accuracy of the TDF method over the crude fiber and detergent methods is demonstrated by the fact that TDF values obtained by this procedure result in low calculated rest fractions in most feed ingredients, indicating small differences between analyzed proximate components and the concentration of dry matter (Fanelli et al. 2023a, 2023b, 2023c, 2024; Ruiz-Arias et al. 2025). However, a limitation is that values for TDF obtained by the enzymatic-gravimetric method only include all soluble non-starch polysaccharides that precipitate in 78% ethanol, but the resistant starch and undigestible soluble oligosaccharides that remain soluble in ethanol are excluded from the analysis (ie oligosaccharides with a low degree of polymerization [low-molecular-weight carbohydrates] McCleary 2023), indicating that these compounds can be equal to those calculated as the rest fraction. However, their exclusion might not be critical in cereal grains and cereal grain co-products because the low-molecular-weight fibers represent a very small fraction of these ingredients. In contrast, oilseed co-products have greater concentration of sucrose and soluble galacto-oligosaccharides, such as raffinose, stachyose, and verbascose, which can have up to more than 15%, and are not analyzed by the enzymatic-gravimetric method (Middelbos and Fahey 2008; Navarro et al. 2018; Lannuzel et al. 2022; McCleary 2023). Therefore, to fully account for all nutrients in oilseeds and oilseed co-products, specific analyses for the low molecular weight carbohydrates are needed (Navarro et al. 2018).

The feed industry has integrated plant-based ingredients into animal feed, including raw materials such as cereal grains, oilseeds, legumes, roots, and tubers, as well as co-products from the human food processing industry (milling, oil, and sugar

extraction), distillery, or industrial processes that result in products that are not usable for human consumption (Ominski et al. 2021). However, these ingredients have variable nutrient composition, and cereal grain co-products from the food industry often have greater concentrations of dietary fiber than the intact cereal grains (Serena et al. 2007; Woyengo et al. 2014). In monogastric animals, the dietary fiber part of feed ingredients pass mostly undigested through the small intestine and become available as a substrate for fermentation by microbes in the large intestine. However, utilization of dietary fiber by monogastric animals varies from 0% to 100% and depends on the activity of the microbiome to hydrolyze and ferment fiber, which also depends on physicochemical characteristics of the fiber, the degree of lignification, the concentration in the diet, and the physiological status of the animal (Kerr and Shurson 2013; Stein 2019). Low fermentation of fiber in monogastric animals results in increased manure excretion and reduced digestibility of nutrients and energy due to the influence of fiber on luminal viscosity or through encapsulation of nutrients (Bachmann et al. 2021; Hung et al. 2022; Lee et al. 2022). Despite these negative impacts of fiber, there is an increasing interest in adding dietary fiber to animal diets due to its influence on intestinal motility and gut development, modulation of feed intake, and establishment of microbial populations that may benefit animal performance, health, and welfare (Bach Knudsen et al. 2013; Jha et al. 2019; Hu et al. 2023). This change is also a consequence of the increased usage of cereal grains and oilseeds in the biofuels industry and the intent to reduce feed costs by including available co-products in diets for poultry and livestock. Likewise, the increased interest in minimizing the impact of the livestock industry on the external environment by reducing greenhouse gas emissions, land use, and water consumption and improved sustainability has resulted in greater focus on using co-products in diets (Jha and Berrocoso 2015; Shurson 2017; Ominski et al. 2021). This in turn has increased the interest in quantifying SDF, IDF, and TDF in feed ingredients, but until now, no comprehensive account of these values has been published, and the current publication, therefore, fills this gap. To increase the number of samples included in this work, data from two laboratories were combined. This was possible because we previously demonstrated that there are no differences in results obtained at the Trouw Nutrition Laboratory (Boxmeer, The Netherlands) and the Monogastric Nutrition Laboratory at the University of Illinois (Nguyen et al. 2019).

Among cereal grains, oats contained the most TDF and IDF, followed by barley and rye, which is in agreement with previous data (Bach Knudsen 1997; Rodehutscord et al. 2016; Menkovska et al. 2017). Oats, paddy rice, and barley are harvested with the hull attached, which accounts for the majority of fiber in these grains; however, some fiber can also be present in the pericarp and cell walls of the aleurone layer (Serna Saldívar and Sánchez Hernández 2020), which is in agreement with lower TDF values in dehulled barley, dehulled oats, and brown rice compared with barley, oats, and paddy rice. Rye has greater concentration of TDF compared with corn, sorghum, and wheat, which is in agreement with previous data (Bach Knudsen 1997; Rodehutscord et al. 2016). The concentration of TDF in sorghum, corn, and wheat are also in agreement with previous data (Bach Knudsen 1997; Picolli da Silva and Santorio-Ciocca 2005;

Rodehutscord et al. 2016; Menkovska et al. 2017), with most of the fiber consisting of IDF in the pericarp and aleurone layers. The IDF in cereal grains consists mainly of arabinoxylans, as the major polymer in the cell wall, followed by cellulose and lignin (Bach Knudsen 2014; Jaworski et al. 2015; Navarro et al. 2018). Oats, rye, and barley contain more SDF than corn, wheat, and sorghum because of the mixed linked  $\beta$ -glucans that are located in the endosperm and aleurone cell wall of these grains (Bach Knudsen 2014). Wheat and brown rice also contain  $\beta$ -glucans, but in much lower concentrations than barley, oats, or rye (Lee et al. 2007; Biel et al. 2020). In contrast, rye SDF is composed mainly of soluble arabinoxylans, a polysaccharide made up of a chain of xylose units with sidechains of arabinose, associated with the starchy endosperm (Bach Knudsen and Lærke 2010). Hybrid rye contains more SDF than conventional rye, which is likely due to the improved grain structure resulting from the hybridization process (Miedaner and Laidig 2019).

The observation that barley and rye had lower IDF to SDF ratios than all other grains is a result of barley and rye containing more SDF than the other cereal grains. In contrast, sorghum has a very low concentration of SDF, and therefore, a high IDF to SDF ratio. These differences imply that cereal grains may result in different fermentation patterns in the intestines because SDF is much more fermentable than IDF (Jaworski and Stein 2017). The reduced IDF to SDF ratio in extruded grains compared with non-extruded grains is a result of the partial solubilization of fiber that takes place during extrusion, which also results in increased digestibility of energy in extruded grains compared with non-extruded grains (Rojas et al. 2016; Rodriguez et al. 2020).

Among cereal grain co-products there is a wide range in TDF depending on the parts of the grain that are retained after processing, but most cereal grain co-products have greater TDF than cereal grains. In general, the TDF in cereal grain co-products consists of mainly IDF, whereas they are low in SDF, but the monosaccharide composition of TDF in cereal grain co-products reflect the composition in the parent grains (Jaworski et al. 2015). Among the cereal grain co-products analyzed, oat hulls contained the most TDF and IDF, which is a result of the fibrous outer layer of the oat grain and has also been previously reported (Bach Knudsen 1997; Flis et al. 2017). Corn bran, corn germ meal, corn gluten feed, and corn DDGS also have high TDF concentration, with IDF as the dominant fraction (Bach Knudsen 1997; Stein et al. 2016). In contrast, corn gluten meal has low TDF because it is the product resulting from separating the bran-free corn into the protein fraction and starch by centrifugation (Rausch and Belyea 2006; Jaworski et al. 2015). Similarly, high-protein DDGS and corn fermented protein are obtained by separating fiber and oil from corn before fermentation or from DDGS after fermentation, resulting in products with greater protein and less fiber compared with conventional corn DDGS (Espinosa and Stein 2018; Acosta et al. 2021). Barley rootlets is a co-product from the malting industry and has greater TDF than both barley grain and malted barley because fiber gets concentrated after the removal of starch during fermentation (Neylon et al. 2020). Sorghum DDGS had a TDF concentration that was not different from corn DDGS, which is in agreement with previous data (Sotak et al. 2014).

Rice bran had high TDF because it is mainly composed of pericarp, aleurone, and germ of the rice kernel, whereas rice mill

feed is a mixture of rice hulls and rice bran. However, rice hulls contain cellulose, xylans, and lignin, and because rice mill feed contains rice hulls, the concentration of TDF is greater in rice mill feed than in rice bran (Serna Saldívar and Sánchez Hernández 2020). In contrast, broken rice, rice flour, and rice protein contain very little TDF, mostly due to the removal of the outer layers (ie hulls and bran) of the rice kernel during processing to separate the starchy endosperm from the rest of the kernel (Casas et al. 2019). Bakery meal consists of food leftovers such as unsalable bread, cookies, dough, flour, cakes, and other products from the food industry; therefore, bakery meal is low in TDF because wheat flour is the main ingredient in most bakery products (Liu et al. 2018). Among wheat co-products, wheat bran is made of the coarse outer layers of the wheat kernel, whereas wheat middlings contain finer product in a mix of bran, germ, and some endosperm. Therefore, wheat bran and wheat middlings contain more TDF than wheat DDGS and wheat gluten feed, which has also been reported previously (Rosenfelder et al. 2013; Stas et al. 2024).

The observation that the IDF to SDF ratio was within a narrow range for co-products from corn, sorghum, and wheat indicates that the processing itself does not change the ratio between IDF and SDF, and there appears to be no solubilization of the fiber happening during processing. This observation is in agreement with data comparing the composition of fiber in corn, sorghum, and wheat and several co-products from these grains (Jaworski et al. 2015). The high IDF to SDF ratio in oat hulls is a result of the very insoluble nature of the fiber in the hulls in oat grains and the high concentration of lignin in oat hulls (Back Knudsen 1997).

The fiber in oilseeds is different from fiber in cereal grains and mainly consists of cellulose, xyloglucans, and pectic polysaccharides (Choct 2015; Navarro et al. 2019). The variation in the TDF among oilseed co-products is due to differences in the composition of the oilseed, the amount of residual oil in the co-products depending on if solvent extraction or the mechanical press method was used to remove oil, and the amount of hulls added back to the co-product after oil extraction (Lannuzel et al. 2022). 00-Rapeseed, which has been selected to be low in both glucosinolates and erucic acid, is called canola in Canada and the United States, and meal and expellers from both canola and 00-rapeseed can be used as feed ingredients for animals (Maison et al. 2015). Therefore, the lack of differences in the concentration of TDF between 00-rapeseed meal and canola meal was expected and is in agreement with previous data (Bach Knudsen 1997; Omotosho et al. 2024). The TDF in copra expellers and copra meal, which is derived from the dried kernel of coconut, as well as in palm kernel meal and palm kernel expellers, are in agreement with previous data, and the fiber in these ingredients is high in  $\beta$ -mannans, xylans, pectins, and cellulose (Düsterhöft et al. 1991; Bach Knudsen 1997; Fanelli et al. 2023c). The fiber in cottonseed meal is between 14.5% and 30% (Ma et al. 2018), and the analyzed TDF in this experiment was within this range. Soybean hulls consist of the soybean seed coat, and the fiber in soybean hulls includes cellulose, soluble arabinogalactans, and pectic polysaccharides, and TDF, IDF, and SDF obtained in this work agree with previous values (Middelbos and Fahey 2008; Kim et al. 2025). The analyzed TDF in full-fat soybeans is also in agreement with previous data (Middelbos and Fahey 2008; Ruiz-Arias et al. 2025). Fermentation or enzyme

treatment can reduce the fiber in oilseed co-products as well as reduce other antinutritional factors, as observed for 00-rape-seed expellers, soybean meal, and full-fat soybeans (Zhu et al. 2023). Processing to purify protein from oilseeds results in the removal of fiber, and high-protein ingredients such as soy protein concentrate, soy protein isolate, or sunflower protein concentrate were low in TDF, which is in agreement with previous data. Sunflower meal contains more TDF than soybean meal and canola meal because of the high concentration of hulls (Lannuzel et al. 2022).

The relatively constant IDF to SDF ratio among most oilseed co-products indicates that despite differences among these ingredients in TDF, the ratio between IDF and SDF is not changed. The observation that expellers for most oilseeds had a slightly lower IDF-to-SDF ratio than solvent-extracted meals indicates that the heat that is generated during mechanical expelling of oil may solubilize a small portion of the IDF in the ingredients.

Other plant-based feed ingredients had a broad range of TDF concentrations, mainly because the TDF reflects both plant origin and different processing characteristics. Pistachio shell powder and pistachio blanks had the greatest TDF among all ingredients analyzed and are composed primarily of cellulose and xylans (Kim et al. 2024). Although high in TDF, pistachio shell powder can be used in diets for sows (Kim et al. 2024). Sugar beet pulp and chicory pulp are high in TDF and have high concentration of SDF due to the high concentration of pectin in the fiber fraction (Bach Knudsen 1997; de Godoy et al. 2015; Wang et al. 2016). The majority of TDF in field peas, faba beans, and lupins are present in the seed coat and cell walls of the cotyledons and include xyloglucans and cellulose, which are included in IDF. The high TDF in alfalfa meal is due to its leaf and stem structure, whereas the high TDF in flaxseed meal is due to the seed outer layer that consists of cellulose and lignin (Bach Knudsen 1997; Kajla et al. 2015). Processing into protein concentrates or pure starch eliminates the fiber, which is the reason for the low TDF in potato protein, pea protein concentrate, and pea starch due to the removal of hulls and other fibrous components during fractionation (Messina et al. 2025).

The pulse ingredients had an IDF to SDF ratio that was close to the ratio observed in corn and wheat and co-products from these grains, which indicates that inclusion of pulse crops or co-products from pulse crops likely will not change the IDF to SDF ratio in a diet. The very low IDF to SDF ratio in chicory pulp and sugar beet pulp, despite high concentrations of TDF in these ingredients, is a result of the high concentration on SDF in pulp from sugar beet and chicory production. These ingredients, therefore, likely result in greater water-binding capacity in the intestinal tract, which likely reduces physical activity of the animals (Rijnen et al. 2002). Indeed, sugar beet pulp is often included in diets for gestating sows who may benefit from being fed ingredients that result in a slower emptying of the intestinal tract and a steadier supply of energy between meals (Wisbech et al. 2024). In contrast, alfalfa meal and pistachio shell powder, which also have high concentrations of TDF have a greater IDF to SDF ratio because of a lower concentration of SDF, and these ingredients, therefore, may not result in as much water binding in the intestinal tract as sugar beet pulp and chicory pulp. The very high IDF to SDF ratio in potato protein concentrate is of minor importance because the TDF is low in this ingredient.

Prediction equations are sometimes used to predict the energy concentration of animal diets and feed ingredients using crude fiber or detergent fiber values (Noblet and van Milgen 2004; Sung and Kim 2021). Although NDF can be used for predicting digestible energy in diets for pigs (Choi et al. 2020), this may result in erroneous prediction equations because the soluble fiber, which is not included in the NDF, may contribute energy to the ingredients and diets. To predict the energy value of a feed ingredient, it is important that all energy-contributing components are accounted for (Navarro et al. 2018). Specifically, it may be important to incorporate SDF into prediction equations for energy because SDF is much more fermentable than IDF (Urriola et al. 2010; Jaworski and Stein 2017). Therefore, research is warranted to develop equations incorporating IDF, SDF, and TDF values into prediction equations for net energy. Likewise, additional research is required to improve analytical methods that account for all low-molecular-weight carbohydrates in feed ingredients and evaluate their energy contribution to animal diets.

## Conclusions

Describing insoluble and soluble fiber fractions in feed ingredients using the enzymatic-gravimetric method allows for accounting for a larger part of fiber in feed ingredients and provides information about fiber characteristics of cereal grains, cereal grain co-products, oilseeds and oilseed co-products, and other feed ingredients. However, for some oilseed meals, additional analyses of the low-molecular-weight carbohydrates are needed to account for the entire ingredient. The present work provides a database that includes the majority of the feed ingredients commonly used in diets for pigs and poultry. By distinguishing between soluble and insoluble fiber fractions, improved information about the energy value of feed ingredients can potentially be obtained. More research is recommended to understand the effects of physicochemical properties of fiber besides solubility and fermentability to enable the strategic inclusion of ingredients in diets for animals, as well as using TDF values for energy prediction equations.

## Author contributions

Jessica P. Acosta (Data curation, Formal analysis, Investigation, Methodology, Resources, Writing—original draft), Lia V. Guardiola (Data curation, Formal analysis, Investigation, Methodology, Writing—review & editing), and Neil W. Jaworski (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing—review & editing), Hans H. Stein (Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing—review & editing)

## Funding

No funding was received for this work.

## Data availability

All generated data are included in the manuscript.

*Conflict of interest statement.* The authors have no real or perceived conflicts of interest.

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