THESIS

PATRICK TAMATEY
M.Sc. Animal Nutrition and Feed Safety Engineering

Kaposvar
2023

Hungarian University of Agriculture and Life Sciences
Kaposvar Campus

M.Sc. Animal Nutrition and Feed Safety Engineering

NUTRITIONAL EVALUATION OF EUROPEAN SOYBEAN MEAL PROCESSED WITH NOVEL TECHNOLOGIES AS REGARDS THE ILEAL DIGESTIBILITY OF AMINO ACIDS IN WEANED PIGLETS

Supervisor:	Ass. Prof. Veronika Halas
	Head of Department
Author:	Patrick Tamatey
Neptun code:	BLAIGO
Institute/Department:	Physiology and Nutrition

Kaposvar
2023

ABSTRACT OF THESIS

NUTRITIONAL EVALUATION OF EUROPEAN SOYBEAN MEAL PROCESSED WITH NOVEL TECHNOLOGIES AS REGARDS THE ILEAL DIGESTIBILITY OF AMINO ACIDS IN WEANED PIGLETS

PATRICK TAMATEY
MSc. Animal Nutrition and Feed Safety Engineering
Institute of Physiology and Nutrition

Thesis advisor: Ass. Professor Veronika Halas
Head of Department
Department of Farm Animal Nutrition

In this study, we compared the nutritive value of novel soy products, flaking cooking pressing, and extrusion pressing process of dehulled beans (FCP-DH and EP-DH, respectively), and flaking cooking pressing and extrusion pressing process of whole beans (FCP-WB and EP-WB, respectively) to a high-quality commercial soybean meal (CNTR) and casein (Casein). For that purpose, performance trials, nitrogen (N)-retention, and *post-mortem* digestibility, that is, Apparent Ileal Digestibility (AID), and Standardized Ileal Digestibility (SID) trials were carried out. The trial products were formulated from soybean of European origin, and the commercial soybean meal was from the USA. Casein was chosen as a reference protein source. The study was conducted with a total of 70 Danbred weaned (5-week-old) barrows, within 2 replicates. Piglets were randomly allocated to each of the 7 treatments (5 animals/treatment/replicate). The experiment consisted of a 28-day-long performance trial and a 5-day-long retention trial.

During the performance trial, two groups (10 pigs/replicate) received the control diet, and the others were assigned to diets containing soybean meal (SBM) from each novel technology or casein. During retention studies, either of the groups that received commercial SBM diets was fed N-free diet to determine endogenous amino acid losses. At the end of the retention study, the ileal digestibility of amino acids was determined *post-mortem*. The experimental data were analyzed with two-way ANOVA (SAS, 2004). It was observed that except for FCP-DH, all the other European soya products were as good as the commercial SBM. In general, except for FCP-DH, there was no difference in the impact of the feed processing methods on the nutritive value of soya products. In conclusion, inadequate thermal processing of FCP-DH could have negatively affected the nutrient digestibility of the feed. I recommend the need for further studies to explain the possible mechanisms of ensuring adequate thermal processing of FCP-DH.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0. INTRODUCTION

1.1. Background of the study

Currently in Europe, protein requirements are mainly covered by soybean meal, which is widely used in diets for farm animals. Soya bean meal is formulated usually based on the two most important components, which are protein and oil (JIDEANI, 2011). Soybeans contain 18.6% oil and 78.7% of soybean meal with the rest being surplus (DEI, 2011). It is highly preferred because it contains a high CP content ranging between 44-48% and contains highly digestible amino acids such as lysine, tryptophan, and isoleucine. The amino acid content is well balanced except for methionine (DEI, 2011). The listed amino acids are the most limiting amino acids in corn, wheat, sorghum, and barley (DEI, 2011). The methionine deficiency in soybean however can easily be corrected in monogastric diets using synthetic sources of methionine (YANG et al., 2020). Soybeans are considered a protein source, but they also contain about 30 to 35% carbohydrates, making soybeans a major carbohydrate contributor to livestock feed (KARR-LILIENTHAL et al., 2005).

Soybean meal and soybean products however contain relatively high amounts of minerals such as potassium, magnesium, and sulfur, and pigs fed diets containing soybean products do not need any of these minerals as supplements in their diets (EDEMA et al., 2005). Soybean oil on the other hand comprises mainly unsaturated fatty acids and less than 15% of the fatty acids in soybean oil are saturated fatty acids. Roughly 50% of the fatty acids in soybean oil are linoleic acid (C18:2) and an additional 22% are accounted for as monounsaturated fatty acids. Soybean oil does, however, also contain more than 6% linolenic acid (C18:3), which may have anti-inflammatory properties in diets (NRC, 2012). Despite the positive effect of soybean on livestock production, it cannot be fed unprocessed because it contains some levels of antinutritional factors (ANFs). Their occurrence exerts a negative impact on the dietary quality of the protein (DEI, 2011). The main ANFs are protease inhibitors (trypsin inhibitors) and lectins (LIENER, 1994), which fortunately can be destroyed by heat treatment (AMER et al., 2020). Dehulled soybean meal has been reported by (AMER et al., 2020) to be high in energy (around 5%) and in lysine by 10 to 15%. The purpose of this study was to evaluate the nutritive impact of processed European soybean using different novel technologies on the ileal amino acid digestibility, growth performance, and nitrogen retention in weaned pigs.

1.2. Aim of the study

The purpose of the piglet study was to determine the nutritive value as well as apparent and standardized ileal digestibility of amino acids of European soybean meal processed with different technologies.

1.3. Specific objectives

1. Undertake performance trials.
2. Perform Nitrogen-retention trials.
3. Run *post-mortem* digestibility trials to determine the apparent and standardized ileal digest amino acid content of different products.

2.0. LITERATURE REVIEW

This chapter presents an overview of previously published works on the topic under study. The literature review of this study assessed the global production, nutritive value, methods of processing as well as digestibility of amino acids of European soybean meal processed with different technologies.

2.1. Global production of soybean

Soybeans have been cultivated as a commercial crop primarily in temperate regions for so many years. At first, it was grown in northern Asia and more recent decades in North America and the South of Latin America (KHOJELY et al., 2018). Global production of soybeans has increased rapidly over the past five decades (TROSTLE, 2010). As of 2009/2010, global production of soybean seeds stood at about 260 million tons. The main producers are Brazil, the USA, China, and Argentina (BANASZKIEWICZ, 2011). These countries altogether produced about 87% total quantity of soybean seeds. Except for China, these countries are the main exporters of soybean seeds with the USA exporting about 44% of the soybean seeds, Brazil exporting 33% and Argentina exporting about 11% (RAO and REDDY, 2010). A report by BANASZKIEWICZ, (2011) also shows that about 90% of soybeans are used as feed for livestock. Argentina exports about 37%, Brazil (about 29%), and the USA (about 8%) of the total soybean as feed for livestock (WILCOX, 2004). *Table 1* shows the main countries involved in the global production of soybean seeds.

Table 1 **Global production of soybean seeds**

Country	**Production, million tons**
United States of America	94.8
Brazil	68
Argentina	54.5
China	14.5
India	9.1
Paraguay	6.7
Other	13
Total	**260.6**

(*RYNEK RZEPAKU, 2010)*

More than half of the soybeans produced by these countries are used for animal feed. This is because global meat production has more than tripled over the last five decades (RITCHIE et al., 2017). A large portion of soybeans are processed into oil and soybean meal, and approximately 75% of the soybean meal that is processed is fed to monogastric (CHEN et al., 2020). The United States, Brazil, and Argentina remain the largest soy producers. Together they account for over 80% of the world's soy production (MEADE et al., 2016). Apart from these countries, China (14 million tons), India (13.8 million tons), Paraguay (11 million tons), Canada (7 million tons), and Ukraine (4.5 million tons) are the next largest producers of soy respectively (FRANKE et al., 2011). The European Union, however, produced about 3 million tons in 2018, which is by far less than 1% of world soy production (FUCHS et al., 2019). The United States and Brazil have achieved the strongest yield increases among the producers of soybean (JÚNIOR et al., 2019).

The European Union is the world's largest importer of soybeans, and soybean products (MCFARLANE and O'CONNOR, 2014). The 27 EU countries altogether in 2007 imported 24.8 million tons of soy meal, 15.5 million tons of soybeans, and almost 1 million tons of soy oil (GE et al., 2021). Furthermore, in 2018, the European Union imported 15.54 million tons of soybeans, 263,000 tons of soybean oil, and 18 million tons of soybean meal (WALLACE, 2020). Compound feed production in Europe has been unstable with a slight upward trend since 2009. This implies the relative use of soy as a feedstock declined around this period (MUELLER et al., 2011). Nonetheless, between July 2019 to June 2020, there has been a rise in soybean meal imports. This was estimated at 16.87 million metric tons (WILKINSON et al., 2022). At the same time, raw soybean purchases were up by 1% at 14.17 million metric tons (NORDIER, 2021). Demand for soybeans is expected to continue increasing in the coming years due to a lot of factors. Meat and soy-based health consumption are on the increase, and population figures are slated to increase (TESHALE et al., 2021). Considering the estimated increase in global meat consumption, this is expected especially among the growing middle class in developing economies, this means that there will be strong demand for soybeans as the animal feed of choice (GASCO et al., 2021). *Table 2* shows the number of soy imports from soy-producing countries into the EU from September 2006 to August 2007

Table 2 EU-27 soy imports by country of origin in 2007

Country of origin	Soybeans* 1,000 tonnes	Soy oil 1,000 tonnes	Soy meal 1,000 tonnes
United States	3,373	6	159
Canada	780		6
Norway		71	147
Argentina	193	221	15,185
Brazil	9,820	619	9,251
Paraguay	994		1
Uruguay	87		2
Other countries	213	44	74
Total	**15,460**	**961**	**24,827**

* Soybeans: September 2006 - August 2007.

(OIL WORLD, 2008)

About two-thirds of soybeans used in the EU feed industry are imported, mostly from the countries shown in *Table 2* above (OIL WORLD, 2008). These countries are progressively growing new genetically modified (GM) soybean varieties (VARACCA and SCKOKAI, 2020). Over the years, there have been difficulties with the import of soy products because of the EU's 'zero tolerance policy' on the presence of traces of unauthorized GM crops (WAGER and MCHUGHEN, 2010). There have been instances where soybean and soybean meal consignments have been disallowed at the port because of the *low-level presence* (LLP) of unapproved GMOs (WAGER and MCHUGHEN, 2010). When soy imports into the EU are curtailed at any point, the EU meat markets would be predominantly affected because of more costly and limited feed substitutions. This could weaken the competitiveness of the EU livestock sector and reduce the EU shares in domestic and world markets (WESTHOEK et al., 2014).

2.2. The nutritional profile of soybean

Soybeans are rich in vitamins and minerals (ERBERSDOBLER et al., 2017). A large portion of the phosphorus in soybeans is bound to phytic acid, and pigs cannot utilize most of the phytic acid-bound phosphorus because they produce little intestinal phytase (HUMER et al., 2015). Therefore, to make sure that there is enough digestible phosphorus in the diet, it is often necessary to add supplemental phosphorus in the form of monocalcium phosphate or dicalcium phosphate, which increases diet costs (HUMER et al., 2015). However, the macronutrient profile of soybeans differs in some important ways from other legumes. It is an ingredient with a high feed value for livestock because it represents the main protein and essential amino acids source for livestock (FLORET et al., 2021). Soybean protein is rich in lysine, threonine, and tryptophan, and these are the most limiting amino acids in corn, wheat, and barley (DEGOLA et al., 2019).

Despite the low levels of sulfur amino acids, soybean is the main source of lysine in swine diets and could be complemented by barley or wheat in diet formulation (DEGOLA et al., 2019). Nevertheless, soybeans contain a lot of antitrypsin, urease, and lectins which can be minimized through thermal processing (REAL-GUERRA et al., 2013). It also contains glycinin and ß-conglycinin, which can cause an immune response, damage the intestinal mucosa, and cause diarrhea in young animals if soybean is not processed appropriately (REAL-GUERRA et al., 2013). Soybeans contain two types of carbohydrates: structural and non-structural carbohydrates. The structural carbohydrates include cellulose and hemicellulose, and the non-structural carbohydrates include sugars and oligosaccharides (HUSSAIN et al., 2019). On the feed market, soybean meal is usually standardized on 44 to 49% of the protein basis (ENSMINGER et al., 1990).

The crude protein content of soybean is 40% and contains about 20% fat. It has a lysine proportion of (6.2g/16gN) and a cysteine content of (2.9g/16gN) (NRC, 1998). The water content of soybean is estimated to be around 5.6 to 11.5%. Crude ash content ranges from 4.5 to 6.4%, NDF ranges between 10 to 14.9%, ADF content varies from 9 to 11.1%, and carbohydrate between 31.7 to 31.85% basis (ENSMINGER et al., 1990; NRC, 1998; POULTRY FEEDING STANDARDS, 2005). The starch content of soybean is very minute (4.6 to 7%). The lysine content is very impressive and so are the isoleucine, valine, and threonine contents. *Table 3* below gives an account of the various amino acids as a percentage of crude protein.

Table 3 **The quality of protein in soybean meal expressed as the percentage of each amino acid as a percentage of crude protein (CP)**

Item	**%**	**%CP**
Crude protein	47.3	-
Amino acids		
Isoleucine	2.14	4.5
Lysine	2.96	6.2
Methionine	0.66	1.4
Threonine	1.86	3.9
Tryptophan	0.66	1.4
Valine	2.13	4.7

(NRC, 2012)

2.3. Full-fat soybean and soybean meal

Full-fat soybean is whole soybeans before the oil is extracted. A variety of procedures are applied to extract the oil from the soya (CAMPBELL et al., 2011). All the procedures have a different effect on product quality depending on the degree of thermal energy applied (CAMPBELL et al., 2011). Generally, soybeans are processed into defatted diets for feed formulation, especially for monogastric (PEREIRA et al., 2020). Nevertheless, the number of full-fat soybeans used has been increasing in the livestock industry due to the development of new varieties with limited numbers or levels of ANFs (GU et al., 2010). Then again, properly processed full-fat soybeans are a valuable feed ingredient for animal feeding because of their high energy content. Soybeans contain 18.6% oil and 78.7% of soybean meals with the rest being waste (FEFAC, 2007).

The oil can be removed mechanically, and by solvent procedures (GRAVELLE et al., 2016). There are two main types of soybean meal (BANASZKIEWICZ, 2011). Depending on whether the seed coat is removed or not, soybean can be classified into two categories: dehulled soybean meal and soybean meal (RAGHUVANSHI and BISHT, 2010). They differ in their nutrient composition but are quite high in protein content with a good amino acid balance except for methionine, low in fiber, high in energy, and have little or no ANFs when properly processed (DEI, 2011). Soybean meal has higher protein content as compared to other vegetable protein sources (AJINOMOTO HEARTLAND LYSINE LLC REVISION 7, 2006). Then again, it matches or surpasses them in both total and digestible amino acid content (*Table 4*).

Table 4 **True digestibility (%) of essential amino acids in common oilseed meal proteins for poultry**

	Soybean	Canola	Cottonseed	Palm kernel	Peanut	Sunflower
Crude protein	43.0	36.2	39.6	13.2	45.2	32.8
Amino acid						
Lysine	90.7	78.6	62.8	58.9	78.1	80.4
Methionine	90.6	88.6	71.9	83.7	85.6	91.2
Cystine	82.1	73.1	70.9	66.6	78.5	79.2
Threonine	84.1	77.6	67.2	69.2	83.8	83.7
Tryptophan	87.9	80.0	80.3	-	75.6	-
Arginine	91.1	90.6	85.3	88.6	89.6	93.1
Isoleucine	91.2	89.0	72.8	81.0	89.3	88.9
Leucine	90.7	94.1	74.8	85.0	89.7	88.7
Valine	88.9	87.8	76.3	80.1	88.9	85.8
Histidine	88.5	88.5	64.1	80.3	85.4	86.1
Phenylalanine	91.6	91.6	84.0	85.3	92.3	90.8

(AJINOMOTO HEARTLAND LYSINE LLC REVISION 7, 2006).

2.4. Main soybean products for swine feeding.

Different methods are used in the processing of soybean to enhance their quality (KAUSHIK et al., 2010). The procedures applied either decrease or remove the ANFs in the soya and help to increase the dietary or nutrient content of the feed (MIRGHELENJ et al., 2013). Quite a few steps are used in the making of these products, and they can either give a positive or negative effect on protein quality (GATLIN et al., 2007). The single most important factor in this procedure is the application of heat (WRIGHT, 1981). It affects the value of soybean meals (WRIGHT, 1981). Appropriate processing conditions such as moisture content, heating time, and temperature deactivate ANFs such as trypsin inhibitors and lectins, which results in enhanced performance when fed to monogastric animals (ARABA, 1990). When extreme temperatures are applied in the procedure, especially in the processing of oilseeds, it has harmful effects on proteins and amino acids due to the formation of Maillard reaction products (HURELL, 1990) or denaturation (PARSONS et al., 1992). *Figure 1* is a diagram that shows the processing of soybeans into various protein products.

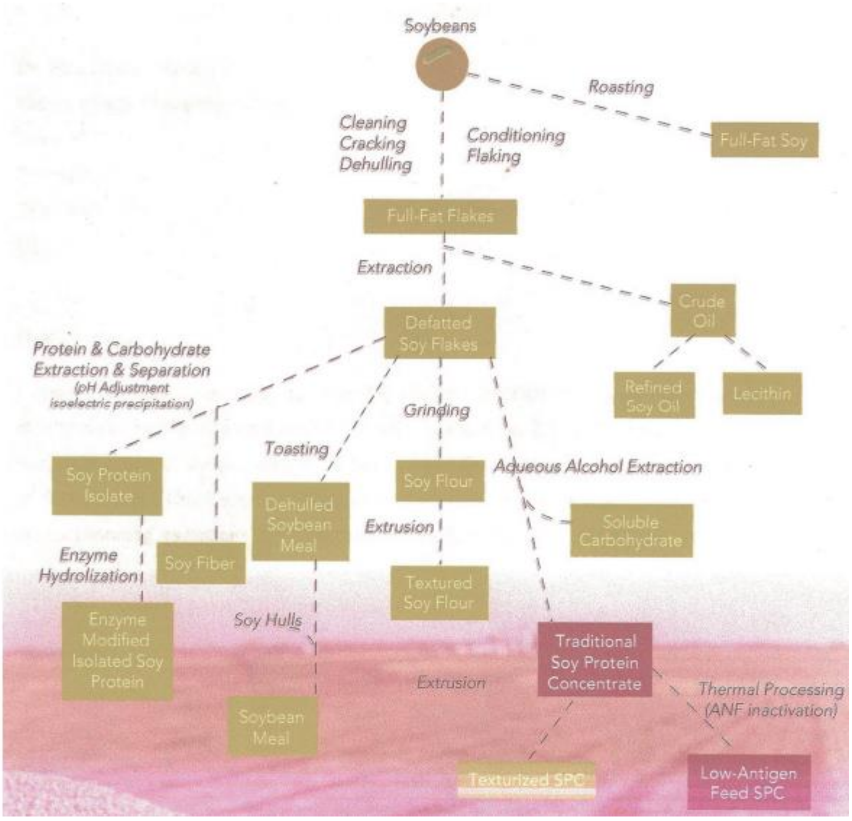

Figure 1 **Processing of soybeans into soybean products**

(USSEC, 2008)

2.5. Some technologies for soybean processing

2.5.1. Dehulling

The first step in processing soybeans is to properly prepare the soybean for dehulling. Before oil extraction, a succession of treatments such as dehulling, cracking, flaking, etc. allows the cell walls to be broken and this makes it ideal for maximum oil yield (DEMARCO and GIBON, 2020). Before dehulling is done, magnets are used to remove metallic substances and impurities that can affect the process. Finally, mechanical rollers are used to make thin flakes and rupture the cells containing the soybean oil (SERNA-SALDIVAR, 2022). There are three different types of dehulling: cold dehulling, warm dehulling, and hot dehulling (DEMARCO and GIBON, 2020). The terms cold, warm, and hot refer to the temperature of the seeds during dehulling (DEMARCO and GIBON, 2020). Moreover, bad-quality seeds require a higher optimal dehulling temperature (CARRÉ et al., 2015). This means that a higher temperature will be needed to get a rational level of dehulling and thus optimal protein content in the meal (CARRÉ et al., 2015). Initially, cold dehulling used to be the most common type and is suitable for all types of soybeans, however, soybeans need to be heated twice, and that is an expensive system with setup costs and expenditures relatively higher compared to the other methods. Warm dehulling, on the other hand, is the most affordable system with a lower setup cost and a single heating step (VAN DOOSSELAERE, 2013). Warm dehulling is an effective means of thorough hull removal in the seed preparation process which ensures the production of high protein, low fiber meal after solvent extraction (VAN DOOSSELAERE, 2013).

2.5.2. Solvent extraction method

Lately, large-scale solvent extraction facilities have been used in place of mechanical oil extraction equipment for processing soybeans (FORE et al., 2011). The solvent process, in which oil is leaked from flakes using hexane, a petroleum product, can easily remove at least 99 percent of the available oil from soybeans (ALI and SINGH, 2010). The protein meal by-product gives large quantities of cheap animal feed and is the base for numerous food and industrial uses. Current technologies for soybean processing come with fewer chemicals and solvent use, less energy consumption, reduced environmental impact, safer process, milder operating conditions, and optimized nutritional properties for the refined oil (ALI and SINGH, 2010). The technology used for the extraction methods is closely associated with the type of oil plant, however, in all cases, the main objective is to ensure that we beat down expenditure as we maximize oil yield (JOOYANDEH, 2011).

2.5.3. Flaking

The main goal of flaking is to expose as much of as possible the oil to the solvent in the solvent extractor. When flaking is done properly, it improves solvent extraction efficiency (PERRIER et al., 2017). During flaking, dehulled soybean is mechanically squeezed into flaked shapes which are about 0.3 to 0.4mm in thickness and 10 to 15mm in diameter (DEMARCO and GIBON, 2020). This procedure opens the cell walls of the seeds and enables the oil to be extracted more readily and efficiently (PERRIER et al., 2017). Flaking machines are used for this procedure, and the machines are designed to convert the dehulled oilseeds into thin flakes for subsequent oil extraction (KAUR et al., 2022).

2.5.4. Extrusion

It involves grinding, crushing, and mechanical processing at high temperatures usually between 130 – 140 °C under high pressure (TAMBE et al., 2021). Soy processed using this technology usually has low levels of anti-nutritional factors, and a high nutrient profile (BORA, 2014). During extrusion, the anti-nutritional factors such as trypsin inhibitors and lectins are removed. Extrusion plays a vital role in monogastric diets by making soybean diets tastier and easier to digest. It also reduces the content of anti-nutritional substances. Compared to conventional soybean, it makes the diet more nutritious, especially in terms of the most valuable nutrients (NIKMARAM et al.,2017).

2.5.5. Cooking

Unprocessed soybeans harbor several anti-growth factors, given this the beans must be cooked before they are used in all pig diets except diets for gestating sows (LAPEGNA, 2016). Soyabean can be cooked with either a roaster (116°C to 121°C for 2.5 to 3.5 minutes) or an extruder (exit temperature of 138°C to 148°C) and this removes a lot of the anti-growth factors and produces an acceptable supplemental protein source for all pigs (COLLETTI et al., 2020). To reduce the time required for cooking soybeans, sodium metabisulfite can be added. This helps to reduce the time required for cooking and effectively removes anti-growth factors (AVILÉS-GAXIOLA et al., 2018). Current research shows extrusion processing produces soybean products of higher nutritional value for weanling pigs as compared to roasting (MILANI et al., 2022). Among the anti-growth factors in soybeans is a compound called Kunitz trypsin inhibitor (HAN et al., 2021). However, new strains of soybeans have been developed that do not contain Kunitz inhibitors so these varieties should require less cooking (AVILÉS-GAXIOLA et al., 2018).

Nonetheless, recent research indicates these new strains must be cooked to the same extent as regular soybeans if they are fed to weanling or growing pigs (5 to 9 kg) (AVILÉS-GAXIOLA et al., 2018). Less cooking time can be applied to soybean fed to finishing pigs for similar efficiency (AVILÉS-GAXIOLA et al., 2018). Cooked soybeans should be checked very often for anti-growth factor activity (KIM et al., 2021). Notwithstanding, cooked, full-fat soybeans contain less protein and lysine than soybean meals, but more fat and energy (*Table 5*) (REESE, 1990). Because of their high-fat content, full-fat soybeans offer a convenient method of adding fat to pig diets. Diets in which full-fat soybeans provide the sole source of supplemental protein contain 3 to 5% added fat (27 to 45 kg of added fat per ton of feed) (REESE, 1990).

Table 5 **Average nutrient composition of soybean meal and cooked full-fat soybeans**

Item	44% Soybean meal	Full-fat Soybean
Protein, %	44	36.7
Lysine, %	2.9	2.25
Lysine digestibility, %	86	71
Fat, %	1.1	18.8
Metabolizable energy	1,461	1,644

(REESE, 1990)

2.6. ANFs in soybean

Soybean is rich in dietary protein; however, it contains some ANFs which include phytates, tannins, trypsin inhibitors, and oligosaccharides (ADEYEMO et al., 2013). They are naturally occurring compounds in feedstuffs that impair the use of nutrients available in soybeans (EMIRE, 2013). The ANFs in soybeans have a negative impact on the nutritional quality of animals (*Table 6*). ANFs such as trypsin inhibitors and lectins fortunately are effortlessly destroyed by heat (TSEHAYNEH, 2022). ANFs such as goitrogens, tannins, phytoestrogens, oligosaccharides, phytate, and saponins are produced by heat-stable factors and therefore their effects are of less significance (LIENER, 1994). Heat-stable ANFs except for oligosaccharides and the antigenic factors are minimal in soybeans and not quite likely to cause problems under practical feeding conditions (DEI, 2011). Soybean quality is improved when oligosaccharides and antigens are eliminated during the manufacture of soybean protein.

Table 6 **The anti-nutritional factors present in various soybean products**

Anti-nutritional factors	Raw soy	Soybean meal	Alpha soy 530	Soy protein concentrates
Trypsin inhibitor(mg/g)	50	8	1.5	2
Lectin (%)	3.5	<0.1	<0.1	<0.1
Glycinin (mg/g)	209	50	26	<0.1
β-conglycinin (mg/g)	76	14	6	<0.1
Stachyose (%)		4-5	3.9	1.4
Raffinose (%)		1-2	14	0.2

According to a report by CHOCT et al. (2010), the complete removal of ANFs from soybeans will improve feed intake and usage and would produce better growth performance in animals. Nonetheless, it is not always true. This is because a new study with 3,600 piglets at the Skjoldborg test station (KRISTENSEN, 2016) reported that feeding special-treated soy protein (Alpha Soy 530) to weaned pigs improved average daily gain (ADG) by 8.7% in comparison with soy protein concentrate at day 28 (P < 0.05, *Figure 2*).

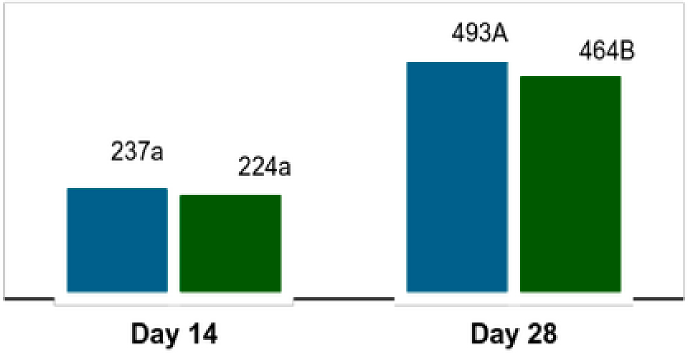

Figure 2 **Daily weight gain of weaned piglets fed special-treated soy protein (Alpha Soy 530, blue) vs. soy protein concentrate (green)**

Different superscript means the significant difference between treatments (P<0.05)

(KRISTENSEN, 2016)

This positive effect of special-treated soy protein on ADG also resulted in a higher average body weight of 0.55 kg per pig compared to soy protein concentrate at day 28 (P<0.05). The trend carried on to the later growing period. As the special-treated soy protein has a higher ANF level compared with soy protein concentrate, these results indicate that it is not necessary to remove ANFs from soy completely but to reduce them to a safe level (KRISTENSEN, 2016). For instance, trypsin inhibitor levels below 3 TIU/mg in diets will not have a negative impact on young animals' growth performance (KRISTENSEN, 2016). Then again, the severe processing of soy may reduce the ANF but will also change the soy grain matrix and especially the protein part which turns out to not benefit the animals. According to ROJAS and STEIN (2014), fermented soy protein has a lower metabolizable energy value compared to soybean meal due to the fermentation process by microbes that consumed starch, sugar, and oligosaccharides.

2.6.1. Trypsin inhibitors

Trypsin inhibitor is one of the most dominant ANFs in soybeans (VOLLMANN et al., 2003). It impedes the action of enzymes such as trypsin, chymotrypsin, etc. that break down protein in the digestive system (GILANI et al., 2005). However, when soy products are refined and enzyme-treated, it results in a drop in trypsin inhibitor activities. *Table 7* shows that among refined soy protein products, fermented and enzyme-treated soy proteins have the lowest trypsin inhibitor activity, but this is mainly due to the extra heat treatment procedures and not the fermentation or enzyme treatment entirely. Regardless of the benefits of heat treatment, it is considered a two-edged sword that necessitates handling with dire attention. Extreme heat treatment can remove trypsin inhibitors completely but may destroy soy protein and consequently reduce protein utilization in animals (WILLIS, 2003).

Table 7 **Refining soybean and meal products reduce the ANF level**

Anti-nutritional factors	Common Soybean and Soybean meal products	Refined soy proteins such as Fermented, hydrothermal, enzyme-treated soy proteins and soy protein concentrates
Trypsin inhibitor, mg/g	1.8-50	0.320-3.02
Trypsin inhibitor, TIU/mg	2.7-112	0.850-3.10
Lectins, mg/g	0.1-7.3	<0.001-0.02
Glycinin, mg/g	17-180	0.090-36
β-conglycinin, mg/g	1.8-22.0	0.001-25
Oligosaccharides, %	10-15	<1-3

Source: *https://www.feednavigator.com/News/Promotional-Features/Anti-nutritional-factors-in-soy-proteins*

2.7. Ileal digestibility of soybean and endogenous essential amino acid losses in pigs

Several experiments have been performed to assess the ileal digestibility of protein and amino acids in a wide range of feedstuffs (NOEL et al., 2021). Given this, it is largely agreed that amino acid digestibility should be measured at the ileal level. It has been reported that there is a large variation in the digestibility of amino acids, not only between different types of feedstuffs but also between different samples of the same feedstuff (MOSENTHIN et al., 2000). The ileal method is a preferred procedure because amino acids are solely absorbed in the small intestine but the microbial fermentation in the large intestine causes a reduction in the number of amino acids recovered from the feces and affects digestibility. The ileal digestibility can be assessed in cannulated pigs at the end of the small intestine by collecting samples of ileal digesta (DEGLAIRE et al., 2009). The ileal digestibility is expressed as apparent (AID), standardized (SID), or true (TID) ileal digestibility, depending on if or how endogenous amino acid losses are considered in the measure of digestibility (KONG and

ADEOLA, 2014). Endogenous amino acid losses are amino acids from proteins that are produced for metabolic functions by the pig and have not been absorbed in the small intestine and are lost (DAVILA et al., 2013). There are two types of endogenous amino acid losses, these are basal and specific losses (KONG and ADEOLA, 2014). Basal losses are amino acids that are unavoidably lost, whereas specific losses signify amino acid losses above the basal losses that are affected by the diet composition (RAVINDRAN, 2021).

Endogenous amino acid losses undervalue the ileal digestibility of amino acids because the endogenous amino acids in ileal digesta are accounted for as non-digested amino acids from the diet. The commonly used method to formulate diets and estimate the digestibility of amino acids is SID (KONG and ADEOLA, 2014). The values for SID of ingredients are more likely to be additive in diets and some of the weaknesses of AID and TID are overcome whereas the AID does not consider any of the endogenous amino acid losses, there is inadequate information about TID, and the ingredient-specific effects on endogenous amino acid losses (STEIN et al., 2007). Soybean meal has been reported to be the most essential plant-based protein source in livestock nutrition (DALSGAARD, et al., 2012). Nonetheless, it has some anti-nutritional effects, and this adversely affects their nutrient digestibility and absorption (WOYENGO and NYACHOTI, 2013). Soybean has a high concentration of non-starch polysaccharides (NSP) and oligosaccharides (CHOCT et al., 2010).

NSP is divided into insoluble and soluble NSP (CHOCT et al., 2010). Monogastric animals do not have enzymes to break down these NSPs (CHOCT, 2006). Hence exogenous enzymes and feed processing methods such as heat treatment, dehulling, and manipulating feed particle size are some of the techniques employed to optimize the digestibility of nutrients available in soybeans (MEJICANOS et al., 2016). The enzymes are used to eliminate antinutritional factors and to digest NSPs to increase nutrient digestibility (WOYENGO and NYACHOTI, 2011). It has also been reported that SBM with lower hulls would have better digestibility and there would be an inter-relationship between enzyme and SBM source in promoting ileal digestibility of nutrients and amino acids (UPADHAYA et al., 2016).

3.0. MATERIALS AND METHODS

3.1. Description of the research products

The soybean meal products were of European origin and produced with four different processes: flaking cooking pressing (FCP) vs. extrusion pressing (EP) and dehulled vs. whole bean (DH vs. WB, respectively).

3.2. Animals and housing

The trial was conducted with a total of 70 DanBred weaned barrows (being 5 weeks old) at the beginning of the trial, within 2 replicates. Pigs were randomly allocated to each of 7 treatments (5 animals/treatment/replicate), having the same mean initial body weight in each group (11.5 +/- 1.40 kg). The experiment consisted of a 28-day-long performance trial and a 5-day-long retention trial. During the performance trial, two groups (10 pigs/replicate) received the diet containing commercial soybean meal, and the others were assigned to diets containing soybean meal (SBM) from each novel technology or casein. During retention studies, groups that received commercial SBM diets were fed N-free diet to determine endogenous amino acid loss. At the end of the retention study, the ileal digestibility of amino acids was determined *post-mortem*. *Post-mortem* studies instead of ileal cannulated piglets were used because pancreatic and jejunal digesta were collected too and analyzed for total protease activity. During the whole trial, the piglets were placed in metabolic cages (1.2 m x 1.2 m). The room temperature was set and controlled in accordance with the needs of weaned piglets.

3.3. Feeds and feeding of animals

The nutritive value of the novel soy products was compared to a high-quality commercial soybean meal (CNTR) from the USA, and casein (Casein). The trial products were from the same European soya, processed by different technologies as follows: flaking cooking pressing and extrusion pressing process of dehulled beans (FCP-DH and EP-DH, respectively), and flaking cooking pressing and extrusion pressing process of whole beans (FCP-WB and EP-WB, respectively). The trypsin inhibitor activity of different soybean meals was 2.9, 7.6, 2.9, 3.6, and 2.6 TIU/mg in commercial SBM, FCP-DH, EP-DH, FCP-WB, and EP-WB, respectively. The trypsin inhibitor activity was determined by IFIP. Soybean meals and casein were used as the sole protein source in each experimental feed. Casein was chosen as a reference protein source expecting a complete digestion of the amino acids in terms of standardized ileal digestibility. The diets were formulated as iso-nitrogenous (180 g CP per kg feed) and iso-caloric on a NE basis (10.9 MJ/kg). Since methionine is the limiting amino acid in soybean meal, the feeds were formulated with methionine supplementation to ensure a realistic feed evaluation in the performance and N-retention studies. All the experimental feeds contained 5.0 g/kg of TiO_2 as a marker. The composition and nutrient content of the feeds is presented in *Table 8* and *Table 9* respectively.

Table 8 **Chemical analysis of raw soybeans and of the four soybean products produced through different processing (Extrusion pressing vs Flaking-pressing-cooking) and hulling methods (Dehulls vs Whole bean)**

Proximate analysis (%)	Raw soybeans	Extrusion-pressing		Flaking-cooking-pressing	
		Dehulled	Whole bean	Dehulled	Whole bean
Dry matter (DM)	86.6	93.85	94.2	92.3	91.3
Crude fat	17.8	4.8	4.6	5.9	7.8
Crude protein (CP)	38.36	52.3	50.1	50.5	46.6
Crude fibre	4.8	2.9	5.53	3.19	5.06
Trypsin inhibitors (TIU/mg)	25	3.5	2.6	7.6	3.6
Soluble NSP 1 (% DM)	-	3.8	3.9	2.2	4.4
Insoluble NSP 1 (% DM)	-	12.6	17.2	15.3	16.9
Total NSP [1] (% DM)	-	16.4	21.1	17.5	21.3

[1] (NSP) non starch polysaccharide

Table 9 **Composition and analyzed nutrients content of the experimental feeds (g/kg)**

	CNTR	**FCP-DH**	**EP-DH**	**FCP-WB**	**EP-WB**	**Casein**
Corn starch	482.7	542.6	555.2	508.9	533.7	624.1
Sugar	50.0	50.0	50.0	50.0	50.0	50.0
Soybean meal[1]	378.0	355.0	343.0	386.6	358.0	0
Casein	0	0	0	0	0	214.3
Arbocel	0	0	0	0	0	50.0
Sunflower oil	45.0	9.0	8.0	12.0	15.0	15.0
MCP	15.5	15.1	15.5	14.2	15.0	19.5
Limestone	8.5	8.0	8.0	8.0	8.0	8.0
NaCl	4.3	4.3	4.3	4.3	4.3	4.3
DL-Methionine	1.0	1.0	1.0	1.0	1.0	1.0
Vitamin and mineral premix 1.0%	10.0	10. 0	10. 0	10. 0	10. 0	10.0
Ti-dioxide	5.0	5.0	5.0	5.0	5.0	5.0

Total	1000	1000	1000	1000	1000	1000
NE[2]	10.9	10.9	10.9	10.9	10.9	10.9
Dry matter	912	916	918	916	919	927
Crude protein	176	174	166	183.5	173	171.5
Ether extract	50	36.5	26	44	32.5	14.5
Crude fibre	15.5	12.0	9.0	21.5	18.5	29.5
Crude ash	54.5	50.5	49.5	52.5	51.5	47.0
Lys[2]	1.04	1.03	0.96	1.09	1.00	1.20
Met[2]	0.29	0.29	0.30	0.27	0.30	0.53
Thr[2]	0.70	0.67	0.63	0.71	0.67	0.67
Trp[2]	0.20	0.20	0.20	0.20	0.20	0.20
Arg[2]	1.22	1.39	1.22	1.42	1.31	0.94
Ile[2]	0.76	0.74	0.71	0.77	0.73	0.73
Val[2]	0.82	0.80	0.77	0.84	0.80	0.99
Ca	7.3	6.6	6.3	66.7	6.7	7.4
P	5.8	5.4	5.4	5.6	5.5	6.1

[1] soybean meal in CNTR, FCP-DH, EP-DH, FCP-WB, and EP-WB was good quality commercial soybean meal, flaking-pressing-cooking processed dehulled, extrusion-pressing processed dehulled, flaking-pressing-cooking processes whole bean, extrusion-pressing processes whole soybean meal, respectively[2] calculated values.

During the performance study, the animals received a coarse meal diet and water *ad libitum*. In the retention study, the feed intake was restricted to 90% of *ad libitum*. To determine the endogenous N and amino acid losses one group of pigs received N-free diet 5 days before (during retention studies). These pigs were fed with a control (commercial) SBM diet during the performance trial. The composition of the N-free diet is shown in *Table 10* below.

Table 10 **Composition of N-free diet fed 5 days before slaughter**

	N-free diet
Corn starch	805.9
Sugar	50.0
Arbocel	50.0
Sunflower oil	42.0
MCP	25.5
Limestone	7.3
NaCl	4.3
Vitamin and mineral premix 1.0%	10.0
Ti-dioxide	5.0
Total	1000
NE	10.9
Crude protein	5.1
Ether extract	49.0
Crude fiber	32.0
Crude ash	42.5
Ca	74.3
P	5.7

3.4. Experimental methods and data recording

The experiment consisted of a 28-day pre-feeding and a 5-day collection period (*Figure 3*). Each animal received the same diet during the trial except for one group assigned to N-free treatment in the last 5 days. The daily feed intake was calculated based on the difference in feed volume offered and not consumed. The daily feed intake was determined with gram precision. The animals were weighed with 0.05 kg precision at the beginning of the trial and at weekly intervals. The general health of the animals and diarrhoea scores were monitored and recorded daily.

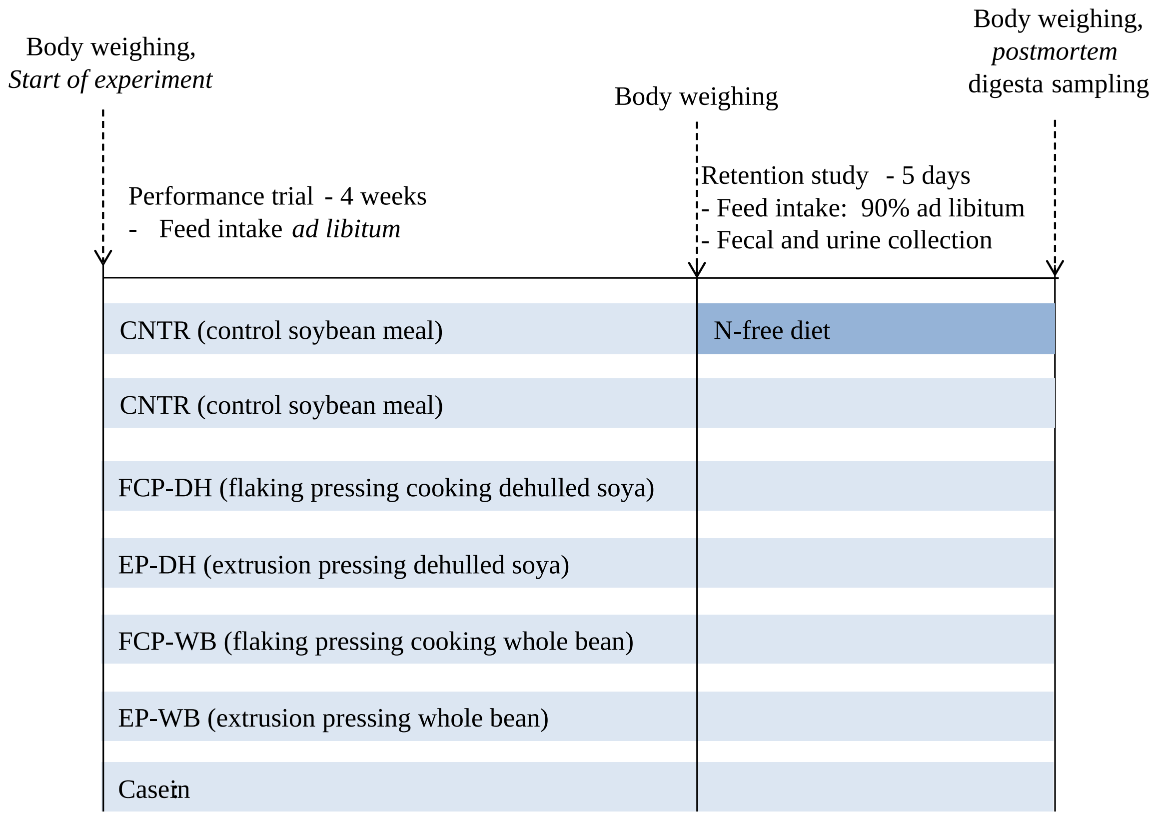

Figure 3 **Experimental design and timeline**

During retention studies, feces produced was collected quantitatively two times daily (following the morning and afternoon feeding), weighed with gram precision, and stored at –18°C until further processing. At the end of the trial, the feces were homogenized and carefully dried (65°C), ground, and prepared for laboratory analysis. Urine was collected continuously into a sealed container connected to the metabolic crate, and its volume was measured following the morning feeding. After homogenizing the urine collected daily, 15 % was filtered through a N-free filter and stored at –18°C until further processing. At the end of the collection period, the urine samples were carefully melted, again homogenized, filtered, and prepared for laboratory analysis. During collection, urine was preserved with 50 % conc. sulfuric acid. The live weight of the animals was recorded at the start and the end of the collection period. *Post-mortem* ileal digestibility of protein and the amino acid was determined after the retention study. The euthanasia was executed with anesthesia by blotting via *vena cava jugularis*. Pigs were injected with 2.5 mg Zoletil (Virbac), 3 mg CP-Xylazin (2%, CP-Pharma Handelsges), and 6 mg Stresnil (Janssen-Cilag) per kg body weight intramuscularly 30 minutes before slaughtering. In the course of bleeding the bodies were held at a desk letting their head hang. The abdomen was dissected, and the intestine and pancreas were removed. The jejunal gut content from the mid of 10-20 cm and the ileal gut content from 10-15 cm anterior to the ileo-caeco-colonic junction was flushed out with distilled water. Ileal digesta samples were used for the determination of ileal digestibility while jejunal digesta and pancreas were examined for total protease enzymes' activity.

3.5. Laboratory analysis

Ileal digesta and fecal samples were dried at 65 ºC for further laboratory analysis. The nutrient contents of the diets such as dry matter, crude protein, crude fat, crude fiber, crude ash, Ca, and P, as well as amino acids and Ti-dioxide, furthermore dry matter, and crude protein, amino acid, and Ti-dioxide contents of the digesta samples were determined by the AOAC (1989) recommendations. Dietary NSP was determined according to the description of Bach KNUDSEN (1997), and the trypsin inhibitor activity was determined according to KAKADE et al. (1974). Dry matter and crude protein content of feces and urine were also determined. The total proteolytic activity was determined at the Institute of Animal Science, Prague (Czech Republic). Pancreas and jejunal digesta samples were stored under CO_2 at -80 °C until analysis. The dry matter of samples was determined by heating at 105 °C for 24 h. Pancreas and digesta samples were diluted with phosphate buffer (pH 7.5) according to MAROUNEK et al. (1995). Azocasein solution was prepared in a concentration of 4 mg/ml in 0.1 M potassium phosphate buffer pH7.5.

For each sample, the following were prepared: four plastic 10 ml polypropylene tubes containing azocasein solution [1], azocasein solution and 25% trichloracetic acid [2], 0.1 M potassium phosphate buffer pH 7.5 [3] and 0.1 M potassium phosphate buffer pH 7.5 + 1 ml 25% trichloracetic acid [4]. All materials and reagents (azocasein, K_2HPO_4, KH_2PO_4, trichloracetic acid, and (NaOH) were purchased from Sigma Aldrich and Lach-Ner (Czech Republic). At *t* = 0, samples were added to all tubes. After 1 h incubation at 39 °C, 25% trichloracetic acid was added to [1] and [3]. Tubes were transferred to ice water and then centrifuged at 4000 g. The supernatant was removed into another tube with 0.5 M NaOH. Absorbance was measured at 440 nm and the result of absorbance was calculated from four values: A_1-A_2-A_3+A_4. Calibration was made by 0.2 mg/ml solution of azocasein. Proteolytic activity was expressed as mg azocasein hydrolysed/h per dry matter of digesta or pancreas sample (HOFFMANN et al., 2010).

3.6. Calculation

In the retention studies, absolute and relative N-retention (g/d as well as % of intake and digested N basis) were determined.

The basal ileal endogenous amino acid flow was calculated as follows:

$$IAA_{endo} = AA_{digesta} \text{ x } (M_{diet} / M_{digesta})$$

The apparent and standardized ileal digestibility of each amino acid was determined as follows:

$$AID (\%) = (1 – AA_{digesta} / M_{digesta} * M_{diet} / AA_{diet}) * 100$$

$$SID (\%) = AID + (\text{basal } IAA_{endo} / AA_{diet}) * 10$$

3.7. Statistical analysis

The experimental data were analyzed with two-way ANOVA (SAS, 2004), considering the treatment and the replication as the main effects. In case of significant treatment effect, the differences among the treatments were checked by the Tukey test (SAS, 2004).

4.0. RESULTS AND DISCUSSION

4.1. Performance and Nitrogen retention trials

From *Table 11*, it can be observed that there were differences in the initial body weights. However, none of the soy products performed better than the control soybean meal (CNTR) in terms of the performance trial. FCP-DH recorded the lowest mean values among all the treatments.

Table 11 **Effect of different processed soybean meals on the growth performance of weaned pigs**

	CNTR	FCP-DH	EP-DH	FCP-WB	EP-WB		P-value	
						RMSE	Trt	R
Body weight (kg)								
initial	11.62	11.59	11.55	11.50	11.45	1.53	ns	ns
week1	15.05[a]	13.04[b]	14.12[ab]	13.99[ab]	14.05[ab]	1.55	ns	ns
week2	19.31[a]	14.92[b]	18.65[a]	17.91[a]	18.35[a]	2.13	0.0005	ns
week3	24.97[a]	17.98[b]	24.45[a]	22.92[a]	23.67[a]	2.49	<0.0001	ns
week4	29.01[a]	20.63[b]	28.79[a]	27.52[a]	28.47[a]	2.70	<0.0001	ns
Average daily gain (g/d)								
week1	490 [a]	206 [c]	366 [b]	355 [b]	372 [b]	88.50	<0.0001	ns
week2	609 [a]	303 [b]	647 [a]	561 [a]	614 [a]	150.00	<0.0001	0.006
week3	809 [a]	438 [b]	829 [a]	716 [a]	761 [a]	118.60	<0.0001	0.07
week4	577 [a]	379 [b]	620 [a]	657 [a]	686 [a]	105	<0.0001	0.06
Total	621 [a]	323 [b]	616 [a]	572 [a]	608 [a]	62.60	<0.0001	0.02
Average daily feed intake (g/d)								
week1	704 [a]	597 [c]	670 [ab]	655 [ab]	637 [bc]	44.5	<0.0001	ns
week2	1008 [a]	772 [b]	949 [a]	905 [ab]	955 [a]	112.8	<0.0001	ns
week3	1183 [a]	920 [b]	1181 [a]	1078 [a]	1133 [a]	108.3	<0.0001	ns
week4	1214 [a]	885 [b]	1175 [a]	1161 [a]	1192 [a]	117.3	<0.0001	ns
Total	1027 [a]	794 [b]	994 [a]	950 [a]	979 [a]	78.7	<0.0001	ns
Feed conversion ratio (kg feed/kg gain)								
week1	1.49 [a]	2.99 [b]	1.86 [a]	1.86 [a]	1.97 [a]	0.711	0.0009	ns
week2	1.76 [a]	2.93 [b]	1.52 [a]	1.78 [a]	1.66 [a]	0.599	<0.0001	0.007
week3	1.48 [a]	2.42 [b]	1.44 [a]	1.52 [a]	1.51 [a]	0.429	<0.0001	0.01
week4	2.15 [ab]	2.52 [b]	1.93 [a]	1.79 [a]	1.77 [a]	0.393	0.0005	0.08
Total	1.66 [a]	2.56 [b]	1.62 [a]	1.66 [a]	1.61 [a]	0.241	<0.0001	ns

[1] soybean meal in CNTR, FCP-DH, EP-DH, FCP-WB, and EP-WB was good quality commercial soybean meal, flaking-pressing-cooking processed dehulled, extrusion-pressing processed dehulled, flaking-pressing-cooking processes whole bean, extrusion-pressing processes whole soybean meal, respectively.

The effect of various processed soybean meals on the growth performance of weaned piglets is shown in *Table 11* above. Processing soybean enhances the digestibility and absorption of nutrients, and this positively impacts growth performance parameters (SAMTIYA et al., 2020). Nonetheless, in this experiment, none of the processed soybean meals performed better in growth performance than the conventional soybean meal. Even though the processed soy products did not show any improvement in the growth trial, the mean values for EP-DH in terms of ADG were seen to be higher in weeks 2, 3, and 4, and also for FCP-WB and EP-WB in week 4. The findings of the current study agree with the findings of a study conducted by SHARMA et al. (2008). They reported that feeding a diet with extruded pea seeds improved the growth performance of pigs. Meanwhile, NOLAND et al. (1976) found no significant differences in the performance of pigs fed either soybean meal, cooked soybean, or extruded soybean as the primary protein source. NOLAND et al. (1976) further reported a significant improvement in the gains of swine when flaked, dehulled soybeans cooked for either 12 or 24 min were fed compared to diets containing flakes cooked for 8 or 36 mins or soybean meal. Moreover, in the current study, FCP-DH recorded the lowest gains for all the growth performance parameters. This could be attributed to the inadequate cooking duration with the processing of FCP-DH.

Several reports including (SAMTIYA et al., 2020; ZHU et al., 2017; MIN et al., 2004) showed that feeding processed soya protein to weaned piglets increased growth performance**,** including average daily feed intake and body weight gain. Nonetheless, in a different study by STEIN et al. (2008), they reported that the thermal overprocessing of grains, such as soybeans and corn, may reduce the nutritive value of cooked products. PETTIGREW et al. (1991), also reported that the deficiency in nutrients can lead to reduced feed intake, delayed weight gain, and in some cases weight loss. There is also an absolute requirement for certain essential nutrients because the body cannot manufacture these nutrients on its own and therefore depends on external sources for their supply (BLAIR, 2017). It can be deduced that FCP-DH lost some nutrients as a result of thermal overprocessing. A deficiency in nutrients can lead to reduced feed intake, digestibility, and absorption.

Table 12 below shows the effects of different processed soybean meals on the N-retention of weaned pigs. All processed soy products did not show any improvement in the N-retention parameters. However, except for Fecal N excretion (g/d), N-retention in % of intake, and N-retention in % of digested N, FCP-DH recorded the lowest mean values for all N-retention parameters. EP-DH was lowest in Fecal N excretion (g/d).

Table 12 **Effect of different processed soybean meals on N-retention of weaned pigs**

	CNTR	FCP-DH	EP-DH	FCP-WB	EP-WB		P-value	
						RMSE	Trt	R
N intake (g/d)	32.8 [a]	25.2 [b]	30.8 [a]	33.0 [a]	31.9 [a]	2.34	<0.0001	ns
Faecal N excretion (g/d)	3.27 [ab]	3.56 [a]	2.31 [c]	2.97[abc]	2.71 [bc]	0.668	0.0014	ns
Urinary N excretion (g/d)	6.60 [a]	3.90 [b]	6.43 [a]	6.22 [a]	6.46 [a]	1.111	<0.0001	ns
Total N excretion (g/d)	9.87 [a]	7.47 [b]	8.74 [ab]	9.19 [a]	9.16 [a]	1.296	0.0029	0.07
N-retention (g/d)	23.0 [a]	17.7 [b]	22.1 [a]	23.8 [a]	22.8 [a]	2.08	<0.0001	0.006
Fecal digestibility of N (%)	90.0 [a]	85.9 [b]	92.5 [a]	91.0 [a]	91.5 [a]	2.15	<0.0001	0.034
N-retention in % of intake	69.8	70.3	71.5	72.1	71.3	3.79	ns	0.003
N-retention in % of digested N	77.5	81.9	77.3	79.2	78.0	3.98	0.08	0.032

[1]soybean meal in CNTR, FCP-DH, EP-DH, FCP-WB, and EP-WB was good quality commercial soybean meal, flaking-pressing-cooking processed dehulled, extrusion-pressing processed dehulled, flaking-pressing-cooking processes whole bean, extrusion-pressing processes whole soybean meal, respectively.

The effect of different processed soybean meals on the N-retention of weaned pigs is shown in *Table 12* above. The findings in this experiment show that all processed soybean meals did not show any improvement in the N-retention parameters. Although there was no improvement in nitrogen retention among the treatments, FCP-DH recorded the lowest mean values for all parameters except for Fecal N excretion (g/d), N-retention in % of intake, and N-retention in % of digested. EP-DH on the other hand recorded the lowest mean value for Fecal N excretion (g/d). Studies by LIENER and KAKADE (1980) showed that extrusion pressing of soybean produces soybean flour, which is free from trypsin inhibitors, and is usually accompanied by an improvement in the nutritional value of the protein. Extruded soy protein also contains amino acids that are more digestible and have higher nitrogen retention than amino acids in most other plant proteins. This could result in the excretion of less nitrogen in pig manure (DEGOLA et al., 2019). VANDERGRIFT et al. (1983) in a different study, reported that the cooking of soy flakes significantly improved the digestibility of nitrogen in pigs. In their study, an increase in the duration of cooking significantly ($P < 0.05$) increased the digestibility and retention of nitrogen in swine. Perhaps the duration of the cooking for FCP-DH in the current study was inadequate. A different study by GRALA et al. (1998) indicated that increased endogenous losses and dietary N losses were associated with a higher dietary trypsin inhibitor activity in pigs. The trypsin inhibitor activity of different soybean meals in the current study was 2.9, 7.6, 2.9, 3.6, and 2.6 TIU/mg in commercial SBM, FCP-DH, EP-DH, FCP-WB, and EP-WB, respectively. From the chemical analysis, it was observed that trypsin inhibitor content (TIU/mg) for FCP-DH was the highest among all treatments. Trypsin inhibitor is present in various foods such as soybeans, grains, cereals, and other legumes.

Most livestock species, predominantly monogastric, experience reduced growth when fed on rations with high levels of unprocessed soybean (NAHASHON and KILONZO-NTHENGE, 2011). This is because unprocessed soybean contains higher levels of trypsin inhibitors. When unprocessed soybean is fed to monogastric, protein digestibility may be reduced, and dietary protein is expelled in the feces. It also results in reduced nitrogen and sulfur absorption. One disadvantage of the inactivation of digestive enzymes by trypsin inhibitors in the intestine is the stimulation of trypsin and chymotrypsin secretion from the pancreas, which can increase the requirements for the sulfur amino acids methionine and cystine (MOKOENA, 2010). In turn, this leads to increased endogenous loss of both nitrogen and sulfur. Finally, the inhibitors can increase the release of cholecystokinin into the bloodstream, which further increases pancreatic secretion. Different methods however have been developed to inactivate trypsin inhibitors, and of these, thermal treatments are the most commonly used. However, they may cause loss of nutrients, affect functional properties, and require high amounts of energy. Given the above, the higher trypsin inhibitor level observed in FCP-DH could be attributed to inadequate thermal processing. This could have negatively affected the digestibility and N retention in weaned piglets.

From *Table 13*, except for Asp, Glu, Pro, Gly, and Trp, the AID of all amino acids was significantly improved by the feeding of EP-DH, FCP-WB, EP-WB, and Casein. Among all treatments, mean values for various amino acids in EP-DH and casein were the highest, except for Gly, Cys, and Arg in Casein. FCP-DH was found to contain the lowest AID of all amino acids among treatments.

Table 13 **Apparent ileal digestibility (AID) of the control soybean meal, European soybean meal processed by different technologies, and casein determined in weaned pigs.**

	CNTR	FCP-DH	EP-DH	FCP-WB	EP-WB	Casein		P-value		
	n=10	n=8	n=10	n=10	n=8	n=6	RMSE	Trt	R	Trt x R
Asp	0.777[a]	0.667 [b]	0.835 [a]	0.850 [a]	0.815 [a]	0.807 [a]	0.0543	<0.0001	ns	0.025
Thr	0.696 [cd]	0.647 [d]	0.796 [ab]	0.811 [ab]	0.750 [bc]	0.830 [a]	0.0538	<0.0001	ns	<0.0001
Ser	0.773 [b]	0.671 [c]	0.855 [a]	0.857 [a]	0.811 [ab]	0.830 [ab]	0.0528	<0.0001	ns	0.002
Glu	0.827 [a]	0.676 [b]	0.895 [a]	0.884 [a]	0.845 [a]	0.873 [a]	0.0652	<0.0001	ns	ns
Pro	0.790 [a]	0.462 [b]	0.826 [a]	0.817 [a]	0.782 [a]	0.900 [a]	0.1125	<0.0001	ns	0.025
Gly	0.663 [ab]	0.555 [b]	0.775 [a]	0.783 [a]	0.658 [ab]	0.625 [b]	0.0945	<0.0001	ns	0.093
Ala	0.648 [b]	0.629 [b]	0.818 [a]	0.818 [a]	0.757 [a]	0.788 [a]	0.0564	<0.0001	ns	<0.0001
Cys	0.569 [b]	0.558 [b]	0.736 [a]	0.758 [a]	0.652 [ab]	0.115 [c]	0.0680	<0.0001	0.0005	0.0003
Val	0.703 [c]	0.628 [d]	0.848 [ab]	0.830 [ab]	0.805 [b]	0.895[a]	0.0452	<0.0001	ns	<0.0001
Met	0.765 [b]	0.790 [b]	0.920 [a]	0.906 [a]	0.901 [a]	0.953 [a]	0.0356	<0.0001	0.0004	<0.0001
Ile	0.694 [b]	0.612 [c]	0.850 [a]	0.828 [a]	0.796 [a]	0.862 [a]	0.0524	<0.0001	ns	<0.0001
Leu	0.744 [c]	0.636 [d]	0.874 [ab]	0.853 [ab]	0.827 [b]	0.901 [a]	0.0431	<0.0001	ns	<0.0001
Tyr	0.762 [cd]	0.658 [d]	0.889 [ab]	0.838 [bc]	0.842 [bc]	0.954 [a]	0.0713	<0.0001	0.015	0.007
Phe	0.766 [c]	0.659 [d]	0.881 [ab]	0.859 [b]	0.843 [b]	0.927 [a]	0.0405	<0.0001	ns	<0.0001
His	0.786 [b]	0.662 [c]	0.842 [ab]	0.829 [ab]	0.793 [b]	0.867 [a]	0.0435	<0.0001	0.0099	0.0008
Lys	0.761 [c]	0.725 [c]	0.886 [ab]	0.878 [ab]	0.843 [b]	0.903 [a]	0.0376	<0.0001	ns	<0.0001
Arg	0.865 [c]	0.771 [d]	0.932 [a]	0.921 [ab]	0.907 [abc]	0.871 [bc]	0.0349	<0.0001	0.058	0.0005
Trp	0.903 [a]	0.821 [a]	0.916 [a]	0.864 [a]	0.874 [a]	.	0.0851	ns	0.0015	ns
Amino acids	0.763 [b]	0.648 [c]	0.861 [a]	0.854 [a]	0.807 [ab]	0.868 [a]	0.0514	<0.0001	ns	0.0002

Apparent ileal digestibility (AID) of amino acids was higher in piglets fed EP-DH and casein than in piglets fed control and other processed soybean diets ($P < 0.05$, *Table 13*). Except for Asp, Glu, Pro, Gly, and Trp, the AID of all amino acids was significantly improved by the feeding of casein and soy products but for FCP-DH. Apart from Trp, all of the amino acids that did not show improvement in AID by processed soybean diets are non-essential amino acids. There was no difference in tryptophan levels across treatments. Tryptophan is an essential amino acid that serves several important purposes. Numerous studies have revealed that tryptophan is not only available in proteins but is also available in non-protein forms in food such as milk and cereals (COMAI et al., 2007). Except for Trp, FCP-DH was found to contain the lowest AID of amino acids among treatments. The finding in the current study is in contrast to what was reported by CABRAL et al. (1995), in that study, dehulling did not affect the protein quality and digestibility of cooked soybeans.

Moreover, in a study by STEIN et al. (2008), the thermal overprocessing of grains, such as soybeans and corn, may reduce the nutritive value of cooked products. Nonetheless, a deficiency in nutrients can lead to reduced nutrient intake, digestibility, and absorption. This could result in FCP-DH recording the lowest mean AID values of amino acids. In the current study, Gly, Arg, and Cys levels in casein were seen to be low. Casein is an example of a lacteal protein and lacteal proteins generally have low glycine content (REIS DE SOUZA et al., 2013). Furthermore, endogenous protein is rich in arginine and cysteine, and lacteal proteins again have low levels of these amino acids (COWIESON and RAVINDRAN, 2007). A combination of these factors could explain the low AID of Gly, Arg, and Cys in casein. The lack of variation in the AIDs of remaining amino acid content in casein could be due to the high levels of these amino acids in the protein. JØRGENSEN and GABERT (2001) fed growing pigs a casein-based diet (13%, 16%, 19%, and 22% CP). They only reported differences between the AID of amino acids only for pigs fed 13% and 16% CP. There were however no differences in AID between groups fed 16%, 19%, or 22% CP. In effect, casein is a complete protein source, and it provides all the essential amino acids needed by growing animals HOFFMAN and FALVO, (2004) There were significant differences in the SID of amino acids among treatments ($p < 0.05$, *Table 14*). Except for Glu, Pro, Cys, and Trp, the SID of all amino acids was significantly improved by the feeding of EP-DH, FCP-WB, EP-WB, and Casein. The SID of Gly was improved significantly only by Casein. CNTR and FCP-DH recorded the least SID of amino acids, and Casein recorded the highest SID, followed by EP-DH and FCP-WB respectively.

Table 14 **Standardized ileal digestibility (SID) of the control soybean meal, European soybean meal processed by different technologies, and casein determined in weaned pigs.**

	CNTR	FCP-DH	EP-DH	FCP-WB	EP-WB	Casein		P-value		
	n=10	n=8	n=10	n=10	n=8	n=6	RMSE	Trt	R	Trt x R
Asp	0.861^{b}	0.752^{c}	0.927^{ab}	0.925^{ab}	0.909^{ab}	0.981^{a}	0.0543	<0.0001	ns	0.014
Thr	0.862^{cd}	0.820^{d}	0.985^{ab}	0.967^{ab}	0.930^{bc}	1.019^{a}	0.0538	<0.0001	ns	<0.0001
Ser	0.904^{b}	0.805^{c}	1.000^{a}	0.977^{a}	0.954^{ab}	0.970^{ab}	0.0528	<0.0001	ns	0.0015
Glu	0.889^{a}	0.740^{b}	0.959^{a}	0.939^{a}	0.914^{a}	0.927^{a}	0.0652	<0.0001	ns	ns
Pro	1.022^{a}	0.694^{b}	1.081^{a}	1.030^{a}	0.930^{a}	1.021^{a}	0.1125	<0.0001	ns	0.025
Gly	0.993^{bc}	0.894^{c}	1.138^{b}	1.095^{bc}	1.037^{bc}	1.405^{a}	0.1650	<0.0001	ns	ns
Ala	0.789^{c}	0.777^{c}	0.972^{ab}	0.951^{ab}	0.911^{b}	1.040^{a}	0.0564	<0.0001	ns	<0.0001
Cys	0.913^{ab}	0.829^{b}	1.004^{ab}	1.026^{a}	0.902^{ab}	1.097^{a}	0.1292	0.02	0.0005	0.06
Val	0.818^{c}	0.747^{d}	0.970^{ab}	0.939^{ab}	0.932^{b}	1.007^{a}	0.0452	<0.0001	ns	<0.0001
Met	0.843^{b}	0.867^{b}	0.992^{a}	0.988^{a}	0.980^{a}	0.993^{a}	0.0356	<0.0001	ns	<0.0001
Ile	0.820^{b}	0.742^{b}	0.984^{ab}	0.949^{ab}	0.932^{b}	1.013^{a}	0.0524	<0.0001	ns	<0.0001
Leu	0.842^{c}	0.736^{d}	0.977^{a}	0.944^{a}	0.937^{a}	1.002^{a}	0.0431	<0.0001	0.08	<0.0001
Tyr	0.828^{bc}	0.731^{c}	0.969^{a}	0.903^{ab}	0.932^{ab}	1.016^{a}	0.0713	<0.0001	0.07	0.002
Phe	0.844^{c}	0.738^{d}	0.962^{ab}	0.930^{b}	0.934^{b}	1.033^{a}	0.0405	<0.0001	ns	<0.0001
His	0.913^{c}	0.791^{d}	0.982^{ab}	0.947^{abc}	0.935^{bc}	1.022^{a}	0.0435	<0.0001	0.047	0.0006
Lys	0.849^{b}	0.814^{b}	0.980^{a}	0.959^{a}	0.942^{a}	0.988^{a}	0.0376	<0.0001	ns	<0.0001
Arg	0.934^{c}	0.832^{d}	1.001^{ab}	0.979^{bc}	0.975^{bc}	1.047^{a}	0.0349	<0.0001	ns	0.0001
Trp	0.998^{a}	0.916^{a}	1.002^{a}	0.959^{a}	0.977^{a}	.	0.0851	ns	0.0017	ns

The standardized ileal digestibility (SID) of the control soybean, various processed soybean, and casein determined in weaned pigs is shown in *Table 14* above. In this study, the SID of some essential amino acids such as Arg, His, Lys, Phe, Tyr, Leu, Ile, Met, and Val was higher for piglets fed EP-DH and Casein diet compared to that of the piglets fed FCP-DH diet. From this result, we can speculate that the difference in results for SID of amino acids may be due to the differences in the hydrothermal treatment during processing. Dehulled grains cook faster, have a slightly different flavor, and have a higher nutritional value than their whole-seed counterparts (THAKUR et al., 2019). However, for FCP-DH, the amino acid content could likely have been reduced as reported by TOOMER et al. (2023), that excessive heat treatment may reduce the amino acid content in addition to lower amino acid digestibility and availability in soybean. Then again, enzymes such as myrosinase and lipase in soybean are rendered inactive by excessive cooking (WILLIAMS, 2018). Myrosinase for instance is responsible for the hydrolysis of anti-nutritional factors such as glucosinolates which results in the production of isothiocyanates, nitriles, thiocyanates, or oxazolidinethiones.

Except for Glu, Pro, Cys, and Trp, the SID of all amino acids was higher in the feed with a protein source of EP-DH, FCP-WB, EP-WB, and casein. Apart from Trp, all the aforementioned amino acids are non-essential amino acids. Non-essential amino acids are the ones that the body synthesizes on its own and are also known as endogenous amino acids. The SID for these amino acids could not be improved by the feeding of EP-DH, FCP-WB, EP-WB, and casein because SID is obtained by correcting apparent ileal digestibility for basal endogenous amino acid flow as described by STEIN et al. (2007). Among the essential amino acids, the highest SID was observed for Trp in all treatments, whereas the lowest SID was observed for His. As reported by COMAI et al. (2007), tryptophan is an essential amino acid that serves several important purposes. Numerous studies have revealed that tryptophan is not only available in proteins but is also available in non-protein forms in food such as milk and cereals. According to (CEMIN et al., 2018), His may be the sixth limiting amino acid in practical swine nursery diets. When a diet deficient in His is ingested, His may be released from hemoglobin and carnosine, a dipeptide that is in abundance in muscles (ROBBINS et al., 1977; CLEMENS et al., 1984). These His releases could result in muscle protein accretion, even though the diet does not contain sufficient His. This may explain why He recorded the lowest mean SID among the treatments.

For all the amino acids, EP-DH had the greatest concentration of total amino acids compared to all other soy products (*Table 15*). EP-DH also recorded the highest mean values for AID and SID of all essential amino acids; however, SID values were higher than AID values. Except for Ser and Cys, EP-DH again was seen to contain the highest amount of nonessential amino acid contents for the AID and SID. However, in terms of total amino acid content, FCP-WB was the lowest for all of the amino acids, and FCP-DH was the worst in terms of AID and SID of all amino acids. Glu level was observed to be highest across the treatments, whiles Cys, Meth, and Trp levels were observed to be the lowest.

Table 15 **Total amino acid content, the AID, and SID of the amino acid content of European soybean meals processed by novel technologies used in the present trial.**

	Total AA content				**AID AA content**				**SID AA content**			
	FCP-DH	EP-DH	FCP-WB	EP-WB	FCP-DH	EP-DH	FCP-WB	EP-WB	FCP-DH	EP-DH	FCP-WB	EP-WB
Asp	5.74	5.95	5.30	5.70	3.83	4.79	4.86	4.67	4.32	5.32	5.33	5.17
Thr	1.96	2.03	1.81	1.94	1.27	1.56	1.58	1.47	1.61	1.94	1.90	1.81
Ser	2.54	2.62	2.33	2.51	1.70	2.17	2.17	2.06	2.05	2.55	2.49	2.41
Glu	9.01	9.34	8.31	8.95	6.09	8.07	7.93	7.63	6.67	8.66	8.45	8.19
Pro	2.47	2.56	2.28	2.46	0.85	2.04	2.01	1.72	1.41	2.67	2.55	2.30
Gly	2.11	2.19	1.94	2.09	1.17	1.63	1.64	1.40	1.89	2.41	2.31	2.12
Ala	2.21	2.29	2.04	2.20	1.39	1.81	1.80	1.69	1.72	2.16	2.11	2.02
Cys	0.73	0.76	0.67	0.73	0.41	0.54	0.55	0.48	0.61	0.73	0.76	0.68
Val	2.44	2.53	2.25	2.42	1.53	2.07	2.02	1.97	1.82	2.38	2.29	2.26
Met	0.70	0.73	0.65	0.70	0.55	0.64	0.63	0.63	0.61	0.70	0.69	0.69
Ile	2.32	2.41	2.14	2.31	1.42	1.97	1.91	1.85	1.72	2.30	2.20	2.16
Leu	3.71	3.85	3.42	3.69	2.36	3.24	3.15	3.08	2.73	3.65	3.51	3.47
Tyr	1.68	1.74	1.55	1.67	1.10	1.49	1.39	1.42	1.23	1.64	1.51	1.55
Phe	2.54	2.63	2.34	2.52	1.67	2.24	2.17	2.15	1.87	2.45	2.36	2.35
His	1.34	1.39	1.24	1.33	0.89	1.13	1.11	1.07	1.06	1.32	1.27	1.24
Lys	3.08	3.20	2.84	3.06	2.23	2.73	2.70	2.61	2.51	3.03	2.96	2.90
Arg	3.74	3.88	3.45	3.71	2.88	3.49	3.44	3.41	3.11	3.75	3.66	3.65
Trp	0.66	0.68	0.61	0.65	0.54	0.60	0.57	0.58	0.60	0.67	0.63	0.64

Table 15 above shows the total amino acid content, the apparent and standardized ileal digestible amino acid content of European soybean meals processed by novel technologies used in the present trial. According to STEIN et al. (2013), the proteins in soy products are highly digestible. Diets are most correctly formulated based on values for SID of amino acids because values for SID of amino acids are additive in mixed diets (STEIN et al., 2007). In this study, it was observed that EP-DH recorded the highest mean values for both the AID and the SID of

amino acids. The contention with AID is that it shows an increase in the endogenous amino acids flow out of the small intestine, and this represents a loss to the weaned piglets. This means that the feedstuff or product has a lower digestibility. In the current study, although EP-DH recorded the highest mean values for both AID and SID, the SID values were observed to be higher, because of this EP-DH can be considered a good quality protein source for weaned piglets. Soybean protein is rich in lysine, threonine, and tryptophan, as these are the most limiting amino acids in corn, wheat, sorghum, and barley (LEWIS and PEO, 1986). Nonetheless in the current study, it is easily seen that the Lys levels are higher than the Thr and Trp levels. This current result agrees with what was reported by STEIN et al. (2013).

5.0. CONCLUSION

In this experiment, the performance trials of the European soya products were as good as the reference high-quality SBM except for FCP-DH. In general, except for FCP-DH, there was no difference in the impact of the feed processing methods on the nutritive value of soya products. The nitrogen retention, AID, and SID of all amino acids were also similar in almost all protein sources except for FCP-DH. This may mean that the processing of FCP-DH had some effect on the nutrient content and could have negatively affected the nutrient digestibility of the feed. According to literature, it could be a result of inadequate thermal processing. However, the SID amino acid content of EP-DH was observed to be the highest, because of this EP-DH can be considered a good quality protein source for weaned piglets.

I recommend the need for further studies to explain the possible mechanisms of ensuring adequate thermal processing of FCP-DH.

6.0. SUMMARY

In this study, we compared the nutritive value of novel soy products, flaking cooking pressing, and extrusion pressing process of dehulled beans (FCP-DH and EP-DH, respectively), and flaking cooking pressing and extrusion pressing process of whole beans (FCP-WB and EP-WB, respectively) to a high-quality commercial soybean meal (CNTR) and casein (Casein). For that purpose, performance trials, nitrogen (N)-retention, and *post-mortem* digestibility, that is, Apparent Ileal Digestibility (AID), and Standardized Ileal Digestibility (SID) trials were carried out. The trial products were formulated from soybean of European origin, and the commercial soybean meal was from the USA. Casein was chosen as a reference protein source. The study was conducted with a total of 70 Danbred weaned (5-week-old) barrows, within 2 replicates. Piglets were randomly allocated to each of the 7 treatments (5 animals/treatment/replicate). The experiment consisted of a 28-day-long performance trial and a 5-day-long retention trial.

During the performance trial, two groups (10 pigs/replicate) received the control diet, and the others were assigned to diets containing soybean meal (SBM) from each novel technology or casein. During retention studies, either of the groups that received commercial SBM diets was fed N-free diet to determine endogenous amino acid losses. At the end of the retention study, the ileal digestibility of amino acids was determined *post-mortem*. The experimental data were analyzed with two-way ANOVA (SAS, 2004). It was observed that except for FCP-DH, all the other European soya products were as good as the commercial SBM. In general, except for FCP-DH, there was no difference in the impact of the feed processing methods on the nutritive value of soya products. In conclusion, inadequate thermal processing of FCP-DH could have negatively affected the nutrient digestibility of the feed. I recommend the need for further studies to explain the possible mechanisms of ensuring adequate thermal processing of FCP-DH.

7.0. ACKNOWLEDGEMENT

Glory be to God Almighty for the grace to complete this master's study and thesis. I would like to express my profound gratitude to the European Union's Horizon 2020 research and innovation program under grant agreement no. 101004770, and the European Commission under grant agreement no. 633531 for funding this PIGWEB research through the Feed-a-Gene project. I am extremely grateful also to the Tempus Family Foundation and the Ghana Scholarship Secretariat who through the Stipendium Hungaricum Scholarship program funded my MSc. degree program in Kaposvar, Hungary.

From the bottom of my heart, I want to say a big thank you to my supervisor, Professor Veronika Halas for her unflinching support and guidance throughout my MSc. studies, and the writing of this thesis. I am extremely grateful for our friendly chats and your support in my academic endeavors. Last, but not least, I am also thankful to all the faculty and staff of the Hungarian University of Agricultural and Life Sciences, Kaposvar campus, for their support.

8.0. REFERENCES

Articles in scientific journals or periodicals:

1. ADEYEMO, S. M., & ONILUDE, A. A. (2013). Enzymatic reduction of anti-nutritional factors in fermenting soybeans by Lactobacillus plantarum isolates from fermenting cereals. *Nigerian Food Journal*, *31*(2), 84-90.
2. AJINOMOTO HEARTLAND LYSINE LLC REVISION 7, 2006. True digestibility of essential amino acids in poultry.
3. AMER, S. A., AHMED, S. A., IBRAHIM, R. E., AL-GABRI, N. A., OSMAN, A., & SITOHY, M. (2020). Impact of partial substitution of fish meal by methylated soy protein isolates on the nutritional, immunological, and health aspects of Nile tilapia, Oreochromis niloticus fingerlings. *Aquaculture*, *518*, 734871.
4. ARABA, M., AND N.M. DALE. 1990. Evaluation of protein solubility as an indicator of under-processing soybean meal. *Poultry Science*, 69:1749-1752
5. AVILÉS-GAXIOLA, S., CHUCK-HERNÁNDEZ, C., & SERNA SALDÍVAR, S. O. (2018). Inactivation methods of trypsin inhibitor in legumes: a review. *Journal of Food Science*, *83*(1), 17-29.
6. BLAIR, R. (2017). *Nutrition and feeding of organic pigs*. Cabi.
7. BORA, P. (2014). Anti-nutritional factors in foods and their effects. *Journal of Academia and Industrial Research*, *3*(6), 285-290.
8. CABRAL, L. C., SERNA-SALDIVAR, S. O., TINKSLEY, A. M., & WEBER, C. W. (1995). Effects of dehulling, cooking, and storage conditions on protein quality and digestibility of soybeans. *Archivos Latinoamericanos de Nutricion*, *45*(1), 41-45.
9. CAMPBELL, K. A., GLATZ, C. E., JOHNSON, L. A., JUNG, S., DE MOURA, J. M. N., KAPCHIE, V., & MURPHY, P. (2011). Advances in aqueous extraction processing of soybeans. *Journal of the American Oil Chemists' Society*, *88*(4), 449-465.
10. CARRÉ, P., QUINSAC, A., CITEAU, M., & FINE, F. (2015). A re-examination of the technical feasibility and economic viability of rapeseed dehulling. *OCL*, *22*(3), D304.
11. CEMIN, H. S., VIER, C. M., TOKACH, M. D., DRITZ, S. S., TOUCHETTE, K. J. J., WOODWORTH, J. C., ... & GOOD BAND, R. D. (2018). Effects of standardized ileal digestible histidine to lysine ratio on growth performance of 7-to 11-kg nursery pigs. *Journal of Animal Science*, *96*(11), 4713-4722.
12. CHEN, J., WEDEKIND, K., ESCOBAR, J., & VAZQUEZ-AÑÓN, M. (2020). Trypsin inhibitor and urease activity of soybean meal products from different countries and impact of trypsin inhibitor on ileal amino acid digestibility in the pig. *Journal of the American Oil Chemists' Society*, *97*(10), 1151-1163.
13. CHOCT, M. (2006). Enzymes for the feed industry: past, present, and future. *World's Poultry Science Journal*, *62*(1), 5-16.
14. CHOCT, M., DERSJANT-LI, Y., MCLEISH, J., & PEISKER, M. (2010). Soy oligosaccharides and soluble non-starch polysaccharides: a review of digestion, nutritive and anti-nutritive effects in pigs and poultry. *Asian-Australasian Journal of animal sciences*, *23*(10), 1386-1398.
15. CLEMENS RA, KOPPLE JD AND SWENDSEID ME 1984. Metabolic effects of histidine-deficient diets fed to growing rat’s gastric tube. Journal of Nutrition 114,
16. COLLETTI, A., ATTROVIO, A., BOFFA, L., MANTEGNA, S., & CRAVOTTO, G. (2020). Valorization of by-products from soybean (Glycine max (L.) Merr.) processing. *Molecules*, *25*(9), 2129.
17. COMAI, S., BERTAZZO, A., BAILONI, L., ZANCATO, M., COSTA, C. V., & ALLEGRI, G. (2007). The content of protein and nonprotein (free and protein-bound) tryptophan in quinoa and cereal flours. *Food Chemistry*, *100*(4), 1350-1355.

18. COWIESON, A. J., & RAVINDRAN, V. (2007). Effect of phytic acid and microbial phytase on the flow and amino acid composition of endogenous protein at the terminal ileum of growing broiler chickens. *British Journal of Nutrition*, *98*(4), 745-752.
19. DALSGAARD, J., VERLHAC, V., HJERMITSLEV, N. H., EKMANN, K. S., FISCHER, M., KLAUSEN, M., & PEDERSEN, P. B. (2012). Effects of exogenous enzymes on apparent nutrient digestibility in rainbow trout (Oncorhynchus mykiss) fed diets with high inclusion of plant-based protein. *Animal feed science and technology*, *171*(2-4), 181-191.
20. DAVILA, A. M., BLACHIER, F., GOTTELAND, M., ANDRIAMIHAJA, M., BENETTI, P. H., SANZ, Y., & TOMÉ, D. (2013). Reprint of "Intestinal luminal nitrogen metabolism: Role of the gut microbiota and consequences for the host". *Pharmacological Research*, *69*(1), 114-126.
21. DEGLAIRE, A., BOS, C., TOMÉ, D., & MOUGHAN, P. J. (2009). Ileal digestibility of dietary protein in the growing pig and adult human. *British Journal of Nutrition*, *102*(12), 1752-1759.
22. DEGOLA, L., STERNA, V., JANSONS, I., & ZUTE, S. (2019). The nutrition value of soybeans grown in Latvia for pig feeding.
23. DEMARCO, A., & GIBON, V. (2020). Overview of the soybean process in the crushing industry. *OCL*, *27*, 60.
24. EDEMA, M. O., SANNI, L. O., & SANNI, A. I. (2005). Evaluation of maize-soybean flour blends for sour maize bread production in Nigeria. *African Journal of Biotechnology*, *4*(9). Effects of dietary crude protein level on odor from pig manure. *Animal*, *1*(5), 734-744.
25. EMIRE, S. A., JHA, Y. K., & MEKAM, F. (2013). Role of anti-nutritional factors in the food industry. *Beverage & Food World*, *2*, 23-28.
26. FEFAC (EUROPEAN FEED MANUFACTURERS FEDERATION). 2007. Industrial compound feed production, FEFAC Secretariat General, Brussels, May 2007.
27. FLORET, C., MONNET, A. F., MICARD, V., WALRAND, S., & MICHON, C. (2021). Replacement of animal proteins in food: How to take advantage of nutritional and gelling properties of alternative protein sources. *Critical Reviews in Food Science and Nutrition*, 1-27.
28. FORE, S. R., PORTER, P., & LAZARUS, W. (2011). Net energy balance of small-scale on-farm biodiesel production from canola and soybean. *Biomass and bioenergy*, *35*(5), 2234-2244.
29. FRANKE, A. C., BREUKERS, M. L. H., BROER, W., BUNTE, F. H. J., DOLSTRA, O., D'ENGELBRONNER-KOLFF, F. M., ... & ZIJL, M. V. (2011). Sustainability of current GM crop cultivation: Review of people, planet, profit effects of agricultural production of GM crops, based on the cases of soybean, maize, and cotton.
30. FUCHS, R., ALEXANDER, P., BROWN, C., COSSAR, F., HENRY, R. C., & ROUNSEVELL, M. (2019). Why the US–China trade war spells disaster for the Amazon.
31. GASCO, L., JÓZEFIAK, A., & HENRY, M. (2021). Beyond the protein concept: Health aspects of using edible insects on animals. *Journal of Insects as Food and Feed*, *7*(5), 715-741.
32. GATLIN III, D. M., BARROWS, F. T., BROWN, P., DABROWSKI, K., GAYLORD, T. G., HARDY, R. W., ... & WURTELE, E. (2007). Expanding the utilization of sustainable plant products in aquafeeds: a review. *Aquaculture Research*, *38*(6), 551-579.

33. GE, J., POLHILL, J. G., MACDIARMID, J. I., FITTON, N., SMITH, P., CLARK, H., ... & APHALE, M. (2021). Food and nutrition security under global trade: a relation-driven agent-based global trade model. *Royal Society open science*, *8*(1), 201587.
34. GILANI, G. S., COCKELL, K. A., & SEPEHR, E. (2005). Effects of antinutritional factors on protein digestibility and amino acid availability in foods. *Journal of AOAC International*, *88*(3), 967-987.
35. GRALA, W., VERSTEGEN, M. W. A., JANSMAN, A. J. M., HUISMAN, J., & VAN LEEUSEN, P. (1998). Ileal apparent protein and amino acid digestibility and endogenous nitrogen losses in pigs fed soybean and rapeseed products. *Journal of Animal Science*, *76*(2), 557-568.
36. GU, C., PAN, H., SUN, Z., AND G. QIN. 2010. Effect of soybean variety on antinutritional factors content, growth performance, and nutrient metabolism in rats. *International*
37. HAN, H., CHOI, J. K., PARK, J., IM, H. C., HAN, J. H., HUH, M. H., & LEE, Y. B. (2021). Recent innovations in processing technologies for improvement of nutritional quality of soymilk. *CyTA-Journal of Food*, *19*(1), 287-303.
38. HOFFMAN, J. R., & FALVO, M. J. (2004). Protein–which is best? *Journal of sports science & medicine*, *3*(3), 118.
39. HUMER, E., SCHWARZ, C., & SCHEDLE, K. (2015). Phytate in pig and poultry nutrition. *Journal of Animal Physiology and Animal Nutrition*, *99*(4), 605-625.
40. JOOYANDEH, H. (2011). Soy products as healthy and functional foods. *Middle East Journal of Scientific Research*, *7*(1), 71-80. *Journal and Molecular Science, 11: 1048-1056.*
41. JÚNIOR, R. D. S. N., & SENTELHAS, P. C. (2019). Soybean-maize succession in Brazil: Impacts of sowing dates on climate variability, yields, and economic profitability. *European Journal of Agronomy*, *103*, 140-151.
42. KAKADE, M. L., RACKIS, J. J., MCGHEE, J. E., & PUSKI, G. (1974). Determination of trypsin inhibitor activity of soy products: a collaborative analysis of an improved procedure.
43. KARR-LILIENTHAL, L. K., KADZERE, C. T., GRIESHOP, C. M., & FAHEY JR, G. C. (2005). Chemical and nutritional properties of soybean carbohydrates as related to nonruminants: A review. *Livestock Production Science*, *97*(1), 1-12.
44. KAUSHIK, G., SATYA, S., & NAIK, S. N. (2010). Effect of domestic processing techniques on the nutritional quality of the soybean. *Mediterranean Journal of Nutrition and Metabolism, 3*(1), 39-46.
45. KHOJELY, D. M., IBRAHIM, S. E., SAPEY, E., AND HAN, T. (2018). History, current status, and prospects of soybean production and research in sub-Saharan Africa. *The Crop Journal*, *6*(3), 226-235.
46. KIM, I. S., KIM, C. H., & YANG, W. S. (2021). Physiologically active molecules and functional properties of soybeans in human health—A current perspective. *International Journal of Molecular Sciences*, *22*(8), 4054.
47. KNUDSEN, K. B. (2001). The nutritional significance of "dietary fiber" analysis. *Animal feed science and technology*, *90*(1-2), 3-20.
48. KONG, C., & ADEOLA, O. (2014). Evaluation of amino acids and energy utilization in feedstuff for swine and poultry diets. *Asian-Australasian Journal of Animal Sciences*, *27*(7), 917.
49. KRISTENSEN, A. R. (2016). Sow Replacement Software.
50. LEWIS, A. J., & PEO JR, E. R. (1986). The threonine requirement of pigs weighing 5 to 15 kg. *Journal of Animal Science*, *62*(6), 1617-1623.

51. LI, B., QIAO, M., & LU, F. (2012). Composition, nutrition, and utilization of okra (soybean residue). *Food Reviews International*, *28*(3), 231-252.
52. LIENER, I. E. (1994). Implications of antinutritional components in soybean foods. *Critical Reviews in Food Science & Nutrition*, *34*(1), 31-67.
53. LIENER, I. E., & KAKADE, M. L. (1980). Protease inhibitors. *Toxic constituents of plant foodstuffs*, *2*, 7-71.
54. MAROUNEK M., VOVK S. J., SKŘIVANOVÁ V. (1995). Distribution of activity of hydrolytic enzymes in the digestive tract of rabbits. British Journal of Nutrition, 73, 463-469.
55. MEJICANOS, G., SANJAYAN, N., KIM, I. H., & NYACHOTI, C. M. (2016). Recent advances in canola meal utilization in swine nutrition. *Journal of animal science and Technology*, *58*(1), 1-13.
56. MILANI, N. C., DE PAULA, V. R. C., AZEVEDO, C. P. F., SEDANO, A. A., SCARPIM, L. B., JUNIOR, H. M., ... & DOS SANTOS RUIZ, U. (2022). Effects of extrusion on ileal and total tract nutrient and energy digestibility of untoasted soybean meal in weanling pigs. *Animal Feed Science and Technology*, *284*, 115206.
57. MIN, B. J., HONG, J. W., KWON, O. S., LEE, W. B., KIM, Y. C., KIM, I. H., ... & KIM, J. H. (2004). The effect of feeding processed soy protein on the growth performance and apparent ileal digestibility in weanling pigs. *Asian-Australasian Journal of animal sciences*, *17*(9), 1271-1276.
58. MIRGHELENJ, S. A., GOLIAN, A., KERMANSHAHI, H., & RAJI, A. R. (2013). Nutritional value of wet extruded full-fat soybean and its effects on broiler chicken performance. *Journal of Applied Poultry Research*, *22*(3), 410-422.
59. MOKOENA, T. (2010). *Establishment of a transformation procedure to study the role of trypsin inhibitors in soybean* (Doctoral dissertation, University of Pretoria).
60. MOSENTHIN, R., SAUER, W. C., BLANK, R., HUISMAN, J., & FAN, M. Z. (2000). The concept of digestible amino acids in diet formulation for pigs. *Livestock Production Science*, *64*(2-3), 265-280.
61. MUELLER, S. A., ANDERSON, J. E., & WALLINGTON, T. J. (2011). Impact of biofuel production and other supply and demand factors on food price increases in 2008. *Biomass and bioenergy*, *35*(5), 1623-1632.
62. NAHASHON, S. N., & KILONZO-NTHENGE, A. K. (2011). Advances in Soybean and Soybean by-products in monogastric nutrition and health. *Soybean and nutrition*, 125-156.
63. NATIONAL RESEARCH COUNCIL. "Nutrient requirements of swine." (2012).
64. NOEL, S. J., JØRGENSEN, H. J. H., & KNUDSEN, K. E. B. (2021). Prediction of protein and amino acid composition and digestibility in individual feedstuffs and mixed diets for pigs using near-infrared spectroscopy. *Animal Nutrition*, *7*(4), 1242-1252.
65. NOLAND, P. R., CAMPBELL, D. R., GAGE JR, R. K., SHARP, R. N., & JOHNSON, Z. B. (1976). Evaluation of processed soybeans and grains in diets for young pigs. *Journal of Animal Science*, *43*(4), 763-769.
66. NORDIER, J. P. (2021). *Identifying possible misspecification in South African soybean oil future contracts* (Doctoral dissertation, University of Pretoria (South Africa)).
67. OIL WORLD, ISTA MIELKE, HAMBURG, May 2008
68. PARSONS, C.M., HATSIMOTO, K., WEDEKING, K.J., HAN, Y., AND D.H. BAKER. 1992. Effect of overprocessing on availability of amino acids and energy in soya bean meal. *Poultry Science, 71*, 133-140.
69. PEREIRA, H., SARDINHA, M., SANTOS, T., GOUVEIA, L., BARREIRA, L., DIAS, J., & VARELA, J. (2020). Incorporation of defatted microalgal biomass (Tetraselmis

sp. CTP4) at the expense of soybean meal as a feed ingredient for juvenile gilthead seabream (Sparus aurata). *Algal Research*, *47*, 101869.
70. PERRIER, A., DELSART, C., BOUSSETTA, N., GRIMI, N., CITEAU, M., & VOROBIEV, E. (2017). The effect of ultrasound and green solvent addition on the oil extraction efficiency from rapeseed flakes. *Ultrasonics Sonochemistry*, *39*, 58-65.
71. POULTRY FEEDING STANDARDS.2005 Ed. The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, 8-39170-977-9onna/Warszawa, Poland
72. QUINSAC, A., CARRE, P., LABALETTE, F., JANOWSKI, M., & FINE, F. (2012). Assessment of Extrusion-Pressing and Cooking-Pressing processes for the production of partly defatted soybean meal with low residual antitrypsin activity.
73. RAGHUVANSHI, R. S., & BISHT, K. (2010). 18 Uses of Soybean: Products and Preparation. *The soybean*, 404.
74. RAVINDRAN, V. (2021). Progress in ileal endogenous amino acid flow research in poultry. *Journal of Animal Science and Biotechnology*, *12*(1), 1-11.
75. REAL-GUERRA, R., STANISÇUASKI, F., & CARLINI, C. R. (2013). Soybean urease: over a hundred years of knowledge. In *A Comprehensive Survey of International Soybean Research-Genetics, Physiology, Agronomy, and Nitrogen Relationships*. Intech Open.
76. REIS DE SOUZA, T. C., BARREYRO, A. A., & MARISCAL-LANDÍN, G. (2013). Estimation of endogenous protein and amino acid ileal losses in weaned piglets by regression analysis using diets with graded levels of casein. *Journal of Animal Science and Biotechnology*, *4*(1), 1-6.
77. RITCHIE, H., ROSADO, P., & ROSER, M. (2017). Meat and dairy production. *Our world is in data*.
78. ROBBINS KR, BAKER DH, AND NORTON HW 1977. Histidine status in chick as measured by the growth rate, plasma-free histidine, and breast muscle carnosine. Journal of Nutrition 107, 2055–2061
79. ROJAS, O. J., LIU, Y., & STEIN, H. H. (2014). The concentration of metabolizable energy and digestibility of energy, phosphorus, and amino acids in lemna protein concentrate fed to growing pigs. *Journal of animal science*, *92*(11), 5222-5229.
80. RYNEK PASZ.2010 Stan I perspektywy. IERiGZ.1428-122814281228
81. SAMTIYA, M., ALUKO, R. E., & DHEWA, T. (2020). Plant food anti-nutritional factors and their reduction strategies: an overview. *Food Production, Processing, and Nutrition*, *2*(1), 1-14.
82. SHARMA, A., YADAV, B. S., & RITIKA. (2008). Resistant starch: physiological roles and food applications. *Food reviews international*, *24*(2), 193-234.
83. STEIN, H. H., SÈVE, B., FULLER, M. F., MOUGHAN, P. J., & DE LANGE, C. F. M. (2007). Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. *Journal of animal science*, *85*(1), 172-180.
84. STEIN, H. H., ROTH, J. A., SOTAK, K. M., & ROJAS, O. J. (2013). Nutritional value of soy products fed to pigs. *Swine Focus*, *4*.
85. TAMBE, S., JAIN, D., AGARWAL, Y., & AMIN, P. (2021). Hot-melt extrusion: Highlighting recent advances in pharmaceutical applications. *Journal of Drug Delivery Science and Technology*, *63*, 102452.
86. TESHALE, D., ZEMEDU, L., REHIMA, M., TESFAYE, A., BEZA, E., DIBABA, R., & DIRO, S. (2021). Soybean Value Chain Analysis in Ethiopia: A Qualitative Study.
87. THAKUR, A., SHARMA, V., & THAKUR, A. (2019). An overview of anti-nutritional factors in food. *Int. J. Chem. Stud*, *7*(1), 2472-2479.

88. TROSTLE, R. (2010). *Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices (rev*. Diane Publishing.
89. TSEHAYNEH, G. Y. (2022). *Potential and Safety of Complementary Foods Developed from Selected Cereals and Legumes Cultivated in Gondar Province, Ethiopia to Alleviate Protein-Energy Malnutrition* (Doctoral dissertation, JKUAT-AGRICULTURE).
90. UPADHAYA, S. D., PARK, J. W., LEE, J. H., & KIM, I. H. (2016). Ileal digestibility of nutrients and amino acids in low-quality soybean meal sources treated with β-mannase for growing pigs. *animal*, *10*(7), 1148-1154.
91. VANDERGRIFT, W. L., KNABE, D. A., TANKSLEY JR, T. D., & ANDERSON, S. A. (1983). Digestibility of nutrients in raw and heated soy flakes for pigs. *Journal of Animal Science*, *57*(5), 1215-1224.
92. VARACCA, A., & SCKOKAI, P. (2020). The Determinants of the EU Import Demand for Soybean and Maize: What Role for GMOs? *Journal of Agricultural & Food Industrial Organization*, *18*(2).
93. VOLLMANN, J., GRAUSGRUBER, H., WAGENTRISTL, H., WOHLESER, H., & MICHELE, P. (2003). Trypsin inhibitor activity of soybean as affected by genotype and fertilization. *Journal of the Science of Food and Agriculture*, *83*(15), 1581-1586.
94. WAGER, R., & MCHUGHEN, A. (2010). Zero sense in the European approach to GM: The European Union's zero-tolerance of trace amounts of unapproved genetically modified material in imported food and feed is scientifically unsound and could lead to economic ruin. *EMBO reports 11*(4), 258-262.
95. WALLACE, M. (2020). Economic Impact Assessment of the tillage sector in Ireland.
96. WESTHOEK, H., LESSCHEN, J. P., ROOD, T., WAGNER, S., DE MARCO, A., MURPHY-BOKERN, D., ... & OENEMA, O. (2014). Food choices, health, and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental*
97. WILKINSON, J., ESCHER, F., & GARCIA, A. (2022). The Brazil-China Nexus in Agrofood: What Is at Stake in the Future of the Animal Protein Sector. *International Quarterly for Asian Studies*, *53*(2), 251-277.
98. WOYENGO, T. A., & NYACHOTI, C. M. (2011). Supplementation of phytase and carbohydrases to diets for poultry. *Canadian Journal of Animal Science*, *91*(2), 177-192.
99. WOYENGO, T. A., & NYACHOTI, C. M. (2013). Anti-nutritional effects of phytic acid in diets for pigs and poultry–current knowledge and directions for future research. *Canadian Journal of Animal Science*, *93*(1), 9-21.
100. WRIGHT, K. N. (1981). Soybean meal processing and quality control. *Journal of the American Oil Chemists' Society*, *58*(3Part2), 294-300.
101. YANG, Z., HTOO, J. K., & LIAO, S. F. (2020). Methionine nutrition in swine and related monogastric animals: Beyond protein biosynthesis. *Animal Feed Science and Technology*, *268*, 114608.
102. ZHU, J., GAO, M., ZHANG, R., SUN, Z., WANG, C., YANG, F., ... & HAO, Z. (2017). Effects of soybean meal fermented by L. plantarum, B. subtilis, and S. cerevisiae on growth, immune function, and intestinal morphology in weaned piglets. *Microbial cell factories*, *16*(1), 1-10.

Articles in books

1. ALI, N., & SINGH, G. (2010). 16 Soybean processing and utilization. *The soybean: botany, production and uses*, 345-374
2. AOAC (1989) Official methods of analysis. Association of Official Analytical Chemist 13th ed. Washington, D.C.

3. BANASZKIEWICZ, T. (2011). Nutritional value of soybean meal. *Soybean and nutrition*, *12*, 1-20.
4. DEI, H. K. (2011). *Soybean as a feed ingredient for livestock and poultry* (pp. 215-226). Intech Open.
5. ENSMINGER, M.E. AND C. G. OLENTINE JR. 1978. *Feeds and Nutrition Complete, 1st ed.* Ensminger Publishing Co., California, USA.
6. ENSMINGERM. E. OLDFIELD. E. HEINEMANN. W.1990. Feeds and Nutrition. The Ensminger Publishing Company, 0-94121-808-2 California
7. ERBERSDOBLER, H. F., BARTH, C. A., & JAH-REIS, G. (2017). Legumes in human nutrition. Nutrient content and protein quality of pulses. *Ernahrungs Umschau*, *64*(9), 134-139.
8. GRAVELLE, A. J., DAVIDOVICH-PINHAS, M., ZETZL, A. K., BARBUT, S., & MARANGONI, A. G. (2016). Influence of solvent quality on the mechanical strength of ethyl cellulose oleo gels. *Carbohydrate polymers*, *135*, 169-179.
9. HOFFMANN E. M., SELJE-ASSMANN N., BECKER K., WALLACE R. J., BRODERICK G. A. (2010). Screening for anti-proteolytic compounds. In vitro screening of plant resources for extra-nutritional attributes in ruminants: nuclear and relates methodologies, vol. 1, pp. 55-86 (P. E. Vercoe, Makker H. P. S., Schlink A. C., editors). Dordrecht: Springer science and Business Media B.V.
10. HURRELL, R.F. 1990. Influence of the Maillard Reaction on the nutritional value of Foods. In: *The Maillard Reaction in foods processing, human nutrition, and Physiology, pp 245-358*. Birkhauser Verlag, Basel, Switzerland.
11. HUSSAIN, S., IQBAL, N., RAHMAN, T., LIU, T., BRESTIC, M., SAFDAR, M. E., ... & YANG, W. (2019). Shade effect on carbohydrates dynamics and stem strength of soybean genotypes. *Environmental and Experimental Botany*, *162*, 374-382.
12. JIDEANI, V. A. (2011). Functional properties of soybean food ingredients in food systems. *Soybean-Biochemistry, chemistry, and physiology*, 345-366.
13. JØRGENSEN, H., & GABERT, V. M. (2001). The ileal digestion of semi-purified diets containing increasing levels of casein and the use of the regression method to estimate the endogenous flow of amino acids at the distal ileum of growing pigs. In *Digestive Physiology of pigs. Proceedings of the 8th Symposium, Swedish University of Agricultural Sciences, Uppsala, Sweden, 20-22 June 2000* (pp. 198-201). Wallingford UK: CABI publishing.
14. KAUR, M., SHARMA, H. K., & KUMAR, N. (2022). Processing of Oilseeds. In *Agro-Processing and Food Engineering* (pp. 483-533). Springer, Singapore.
15. LAPEGNA, P. (2016). *Soybeans and Power: Genetically modified crops, environmental politics, and social movements in Argentina*. Oxford University Press.
16. MCFARLANE, I., & O’CONNOR, E. (2014). World soybean trade: growth and sustainability. *Modern Economy*, *5*(5), 580-588.
17. MEADE, B., PURICELLI, E., MCBRIDE, W. D., VALDES, C., HOFFMAN, L., FOREMAN, L., & DOHLMAN, E. (2016). Corn and soybean production costs and export competitiveness in Argentina, Brazil, and the United States. *USDA Economic Information Bulletin*, *154*.
18. NATIONAL RESEARCH COUNCIL .1998. Nutrient Requirements of Swine (Tenth revised Ed). National Academy Press, 0-30905-993-3DC. USA
19. NIKMARAM, N., LEONG, S. Y., KOUBAA, M., ZHU, Z., BARBA, F. J., GREINER, R., ... & ROOHINEJAD, S. (2017). Effect of extrusion on the anti-nutritional factors of food products: An overview. *Food control*, *79*, 62-73.
20. PETTIGREW, J. E., MOSER, R. L., MILLER, E. R., ULLREY, D. E., & LEWIS, A. J. (1991). Fat in swine nutrition. *Swine nutrition*, 133-145.

21. RAO, A. S., & REDDY, K. S. (2010). Nutrient management in soybeans. *The soybean: botany, production and uses*, 161-190.
22. REESE, D. (1990). G90-994 Full-Fat Soybeans for Pigs (Revised July 1992). *Historical Materials from University of Nebraska-Lincoln Extension*, 1379.
23. SERNA-SALDIVAR, S. O. (2022). Production of Cereal-Based Raw Materials for the Snack Industry. In *Snack Foods* (pp. 131-154). CRC Press.
24. STEIN, H. H., BERGER, L. L., DRACKLEY, J. K., FAHEY JR, G. C., HERNOT, D. C., & PARSONS, C. M. (2008). Nutritional properties and feeding values of soybeans and their co-products. In *Soybeans* (pp. 613-660). AOCS Press.
25. TOOMER, ONDULLA T., EDGAR O. OVIEDO, MUHAMMAD ALI, DANNY PATINO, MICHAEL JOSEPH, MIKE FRINSKO, THIEN VU, PRAMIR MAHARJAN, BEN FALLEN, AND ROUF MIAN. "Current Agronomic Practices, Harvest & Post-Harvest Processing of Soybeans (Glycine max)—A Review." *Agronomy* 13, no. 2 (2023): 427.
26. USSEC (UNITED STATES SOYBEAN EXPORT COUNCIL). 2008. Processing of soybeans into soybean products. Annual Report, 2008. Washington, D.C.
27. VAN DOOSSELAERE, P. (2013). Production of oils. *Edible oil processing*, 55-96.
28. WILCOX, J. R. (2004). World distribution and trade of soybean. *Soybeans: improvement, production, and uses*, *16*, 1-14.
29. WILLIAMS, M. A. (2018). Extraction of lipids from natural sources. In *Lipid Technologies and Applications* (pp. 113-135). Routledge.
30. WILLIS, S. (2003, February). The use of soybean meal and full-fat soybean meal by the animal feed industry. In *12th Australian soybean conference. Soy Australia, Bundaberg*. *Change*, *26*, 196-205.

Articles on the website

1. www.usda.gov/media/press-releases/2019/04/12/usda-update-farm-bill implementation-progress
2. https://www.feednavigator.com/News/Promotional-Features/Anti-nutritional-factors-in-soy-proteins

STUDENT DECLARATION

Signed below, **Patrick Tamatey**, student of the Kaposvar campus of the Hungarian University of Agriculture and Life Science, at the MSc. course of **Animal Nutrition and Feed Safety Engineering** declares that the present thesis is my work and I have used the cited and quoted literature by the relevant legal and ethical rules. I understand that the one-page summary of my thesis will be uploaded on the website of the Kaposvar campus, Institute of Physiology and Nutrition, MSc. Animal Nutrition and Feed Safety Engineering, and my thesis will be available at the Department of Farm Animal Nutrition, Institute of Physiology and Nutrition, and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no*

Date: Kaposvar, 2023.04.29

Student

SUPERVISOR'S DECLARATION

As the primary supervisor of the author of this thesis, I hereby declare that the review of the thesis was done thoroughly; the student was informed and guided on the method of citing literature sources in the dissertation, and attention was drawn to the importance of using literature data in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes no *

Approval of thesis for oral defense on Final Examination: approved not approved *

Date: Kaposvár 20 23. May month 2. day

signature

DECLARATION

on authenticity and public assessment of final master's thesis

Student's name:	Patrick Tamatey
Student's Neptun ID:	BLAIGO
Title of the document:	Nutritional Evaluation of European Soybean Meal Processed with Novel Technologies as Regards the Ileal Digestibility of Amino Acids in Weaned Piglets
Year of publication:	2023
Department:	Department of Farm Animal Nutrition

I declare that the submitted final master's thesis is my own, original individual creation. Any parts taken from another author's work are clearly marked and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take the final exam if I submit another final master's thesis.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of the Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectual property.

I acknowledge that the electric version of my work is uploaded to the repository system of the Hungarian University of Agriculture and Life Sciences.

Place and date: Kaposvar, 2023.04.29

Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Patrick Tamatey (BLAIGO), I here declare that the final master's thesis has been reviewed by me, and the student was informed about the requirements of literary sources management and its legal and ethical rules.

I recommend/don't recommend[1] the final master's thesis to be defended in a final exam.

The document contains state secrets or professional secrets: yes no*[2]

Place and date: Kaposvár 2023 year May month 2. day

Internal supervisor

[1] Please underline applicable.
[2] Please underline applicable.