THE NUTRITIONAL VALUE OF FIELD PEAS FROM DIFFERENT ORIGINS AND WITH DIFFERENT PARTICLE SIZES FED TO GROWING PIGS

BY

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Abstract

Five experiments were conducted to determine the nutritional composition and digestibility of three sources of field peas ground to different particle sizes and fed to growing pigs. One source was obtained from the U.S., and two sources were obtained from Canada (i.e., Canada 1, Canada 2). In Exp. 1, the objective was to test the hypothesis that particle size and origin of field peas influence the apparent ileal digestibility (**AID**) of starch and the standardized ileal digestibility (**SID**) of amino acids (**AA**). Six ileal cannulated barrows with an initial body weight (**BW**) of 50.5 kg (SD = 3.7) were randomly allotted to a 6 × 6 Latin square design with six periods and six experimental diets. The U.S. source and one of the sources from Canada (i.e., Canada 1) were each divided into two batches and ground to 246 or 434 µm, whereas the other source from Canada (i.e., Canada 2) was only ground to 246 µm. Therefore, five diets in which field peas was the sole source of CP and AA, were formulated. A N-free diet was used to determine the basal endogenous losses of CP and AA. The AID of starch was increased by reducing the particle size in the U.S. source of field peas, but that was not the case for the Canada 1 source (interaction; $P < 0.001$). The SID of CP and AA was not affected by the particle size of field peas. The SID of some AA and CP were greater ($P < 0.05$) in the Canada 2 source compared with field peas from the U.S., but there was no effect on SID of AA of reducing the particle size of field peas from 434 to 246 µm. In Exp. 2 and 3, the objective was to test the hypothesis that there are no differences in the standardized total tract digestibility (**STTD**) of P among three sources of field peas ground to different particle sizes and to determine the effect of increasing levels of phytase on the STTD of P in one source of field peas when fed to pigs. In Exp. 2, 50 growing pigs with an initial BW of 16.4 kg (SD = 1.2) were allotted to one of five diets in a randomized complete block design. The U.S. field peas were ground to 265, 457, or 678 µm, whereas the Canada 1 peas were ground only to 253 µm, and the Canada 2 source was ground to 411 µm. In Exp. 3, six diets were used. Diets were based on the U.S. field peas ground to 678 µm and included 0, 250, 500, 1,000, 2,000, or 4,000 units per kg of microbial phytase. Forty-eight growing pigs with an initial BW of 15.3 kg (SD = 0.9) were allotted to a randomized complete block design with six diets and three blocks. Results from Exp. 2 and 3 indicated that the STTD of P was not affected by the source of field peas or by particle size, but the apparent ileal digestibility (**ATTD**) of Ca and P and the STTD P increased (linear, $P < 0.05$) as phytase increased in the diets. For the last two experiments, the objective was to test the hypothesis that the particle size of field peas and the location where field peas were grown may affect the ATTD of nutrients, and gross energy (**GE**), concentrations of digestible energy (**DE**), metabolizable energy (**ME**), and net energy (**NE**), the AID of starch, and SID of crude protein (**CP**) and AA in field peas when fed to growing group-housed pigs. In both experiments, three sources of field peas were used. The U.S. field peas were ground to 265, 457, or 678 µm, whereas both sources of the Canadian peas were ground to 400 µm. A basal diet contained corn and soybean meal as the sole energy sources, and five diets containing corn and soybean meal and 50% of each source of field peas were formulated. For Exp. 4, an N-free diet was also used to calculate basal endogenous losses of AA and CP, but in Exp. 5, no N-free diet was used. In Exp. 4, seven ileal cannulated barrows with initial **BW** = 60.6 kg (SD = 2.1) were randomly allotted to a 7 × 7 Latin square design with seven periods and seven experimental diets. In Exp. 5, twenty-four pigs with an average initial body weight of 30.8 kg (SD = 1.0) kg were used in a 6 × 6 Latin square design with six calorimetry chambers and six consecutive periods. Four pigs were housed in each chamber. The six diets were fed to pigs in 1 chamber in each period, and no chamber received the same diet twice. The SID of CP and AA was not influenced by the origin of the peas or the particle size, but the AID of starch increased when particle size was reduced from 678 µm to 457 or 265 µm. Location did not affect concentrations of DE, ME, or NE of field peas, but concentrations of DE, ME, and NE increased when the particle size was reduced from 678 µm to 457 or 265 µm. In conclusion, the SID of AA in field peas is not affected by the growing location or the particle size; however, the AID of starch increased when particle size was reduced from 678 to 457 or 265 µm. The STTD of P in field peas is not affected by the growing location or particle size, but the STTD of P was increased as the inclusion level of microbial phytase increased in the diet. Inclusion of field peas in corn-soybean meal diets did not affect NE of diets. The DE, ME, or NE of field peas is not affected by growing location, but when the particle size was reduced from 678 µm to 457 or 265 µm, concentrations of DE, ME, and NE increased.

Keywords: amino acids, energy, field peas, growing pigs, particle size, phosphorus digestibility

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Table of Contents

CHAPTER 1: Introduction

Field peas are mainly grown for human consumption, and peas are used as a plant-based protein that can contribute to meeting dietary requirements for amino acids in populations where the availability of animal-based protein is limited (Dahl et al., 2012). Field peas are also consumed by populations who choose not to consume animal protein (Fanelli et al., 2022). Field peas may also be included in diets for swine, but inclusion level is limited by the presence of antinutritional factors in the peas (Vidal-Valverde et al., 2003; Stein et al., 2004), but the antinutritional factors may be reduced by using thermal processing such as pelleting or extrusion of the peas (Stein and Bohlke, 2007). Grinding peas to a small particle size may increase energy digestibility (Montoya and Leterme, 2011) because particle size reduction may change the structure of proteins and starch, making AA and starch more available for digestive enzymes in the small intestine and improving their utilization (Stein and Bohlke, 2007; Rojas and Stein, 2017). Field peas also offer several agronomic benefits, including winter hardiness, and pest resistance, compared with cultivation of cereal grains and oilseed lower cost of cultivation compared with cultivation of cereal grains and oilseeds (Nielsen, 2001; McMurray et al., 2011; Urbatzka et al., 2011; Tolessa, 2017). Therefore, field peas offer farmers an option to grow a crop with high energy and protein in areas where corn or soybeans cannot be grown (McMurray et al., 2011).

The nutritional profile of field peas has been reported, and because of their protein and starch content, the nutritive value of peas is intermediate between corn and soybean meal (Stein et al., 2004). Likewise, the fiber portion of field peas is highly fermentable and may provide intestinal benefits to pigs and humans (Canibe and Bach Knudsen, 1997; Loo et al., 2007; Tosh and Yada, 2010).

Although field peas is a very suitable feed ingredient in diets for pigs, there is limited information about the effects of particle size of peas on energy and nutrient digestibility. It is also not known if growing location impact in vivo digestibility of energy and nutrients of field peas. Therefore, the objectives of this research were to:

1. Compare the apparent ileal digestibility of starch and the standardized ileal digestibility of CP and AA in field peas grown in Canada with the values of peas grown in the U.S.
2. Determine the apparent and standardized total tract digestibility of P in field peas from Canada and the U.S. ground to different particle sizes.
3. Determine the effect of different levels of phytase on the digestibility of P in field peas.
4. Determine effects of origin and particle size of field peas on the apparent total tract digestibility of energy and concentrations of DE, ME, and NE in field peas when fed to growing pigs.

To address the 4 objectives, 5 experiments were conducted.

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CHAPTER 2: Field peas in the nutrition of pigs: Literature review

Introduction

Field peas are pulses from the legume plant *Pisum sativum L.* and are referred to as a cool-season pulse crop because peas are well adapted to the soil and climate in cool regions because their cotyledons, or growing points, remain below ground through frosty seasons (Howieson et al., 2000). During the last 20 years, Canada, Russia, China, and the United States have become the largest producers of field peas, accounting for approximately 60% of global production (FAOSTAT, 2022). Production of field peas has been increasing due to the capacity of peas for nitrogen fixation, easy cultivation, use in crop rotation, and use as a green fallow crop. As a consequence, the use of N fertilizers and pesticides, as well as weed growth in the subsequent crop, are reduced when field peas are cultivated, which results in a reduction in the environmental impacts of growing peas compared with growing other agricultural crops (Jezierny et al., 2010; Nemecek et al., 2015; Lienhardt et al., 2019). Like chickpeas, lentils, and dry beans, one of the primary uses of field peas is for human consumption as green immature seeds or as yellow mature seeds (Iqbal et al., 2005). Field peas are also used for livestock feeding in areas where production of other protein crops is limited or if quality standards of peas meant for human consumption are not met (Harrold et al., 2002; Stein et al., 2016). Field peas are one of the few feed ingredients with comparatively high quantities of crude protein and starch, providing a unique alternative to conventional livestock energy and protein sources like soybean meal, corn, and barley. Inclusion of field peas in diets for pigs is sometimes restricted because of the antinutritional factors in peas, which may inhibit absorption and proper utilization of nutrients. However, antinutritional factors may be reduced or eliminated by thermal treatments such as pelleting or extrusion (Stein and Bohlke, 2007; Stein et al., 2004; 2010). Protein structure also changes and starch is gelatinized after proper extrusion or pelleting of field peas, which makes more starch and amino acids (**AA**) available for digestive enzymes in the small intestine, resulting in improved utilization of protein and starch by pigs (Stein and Bohlke, 2007; Rojas and Stein, 2017). Particle size reduction is another processing method that is used to modify constituent structures and improve the nutritional value (Kim et al., 2009; Rojas and Stein, 2017). For instance, including up to 36% field peas in diets for growing and finishing pigs did not affect growth performance or carcass characteristics (Stein et al., 2004; 2006). However, besides processing, nutritional value may be impacted by differences among cultivars, growing regions, and other environmental factors. Therefore, there is a need to investigate the nutritional value of field peas grown in different areas or under different environmental conditions (Lu et al., 2020).

Agronomic characteristics of peas

Field pea is an annual season grain legume crop cultivated worldwide, and it has been adapted to humid environments and has tolerance to freezing temperatures and diseases (Stoddard et al., 2006; Siddique et al., 2013). Nitrogen is the most important limiting element for plant development and crop productivity, after carbon and water (Peoples et al., 1995). However, usage of legumes, including field peas, as green manure in a cereals crop rotation can reduce the need for mineral N fertilizer for the subsequent crop because of the ability of peas to fix atmospheric N_2 in the soil with the *Rhizobia* microbes (Kakraliya et al. 2018; Chan and Heenan, 1991; Mayer et al., 2003). If used as a cover crop, field peas are killed in the flowering stage when they are 45 to 60 cm tall (Akemo et al., 2000). If planted with the intention to harvest, it takes 13 to 16 weeks to grow peas to harvest, depending on the desired moisture content and desired end usage (Fraser et al., 2001; Nielsen, 2001; Borreani et al., 2009).

Field peas can grow on a wide range of soil types, but mostly in neutral to alkaline soils (Brennan and Bolland, 2004). They are more frost-tolerant than soybeans and faba beans, but field peas have low tolerance for soil compaction and anaerobic soil conditions. Therefore, good drainage and dry weather for adequate oxygen supply for the roots is essential (Belford et al., 1980; Swensen and Murray, 1983; Doré et al., 1998; Meyer and Badaruddin, 2001; Semaškienė et al., 2022). In field pea crops, yield depends on the number of seeds produced and their quality. Variations in yield are mainly caused by diseases, biotic and abiotic stresses, and can also be related to the environment and the genotype of field peas used (Doré et al., 1998; Guilioni et al., 2003). Winter peas are more efficient in suppressing weeds and have greater yield potential than spring peas (Urbatzka et al., 2011). However, waterlogging and pre-freezing growth temperatures during winter may result in abiotic stress that can influence the yield of field peas and the quality of seeds (Meyer and Badaruddin, 2001; Guilioni et al., 2003; Jackson and Colmer, 2005; Stoddard et al., 2006). Tolerance to cold and waterlogging environments may be improved by using a cropping mixture with winter cereals or grasses (e.g., winter rye, oats, ryegrass; Urbatzka et al., 2011; Gronle et al., 2015). Therefore, as a cover crop in controlled soil and under wet conditions, field peas in a crop combination with oat has a greater dry matter (**DM**) yield compared with field peas monoculture yield (Karpenstein-Machan and Stuelpnagel, 2000; Kaiser et al., 2007; Tolessa et al., 2013).

Diseases and pests in field peas may decrease the productivity and quality of the pea seed (Clerkx et al., 2004; Davidson et al., 2004). Field pea crops grown in locations with continuous wet weather, poor draining, and high relative humidity are more exposed to developing diseases and pests. Some common diseases in field peas (e.g., mycosphaerella blight and ascochtya foot rot) are spread with high soil temperature and moisture (Skoglund et al., 2011). Therefore, the optimal environment for growth and development of field peas is in dry weather and dry soils (Skoglund et al., 2011; McMurray et al., 2011; Sadras et al., 2012). Management and breeding advances in field peas may help improve production and resistance to pests, diseases, and environmental stresses (McMurray et al., 2011), and the use of field peas as a cover crop may disrupt weed, fungus, and bacterial root cycles and improve growth and yield in the subsequent cereal crop (Abdin et al., 2000; Horner et al., 2019).

Genetic variability in field peas has been considered essential in obtaining high-yield cultivar progenies, high seed protein concentration, early maturity, and resistance to biotic and abiotic stresses (Tayeh et al., 2015; Tolessa, 2017). Around 75% of the global production of field peas is yellow peas, and during recent years, yield increases in yellow field peas have averaged approximately 2% per year (Warkentin et al., 2015). Environment and variety have an impact on the compounds stored in the seeds, such as protein and AA, starch, lectins, and proteases (Griffiths, 1984; Hood-Niefer et al., 2012). Protein concentration is usually greater in field peas that have been grown in drier climates than in wet climates (Hood-Niefer et al., 2012). However, lower rainfalls in the growing location of field peas may decrease starch concentrations (Nikolopoulou et al., 2007).

Selection of field peas for cultivation has brought a significant interest in breeding new cultivars with increased yield and improved agronomic traits, including protein and starch (Santalla et al., 2001; Tar'an et al., 2004). Therefore, new pea varieties are currently available due to breeding of numerous pea types in different regions with different final usage destinations (Gali et al., 2018; SasKSeed., 2022).

Nutrient Composition of Field Peas

Field peas are grain legumes with high concentration of carbohydrates in the cotyledons. Sucrose, oligosaccharides, starch, and crude fiber comprise around 70% of the total grain (Khan and Croser, 2004). Most of the digestible energy in field peas is derived from starch, which is between 35 and 45% of the grain (Ratnayake et al., 2002; Simsek et al., 2009; Wang et al., 2011; NRC, 2012; INRAE, 2021; Yu et al., 2021). The gross energy (**GE**) concentration is approximately 3,900 Kcal/kg on a DM basis (Stein and Bohlke, 2007; NRC, 2012; Stein et al., 2016; FEDNA, 2021; Hugman et al., 2021; Woyengo and Zijlstra, 2021; Adekoya and Adeola, 2022). The conformation of starch in the field pea seed occurs as insoluble semi-crystalline and birefringent granules composed of 2 polysaccharides: amylopectin and amylose (NRC, 2012). The content of amylose as a percentage of starch in field peas is 30 to 35%, while amylopectin comprises the remaining starch (Guillon and Champ, 2007). Amylopectin forms a crystalline system in the starch molecule that consists of α (1-4) and α (1-6) glycosidic linkages, whereas amylose forms a linear dispersed system of α (1-4) glycoside linkages (Bach Knudsen, 1997; Cummings and Stephen, 2007; NRC, 2012).

Monogastric animals efficiently digest the majority of the ingested starch by the combination of α-amylase and enzymes secreted by glands in the small intestinal brush border (Bach Knudsen and Jørgensen, 2001). Starch is usually classified according to the rate of digestion of their fractions in the small intestine: rapidly digestible starch (**RDS**), slowly digestible starch (**SDS**), and resistant starch (Englyst et al., 1992). For instance, the digestion of amylose by the pancreatic amylase enzyme is slow due to the reduced surface area and the presence of more hydrogen bonds in its structure compared with the amylopectin fraction (Regmi et al., 2011). However, when starch granules are heated in water at more than 100℃ or are ground, solubilization of amylose improves because the structure of the semi-crystalline granules is disrupted or eliminated, and water can be linked to the hydrogen bonding of the exposed hydroxyl groups (Miles et al., 1985; Ratnayake and Jackson, 2008). In fact, digestibility studies demonstrated that field peas treated with heat or water by extrusion, pelleting, and heated water soaking had increased apparent ileal digestibility (**AID**) of starch by monogastric animals as a result of the gelatinization of the starch granules, which made it more susceptible to hydrolysis by digestive enzymes (Mariscal-Landín et al., 2002; Sun et al., 2006; Stein and Bohlke, 2007).

Field peas contain between 10 and 20% total dietary fiber (**TDF**), including oligosaccharides, non-starch polysaccharides (**NSP**), resistant starch, and lignin (Stoughton-Ens et al., 2010; NRC, 2012; Stein et al., 2016; Bach Knudsen et al., 2017). The approximate concentration of insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) in field peas as a percentage of TDF is 90 and 10%, respectively (Wang and Daun, 2004; Wang et al., 2008). The IDF in field peas is greater than in winter wheat, sorghum, and corn (Rosenfelder et al., 2013; Cervantes-Pahm et al., 2014; Stein et al., 2016; Abdulla et al., 2021; Adekoya and Adeola, 2022). Oligosaccharides are low molecular weight carbohydrates including sucrose and the galacto-olisaccharides (e.g., raffinose, stachyose, and verbascose; Johansen et al., 1996). The total concentration of galacto-oligosaccharides in field peas is approximately 3% (Bach Knudsen, 1997; Canibe and Bach Knudsen, 1997; Wang et al., 2008; Stein et al., 2010). The galacto-galactosides are bound by α (1-6) glycosidic bonds and are degraded by the alpha-galactoside enzyme (Rehms and Barz, 1995). Monogastric animals do not digest oligosaccharides in the small intestine due to the lack of the α-galactoside enzyme, but the large and small intestine microbes rapidly ferment them. In addition to the high fermentability, they are also considered prebiotics that may modify the composition of the colon bacteria microflora improving animal and human gut health (Gulewicz et al., 2002; Loo et al., 2007; Choct et al., 2010).

Non-starch polysaccharides are present in moderate proportions in field peas, with uronic acid, arabinose, and cellulose being the most abundant compounds (Bach Knudsen, 1997). Field peas contain more soluble pectins and arabinoses than corn and wheat, and these substances are correlated with increased digesta viscosity and reduced gastric emptying (Bach Knudsen, 1997; Choct et al., 2010). The concentration, structure, and solubility of arabinose-containing pectic substances in the hull of the seed of field peas are influenced by plant genotype and growing conditions (Hood-Niefer et al., 2012; Maharjan et al., 2019). These characteristics of arabinose and uronic acid can impact nutrient digestibility when field peas are fed to monogastric animals (Choct, 2015). However, the digestibility of arabinose and pectins in field peas is relatively high as a result of the high fermentability of those components (Canibe and Bach Knudsen, 1997; Sun et al., 2006). The concentration of Klason lignin in field peas is 1 to 2%, whereas acid detergent lignin (ADL) concentration is approximately 0.4% (Bach Knudsen, 1997; FEDNA, 2021; INRAE, 2021). Lignin is an undesirable component because microbes or endogenous enzymes do not ferment lignin, and it may reduce the digestibility of other nutrients (Bach Knudsen, 2001; Bach Knudsen and Jørgensen, 2001).

The concentration and composition of fiber vary among field peas sources, and the same is true for the concentration of crude protein (**CP**). The amount of N in the field pea seed, as is the case with most feed ingredients, depends on genotype, growing conditions, agronomic practices, and soil (Stein et al., 2004; Lu et al., 2020; Abdulla et al., 2021). Published values for the concentration of CP in field peas range from 19 to 25% (Ravindran et al., 2010; Stein et al., 2010; Hugman et al., 2021; INRAE, 2021) with an average of 22.75%. Field peas contain more Lys than corn, barley, and wheat, with an average concentration of 1.5% (Jezierny et al., 2010; NRC, 2012; Stein et al., 2016; INRAE, 2021), and the concentrations of Met, Thr, and Trp are 0.21%, 0.83%, and 0.21%, respectively, where Met and Trp are lower compared with cereal grains. Field peas also have a greater concentration of Arg (1.91%), Leu (1.56%), and Val (1.03%) than cereal grains (NRC, 2012; Stein et al., 2016; FEDNA, 2021).

Like other legumes, the concentration of Ca in field peas is low – usually around 0.09% (NRC, 2012; INRAE, 2021; Adekoya and Adeola, 2022). Phosphorus, however, is more abundant in field peas. The concentration of total P is 0.20 to 0.40%, but a significant portion of the P in peas is bound to phytate (Lott et al., 2007; NRC, 2012; Kumar and Sinha, 2018; INRAE, 2021). Phytate is insoluble at the physiological pH in the intestines of monogastric animals. Dietary phytate can create insoluble complexes with other mineral cations (i.e., Zn, Fe, Ca, Mg, Mn, and Cu), decreasing their digestibility (Kumar and Sinha, 2018). However, the exogenous phytase enzyme used in the animal feed industry has the ability to reduce phytate in food processing and catalyze the conversion of phytate to inositol and inorganic phosphate (Haertlé, 2016). As a result, including exogenous phytase in diets containing legumes fed to monogastric animals may increase the digestibility of P and Ca (Stein et al., 2006; Kahindi et al., 2015).

Legumes such as field peas are well suited to meet the food industry demands due to their high protein, carbohydrate, and mineral content. Field peas may contain antinutritional factors (ANF), such as inhibitors of proteolytic enzymes in different concentrations, depending on the characteristics of the growing region, cultivar, and variety (Vidal-Valverde et al., 2003; James et al., 2005). The content of inhibitors of proteolytic enzymes, such as trypsin inhibitors in field peas, may limit protein and AA digestibility in humans, pigs, and poultry decreasing the biological value of pea protein (Stein et al., 2004; Avilés-Gaxiola et al., 2018). The trypsin inhibitory activity (**TIU**) has been reported for field peas in different varieties and cultivars in the range between 0.40 to 2.5 mg pero kg on a DM basis (Canibe and Eggum, 1997; James et al., 2005; Stein et al., 2010). Heating may be used to eliminate trypsin inhibitors, and other processes, such as fermentation, germination, and heat water-soaking, may also be used to remove the activity (Trugo et al., 2000; Fasina et al., 2001). Although heat treatment may reduce the concentration of trypsin inhibitors in field peas (Avilés-Gaxiola et al., 2018; Hugman et al., 2021), improvement in the digestibility of protein and AA in field peas by monogastric animals after heat treatment has been inconsistent. For example, Canibe and Eggum (1997) and Stein et al. (2010) reported no differences in the digestibility of protein and AA, or in pig growth performance between pigs fed raw or heat-treated field peas. In contrast, Stein and Bohlke (2007) reported an improvement in the digestibility of AA after extrusion of field peas. Therefore, the efficiency of heat treatment in decreasing ANFs depends on the type and duration of heat and also on the variety and cultivar of the field peas.

Digestibility of Nutrients and Energy

The digestibility of most nutrients in different cultivars and varieties of field peas has been evaluated in pigs and chickens (Grosjean et al., 1998; Stein et al., 2004; Adekoya and Adeola, 2022), but because new varieties have been developed, it is important to keep evaluating the nutritional composition and digestibility of field peas grown in different regions to avoid an underestimation by feed manufacturers. The apparent ileal digestibility of CP was greater in field peas (77 to 80%) than in meat and bone meal (Moughan et al., 1984), and the standardized ileal digestibility (**SID**) of CP is approximately 80% and 87% in field peas and soybean meal (**SBM**), respectively (NRC, 2012). However, the SID of CP in field peas maybe greater than 88% in some cultivars of field peas (Nørgaard et al., 2012). The SID of most AA in field peas is similar to that in SBM, but greater or equal to cereal grains such as corn, wheat, and rye (NRC, 2012). Unlike Lys, one of the limiting AA in cereal grains, the limiting AA in field peas are Trp and the sulfur-containing AA (Met and Cys; NRC, 2012; Stein et al., 2016). The SID of Lys, Met, Thr, Trp, and Cys in field peas is 88%, 80%, 79%, 74%, and 67%, respectively (Stein et al., 2004; NRC, 2012; Stein et al., 2016). It is hypothesized that the lower digestibility of Met, Thr, Trp, and Cys in field peas compared with SBM may be a result of the AA profile of legumins, vicilins, and albumins within the pea seed (Daba and Morris, 2021). For instance, albumins, which are less digestible than the other legume proteins, are abundant in sulfur-containing AA, whereas vicilins are very deficient in these AA (Mariscal-Landín et al., 2002). The low digestibility of some AA may also be due to the contents of trypsin inhibitors in raw field peas acting with proteases to form insoluble indigestible complexes with proteins, which can alter protein structures, thereby limiting protease activity (Avilés-Gaxiola et al., 2018).

The digestible carbohydrate fraction in field peas consists mainly of 4% to 5% of sucrose and maltose and 40% to 45% starch (Canibe and Bach Knudsen, 1997; NRC, 2012). The AID of sucrose and maltose is 98 to 99%, whereas the AID of starch is 90 to 97% (Canibe and Bach Knudsen, 1997; Stein and Bohlke, 2007). The AID of starch in raw field peas is approximately 90% but may increase by 4 to 5 percentage units with thermal treatments (Stein and Bohlke, 2007). The non-digestible fraction of carbohydrates in field peas consists mainly of galacto-oligosaccharides and NSP (Bach Knudsen, 1997). Galacto-oligosaccharides are easily fermented by the intestinal microbes, which can synthesize the alpha-galactosidase enzyme; therefore, the AID of the alpha-oligosaccharides is approximately 77% (Bengala et al., 1991). The apparent total tract digestibility (**ATTD**) of NSP is not affected by heat treatments, but NSP is relatively highly fermented by microbes in the hindgut of pigs, and the ATTD of NSP is close to 87% (Canibe and Bach Knudsen, 1997; Stein and Bohlke, 2007).

The standardized total tract digestibility (**STTD**) of P is 56% in field peas (NRC, 2012). Although this value is based on 7 observations, it does not consider the newest varieties of field peas (i.e., low-phytate or high-phytate field peas). Additionally, the ATTD of P in field peas is 67% if microbial phytase is included in the diet (Stein et al., 2006). Digestibility of P is greater in field peas than in SBM, corn, and sorghum but less than in wheat (NRC, 2012). The lower intrinsic phytase activity in legumes may be responsible for improving P digestibility by exogenous phytase in pea varieties with high phytate-P because phytase has more substrate to act on in high phytate peas, releasing more available P (Viveros et al., 2000; Dersjant-Li et al., 2015). Therefore, adding field peas without or with phytase to swine diets may reduce the need for feed phosphates in the diets.

Field peas have a greater net energy (**NE**) concentration than soybean meal and corn (2,419 kcal/kg DM; NRC, 2012; INRAE, 2021). However, these values were predicted based on the digestible energy (**DE**) or metabolizable energy (**ME**) value of field peas and its macronutrients in complete diets, but not in the ingredient itself (Eq. 1-8; NRC, 2012; Noblet et al., 1994). The DE is calculated by subtracting the GE in feces from the GE the ingredient, only taking into account fermentation in the hindgut (NRC, 2012). Therefore, because much of the energy in field peas is from starch, greater concentration of starch in field peas is positively correlated with greater DE and, consequently, greater NE. On the other hand, energy digestibility and NE are negatively correlated with the concentration of fiber (Navarro et al., 2018) due to increased rate of passage in the digestive tract if fiber is increased in the diet (Le Goff and

Noblet, 2001; Navarro et al., 2018; Liu et al., 2021). However, field peas contain arabinose-containing pectic substances that may be fermented in the hindgut (Canibe and Bach Knudsen, 1997). The NE in field peas measured by indirect calorimetry is around 2,010 kcal/kg (Woyengo and Ziljistra, 2021), but a value of 2,419 has also been reported (NRC, 2012).

The concentration of ME in field peas is 3,353 kcal per kg on a DM basis, which is similar to corn and wheat, but greater than in barley (NRC, 2012; Woyengo and Zijlstra, 2021). On a DM basis, the DE in field peas is approximately 3,504 kcal per kg (Montoya and Leterme, 2011; NRC, 2012) but this value may be influenced by processing of the field peas and by cultivars (Zijlstra et al., 1998, cited by Stein and Bohlke, 2007; Montoya and Leterme, 2011). The AID of GE in field peas is approximately 73%, which is similar to corn but greater than in rye and wheat (Stein and Bohlke, 2007; Cervantes-Pahm et al., 2014; Woyengo and Zijlstra, 2021), and the ATTD of GE in field peas is 85% (Stein and Bohlke, 2007; Woyengo and Zijlstra, 2021). Thermal processing techniques such as extrusion applied to field peas resulted in a numerical increase in the ATTD of GE of 5 percent units and a significant increase of approximately 7 percentage units in the AID of GE (Stein and Bohlke, 2007).

The increase in the ATTD compared with the AID of GE is due to microbial fermentation in the hindgut. The large intestine microbiota degrades dietary fiber to generate short-chain fatty acids, which pigs can absorb for energy utilization (Navarro et al., 2019). Fiber in field peas often is poorly fermented in the small intestine, but in the hindgut, microbial fermentation increases energy absorption from field peas (Jensen and Jørgensen, 1994; Canibe and Bach Knudsen, 1997). Therefore, the increase in the ATTD of GE in peas compared with the AID is due to microbial fermentation of NSP in the hindgut (Canibe and Bach Knudsen, 1997).

Effects of particle size on Digestibility of Nutrients

The principal cost of swine production is feed, representing 60% to 70% of the total cost (Patience et al., 2015). Plant-based feed ingredients provide most energy and AA in swine diets, but a reduction in profitability is notable when feed prices are high (Stein et al., 2016). As a result, any processing treatment that increases nutrient utilization of feed ingredients is of economic importance (Lancheros et al., 2020). Processing feed ingredients by grinding facilitates mixing and improves feed uniformity and feed efficiency by pigs (Fastinger and Mahan, 2003; Rojas and Stein, 2015). Effects of particle size on energy and nutrient digestibility in many feed ingredients have been documented (Wondra et al., 1995a; Fastinger and Mahan, 2003; Kim et al., 2009; Rojas and Stein, 2015). For example, Healy et al. (1994) and Wondra (1995a) suggested that a reduction in particle size of corn and sorghum to 600 to 700 µm in diets for nursery and growing-finishing pigs may increase nutrient and energy digestibility as well as growth performance in pigs compared with pigs fed diets containing corn or sorghum ground to around 1,200 µm. However, finely ground ingredients may adversely affect the gastrointestinal tract of pigs (Goodband et al., 2002; Rojas and Stein, 2017). Therefore, nutrient digestibility of ingredients is strongly correlated with average particle size, but impacts on health of pigs also need to be considered (Goodband et al., 2002; Rojas and Stein, 2017).

Grinding increases nutrient digestibility in monogastric animals by providing a larger surface area for contact between the digestive enzymes and the substrate (Kim et al., 2002). The AID of starch in cereal grains such as corn and wheat increases when particle size is reduced from 865 to 339 µm and 1000 to 500 µm, respectively (Kim et al., 2005; Lahaye et al., 2008; Rojas and Stein, 2015). Increased in-vitro and in vivo starch digestibility was also observed in field peas by reducing particle size (Montoya and Leterme, 2011), but in vivo data for the impact of reduced particle size on digestibility in pigs have not been reported.

An improvement in the ATTD of GE and DM by sows and growing finishing pigs of approximately 7% was observed in corn when the particle size was reduced from 1,200 to 400 µm (Wondra et al., 1995a,b). Similar results were observed in finishing pigs when the particle size in corn-corn germ or corn-corn germ meal diets was reduced from 768 µm to 441 µm (Lyu et al., 2020). Likewise, an improvement in the ATTD of GE and DE of 15 percent units was observed when the particle size of field peas was reduced from 1035 µm to 156 µm (Montoya and Leterme, 2011). However, the type of mill used to grind reduce particle size of corn may affect energy digestibility because the ATTD of GE and DM in finishing pigs increased more if a roller-milled rather than a hammer mill was used to reduce the particle size from 700 µm to 300 µm (Acosta et al., 2020).

Reduction of particle size of SBM from 949 to 185 µm did not affect digestibility of most AA by growing pigs (Fastinger and Mahan, 2003), and no improvement in the SID of AA in corn was observed when particle size was reduced from 865 to 339 µm (Rojas and Stein, 2015). However, the AID of AA in lupins increased in pigs fed diets with a particle size of 567 µm compared with pigs fed diets containing lupins with a particle size of 1,304 µm (Kim et al., 2009). A reduction in particle size from 850 or 700 µm to 400 µm improved the ATTD of N by 5 percentage units and reduced total N excretion from pigs fed barley-field peas diets (Oryschak et al., 2002). The ATTD of N and DM in wheat also increased if particle size was reduced from 1,300 to 600 µm (Mavromichalis et al., 2000), and ATTD of N and DM increased in roller-milled corn with a particle size of 300 µm compared with corn with a particle size of 700 µm (Acosta et al., 2019).

Conclusion

As a feed ingredient, field peas provide a nutritional profile intermediate between corn and soybean meal, providing energy and protein to the pig. The concentration of CP in field peas is greater than in cereal grains. Starch comprises 40 to 45% of field peas and is digested by 85% to 95% in the small intestine. The fiber in field peas includes alpha-oligosaccharides, which are well fermented in the small intestine of pigs, whereas NSP in field peas are mainly fermented in the large intestine. Physical and thermal treatments, particle size reduction, pelleting, and extrusion increase the digestibility of nutrients and energy. Like other cereal grains, field peas have low concentrations of Ca but contain approximately 0.40% P. Digestibility of P is around 50% but may be increased by exogenous phytase. Overall, field peas contain easily digestible nutrients and may be used in swine diets.

Figure

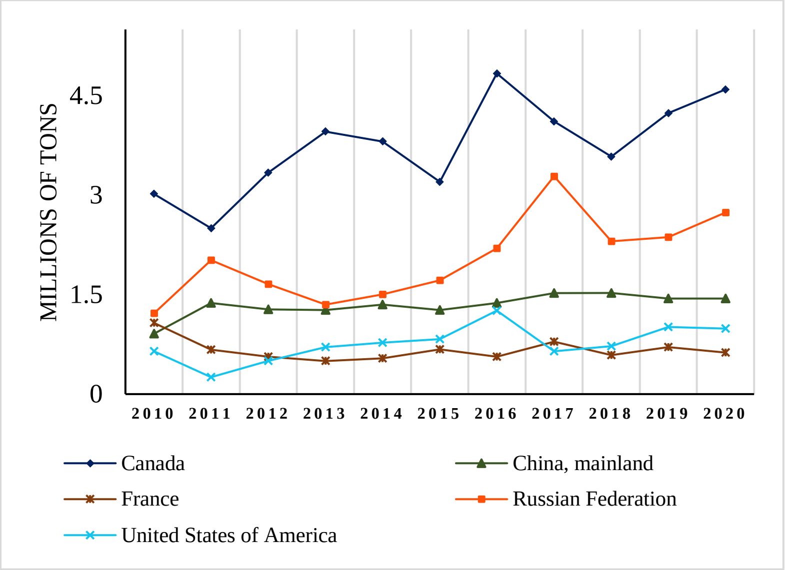

Figure 2.1 Production of field peas from 2010 to 2020 crop/year of 5 of the major producers of field peas in the world.

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CHAPTER 3: Impact of particle size and source of field peas on apparent ileal digestibility of starch and standardized ileal digestibility of amino acids by growing pigs

Abstract

The objective was to test the hypothesis that particle size and origin of field peas influence the apparent ileal digestibility (**AID**) of starch and the standardized ileal digestibility (**SID**) of amino acids (**AA**). Three sources of field peas were procured. One source was from the U.S. and 2 sources were from Canada. The U.S. source and 1 of the sources from Canada (i.e., Canada 1) were each divided into 2 batches and ground to 246 or 434 µm, whereas the other source from Canada (i.e., Canada 2) was only ground to 246 µm. Each batch of field peas was included in one diet as the only source of AA. An N-free diet was used to determine the basal endogenous losses of crude protein (**CP**) and AA. Six barrows (initial weight: 50.5 kg; SD = 3.7) that had a T-cannula installed in the distal ileum were randomly allotted to a 6 × 6 Latin square design with 6 diets and six 7-d periods. Ileal digesta from pigs were collected for 2 days after 5 days of adaptation. The statistical model included batch of field peas as the fixed effect and animal and period as the random effects. Contrast statements were used to analyze effects of particle size, origin, and the interaction between particle size and origin. Results indicated that the AID of starch was increased by reducing the particle size in the U.S. source of field peas, but that was not the case for the Canada 1 source (interaction; $P < 0.001$). No interactions between source and particle size were observed for the SID of CP or AA, but the SID of CP and AA was not affected by particle size of field peas. The SID of CP and Trp was greater ($P < 0.05$) and the SID of His, Ile, and Thr tended ($P < 0.10$) to be greater in the Canada 2 source compared with the U.S.

source, but no differences between the 2 Canada sources were observed. In conclusion, a few differences in the SID of AA in field peas produced in the U.S. or Canada were observed, but there was no effect on SID of AA of reducing the particle size of field peas from 434 to 246 µm. However, the effect of particle size on the AID of starch was greater in field peas from the U.S. compared with field peas from Canada.

Key Words: field peas, ileal digestibility, particle size

Abbreviations: AA, amino acids; AID, apparent ileal digestibility; CP, crude protein; SID, standardized ileal digestibility

Introduction

Market opportunities for field peas (*Pisum sativum L.*) have increased for livestock feed and human food, due to the high nutritional quality of pea protein (Stein et al., 2004). The nutritional value of field peas and their inclusion in corn-based diets fed to swine has been reported (Stein et al., 2006; Stein and Bohlke, 2007; Montoya and Leterme, 2011; Hugman et al., 2021). However, as is the case with most feed ingredients, differences in soil, varieties, agronomic practices, and growing conditions may change the nutritional characteristics of the peas as well as the digestibility of nutrients (Stein et al., 2004). Differences in particle size of field peas may also change the digestibility of energy and nutrients as has been reported for other ingredients (Kim et al., 2009; Rojas and Stein, 2015; 2017; Lancheros et al., 2020). An increase in energy digestibility was also observed by reducing the particle size of field peas, which was attributed to an increase in in-vitro digestibility of starch (Montoya and Leterme, 2011). There is, however, to the best of our knowledge, no information about the effects of particle size of peas on in vivo digestibility of starch and amino acids (**AA**). It is also not known if the growing location of field peas influences the digestibility of AA and starch. Therefore, the objective of this research was to test the hypothesis that the apparent ileal digestibility (**AID**) of crude protein (**CP**), AA, and starch, as well as the standardized ileal digestibility (**SID**) of CP and AA in field peas, may be affected by the particle size of the field peas and the location where the field peas were grown.

Materials and Methods

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Experimental diets

Three sources of field peas were procured. One source was obtained from the U.S. (U.S. field peas) and the other 2 sources (CDC Amarillo Yellow and CDC Meadow Yellow) were obtained from Canada (i.e., Canada 1, Canada 2). The source of field peas from the U.S. and 1 of the sources from Canada were each divided into 2 batches and ground to approximately 246 or 434 µm, whereas the other source from Canada was only ground to 246 µm. Therefore, 5 batches of field peas were used in the experiment (Table 3.1). Each batch was included in 1 diet as the sole source of AA. An N-free diet that was used to calculate basal endogenous losses of AA and CP was also formulated. Thus, a total of 6 diets were used (Tables 3.2 and 3.3). Vitamins and minerals were included in all diets to meet or exceed current requirement estimates for growing pigs (NRC, 2012). All diets contained 0.40% chromic oxide as an indigestible marker. The daily feed allowance was calculated as 3.0 times the maintenance requirement for metabolizable energy (i.e., 197 kcal metabolizable energy per kg body weight$^{0.60}$; NRC, 2012). Feed allowance was adjusted according to the body weight of pigs at the beginning of each period, and water was available on an ad libitum basis.

Animals and housing

Six growing pigs with an average initial body weight of 50.5 ± 3.7 kg had a T-cannula installed in the distal ileum (Stein et al., 1998). Pigs were the offspring of Line 359 males mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA) and were allotted to a 6 × 6 Latin square design with 6 diets and 6 periods (Kim and Stein, 2009). Pigs were individually housed in pens (1.2 × 1.5 m) located in an environmentally controlled room with the ambient temperature maintained between 20 and 24 °C. Pens had smooth sidings and fully slatted tribar floors, and a feeder and a water nipple were installed in each pen.

Sample Collection

Each period of the Latin square lasted 7 days with the initial 5 days being the adaptation period to the diet, whereas ileal digesta were collected on day 6 and 7 for 9 h each day (Stein et al., 1998). By attaching a plastic bag to the opened cannula barrel using a cable tie, digesta that flowed into the bag was collected. Bags were replaced every time they were filled with digesta or at least once every 30 min. Digesta samples were immediately stored at −20 °C to prevent bacterial degradation of AA.

Chemical analysis

At the conclusion of the experiment, ileal digesta samples were thawed at room temperature and mixed within animal and diet. A sub-sample was collected, lyophilized, ground, and analyzed. One sample of each diet and each source of field peas was collected at the time of mixing. All samples were analyzed in duplicate. The concentration of chromium was determined in diets and ileal digesta using the Inductive Coupled Plasma Atomic Emission Spectrometric method (method 990.08; AOAC Int., 2019). Samples were prepared for analysis using nitric acid-perchloric acid [method 968.08D(b); AOAC Int., 2019]. Diets, ingredients, and ileal digesta samples were analyzed for dry matter via oven drying at 135 °C for 2 h (method 930.15; AOAC Int., 2019) and ingredients were also analyzed for dry ash (method 942.05; AOAC Int., 2019). Nitrogen in ingredients, diets, and in the ileal digesta samples was determined by the combustion procedure using a LECO FP628 Nitrogen Analyzer (LECO Corp., St. Joseph, MI, USA; method 990.03; AOAC Int., 2019) and CP was calculated as analyzed N × 6.25. Ingredients, diets, and ileal digesta samples were also analyzed for AA on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc.; Pleasanton, CA, USA) using ninhydrin for post-column derivatization and nor-leucine as the internal standard. Before analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110 °C [method 982.30 E9(a); AOAC Int., 2019]. Methionine and Cys were determined after cold performic acid oxidation overnight before hydrolysis [method 982.30 E(b); AOAC Int., 2019]. Tryptophan was determined after NaOH hydrolysis for 22 h at 110 °C [method 982.30 E(c); AOAC Int., 2019].

Gross energy in the ingredient samples was measured using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA). Benzoic acid was used as the standard for calibration. Ingredients were also analyzed for acid-hydrolyzed ether extract using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System; Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019) AnkomXT15 Extractor; Ankom Technology, Macedon, NY, USA. Insoluble dietary fiber and soluble dietary fiber were analyzed in ingredients according to method 991.43 (AOAC Int., 2019) using the Ankom^{TDF} Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber was calculated as the sum of soluble dietary fiber and insoluble dietary fiber. Ingredient samples were also analyzed for sugars, including maltose, sucrose, stachyose, and raffinose, using high-performance liquid chromatography (Dionex App Notes 21 and 92). Ingredients, diets, and ileal digesta samples were analyzed for total starch by the glucoamylase procedure (method 979.10; AOAC Int., 2019).

Calculations and statistical analysis

The AID of CP, AA, and starch in diets was calculated from analyzed concentrations of CP, AA, starch, and Cr in diets and ileal digesta (Stein et al., 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the N-free diet and the SID of CP and AA was calculated by correcting AID values for basal endogenous losses of CP and AA (Stein et al., 2007). Because field pea was the sole source of CP and AA in each diet, values for AID and SID in diets were considered the AID or SID in field peas.

Data were analyzed using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC, USA). Normality of residuals were confirmed using the MIXED procedure and homogeneity of the variance of the residuals was tested using Brown-Forsythe test in the GLM procedure of SAS. The statistical model included field pea batch as fixed effect and period and animal as random effects. Contrast statements were used to compare results for field peas ground to 246 µm with results for field peas ground to 434 µm, the origin of the source, and the interaction between the source and the particle size. Results were considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$. The pig was the experimental unit for all analyses.

Results

The gross energy among all sources of field peas ranged from 3,913 to 3,933 kcal/kg, and the CP ranged from 17.86% to 19.81%. Values for acid hydrolyzed ether extract varied between 0.90%

and 1.03%. The concentration of total dietary fiber in peas from the U.S. and one of the sources from Canada was around 17.65%, but for the other source from Canada, total dietary fiber was 20.10%. The 2 sources of field peas from Canada had the numerically greatest concentrations of all AA and also the greatest Lys:CP ratio. All sources of peas contained around 40% starch.

The AID of CP was greater ($P < 0.05$) in the 2 Canadian sources of peas than in the U.S. peas (Table 3.4). When ground to 246 µm, no differences among sources were observed for the AID of starch, but the U.S. field peas ground to 434 µm had reduced AID of starch compared with the Canada 1 source ground to 434 µm (interaction $P < 0.001$). There were no differences in the AID of indispensable AA among the 5 batches of peas with the exception of Trp, which had a lower ($P < 0.05$) AID in the U.S. field peas than in the Canada 1 source of peas. Among dispensable AA, the AID of Ala, Cys, Gly, and Tyr was less ($P < 0.05$) in the U.S. peas compared with both Canadian sources. The AID of Glu was lower ($P < 0.05$) when field peas were ground to 246 µm compared with field peas ground to 434 µm.

The SID of CP was greater ($P < 0.05$) in both Canadian sources of field peas than in U.S. peas (Table 3.5). No interaction between particle size and source of field peas was observed for the SID of AA. The SID of indispensable AA was not different among sources of peas, but the SID of Ala, Cys, Gly, and Tyr was greater in field peas from Canada than in peas from the U.S. Reduction of the particle size from 434 to 246 did not impact SID of CP or AA.

Discussion

Field peas may be cultivated in climates that are too cold for cultivation of soybeans including areas of Europe, Canada, and the Pacific Northwest of the U.S. (Stein, 2006; Jezierny et al., 2010). The global production of dry peas is approximately 14 million metric tonnes per year and the majority of peas are grown for human consumption. The major producers, including Canada, Russia, China, and the U.S., have expanded production of field peas by approximately 10% in recent years (FAO, 2022). Because of their high-quality protein and carbohydrate content, field peas are an excellent ingredient in pig diets (Stein et al., 2004), and inclusion of field peas in diets for pigs when markets are favorable may lower production costs.

The field peas used in this experiment were originated from different varieties of field peas. Some of the variability in nutrient composition among pulses may be related to differences in growing regions, climate, and among cultivars (Lu et al., 2020; Abdulla et al., 2021). The gross energy of field peas used in this experiment was close to values from different varieties (Stein et al., 2010; NRC, 2012; Landero et al., 2014; Adekoya and Adeola, 2022), but greater than the values reported by Hugman et al. (2021). Analyzed CP and AA were lower than the CP and AA reported by NRC (2012) but were within the range of other reported values (Stein et al., 2016; Adekoya and Adeola, 2022; Hugman et al., 2021). The variation in CP between the field peas used in this experiment and peas used in some previous experiments may be a result of differences in varieties or environmental factors (Wang and Daun, 2004). The starch content of field peas used in this experiment was within the range of 39 to 42%, which is in agreement with values reported by Stein et al. (2016) and Ravindran et al. (2010), but greater than other reported values (Landero et al., 2014; Hugman et al., 2021; Woyengo and Zijlstra, 2021).

The SID of CP and AA in the U.S. field peas ground to 246 or 434 µm was lower than some previous values (Stein et al., 2004; NRC, 2012), but both Canadian sources of field peas ground to 246 µm had SID of AA close to reported values (Stein et al., 2004; Friesen et al., 2005; NRC, 2012; Hugman et al., 2021). Digestibility of CP and AA in field peas may vary due to differences among varieties and concentrations of antinutritional factors (Leterme et al., 1990; Mariscal-Landín et al., 2002).

The AID of starch for the field peas used in this experiment was lower than the values reported by Woyengo and Zijlstra (2021) and Hugman et al. (2021), but close to the values reported by Stein and Bohlke (2007). Processing of cereal grains, legumes, and other plant energy sources is used to maximize the utilization of nutrients (Goodband et al., 2002; Rojas and Stein, 2017). Pelleting, extrusion, and particle size reduction are some of the processing technologies that can modify the physical structure of feed ingredients and positively impact their nutritional characteristics (Lancheros et al., 2020). The inactivation of antinutritional factors and change in protein conformation by heat in extruded or pelleted field peas makes more AA available for digestive enzymes in the small intestine and, therefore, improves the SID of AA and CP. Proper extrusion of cereal grains or pulse crops may also increase the digestibility of starch by gelatinization of starch granules (Stein and Bohlke, 2007; Rojas and Stein, 2017; Rodriguez et al., 2020).

By providing a larger surface area for contact between the digestive enzymes and the substrate, grinding increases the digestibility of nutrients (Kim et al., 2002); however, ingredients that are finely ground may generate problems with flowability and management of the diets as well as ulcers and parakeratosis in pigs (Wondra et al., 1995; Rojas and Stein, 2015). Digestibility of starch in cereal grains and legumes is correlated with the average particle size (Montoya and Leterme, 2011). Indeed, changes in the anatomy of the granules of starch by decreasing the particle size may increase access of α-amylase to the starch granules, increasing the digestion of starch (Kim et al., 2002; Kim et al., 2009; Rojas and Stein., 2015). The observation that particle size influenced the AID of starch in only one of the sources of peas used in the current experiment indicates that the ranges of reduction (e.g., 434 to 246 µm) in the particle size may not have been big enough to improve starch digestion.

The SID of AA and CP among cereal and legume ingredients may increase as particle size decreases (Lahaye et al., 2007; Kim et al., 2009). However, Rojas and Stein (2015), demonstrated that a reduction in particle size of corn did not influence the digestibility of AA, and the result of the present experiment is in agreement with Rojas and Stein (2015). It is, however, possible that a greater reduction in particle size than used in this experiment would have had an impact on AA digestibility.

Conclusion

Under the conditions of this experiment, reduction in particle size did not increase or affect the SID of AA and CP, but the SID of CP and some dispensable AA was greater in field peas from Canada than in U.S. field peas. The AID of starch increased with reduction of particle size in the U.S. source of peas, but the AID of starch was not impacted by particle size in the Canadian sources.

Tables

Table 3.1. Analyzed nutrient composition of 5 sources of field peas[1]

	Field peas particle size (µm)				
Item, %	265	220	253	457	411
Source:	U.S.	Canada 1	Canada 2	U.S.	Canada 1
Gross energy, kcal/kg	3,919	3,933	3,925	3,913	3,923
Dry matter	89.54	89.99	89.72	89.21	89.79
Crude protein	19.90	19.52	20.03	19.63	19.84
Ash	2.83	2.55	2.59	2.80	2.61
Starch	38.62	40.88	39.23	40.29	42.12
Acid hydrolyzed ether extract	0.93	1.00	1.03	0.95	1.00
Insoluble dietary fiber	15.53	17.11	15.89	15.84	16.72
Soluble dietary fiber	1.87	2.54	1.37	1.82	1.95
Total dietary fiber	17.40	19.66	17.26	17.66	18.67
Sucrose	2.65	2.90	1.72	2.51	3.05
Maltose	1.94	1.60	2.01	1.90	1.71
Stachyose	2.39	2.82	2.45	2.33	2.82
Raffinose	0.63	0.59	0.57	0.64	0.60
Indispensable amino acids					
Arg	1.59	1.60	1.64	1.61	1.62
His	0.49	0.51	0.51	0.50	0.50
Ile	0.93	0.98	0.93	0.93	0.94
Leu	1.44	1.51	1.50	1.45	1.50

Table 3.1. (Cont.)

Lys	1.54	1.58	1.59	1.54	1.59
Met	0.21	0.20	0.21	0.21	0.21
Phe	1.03	1.05	1.05	1.03	1.05
Thr	0.72	0.74	0.77	0.73	0.77
Trp	0.17	0.18	0.18	0.17	0.19
Val	0.99	1.03	1.00	1.00	1.00
Total	9.12	9.37	9.38	9.18	9.35
Dispensable amino acids					
Ala	0.88	0.90	0.90	0.88	0.90
Asp	2.26	2.35	2.37	2.27	2.36
Cys	0.33	0.30	0.30	0.32	0.31
Glu	3.34	3.37	3.41	3.37	3.39
Gly	0.91	0.93	0.93	0.91	0.93
Pro	0.80	0.81	0.82	0.83	0.82
Ser	0.85	0.85	0.91	0.85	0.90
Tyr	0.62	0.58	0.64	0.62	0.61
Total	19.12	19.46	19.68	19.23	19.56
Total AA	28.24	28.83	29.05	28.41	28.91
Lys:CP[2]	7.62	7.98	7.80	7.73	7.87

[1] All values except dry matter are expressed on an 88% dry matter basis. Peas were ground to a target particle size of 246 or 434.

[2] Lys:CP ratio was calculated by expressing the concentration of Lys in each source of field peas as a percentage of the concentration of CP (Stein et al., 2009).

Table 3.2. Ingredient composition of experimental diets containing field peas

Item%		Field peas					
	Particle size:	246 µm			434 µm		N-free
	Source:	U.S.	Canada 1	Canada 2	U.S.	Canada 1	
Field peas		77.90	77.90	77.90	77.90	77.90	-
Corn starch		-	-	-	-	-	72.65
Soybean oil		4.00	4.00	4.00	4.00	4.00	4.00
Solka floc[1]		-	-	-	-	-	4.00
Dicalcium phosphate		0.70	0.70	0.70	0.70	0.70	2.10
Ground limestone		1.10	1.10	1.10	1.10	1.10	0.45
Sucrose		15.0	15.0	15.0	15.0	15.0	15.0
Sodium chloride		0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[2]		0.50	0.50	0.50	0.50	0.50	0.50
Chromic oxide		0.40	0.40	0.40	0.40	0.40	0.40
Potassium carbonate		-	-	-	-	-	0.40
Magnesium oxide		-	-	-	-	-	0.10

[1] Fiber Sales and Development Corp., Urbana, OH.

[2] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E as DL alpha-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

Table 3.3. Analyzed nutrient composition of experimental diets containing field peas, as fed basis

	Field peas					
Item% Particle size:	246 µm			434 µm		N-free
Source:	U.S.	Canada 1	Canada 2	U.S.	Canada 1	
Dry matter	89.98	89.13	89.03	89.96	89.20	91.10
Crude protein	14.62	14.87	15.14	15.22	14.99	0.14
Starch	31.4	31.3	31.1	30.1	31.1	62.9
Indispensable amino acids						
Arg	1.22	1.16	1.19	1.13	1.18	0.01
His	0.38	0.37	0.37	0.36	0.37	-
Ile	0.72	0.68	0.70	0.69	0.69	0.01
Leu	1.16	1.10	1.13	1.12	1.1	0.02
Lys	1.18	1.09	1.15	1.11	1.11	0.01
Met	0.17	0.16	0.16	0.15	0.16	-
Phe	0.80	0.75	0.78	0.78	0.76	0.01
Thr	0.57	0.55	0.56	0.54	0.55	0.01
Trp	0.12	0.12	0.12	0.12	0.14	< 0.02
Val	0.76	0.73	0.76	0.72	0.74	0.01
Total	7.08	6.71	6.92	6.72	6.80	0.08
Dispensable amino acids						
Ala	0.7	0.68	0.68	0.67	0.68	0.01
Asp	1.72	1.64	1.73	1.66	1.66	0.02

Table 3.3. (Cont.)

Cys	0.24	0.21	0.22	0.21	0.23	-
Glu	2.61	2.47	2.51	2.55	2.54	0.04
Gly	0.7	0.68	0.69	0.67	0.68	0.01
Pro	0.66	0.63	0.61	0.63	0.63	0.01
Ser	0.67	0.64	0.66	0.65	0.64	0.01
Tyr	0.48	0.46	0.48	0.45	0.47	0.01
Total	7.78	7.41	7.58	7.49	7.53	0.10
Total AA	15.11	14.38	14.73	14.47	14.57	0.37

Table 3.4. Apparent ileal digestibility (AID) of crude protein, starch, and amino acids (AA) %, in 3 sources of field peas ground to 2 particle sizes[1]

Item, %	Field peas						Contrast *P*-value		
Particle size:	246			434 μm					
Source	U.S.	Canada 1	Canada 2	U.S.	Canada 1	SEM	Particle size	Source	Interaction
Crude protein	63.32	69.45	72.16	67.75	72.83	2.38	0.326	0.017	0.809
Starch	87.33	85.08	85.91	78.90	85.20	1.28	< 0.001	0.061	< 0.001
Indispensable AA									
Arg	84.45	84.81	87.39	85.45	87.35	1.40	0.409	0.318	0.497
His	75.50	78.38	80.08	78.32	80.93	1.78	0.241	0.079	0.929
Ile	69.41	71.98	74.48	71.68	75.69	2.30	0.342	0.106	0.716
Leu	70.30	73.41	76.33	74.29	77.05	2.30	0.208	0.148	0.929
Lys	78.72	80.93	83.12	80.33	83.25	1.87	0.566	0.129	0.829
Met	69.90	73.45	75.34	70.05	75.12	2.78	0.895	0.104	0.767
Phe	71.44	73.83	76.78	75.44	77.89	2.10	0.109	0.178	0.988
Thr	62.79	67.42	69.68	64.79	70.13	2.83	0.729	0.068	0.893

Table 3.4. (Cont.)

Trp	62.99	67.91	69.80	66.09	74.72	2.84	0.172	0.021	0.502
Val	66.27	69.52	72.89	69.44	73.50	2.57	0.355	0.113	0.859
Total	73.29	75.77	78.37	75.72	78.98	2.05	0.344	0.115	0.827
Dispensable AA									
Ala	64.55	69.18	71.58	65.66	71.91	2.63	0.874	0.034	0.738
Asp	72.20	74.38	77.42	74.23	77.47	1.98	0.425	0.104	0.744
Cys	54.07	56.21	59.80	48.89	61.81	3.42	0.654	0.030	0.110
Glu	77.42	79.49	80.80	81.60	82.85	1.86	0.029	0.242	0.766
Gly	53.93	59.45	62.13	54.30	63.61	3.83	0.884	0.041	0.578
Ser	69.59	72.45	74.80	72.01	75.49	1.97	0.369	0.084	0.863
Tyr	73.27	76.65	78.79	74.53	79.29	1.98	0.675	0.029	0.693
Total	70.78	73.63	75.84	73.22	76.95	2.08	0.291	0.065	0.797
Total AA, (%)	72.03	74.70	77.10	74.46	77.96	2.05	0.312	0.083	0.808

[1] Each least squares mean is the mean of 5 observations per treatment.

Table 3.5. Standardized ileal digestibility (SID) of crude protein, and AA (%) in 3 different sources of field peas ground at 2 different particle size[1,2]

Item, %	Field peas						Contrast *P*-value		
Particle size:	246 µm			434 µm					
Source	U.S.	Canada 1	Canada 2	U.S..	Canada 1	SEM	Particle size	Source	Interaction
Crude protein	73.88	79.73	82.25	77.88	83.03	2.4	0.360	0.019	0.872
Indispensable AA									
Arg	90.05	90.65	93.08	91.50	93.09	1.4	0.316	0.333	0.659
His	80.49	83.45	85.15	83.58	86.00	1.8	0.208	0.084	0.858
Ile	73.95	76.75	79.11	76.43	80.39	2.3	0.321	0.098	0.766
Leu	74.58	77.89	80.68	78.73	81.54	2.3	0.192	0.134	0.900
Lys	82.02	84.46	86.46	83.83	86.72	1.9	0.524	0.115	0.893
Met	74.40	78.18	80.06	75.15	79.85	2.8	0.984	0.109	0.857
Phe	75.39	78.00	80.79	79.49	82.01	2.1	0.104	0.154	0.978
Thr	71.10	75.96	78.06	73.56	78.67	2.8	0.652	0.068	0.962
Trp	70.33	75.18	77.06	73.42	80.96	2.8	0.239	0.033	0.627

Table 3.5. (Cont.)

Val	71.71	75.14	78.27	75.18	79.04	2.6	0.316	0.115	0.924
Total	78.17	80.87	83.31	80.86	84.01	2.1	0.310	0.108	0.899
Dispensable AA									
Ala	73.43	78.23	80.63	74.94	80.97	2.6	0.812	0.034	0.799
Asp	76.64	78.99	81.78	78.83	82.03	2.0	0.386	0.096	0.794
Cys	61.64	64.78	67.97	57.54	69.64	3.4	0.687	0.028	0.180
Glu	81.08	83.32	84.56	85.35	86.58	1.9	0.030	0.222	0.715
Gly	78.64	84.64	86.93	80.11	88.82	3.8	0.732	0.042	0.690
Ser	76.59	79.71	81.84	79.22	82.75	2.0	0.326	0.071	0.910
Tyr	77.91	81.45	83.38	79.48	83.99	2.0	0.609	0.031	0.780
Total	78.17	80.87	83.31	80.86	84.01	2.1	0.310	0.108	0.899
Total AA	77.72	80.85	82.86	80.42	84.05	2.1	0.265	0.058	0.884

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[1] Each least squares mean is the mean of 5 observations per treatment.

[2] Values for SID were calculated by correcting values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of dry matter intake) as CP, 14.54; Arg, 0.66; His, 0.18; Ile, 0.32; Leu, 0.48; Lys, 0.38; Met, 0.07; Phe, 0.31; Thr, 0.46; Trp, 0.09; Val, 0.40; Ala, 0.60; Asp, 0.74; Cys, 0.18; Glu, 0.93; Gly, 1.68; Ser, 0.46; and Tyr, 0.22.

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CHAPTER 4: Increasing levels of phytase increase standardized total tract digestibility of phosphorus in field peas by growing pigs, but particle size and origin of field peas do not affect digestibility of phosphorus

Abstract

Two experiments were conducted to test the hypotheses that there are no differences in the apparent total tract digestibility (**ATTD**) or the standardized total tract digestibility (**STTD**) of P among three sources of field peas ground to different particle sizes and to determine the effect of increasing levels of phytase on the ATTD and STTD of P in one source of field peas when fed to growing pigs. In Exp. 1, three sources of field peas were used. One source was obtained from the U.S., and two sources were obtained from Canada (i.e., Canada 1, Canada 2). The U.S. field peas were ground to 265, 457, or 678 µm, whereas the Canada 1 peas were ground to 253 µm, and the Canada 2 source was ground to 411 µm. Therefore, five diets were used. Fifty weanling pigs with an initial body weight (**BW**) of 16.36 kg (SD = 1.19) were allotted to one of the five diets in a randomized complete block design with ten replicate pigs per diet. In Exp. 2, six diets were used. Diets were based on the U.S. field peas and included 0, 200, 500, 1,000, 2,000, and 4,000 units per kg of microbial phytase. Forty-eight weanling pigs with an initial BW of 15.26 kg (SD = 0.91) were allotted to a randomized complete block design with six diets in three blocks of 12, 24, and 12 pigs for a total of eight replicate pigs per diet. In both experiments, pigs were housed in individual metabolism crates and fed experimental diets for 12 d, with the initial five days being the adaptation period to the diet, followed by four days of fecal collection according to the marker-to-marker procedure. Results of Exp. 1 indicated that the ATTD and STTD of P were not affected by the source of peas or the particle size of the field peas. Results of Exp. 2 indicated that the ATTD of Ca and P and the STTD of P increased (linear, $P < 0.05$) as phytase increased in the diets. In conclusion, no effect of the growing region or grinding process on STTD of P was observed, but STTD of P increased if increasing levels of phytase was added to diets.

Keywords: field peas, phosphorus, phytase, standardized total tract digestibility, pig

Abbreviations: ATTD, apparent total tract digestibility; DM, dry matter; EPL, endogenous phosphorous losses; FTU, phytase units; STTD, standardized total tract digestibility.

Introduction

The value of field peas as a source of high-quality protein and energy in the swine feed industry is globally acknowledged (Stein et al., 2004; 2006), and during the last ten years, field pea production has increased in Canada and the U.S. by 60 and 20%, respectively (FAOSTAT, 2022). However, the value of field peas in swine diets may be increased by using processing techniques that maximize nutrient usage and reduce production costs (Stein and Bohlke, 2007; Lancheros et al., 2020). For example, the fineness of ground ingredients, such as corn, soybean meal, and field peas, impact the digestibility of nutrients; thus, the nutritional value of diets fed to pigs containing ground ingredients will be improved by reducing the particle size (Montoya and Leterme, 2011; Rojas and Stein, 2015; 2017).

Phosphorus is one of the most expensive nutrients in diets for pigs, and much of the P in plants is bound to phytate, which makes phosphorus undigestible to pigs (Liao et al., 2005). Consequently, the digestibility of P in field peas is low (Stein et al., 2006; Lott et al., 2007; NRC, 2012), and feed phosphate needs to be added to the diet to provide sufficient P, which increases diet cost. Non-digested P excreted by pigs in feces also may have negative environmental effects (Pizzeghello et al., 2011). Therefore, exogenous phytase is often included in diets for pigs because it increases apparent total tract digestibility (**ATTD**) and standardized total tract digestibility (**STTD**) of P in oilseed meals, legumes, and cereal grains, due to the ability of phytase to hydrolyze the phytate-bound P (Stein et al., 2006; Almeida and Stein, 2010). Although values for digestibility of P in field peas without and with phytase have been reported (Helander et al., 1996; Stein et al., 2006), there is no information about comparative values of digestibility of P in field peas from Canada and the U.S. and is not known if the ATTD and STTD of P in field peas are affected by particle size or by the variety of the pea. Likewise, to our knowledge, there is no information about the impact on STTD of P in field peas of adding graded levels of microbial phytase to diets containing field peas. Therefore, the objectives of these experiments were to test the hypotheses that 1) there are no differences in the STTD of P between field peas from Canada and peas from the U.S.; 2) particle size of field peas does not affect STTD of P; and 3) increasing levels of microbial phytase will increase the STTD of P in field peas when fed to growing pigs.

Materials and Methods

Two experiments were conducted, and protocols for both experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois before animal work was initiated. Pigs used in both experiments were the offspring of Line 800 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

Animals and experimental diets

Exp. 1: Digestibility of P in three sources of field peas

Three sources of field peas were used. One source was obtained from the U.S. (U.S. field peas), and two sources (CDC Meadow Yellow and CDC Amarillo Yellow) were obtained from Canada (i.e., Canada 1, Canada 2). Field peas from the U.S. were ground using a hammer mill to a mean particle size of 265, 457, or 678 µm, whereas the Canada 1 source was only ground to 253 µm, and the Canada 2 source was ground to 411 µm. Therefore, five batches of field peas were used in the experiment (Table 4.1). Field peas were the only P-contributing ingredient in the diets. Five diets containing each source of field peas in addition to sucrose and soybean oil were formulated (Table 4.2). Limestone was included in the diets to satisfy an overall Ca concentration of 0.35%. Vitamins, and minerals with the exception of Ca and P, were included in all diets to meet or exceed current nutritional requirement estimates for weanling pigs (NRC, 2012). Fifty weanling pigs with an average initial body weight of 16.36 kg (SD = 1.19) were allotted to a randomized complete block design with five diets and two blocks of 25 pigs originating from two weaning groups. Within each block, the 25 pigs were randomly allotted to the five diets with five replicate pigs per diet, resulting in a total of 10 replicate pigs per diet for the two blocks. The weaning group was the blocking factor.

Exp. 2: Effects of increasing levels of phytase on STTD of P

Six field peas-sucrose-based diets based on the U.S. field peas ground to 678 µm were formulated (Table 4.3). These diets included 0, 250, 500, 1,000, 2,000, or 4,000 units of microbial phytase (Quantum Blue; AB Vista Feed Ingredients, Marlborough, UK) per kg of diet. Field peas was the sole source of P in all diets. Limestone was included in the diets to satisfy an overall Ca concentration of 0.35%. Vitamins and minerals other than Ca and P were included in all diets to meet or exceed the estimated nutrient requirements for weanling pigs (NRC, 2012). A total of 48 barrows with an average initial body weight of 15.26 kg (SD= 0.91) were allotted to a randomized complete block design with six diets and three blocks of 12, 24, and 12 pigs each, and two replicate pigs per diet in the first block, four replicate pigs per diet in the second block, and two pigs per diets in the third block for a total of eight replicate pigs per diet. The three blocks contained pigs from three weaning groups that were weaned 14 days apart.

Housing, feeding, and sample collection

In both experiments, pigs were placed in individual metabolism crates that were equipped with a self-feeder, a nipple waterer, a fully slatted floor, and a screen floor to allow for the total collection of fecal materials. The daily feed allowance was calculated as three times the estimated maintenance requirement for metabolizable energy (i.e., 197 kcal metabolizable energy per kg body weight$^{0.60}$; NRC, 2012) and was provided each day in two equal meals at 0730 and 1400 h. Feed consumption was recorded daily. Water was available at all times throughout the experiment. All pigs were fed experimental diets for 12 days, the initial five days of the experiment being the adaptation period to the diet, whereas fecal materials were collected from the feed provided during the following four days according to standard procedures for the marker-to-marker method (Adeola, 2001). Indigo carmine was used to mark the initiation of feces collection and was included in the morning meal on day six. Fecal collection ceased when the second marker, ferric oxide, which was included in the morning meal on day 10, appeared in the feces. Orts were collected daily and weighed to determine feed intake from day six to 10. During the collection period, feces were collected twice daily and stored at −20 ^{o}C immediately after collection**.**

Chemical analysis

At the conclusion of each experiment, all fecal samples were thawed and then dried in a 65°C forced air-drying oven (Metalab Equipment Corp., Hicksville, NY, USA) and finely ground using a 500G stainless steel mill grinder (RRH, Zhejiang, China). Samples of field peas and diets were collected at the time of diet mixing. In both experiments, field peas, diets, and dried fecal materials were analyzed in duplicate for dry matter (**DM**) using oven drying at 135°C for 2 h (method 930.15; AOAC Int., 2019) and ash was analyzed at 600°C (method 942.05; AOAC Int., 2019). Diets and dried fecal materials were also analyzed for Ca and P (method 985.01 A, B, and C; AOAC Int., 2019) using inductively coupled plasma-optical emission spectrometry (ICP-OES; Avio 200, PerkinElmer, Waltham, MA, USA). Sample preparation included dry ashing at 600°C for 4 h (method 942.05; AOAC Int., 2019) and wet digestion with nitric acid (method 3050 B; Environmental Protection Agency, 2000). Ingredient samples were analyzed for phytic acid (Ellis et al., 1977). Phytate-bound P in ingredients was calculated as 28.2% of analyzed phytate (Tran and Sauvant, 2004), and non-phytate P was calculated as total P (%) minus phytate-bound P (%). Ingredients were also analyzed for Ca, P, K, Mg, Na, Cu, Fe, Mn, and Zn using the same procedure as used to analyze Ca and P in diets and fecal samples. Nitrogen in ingredients was determined by the combustion procedure using a LECO FP628 Nitrogen Analyzer (LECO Corp., St. Joseph, MI, USA; method 990.03; AOAC Int., 2019), and CP was calculated as analyzed N × 6.25. Gross energy in the ingredient samples was measured using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA). Benzoic acid was used as the standard for calibration. Ingredients were also analyzed for acid-hydrolyzed ether extract using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System; Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019) AnkomXT15 Extractor; Ankom Technology, Macedon, NY, USA.

Calculations and statistical analysis

The ATTD of P in each diet was calculated using the direct procedure, as described by Almeida and Stein (2010):

$$ATTD_P, \% = \left(\frac{P_i - P_f}{P_i}\right) \times 100$$

Where $ATTD_P$ (%) is the apparent total tract digestibility of P (%), P_i is the total P intake (g) from day six to ten; and P_f is the total fecal P output (g) in the feces originating from the feed that was provided from day six to ten. The same equation was used to calculate the ATTD of Ca and DM.

The STTD of P was calculated by correcting ATTD values for the basal endogenous loss of P (**EPL**) using the following equation (NRC, 2012):

$$STTD_P, \% = \left(\frac{P_i - (P_f - EPL)}{P_i}\right) \times 100$$

where $STTD_P$ (%) is the standardized total tract digestibility of P, and EPL is the basal endogenous loss of P; a basal endogenous loss of P of 190 mg per kg DM intake was assumed for all pigs (NRC, 2012).

Model assumptions on the residuals for both experiments were confirmed using the MIXED procedure and the Brown-Forsythe test of the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA). Outliers were detected using the ROBUSTREG procedure and were removed before final statistical analyses. No outliers were detected in Exp. 1, but two outliers were removed from the data in Exp. 2 for pigs fed diets containing 0 or 250 phytase units per kg. Data for Ca and P digestibility were analyzed using the MIXED procedure of SAS with the pig as the experimental unit for all analyses. In Exp. 1, the statistical model included the source of field peas as the main effect and block and replicate within block as random effects. Orthogonal polynomial contrasts were also used to determine the linear effects of particle size within the U.S. source on the digestibility of Ca and P. In Exp. 2, the model included diet as the main effect and orthogonal polynomial contrasts were used to determine linear and quadratic effects of phytase inclusion level. Block and replicate within block were considered random effects. Least-square means were calculated, and if significant differences were observed, means were separated using the PDIFF option with Tukey's adjustment. Results were considered significant at $P \leq 0.05$ and considered a tendency at $0.05 < P \leq 0.10$.

Results

For both experiments, all pigs consumed their diets throughout the experiment without apparent problems. The DM of field peas ranged from 89.14 to 89.99%, and ash ranged from 2.55 to 2.83%. All field peas contained close to 0.09% Ca. The concentration of P ranged between 0.45 and 0.48%.

Exp. 1

Feed intake and the weight of feces were not affected by source of field peas, but a tendency for a linear decrease in fecal excretion as particle size of the U.S. field peas was reduced (Table 4.4). Intake of P was greater ($P < 0.05$) by pigs fed the diet containing field peas from the U.S. ground to 434 µm than if pigs were fed the diet containing the Canada 1 peas. A linear increase ($P < 0.05$) in the concentration of P in feces as a percentage of feces was observed when particle size of the U.S. sources was reduced. Pigs fed the U.S. source of peas ground to 434 µm or the Canada 2 source had greater ($P < 0.05$) absorption of P compared with pigs fed the Canada 1 source ground to 253 µm, but the absorption of P in pigs fed diets containing the U.S. field peas was not affected by particle size ($P < 0.05$). The ATTD and STTD of P were not affected by the source of field peas, and the particle size of peas did not affect ATTD or STTD of P.

Daily intake of Ca was not different among field pea sources (Table 5.5). Total daily output of Ca tended ($P < 0.10$) to be less from pigs fed the Canada 2 peas than from pigs fed the U.S. field peas ground to 265 µm, but the output of Ca tended ($P < 0.10$) to increase as particle size of the U.S. field peas was reduced. Likewise, the percentage of Ca in feces was also less ($P < 0.05$) in the Canada 2 peas than in the U.S. peas ground to 265 µm, and the percentage of Ca in feces increased ($P < 0.05$) as the particle size of the U.S. field peas was reduced. Absorption and ATTD of Ca were greater ($P < 0.05$) for Canada 2 peas than for the U.S. peas ground to 265 µm. The ATTD of Ca also tended to be reduced ($P < 0.10$) as particle size of the U.S. peas was reduced.

Exp. 2

Feed intake and P intake tended ($P < 0.10$) to increase, whereas fecal excretion linearly ($P < 0.01$) decreased, as phytase increased in the diets. Excretion of P in feces expressed as a percent of feces and as g/d linearly ($P < 0.01$) decreased as phytase increased in the diets. In contrast, absorbed P and the ATTD and STTD of P as well as the ATTD of DM linearly ($P < 0.01$) increased by increasing phytase in the diets.

Calcium intake linearly increased ($P = 0.042$) as phytase increased in diets (Table 4.7). There was a quadratic decrease ($P = 0.005$) in the concentration of Ca in feces when phytase increased in diets, and Ca excretion in feces expressed as g/d linearly ($P < 0.001$) decreased as phytase increased in the diets. However, absorbed Ca and ATTD of Ca linearly ($P < 0.001$) increased by increasing phytase in diets.

Discussion

Analyzed concentration of Ca in the field peas used in these experiments agrees with reported values (NRC, 2012). However, the average P concentration (0.479%) in all sources of field peas used in this experiment was greater than the values reported by NRC (2012) and Adekoya and Adeola (2022). Most of the P in plant-based ingredients is stored as phytic acid, and pigs lack endogenous phytase to degrade phytate; therefore, the phytate-P is unavailable for absorption (Cowieson et al., 2006; Iyayi et al., 2013). The phytate-P concentration in the field peas used in the present experiments ranged from 0.22% to 0.24% and was greater than reported values (NRC, 2012; Kahindi et al., 2015). Phytate-P concentration in feed ingredients may vary due to variations in P concentration among different varieties of the same ingredient, but values may also be influenced by the methods used to estimate phytate-P concentration (Steiner et al., 2007). Nevertheless, in agreement with previous data (NRC, 2012), results from the current experiment demonstrated that less than 50% of the P in field peas is bound to phytate, which is less than in most other plant ingredients. The STTD of P in the field peas used in the current experiments was slightly greater than the STTD of P in field peas reported previously (Stein et al., 2006; NRC, 2012; Johnston et al., 2013), which may be a result of the lower amount of phytate-bound P in the peas used in this experiments compared with peas used previously (Johnston et al., 2013).

Feed ingredients are ground to minimize particle size and improve nutrient and energy digestibility (Kim et al., 2002). The ATTD of gross energy and DM improved in sows and growing-finishing pigs when the particle size of cereal grains was reduced (Healy et al., 1994; Wondra 1995). However, Rojas and Stein (2015) did not observe any effect on the ATTD or STTD of P in corn fed to growing pigs when particle size was reduced from 865 µm to 339 µm.

Likewise, particle size reduction from 818 µm to 308 µm had no effect on the ATTD of P in pigs fed distiler's dried grain with solubles (DDGS) (Liu et al., 2012). Likewise, when weanling pigs were fed coarse or fine-ground corn, the ATTD of Ca did not differ between treatments (Huang et al., 2015). Therefore, the observation that particle size did not affect the ATTD or STTD of P and Ca in field peas is in agreement with observations from other ingredients (Rojas and Stein, 2015; Liu et al., 2012; Huang et al., 2015). However, diets used in the current experiment contained almost 0.80% of limestone, and values for ATTD of Ca in the diets are a combination of the ATTD of Ca in limestone and the ATTD of Ca in field peas. The particle size of limestone does not affect the digestibility of Ca in limestone (Merriman and Stein, 2016), and the lack of an effect of treatments on the ATTD of Ca in Exp. 1 was, therefore, expected.

Pigs do not produce sufficient endogenous phytate to release the phytate-bond P in field peas prior to the end of the small intestine (Liao et al., 2005), but inclusion of microbial phytase in diets for pigs results on hydrolysis of some of the phytate in the stomach and small intestine, thus, releasing P and increasing P digestibility (Campbell and Bedford, 1992; Olsen et al., 2018). However, the amount of phytase required to optimize P digestibility may not be the same in all ingredients due to different amounts of phytate-bound P (Almeida et al., 2017). An improvement in the ATTD and STTD of P in field peas upon phytase supplementation has been reported (Stein et al., 2006; Kahindi et el., 2015), and results of Exp. 2 were, therefore, in agreement with previous data and also confirmed the hypothesis for the experiment.

The effectiveness of phytase may be affected by the source of phytase and ingredient composition of the diet (Dias, et al., 2010). The amount of P released by phytase is also highly correlated with the amount of phytase included in the diet (Almeida and Stein, 2012), and a linear increase in the STTD of P in corn was observed as supplementation of phytase increased from 0 to 1,100 phytase units per kg (Almeida and Stein, 2012). Likewise, the STTD of P in corn-soybean meal diets linearly increased when phytase addition increased from 0 to 4,000 phytase units per kg (Lagos et al., 2022). Therefore, the observation that the ATTD and STTD of P in field peas increased linearly with the increase of phytase in diets is in agreement with data from experiments where phytase was added to diets containing other ingredients (Almeida and Stein, 2012; Dersjant-Li et al., 2017; Lagos et al., 2022). The observation that the response to phytase was linear rather than quadratic indicates that the source of phytase used in this experiment has the ability to continue to remove P from phytate without reacting saturation in the release.

Conclusion

Neither the origin of field peas nor the particle size affected the STTD of P, and field peas grown in Canada have the same STTD of P as peas grown in the U.S. However, increased concentration of microbial phytase linearly increased STTD of P, whereas fecal excretions of P and Ca were reduced by adding phytase to the diets. Therefore, adding phytase to diets containing field peas may reduce the need to include inorganic phosphates in swine diets.

Tables

Table 4.1. Analyzed nutrient composition of 5 sources of field peas[1]

	Field peas particle size (µm)				
Item, %	265	253	457	411	678
Source:	U.S.	Canada 1	U.S.	Canada 2	U.S.
Gross energy, kcal/kg	3,919	3,933	3,913	3,925	3,928
Dry matter	89.54	89.99	89.21	89.72	89.14
Crude protein	19.90	19.52	19.63	20.03	19.85
Ash	2.83	2.55	2.80	2.59	2.60
Acid hydrolyzed ether extract	0.93	1.00	0.95	1.03	0.95
Total P, %	0.481	0.472	0.478	0.451	0.474
Phytic Acid, %	0.776	0.753	0.809	0.814	0.829
Phytate bound P[2], %	0.219	0.212	0.228	0.230	0.234
Non-phytate P[3], %	0.262	0.260	0.250	0.221	0.240
Ca, %	0.087	0.091	0.089	0.086	0.088
K, %	1.005	0.968	1.019	0.920	0.990
Mg, %	0.129	0.139	0.120	0.133	0.130
Na, mg/kg	0.008	0.010	0.008	0.008	0.009
Cu, mg/kg	0.001	0.001	0.001	0.001	0.001
Fe, mg/kg	0.007	0.005	0.007	0.005	0.007
Mn, mg/kg	0.002	0.002	0.002	0.002	0.002
Zn, %	0.004	0.003	0.004	0.003	0.003

[1] All values except dry matter are expressed on an 88% dry matter basis. Peas were ground to a target particle size of 259 or 434 µm.

[2] Phytate-bound P was calculated as 28.2% of P by phytic acid (Tran and Sauvant, 2004).

[3] Non-phytate P was calculated as the difference between total P and phytate-bound P.

Table 4.2. Ingredient and analyzed nutrient composition of experimental diets containing field peas, Exp. 1, as fed basis

	Field peas particle size (µm)				
Item, %	259		434		678
Source:	U.S.	Canada 1	U.S.	Canada 2	U.S.
Field peas	74.34	74.34	74.34	74.34	74.34
Soybean oil	4.00	4.00	4.00	4.00	4.00
Ground limestone	0.76	0.76	0.76	0.76	0.76
Sucrose	20.00	20.00	20.00	20.00	20.00
Sodium chloride	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.50	0.50	0.50	0.50	0.50
Total	100	100	100	100	100
Analyzed composition					
Dry matter, %	92.14	90.86	91.99	91.47	92.65
Ash, %	3.46	3.19	3.32	3.23	3.22
Organic matter[2], %	88.68	87.67	88.67	88.24	89.43
P, %	0.36	0.35	0.36	0.36	0.38
Ca, %	0.48	0.47	0.47	0.47	0.36

[1] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E as DL-alpha-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

[2] Organic matter (%) was calculated as dry matter – % ash.

Table 4.3. Ingredient and analyzed nutrient composition of experimental diets containing field peas, Exp. 2, as fed basis

	Phytase, units/ kg diet					
Item, %	0	250	500	1,000	2,000	4,000
Field peas	74.26	74.26	74.26	74.26	74.26	74.26
Soybean oil	4.00	4.00	4.00	4.00	4.00	4.00
Ground limestone	0.76	0.76	0.76	0.76	0.76	0.76
Sucrose	20.00	20.00	20.00	20.00	20.00	20.00
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.50	0.50	0.50	0.50	0.50	0.50
Phytase concentrate[2]	-	0.005	0.01	0.02	0.04	0.08
Cornstarch	0.08	0.075	0.07	0.06	0.04	-
Total	100	100	100	100	100	100
Analyzed composition						
Dry matter, %	92.92	92.62	92.67	92.84	92.38	94.00
Ash, %	3.04	3.14	3.12	3.11	3.11	3.07
Organic matter, %	89.88	89.48	89.55	89.73	89.27	90.93
P, %	0.32	0.30	0.29	0.30	0.30	0.33
Ca, %	0.35	0.39	0.35	0.37	0.42	0.35

[1] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D3 as cholecalciferol, 1,660 IU; vitamin E as DL-alpha-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

[2] The phytase concentrate contained 5,000 units of phytase/g (Quantum Blue; AB Vista Feed Ingredients, Marlborough, UK).

Table 4.4. Effects of source of field peas and particle size on apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P, Exp. 1[1]

Item[2], %	Field peas particle size (μm)					Field peas source		Linear contrast *P*-value[3]
Particle:	259		434		678			
Source:	U.S.	Canada 1	U.S.	Canada 2	U.S.	SEM	*P*-value	Particle size
Feed intake, kg/d	816.76	801.93	847.28	834.00	779.95	31.85	0.132	0.176
Fecal output, g/d	72.19	72.54	79.95	80.71	84.06	5.22	0.231	0.061
P intake, g/d	2.97^{ab}	2.74^{b}	3.08^{a}	3.00^{ab}	2.84^{ab}	0.12	0.011	0.172
P in feces, %	1.57^{a}	1.43^{ab}	1.30^{ab}	1.43^{ab}	1.23^{b}	0.09	0.016	0.001
Fecal P output, g/d	1.14	1.09	1.03	1.05	1.04	0.11	0.738	0.263
P absorption, g/d	1.83^{ab}	1.67^{b}	2.03^{a}	1.93^{a}	1.81^{ab}	0.06	0.003	0.810
Basal EPL[4], mg/d	142.99	139.37	148.08	143.97	137.30	5.58	0.218	0.231
ATTD of DM, %	91.12^{a}	91.17^{a}	90.11^{ab}	90.11^{ab}	89.35^{b}	0.42	0.016	0.004
ATTD of P, %	61.61	60.81	65.20	61.75	63.90	3.07	0.591	0.469
STTD of P[5], %	66.83	65.83	70.03	69.37	68.67	2.45	0.505	0.494

[1] Data are least squares means of 10 observations per treatment.

[2] DM = dry matter; EPL = endogenous P loss.

[3] Linear contrast effect of particle size was determined among the U.S. sources.

[4] Values were calculated as basal EPL multiplied by daily DM dry matter intake

[5] Values for the STTD of P were calculated by correcting the ATTD of P for basal endogenous loss of P (i.e., 190 mg/kg DM intake; NRC, 2012).

Table 4.5. Effects of source of field peas and particle size on apparent total tract digestibility (ATTD) of Ca, Exp. 1[1]

Item, %	Field peas particle size (µm)					Field peas source		Linear contrast *P*-value[2]
Particle:	259		434		678			
Source:	U.S.	Canada 1	U.S.	Canada 2	U.S.	SEM	*P*-value	Particle size
Ca intake, g/d	3.02	2.96	3.04	3.12	2.88	0.14	0.317	0.600
Ca output, g/d	1.17	0.95	1.00	0.87	0.84	0.13	0.068	0.072
Ca in feces, %	1.59	1.32	1.25	1.12	0.98	0.12	< 0.001	0.034
Ca absorption, g/d	1.87^{b}	2.01^{ab}	2.04^{ab}	2.23^{a}	2.06^{ab}	0.08	0.036	0.166
ATTD of Ca, %	62.26^{a}	68.11^{a}	67.16^{a}	71.91^{a}	71.47^{a}	3.13	0.043	0.082

[1] Data are least squares means of 10 observations per treatment.

[2] Linear effect of particle size was determined among the U.S. sources.

Table 4.6. Effects of level of microbial phytase on apparent total tract digestibility (ATTD) and standardized total tract digestibility (STTD) of P in field peas, Exp. 2[1]

Item[2], %	Phytase, unit/kg diet							Contrast *P*-value	
	0	250	500	1,000	2,000	4,000	SEM	Linear	Quadratic
Feed intake, g/d	730.96	737.06	762.02	742.52	756.20	793.18	46.92	0.089	0.614
Fecal excretion, g/d	67.48	59.46	62.30	61.86	47.78	47.18	3.90	< 0.001	0.397
P intake, g/d	2.66	2.68	2.77	2.70	2.75	2.89	0.17	0.089	0.614
P in feces, %	1.39	1.08	1.03	0.88	0.74	0.76	0.05	< 0.001	0.009
Fecal P output, g/d	0.92	0.64	0.65	0.54	0.43	0.36	0.05	< 0.001	0.221
P absorption, g/d	1.67	2.05	2.13	2.11	2.34	2.54	0.18	< 0.001	0.797
Basal EPL[3], mg/d	129.05	129.71	134.17	130.97	135.07	139.22	8.28	0.078	0.675
ATTD of DM, %	90.40	91.48	91.61	90.87	92.29	94.02	0.86	0.003	0.229
ATTD of P, %	68.27	77.92	76.41	78.35	84.45	87.53	2.24	< 0.001	0.901
STTD of P[4], %	73.12	82.76	81.25	83.19	89.36	92.36	2.24	< 0.001	0.896

[1] Data are least squares means of 8 observations per treatment.

[2] DM = dry matter ; EPL = endogenous P loss.

[3] Values were calculated as basal EPL multiplied by daily DM dry matter intake.

[4] Values for the STTD of P were calculated by correcting the ATTD of P for basal endogenous loss of P (i.e., 190 mg/kg DM intake; NRC, 2012).

Table 4.7. Effects of of phytase on apparent total tract digestibility (ATTD) of Ca in diets containing field peas, Exp. 2[1]

Item, %	Phytase, unit/kg diet							Contrast *P*-value	
	0	250	500	1,000	2,000	4,000	SEM	Linear	Quadratic
Ca intake, g/d	2.55	2.71	2.62	2.62	2.70	2.84	0.17	0.042	0.415
Ca in feces, %	0.96	0.73	0.60	0.66	0.56	0.54	0.05	< 0.001	0.005
Ca output, g/d	0.64	0.45	0.42	0.36	0.31	0.22	0.03	< 0.001	0.151
Ca absorption, g/d	1.95	2.27	2.21	2.23	2.38	2.57	0.18	< 0.001	0.835
ATTD of Ca, %	74.97	83.63	84.42	86.46	88.30	92.18	1.46	< 0.001	0.147

[1] Data are least squares means of 8 observations per treatment, except for diets containing 0 or 250 units of phytase (*n* = 7).

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CHAPTER 5: Concentration of net energy and standardized ileal digestibility of amino acids and apparent ileal digestibility of starch by growing pigs in diets containing three different sources of field peas with different particle sizes

Abstract

Two experiments were conducted to test the hypothesis that the particle size of field peas and the location where field peas were grown may affect the apparent total tract digestibility (**ATTD**) of nutrients and gross energy (**GE**), concentrations of digestible energy (**DE**), metabolizable energy (**ME**), and net energy (**NE**), the apparent ileal digestibility (**AID**) of starch, and the standardized ileal digestibility (**SID**) of crude protein (**CP**) and amino acids (**AA**) corn-soybean meal diets containing 50% field peas and fed to group-housed pigs. In both experiments, 3 sources of field peas were used. One source was obtained from the U.S., and 2 sources were obtained from Canada (i.e., Canada 1, Canada 2). The U.S. field peas were ground to 265, 457, or 678 µm, whereas the Canadian pea were ground to 400 µm. Therefore, 5 sources of field peas were used. A basal diet contained corn and soybean meal as the sole energy sources, and 5 diets containing corn and soybean meal and 50% of each source of field peas were formulated. The ratio between corn and soybean meal was 1.92:1 in all diets. For Exp. 1, an N-free diet was also used to calculate basal endogenous losses of AA and CP, but in Exp. 2, no N-free diet was used. In Exp. 1, 7 barrows with an average initial body weight of 60.6 kg (SD = 2.1) were equipped with a T-cannula in the distal ileum and allotted to a 7 × 7 Latin square design with 7 diets and 7 periods. In Exp. 2, 24 pigs with an average initial body weight of 30.75 kg (SD = 1.0) kg were used in a 6 × 6 Latin square design with 6 calorimetry chambers and 6 consecutive periods. Four pigs were housed in each chamber. The 6 diets were fed to pigs in 1 chamber in each period and no chamber received the same diet twice. Therefore, there were 6 replicate chambers per treatment. Results of Exp. 1 indicated that SID of CP and AA was not influenced by the origin of the peas or the particle size, but the AID of starch increased when particle size was reduced from 678 µm to 457 or 265 µm. Results of Exp. 2 indicated that growing location did not affect concentrations of DE, ME, or NE of field peas, but concentrations of DE, ME, and NE increased when the particle size was reduced from 678 µm to 457 or 265 µm. In conclusion field peas grown in Canada and the U.S. have the same nutritional value, but starch digestibility and NE are increased if particle sizes is reduced.

Keywords: field peas, ileal digestibility, energy digestibility, net energy, particle size

Abbreviations: AA, amino acids; AEE, acid hydrolyzed ether extract; AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; CP, crude protein; DE, digestible energy; DM, dry matter; FHP, fasting heat production; GE, gross energy; ME, metabolizable energy; NE, net energy; RQ, respiratory quote; SID, standardized ileal digestibility; TDF, total dietary fiber; THP, total heat production.

Introduction

Field peas (*Pisum sativum L.*) is an annual season grain legume crop and is cultivated in areas that are too cold for cultivation of soybeans (Siddique et al., 2013). Market opportunities for field peas have increased in recent years, and cost of cultivation is less for peas than for soybeans (Jezierny et al., 2010). The concentration of starch in field peas is less, but crude protein (**CP**), and amino acids (**AA**) are greater, than in cereal grains (Stein et al., 2016). Therefore, in addition to providing AA, field peas also provide energy to swine diets, which is important because energy is the most expensive component in swine diets (Patience et al., 2015). As a consequence, it is important to determine the energy value of field peas. Agronomic practices, growing location, and differences among varieties may impact the nutritional properties of field peas, including energy digestibility (Stein et al., 2004; Stein and Bohlke, 2007). It was also observed that in-vitro energy digestibility of field peas was increased by reducing the particle size (Montoya and Leterme, 2011). However, there is no information on effects of reducing particle size on concentrations of digestible energy (**DE**), metabolizable energy (**ME**), or net energy (**NE**) in field peas fed to group-housed pigs. Likewise, the digestibility of energy in field peas grown in the U.S. has not been compared with the digestibility of energy of field peas grown in Canada. Therefore, the objective of this research was to test the hypothesis that the particle size of field peas and the location where field peas were grown may affect the apparent total tract digestibility (**ATTD**) of nutrients and gross energy (**GE**), concentrations of ME and NE, the apparent ileal digestibility (**AID**) of starch, and the standardized ileal digestibility (**SID**) of CP and AA when fed to growing pigs.

Materials and Methods

Two experiments were conducted, and the protocols for both experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois before animal work was initiated. Pigs used in both experiments were the offspring of Line 800 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

Experimental diets, animals, and feeding

In both experiments, 3 sources of field peas were used. One source was obtained from the U.S.

(U.S. field peas), and the other 2 sources (CDC Meadow Yellow and CDC Amarillo Yellow) were obtained from Canada (i.e., Canada 1, Canada 2). The field peas from the U.S. were ground using a hammer mill to 3 different particle sizes with a mean particle size of 265, 457, or 678 µm, whereas both Canadian sources were ground to 400 µm. Therefore, 5 batches of field peas were used (Table 5.1). A basal diet containing corn and soybean meal as sole energy sources and 5 diets containing corn, soybean meal, and 50% field peas were used in both experiments (Tables 5.2 and 5.3). The ratio between corn and soybean meal was 1.92:1 in all diets. In Exp. 1, an N-free diet was also used to calculate basal endogenous losses of AA and CP. Vitamins and minerals were included in all diets to meet or exceed current requirement estimates for growing pigs (NRC, 2012). All diets contained 0.40% titanium dioxide as an indigestible marker. A sample of the main ingredients and all diets was collected at the time of diet mixing and used for chemical analysis.

In Exp. 1, 7 barrows with an average initial body weight of 60.6 kg (SD = 2.1) were equipped with a T-cannula in the distal ileum (Stein et al., 1998) and allotted to a 7 × 7 Latin square design with 7 diets and 7 periods (Kim and Stein, 2009). Pigs were housed in individual pens (1.2 × 1.5 m) in an environmentally controlled room with the ambient temperature maintained between 20 and 24 °C. Pens had smooth sides and fully slatted tribar floors, and a feeder and a nipple drinker were installed in each pen. Feed allowance was calculated as 3.0 times the maintenance requirement for ME (i.e., 197 kcal ME per kg body weight$^{0.60}$; NRC, 2012) and was adjusted according to the body weight of pigs at the beginning of each period. All pigs had free access to water.

In Exp. 2, 24 pigs with an average initial body weight of 30.75 kg (SD = 1.0) kg were allotted to the 6 diets in a 6 × 6 Latin square design with 6 calorimetry chambers and 6 consecutive periods. Four pigs (i.e., 2 gilts and 2 barrows) were housed in each chamber. The 6 diets were fed to pigs in each chamber in 1 period and the same diet was fed only once to each chamber. Therefore, there were 6 replicate chambers per treatment. Each chamber was equipped with a feeder, a nipple waterer, a fully slatted floor, 4 stainless steel screens to collect fecal materials, and 2 urine pans for total, but separate collection of feces and urine. The temperature was maintained between 22 and 23 °C, and the relative humidity inside the chambers was 55%, controlled by temperature and humidity control units (PGC, Parameter, Black Mountain, NC, USA). The air velocity was 1.13 m^3/min, which was controlled using an airflow meter (AccuValve; Accutrol, LLC, Danbury, CT, USA). Diets were fed for 13 d on an ad libitum basis, but in the morning of day 14, feeders were emptied, and pigs were deprived of feed during the following 36 h. Throughout the experiment, water was freely available.

Sample collection

In Exp. 1, each period lasted 7 days, with the initial 5 days being the adaptation period to the diet and ileal digesta being collected on days 6 and 7 for 9 h each day (from 0700 to 1600 h) following standard procedures (Stein et al., 1998). In short, a plastic bag was attached to the opened cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed and replaced every time they were filled with ileal digesta or at least once every 30 min and immediately stored at −20 °C to prevent bacterial degradation of AA in the digesta (Lee et al., 2021). At the conclusion of the experiment, ileal digesta samples were thawed at room temperature, mixed within animal and diet, and a sub-sample was lyophilized and finely ground prior to chemical analysis.

In Exp. 2, pigs were fed experimental diets for 13 d, with the initial 7 d being the adaptation period to the diet. In the morning (0700 h) on day 8, gas analyzers started measuring

O_2 consumption and CO_2 and CH_4 productions for determination of total heat production (**THP**). Fecal and urine samples were also collected quantitatively from day 8 to day 13. Starting at 0700 h on day 14, pigs were deprived of feed for 36 h. This time was considered the fasting period to determine fasting heat production (**FHP**). The initial 24 h of fasting was considered the time for the animals to digest and metabolize remaining feed in the intestinal tract, whereas gas exchange was measured and urine were collected during the following 12 h, which was considered the actual period when animals mobilized endogenous nutrients to produce energy (de Lange et al., 2006). Therefore, each period lasted 14.5 d.

All pigs were weighed at the beginning of the experiment, prior to moving into calorimetry chambers and at the end of each collection period. Chambers were opened for approximately 1 hour daily to feed pigs and collect feces and urine. Heat production calculations did not include data recorded during this time and until the chambers reached the condition set by the temperature and humidity control unit. To avoid N loss in the urine, 50 ml of 6*N* HCl was added to each urine pan daily. Feed spillage on the screens was collected daily during the collection period, and the weight of feed spilled was recorded to determine feed intake. Collected feces were dried immediately after collection in a 65 ºC forced air drying oven (Thermo Fisher Scientific Inc.; model: Heratherm OMH750, Waltham, MA, USA) and ground through a 1-mm screen using a hammermill (model: MM4; Schutte Buffalo, NY, USA). Collected urine was weighted and 5% was stored at −20 °C immediately after collection. At the conclusion of the experiment urine samples collected from d 8 to 13 were thawed and mixed within chamber and diet, and 2 subsamples were collected. One urine subsample was lyophilized, and the other subsample was stored at −20 ºC until analyzed for N. Likewise, a subsample of the urine collected during the fasting period was stored at −20 ºC until analyzed for N.

Chemical analyses

In both experiments, all diet and ingredient samples were analyzed for dry matter (**DM**; method 927.05; AOAC Int., 2019) and ash (method 942.05; AOAC Int., 2019). Gross energy was analyzed using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA). Benzoic acid was used for standard calibration. The concentration of N was analyzed by combustion (method 990.03; AOAC Int., 2019) using a LECO FP628 analyzer (LECO Corp., Saint Joseph, MI, USA) with subsequent calculation of CP as N × 6.25. All diets and ingredients were sent to the Agricultural Experiment Station Chemical Laboratories at the University of Missouri (Columbia, MO, USA) and analyzed for AA [method 982.30 E (a, b, c); AOAC Int., 2019] and for total starch using the glucoamylase procedure (method 979.10; AOAC Int., 2019). Diet and ingredient samples were also analyzed for acid hydrolyzed ether extract (**AEE**) using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System; Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019) AnkomXT15 Extractor; Ankom Technology, Macedon, NY, USA. Sugars, including maltose, sucrose, stachyose, and raffinose, were analyzed in diets and ingredients using high-performance liquid chromatography (Dionex App Notes 21 and 92). Insoluble dietary fiber and soluble dietary fiber were analyzed in diets and ingredients according to method 991.43 (AOAC Int., 2019) using the Ankom Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber (**TDF**) was calculated as the sum of insoluble dietary fiber and soluble dietary fiber.

In Exp. 1, ileal digesta samples were also analyzed for DM, CP, AA, and starch as described for diets and ingredients. Diet and all ileal digesta samples were analyzed for Ti following the procedure by Myers et al. (2004).

In Exp. 2, the lyophilized urine samples and dried fecal samples were analyzed for GE as described for diets and ingredients, and urine samples that were not lyophilized were analyzed for N using the Kjeldahl method (method 984.13; AOAC Int., 2007) on a Kjeltec^{TM} 8400 (FOSS Inc., Eden Prairie, MN, USA). Fecal samples were analyzed for N, DM, and ash as described for ingredients and diets.

Calculation and statistical analysis

In Exp. 1, AID of CP, AA, and starch was calculated using analyzed CP, AA, starch, and Ti in diets and ileal digesta (Stein et al., 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the N-free diet, and the SID of CP and AA was calculated by correcting AID values for basal endogenous losses of CP and AA (Stein et al., 2007). For all diets, the contribution of digestible AA and starch from corn and soybean meal was subtracted from the AID or SID values for the diets, and the AID and SID of AA and CP and the AID of starch in field peas was calculated by difference (Kong and Adeola, 2014).

In Exp. 2, the ATTD of DM, GE, CP, and TDF was calculated for each diet (Adeola, 2001). The DE, ME, and NE in diets were calculated (NRC, 2012), and the retention of N for each pig was also calculated (Pedersen et al., 2007). The contribution of DE, ME, and NE from corn and soybean meal to the DE, ME, and NE in the 5 diets containing corn and soybean meal, and 50% field peas were subtracted from the DE, ME, and NE of each diet; therefore the DE, ME, and NE in field peas were calculated by difference (Kong and Adeola, 2014). The difference procedure was also used to calculate the ATTD of DM, GE, CP, and TDF in field peas.

Data for O_2, CO_2, and CH_4 were averaged within the collection period and for the last 12 h of the fasting period. The THP from pigs during the collection period was calculated using the following equation (Brouwer, 1965):

$$THP_{kcal} = [(3.866 \times O2 + 1.200 \times CO2 – 0.518 \times CH4 – 1.431 \times \text{Urine N})],$$

where O_2, CO_2, and CH_4 are expressed as liters, and urine N is expressed in grams. The FHP from pigs during fasting was calculated as described for the THP. Heat increment was calculated by subtracting FHP from THP, and the concentration of NE was then calculated (NRC, 2012):

$$NE_{kcal/kg} = ME – (THP – FHP)/\text{feed intake},$$

where ME is in kcal/kg, THP and FHP are in kcal, and feed intake is in kg. The respiratory quotient (**RQ**) was calculated as the ratio between CO_2 production and O_2 consumption.

Model assumptions on the residuals for both experiments were confirmed using the MIXED procedure and the Brown-Forsythe test of the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, USA). Outliers were detected using the ROBUSTREG procedure and were removed before final statistical analyses. Data were analyzed with the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). In Exp. 1, the statistical model included the source of field peas as the main effect, and period and animal as random effects. Polynomial contrasts were also used to determine the linear and quadratic effects of particle size within the U.S. peas on the ileal digestibility of AA, starch, and CP. The pig was the experimental unit for all analyses. In Exp. 2, the model included diet as the main effect and chamber and period as random effects. Polynomial contrasts were also used to determine linear and quadratic effects of particle size on the digestibility of energy and nutrients in diets and field peas and to determine effects of DE, ME and NE. The chamber was the experimental unit. Least-square means were calculated and separated for both experiments using the PDIFF option with Tukey's adjustment if the model is significant. Results were considered significant at $P \leq 0.05$ and considered a tendency at 0.05 <

$P \leq 0.10$.

Results

For both experiments, all pigs consumed their diets throughout the experiment without apparent problems. Analyzed concentrations of energy and nutrients in diets were in accordance with calculated values.

Experiment 1

The AID and SID of CP was not affected ($P < 0.05$) by origin of peas or by particle size (Table 5.4). The AID and SID of Arg was linearly ($P < 0.05$) increased and the AID and SID of Trp had a tendency (quadratic, $P < 0.10$) to increase as particle size of peas was reduced. However, for all other AA, neither particle size nor origin impacted AID or SID, but the AID of starch increased ($P < 0.05$) when particle size was reduced from 678 µm to 265 µm.

Experiment 2

Feed intake and the daily GE intake of pigs fed diets containing field peas from the U.S. or from Canada were not different ($P < 0.05$) from that of pigs fed the corn-soybean meal diet (Table 5.6). However, feed intake had a tendency to be reduced (linear, $P < 0.10$) in pigs fed the diets containing the U.S. field peas when particle size was reduced from 648 µm to 265 µm. The intake of DM and CP was not different ($P < 0.05$) among diets, but the intake of TDF was greater ($P < 0.05$) by pigs fed the corn-soybean meal diet than by pigs fed diets containing field peas from the U.S. or Canada 2. The TDF intake linearly decreased ($P < 0.05$) as particle size was reduced.

Fecal output of DM, GE, CP, and TDF and the ATTD of DM, GE, CP, and TDF were not different among pigs fed the basal diet and pigs fed diets containing peas from Canada.

However, excretion of DM, GE, CP, and TDF in feces was reduced (linear, $P < 0.05$) as particle size of the U.S. field peas was reduced, whereas the ATTD of DM, GE, and CP increased (linear, $P < 0.05$) as particle size was reduced. The weight of urine was not influenced by diet, but urine excretion of GE tended to be greater ($P < 0.10$) for pigs fed the corn-soybean meal diet than for pigs fed diets containing field peas.

The daily THP was not affected by the source of peas, but daily THP by pigs fed diets containing field peas from the U.S. tended to decrease linearly ($P < 0.10$) when particle size was reduced from 648 µm to 265 µm (Table 5.7). The daily FHP was not affected by dietary treatments and had an average of 2,472 kcal/kg among diets. The RQ was not affected by diets in the fed state nor in the fasted state, but a tendency for a linear increase ($P < 0.10$) in RQ in the fasted state by pigs previously fed diets containing field peas from the U.S. was observed as a result of reducing particle size of peas from 648 µm to 265 µm. No differences were observed in the ME:DE ratios among diets. The NE:ME ratio in diets containing the Canada 2 field peas and the U.S peas ground to 457 µm was greater ($P < 0.05$) than in the diet containing field peas from the U.S. ground to 648 µm. The NE:ME ratio increased (linear, $P < 0.05$) as particle size was reduced from 678 to 265 µm.

The DE, ME, and NE were not different among diets, with the exception that the diet with the U.S. peas ground to the greatest particle size had reduced ($P < 0.05$) DE, ME, and NE, compared with the other diets (DM basis and as-is basis). However, DE, ME, and NE in diets containing the U.S. field peas increased (linear, $P < 0.05$) as particle size was reduced (DM basis and as-is basis).

The ATTD of GE in the field peas from the U.S. ground to 678 µm was less ($P < 0.05$) than in both sources of field peas from Canada (Table 5.8), but a linear increase ($P < 0.05$) in the

ATTD of GE for the U.S. field peas was observed as particle size was reduced from 678 to 457 or 265 µm. The ATTD of CP in both sources of peas from Canada was greater ($P < 0.05$) than in the field peas from the U.S. The ATTD of TDF in field peas from the U.S. increased (linear, $P < 0.05$) as particle size was reduced. The DE, ME, and NE of field peas were less ($P < 0.05$) in field peas from the U.S. ground to 678 µm than in the other sources of field peas, but a linear increase in the DE, ME, and NE was observed as particle size in field peas from the U.S. was reduced (DM basis and as-is basis).

Discussion

The majority of research on field peas fed to pigs that are conducted in North America is conducted in Canada, but it is not known if the nutritional value of Canadian field peas also is representative of field peas grown in the U.S. Therefore, the current research aimed at determining the nutritional value of field peas grown in the U.S. is different from that of peas grown in Canada.

Field peas (*Pisum sativum L.)* is a cool-season pulse crop cultivated mainly for human consumption, but can also be used in pig diets as a source of AA and starch (Stein et al., 2006). The nutritional composition of field peas used in the current experiment was in agreement with previous values (NRC, 2012). However, peas have a lower concentration of starch (40%) compared with cereal grains (NRC, 2012), but the concentration of CP in field peas is greater (22%) than in cereal grains (NRC, 2012; Rojas and Stein, 2015; Song et al., 2022).

Values for AID of starch that were observed in Experiment 1 for field peas ground to 265 µm are in agreement with values reported by Stein and Bohlke (2007) but lower than those reported by Woyengo and Ziljistra (2021). Starch in field peas and most cereal grains contain amylose and amylopectin, but digestibility of starch is greater in amylopectin than in amylose due to greater access to glycosidic bonds by digestive enzymes in the small intestine (Miles et al., 1985; Regmi et al., 2011). An increase in the digestibility of starch after the reduction of particle size has been reported in lupins, corn, and wheat (Kim et al., 2002; Kim et al., 2005; Rojas and Stein, 2015). Therefore, the increase in the AID of starch in field peas that were observed as particle size was reduced from 678 to 457 or 265 µm is in agreement with data from other ingredients and likely is a result of the increased gelatinization and rupture of the seed cell matrix during grinding (Kim et al., 2002; Sun et al., 2006; Woyengo and Ziljitsra 2021). Grinding may also reduce resistant starch due to the release of encapsulated starch in the fiber matrix (Sun et al., 2006; Rodriguez et al., 2020).

The SID of AA in field peas obtained in Exp. 1, is within the range of values reported in previous experiments (Stein et al., 2004; Friesen et al., 2006; Hugman et al., 2021). The SID of most AA in field peas were close to the SID of AA in soybean meal (Stein et al., 2004), which is likely the reason that inclusion of 50% field peas in the corn-soybean meal diet did not result in changes in the SID of AA. The observation that the reduction of particle size did not affect the SID of AA and CP indicates that protein-digesting as enzymes are efficient at hydrolyzing the peptide bonds in peas ground to 678 µm as in peas ground to a smaller particle size. The SID of AA in corn is also not increased by reducing the particle size (Rojas and Stein, 2015).

The observation that the reduction of particle size of field peas from 678 µm to 265 increased the ATTD of DM and GE is likely a consequence of the increase in the AID of starch because increased digestibility of starch is positively correlated with greater digestibility of GE in field peas and corn (Stein and Bohlke, 2007; Rojas and Stein, 2015). The observation that reduced particle size also increased NE indicates that the increased ATTD of GE results in increased availability of utilizable energy.

The ME:DE ratio was 96 in average for all diets, which is within the range of reported values for complete diets (NRC, 2012; Kim and Nyachoti, 2017), and the NE:ME ratio in the field peas-containing diets was not different from the corn-soybean meal diet. The increase in the NE:ME ratio that was observed when the particle size of field peas was reduced from 678 to 457 µm, is likely a consequence of increased efficiency of utilization of starch in the diet (Noblet, 2007). The NE:ME ratios for all diets in this experiment were in agreement with the 75% that has been reported as an average for conventional diets (Noblet et al. 1994). The observation that the NE in the corn-soybean meal diet (2,608 kcal/kg DM) was not different from the NE in the diets containing 50% of field peas demonstrated that field peas could be included in diets for swine without changing the NE of the diet.

Conclusions

Results of these experiments indicate that including field peas ground to approximately 400 µm in corn-soybean meal diets does not change the AID or SID of AA, nor the ATTD of DM, GE, CP, and TDF. It was also observed that inclusion of field peas does not change NE in corn-soybean meal diets. However, the ATTD of energy and nutrients and the NE may increase if the particle size of field peas is reduced.

Tables

Table 5.1. Analyzed nutrient composition of ingredients[1]

	Field peas particle size (µm):						
Item, %	U.S.			Canada 1	Canada 2	Corn	Soybean meal
Particle size:	678	457	265	411	415		
Gross energy, kcal/kg	3,913	3,946	3,942	3,919	3,925	3,808	4,106
Dry matter	89.54	89.21	89.33	89.77	89.72	90.52	91.00
Crude protein	22.50	22.31	21.35	22.55	22.76	8.69	44.82
Ash	3.13	3.18	3.22	2.96	2.94	1.20	6.38
Starch	43.89	45.96	46.12	47.57	44.58	63.39	2.22
Acid hydrolyzed ether extract	1.04	1.10	1.13	1.06	1.11	3.56	2.17
Insoluble dietary fiber	17.72	17.95	17.43	17.65	18.64	10.21	15.18
Soluble dietary fiber	2.07	2.65	1.44	2.03	2.17	0.78	0.77
Total dietary fiber	19.79	20.59	18.87	19.67	20.81	10.99	15.96
Sucrose	3.38	3.19	3.37	3.87	2.18	1.09	7.81
Maltose	2.57	2.42	2.47	2.16	2.54	0.06	0.12
Stachyose	3.14	2.97	3.04	3.56	3.10	0.06	5.84

Table 5.1. (Cont.)

Raffinose	0.87	0.82	0.81	0.76	0.72	0.15	1.14
Indispensable amino acids							
Arg	1.79	1.82	1.77	1.88	1.84	0.40	3.14
His	0.56	0.57	0.55	0.59	0.58	0.22	1.17
Ile	1.07	1.09	1.07	1.11	1.11	0.29	2.29
Leu	1.64	1.66	1.63	1.74	1.73	0.84	3.44
Lys	1.74	1.77	1.72	1.83	1.82	0.30	2.79
Met	0.23	0.24	0.22	0.23	0.23	0.17	0.62
Phe	1.16	1.18	1.16	1.20	1.19	0.37	2.34
Thr	0.82	0.83	0.81	0.86	0.86	0.26	1.66
Trp	0.18	0.18	0.18	0.20	0.19	0.05	0.58
Val	1.14	1.15	1.13	1.19	1.19	0.38	2.25
Total	10.33	10.48	10.25	10.84	10.74	3.29	20.30
Dispensable amino acids							
Ala	0.99	1.01	0.99	0.98	1.00	0.53	1.91

Table 5.1. (Cont.)

Asp	2.57	2.60	2.54	2.53	2.63	0.52	4.98
Cys	0.37	0.38	0.36	0.36	0.35	0.17	0.64
Glu	3.72	3.77	3.67	3.75	3.78	1.28	7.88
Gly	1.03	1.04	1.01	1.01	1.04	0.33	1.89
Pro	0.90	0.93	0.91	0.92	0.91	0.57	2.17
Ser	0.90	0.92	0.90	0.95	1.00	0.32	1.89
Tyr	0.66	0.68	0.67	0.69	0.68	0.21	1.49
Total	11.15	11.33	11.04	11.20	11.39	3.96	22.84
Total AA	21.73	22.06	21.56	22.69	22.50	7.24	43.14
Lys:CP[2]	8.65	8.90	8.67	9.03	8.90	3.37	6.03

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[1] All values except dry matter are expressed on a dry matter basis.

[2] Lys:CP ratio was calculated by expressing the concentration of Lys in each source of field peas as a percentage of the concentration of CP (Stein et al., 2009).

Table 5.2. Ingredient composition of experimental diets containing field peas in experiment 1 and 2

		Field peas					
Item% Source:	Basal	U.S.			Canada 1	Canada 2	N-free
Particle size (µm):		678	457	265	411	415	
Field peas	-	50.00	50.00	50.00	50.00	50.00	-
Soybean meal	33.20	16.10	16.10	16.10	16.10	16.10	-
Corn	63.80	30.84	30.84	30.84	30.84	30.84	-
Corn starch	-	-	-	-	-	-	68.15
Soybean oil	-	-	-	-	-	-	4.00
Solka floc[1]	-	-	-	-	-	-	4.00
Dicalcium phosphate	0.90	0.70	0.70	0.70	0.70	0.70	1.75
Ground limestone	0.80	0.98	0.98	0.98	0.98	0.98	0.30
Sucrose	-	-	-	-	-	-	20.0
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
DL - Met	-	0.08	0.08	0.08	0.08	0.08	-
Vitamin-mineral premix[2]	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Titanium Oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Potassium carbonate	-	-	-	-	-	-	0.40
Magnesium oxide	-	-	-	-	-	-	0.10

[1] Fiber Sales and Development Corp., Urbana, OH.

[2] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 10,622 IU; vitamin D_3 as cholecalciferol, 1,660 IU; vitamin E DL-alpha-tocopheryl acetate, 66 IU; vitamin K as menadione

Table 5.2. (Cont.)

nicotinamide bisulfate, 1.40 mg; thiamin as thiamine mononitrate, 1.08 mg; riboflavin, 6.49 mg; pyridoxine as pyridoxine hydrochloride, 0.98 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.2 mg; niacin, 43.4 mg; folic acid, 1.56 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 123 mg as iron sulfate; I, 1.24 mg as ethylenediamine dihydriodide; Mn, 59.4 mg as manganese hydroxychloride; Se, 0.27 mg as sodium selenite and selenium yeast; and Zn, 124.7 mg as zinc hydroxychloride.

Table 5.3. Analyzed nutrient composition of experimental diets containing field peas, as fed basis

		Field peas				
Item% Source:	Basal	U.S.			Canada 1	Canada 2
Particle size (µm):		678	457	265	411	415
Gross energy, kcal/kg	3,775	3,780	3,742	3,808	3,765	3,738
Dry matter, %	90.33	90.96	91.20	91.23	90.72	90.61
Crude protein, %	17.24	16.47	16.69	17.20	16.14	16.42
AEE[1], %	1.53	1.29	1.78	1.51	1.50	1.50
Ash, %	5.31	5.20	5.53	5.90	5.12	5.09
Insoluble dietary fiber	10.50	13.90	12.70	12.60	15.50	14.40
Soluble dietary fiber	13.10	6.10	6.40	6.30	5.10	6.20
TDF[1]	23.60	20.00	19.10	18.90	20.60	20.50
Organic matter[2], %	85.03	85.76	85.67	85.33	85.60	85.52
Starch	42.50	39.00	40.00	40.50	39.20	38.50
Sucrose	3.68	3.11	3.14	3.09	4.34	2.89
Maltose	0.16	1.35	1.35	1.44	0.95	1.4
Stachyose	2.11	2.39	2.61	2.36	2.57	2.43
Raffinose	0.49	0.58	0.68	0.63	0.53	0.55
Indispensable AA						
Arg	1.26	1.40	1.50	1.43	1.45	1.43
His	0.51	0.51	0.53	0.50	0.51	0.50
Ile	0.93	0.94	0.98	0.94	0.95	0.93

Table 5.3. (Cont.)

Leu	1.70	1.59	1.63	1.57	1.60	1.58
Lys	1.10	1.31	1.39	1.33	1.33	1.33
Met	0.30	0.31	0.34	0.34	0.33	0.31
Phe	1.02	1.02	1.06	1.02	1.03	1.01
Thr	0.71	0.72	0.75	0.72	0.73	0.72
Trp	0.23	0.18	0.20	0.18	0.21	0.19
Val	0.99	1.00	1.04	0.99	1.02	1.00
Total	8.75	8.98	9.42	9.02	9.16	9.00
Dispensable AA						
Ala	0.98	0.94	0.97	0.93	0.94	0.93
Asp	1.97	2.12	2.22	2.12	2.12	2.12
Cys	0.30	0.31	0.32	0.29	0.31	0.29
Glu	3.47	3.41	3.55	3.38	3.46	3.34
Gly	0.81	0.87	0.90	0.86	0.86	0.86
Pro	1.11	0.98	0.99	0.95	0.97	0.94
Ser	0.81	0.82	0.84	0.81	0.81	0.81
Tyr	0.65	0.60	0.66	0.65	0.64	0.63
Total	10.10	10.05	10.45	9.99	10.11	9.92
Total AA	18.85	19.03	19.87	19.01	19.27	18.92

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[1] AEE = acid hydrolyzed ether extract; TDF = total dietary fiber.

[2] Organic matter (%) was calculated as dry matter – % ash.

Table 5.4. Apparent ileal digestibility (AID) of crude protein, starch, and amino acids (AA, %), in field peas, Exp. 1[1,2]

	Field peas								
Item, % Source:	U.S.			Canada 1	Canada 2			U.S. peas Contrast *P*-Value	
Particle size (μm):	678	457	265	411	415	SEM	*P*-value	Linear	Quadratic
Crude protein	62.93	67.54	69.58	66.27	61.62	3.685	0.420	0.164	0.749
Starch	74.08	78.79	87.06	77.28	75.48	2.402	0.003	< 0.001	0.512
Indispensable AA									
Arg	84.02	88.36	88.30	85.52	86.21	0.164	0.164	0.040	0.210
His	77.50	82.43	78.83	79.60	78.60	0.642	0.642	0.691	0.148
Ile	73.02	77.00	74.61	75.44	73.86	0.851	0.851	0.675	0.338
Leu	73.49	77.11	74.54	75.23	74.32	0.910	0.910	0.791	0.372
Lys	81.89	85.47	82.99	84.41	81.53	0.544	0.544	0.682	0.201
Met	87.07	90.79	88.97	88.69	85.84	0.602	0.602	0.560	0.329
Phe	73.32	77.50	75.27	75.37	74.53	0.854	0.854	0.610	0.337
Thr	65.48	71.93	67.88	69.15	65.18	0.568	0.568	0.604	0.198
Trp	60.15	70.88	63.30	69.52	64.59	0.291	0.291	0.568	0.067

Table 5.4. (Cont)

Val	71.63	76.17	72.43	74.85	72.38	0.761	0.761	0.843	0.248
Total	76.15	80.58	78.16	78.55	77.01	0.726	0.726	0.552	0.249
Dispensable AA									
Ala	70.61	73.18	68.52	72.02	69.32	0.830	0.830	0.646	0.362
Asp	71.19	76.32	72.38	73.72	71.64	0.678	0.678	0.759	0.186
Cys	54.81	61.64	51.06	58.31	49.28	0.331	0.331	0.569	0.137
Glu	71.41	76.58	70.35	73.54	69.06	0.597	0.597	0.833	0.199
Gly	54.22	59.93	54.98	60.70	53.61	0.653	0.653	0.901	0.321
Ser	68.83	73.32	70.48	70.46	66.93	0.623	0.623	0.691	0.313
Tyr	73.00	80.64	79.21	77.62	76.33	0.397	0.397	0.135	0.205
Total	68.73	73.99	69.08	71.64	67.76	0.662	0.662	0.941	0.215
Total AA, (%)	72.46	77.32	73.68	75.15	72.45	0.705	0.705	0.762	0.229

[1] Each least squares mean is the mean of 7 observations per treatment.

[2] Values for the AID of crude protein and AA in field peas were calculated by difference (Kong and Adeola, 2004).

Table 5.5. Standardized ileal digestibility (SID) of crude protein, and (AA, %) in field peas, Exp. 1[1,2,3]

	Field peas								
Item, % Source:	U.S.			Canada 1	Canada 2	SEM	*P*-value	U.S. peas Contrast *P*-value	
Particle size (μm):	678	445	265	411	415			Linear	Quadratic
Crude Protein	72.90	77.49	79.39	72.21	71.55	3.69	0.356	0.174	0.739
Indispensable AA									
Arg	88.17	92.23	92.40	87.58	90.22	1.63	0.064	0.042	0.266
His	81.88	86.62	83.35	81.84	82.98	2.63	0.596	0.660	0.173
Ile	77.87	81.65	79.47	77.92	78.67	2.95	0.841	0.673	0.369
Leu	77.98	81.50	79.11	77.50	78.70	3.00	0.864	0.774	0.395
Lys	85.09	88.48	86.17	86.06	84.62	2.04	0.646	0.689	0.227
Met	91.32	94.68	92.96	90.17	90.08	2.56	0.567	0.613	0.370
Phe	77.50	81.52	79.46	77.51	78.68	2.89	0.810	0.608	0.361
Thr	75.57	81.60	78.06	74.23	75.00	3.57	0.499	0.590	0.239
Trp	68.83	78.72	72.00	73.03	72.52	4.11	0.498	0.565	0.094
Val	76.76	81.11	77.65	77.42	77.39	3.08	0.824	0.826	0.275

Table 5.5. (Cont)

Total	80.93	85.14	82.95	80.94	81.68	2.55	0.688	0.550	0.281
Dispensable AA									
Ala	78.68	81.00	76.75	76.15	77.32	3.62	0.824	0.670	0.407
Asp	75.44	80.38	76.66	75.94	75.78	2.97	0.691	0.752	0.206
Cys	63.00	69.50	59.96	62.60	58.27	4.89	0.496	0.644	0.169
Glu	75.24	80.26	74.24	75.45	72.91	4.14	0.651	0.844	0.213
Gly	71.73	76.86	72.91	69.94	71.03	5.43	0.812	0.847	0.396
Ser	76.44	80.74	78.25	74.44	74.49	3.20	0.506	0.663	0.349
Tyr	78.76	85.82	84.50	80.32	81.67	2.96	0.402	0.167	0.241
Total	75.17	80.15	75.59	74.87	74.14	3.65	0.710	0.928	0.244
Total AA	78.06	82.67	79.32	77.95	77.97	3.07	0.718	0.754	0.259

[1] Each least squares mean is the mean of 7 observations per treatment.

[2] Values for SID were calculated by correcting values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of dry matter intake) as CP, 10.54; Arg, 0.39; His, 0.13; Ile, 0.28; Leu, 0.40; Lys, 0.29; Met, 0.07; Phe, 0.26; Thr, 0.44; Trp, 0.08; Val, 0.31; Ala, 0.43; Asp, 0.58; Cys, 0.16; Glu, 0.76; Gly, 0.97; Ser, 0.37; and Tyr, 0.20.

[3] Values for the AID of crude protein and AA in field peas were calculated by difference (Kong and Adeola, 2004).

Table 5.6. Intake, output, and the apparent total tract digestibility (ATTD) of energy and nutrients in the basal diet and diets containing field peas, Exp. 2, as fed basis[1]

Item	Basal	U.S.			Canada 1	Canada 2	SEM	*P*-value	U.S. peas Contrast *P*-value
Particle size (µm):		678	457	265	411	415			Linear
Intake									
Feed intake, kg/d	2.66	2.70	2.63	2.49	2.78	2.65	0.19	0.383	0.099
Dry matter, kg/d	2.40	2.46	2.39	2.27	2.46	2.40	0.17	0.597	0.113
Gross energy, kcal/d	10.08	10.10	9.92	9.33	10.2	9.97	0.73	0.457	0.109
Crude protein, g/d	458.46	445.01	438.1	428.86	438.31	434.68	5.26	0.988	0.472
TDF[2], g/d	627.68^{a}	540.29^{bc}	501.45^{bc}	471.14^{c}	559.43^{ab}	542.71^{bc}	6.60	0.003	0.025
Fecal excretion									
Dry feces output, kg/d	0.26^{ab}	0.32^{a}	0.28^{ab}	0.25^{b}	0.26^{ab}	0.26^{ab}	0.02	0.036	0.003
Gross energy, kcal/d	4,261^{a}	4,268^{a}	4,207^{a}	4,063^{b}	4,274^{a}	4,183^{a}	25.58	< 0.001	< 0.001
Crude protein, kg/d	58.87^{b}	85.70^{a}	75.90^{ab}	55.99^{b}	69.77^{ab}	66.17^{ab}	0.68	0.023	0.002
TDF[2], kg/d	95.54	118.38	101.83	92.25	98.64	94.46	0.84	0.120	0.012
Urine excretion									

Table 5.6. (Cont)

Urine output, kg/d	5.50	6.30	5.32	6.37	4.99	5.94	0.80	0.592	0.932
Gross energy, kcal/d	53.11	40.06	36.72	42.04	44.87	50.36	4.29	0.091	0.747
ATTD, %									
Dry matter	90.09^{ab}	88.23^{b}	89.33^{ab}	89.85^{ab}	90.28^{a}	89.93^{ab}	0.50	0.042	0.018
Gross energy	88.86^{ab}	86.55^{b}	88.13^{ab}	88.96^{a}	88.99^{a}	88.80^{ab}	0.59	0.023	0.004
Crude protein	86.83^{a}	80.67^{b}	82.80^{ab}	86.65^{a}	84.10^{ab}	84.44^{ab}	1.32	0.012	0.002
TDF[2]	84.69^{a}	78.15^{c}	79.55^{bc}	80.20^{bc}	82.46^{ab}	82.42^{abc}	1.03	0.001	0.154

[1] Each least squares mean represents 6 observations.

[2] TDF = total dietary fiber.

[a-c] Within a row, means without a common superscript letter are different ($P < 0.05$)

Table 5.7. Effect of diet composition and source of field peas on energy balance of pigs, Exp. 2[1,2]

Item	Basal	U.S.			Canada 1	Canada 2	SEM	*P*-value	U.S. Contrast *P*-value
Particle size (µm):		678	457	265	411	415			Linear
Energy balance, kcal/kg									
Total heat production	4,402	4,517	4,310	4,135	4,467	4,300	414	0.107	0.010
Fasting heat production	2,458	2,431	2,520	2,432	2,462	2,526	254	0.991	0.998
Respiratory quotient (RQ)									
Fasted state	0.66	0.62	0.70	0.79	0.78	0.67	0.06	0.324	0.069
Fed state	1.05	1.00	1.02	1.02	1.02	0.99	0.04	0.218	0.449
Energy utilization, %									
ME/DE	96.67	96.72	97.5	96.83	97.50	96.67	0.42	0.196	0.818
NE/ME	76.11^{ab}	73.29^{b}	79.33^{a}	76.91^{ab}	77.83^{ab}	79.00^{a}	1.22	0.008	0.035
Energy values, kcal/kg DM									
DE	$3,728^{a}$	$3,556^{b}$	$3,652^{a}$	$3,649^{ab}$	$3,703^{a}$	$3,690^{a}$	24.44	< 0.001	0.006
ME	$3,607^{a}$	$3,453^{b}$	$3,564^{a}$	$3,535^{ab}$	$3,603^{a}$	$3,569^{a}$	27.31	0.001	0.021
NE	$2,887^{a}$	$2,419^{b}$	$3,031^{a}$	$2,947^{a}$	$2,920^{a}$	$2,982^{a}$	90.24	0.001	0.001

Table 5.7. (Cont)

Energy values, kcal/kg as-is									
DE	3,367^{a}	3,235^{b}	3,331^{a}	3,329^{a}	3,359^{a}	3,344^{a}	22.18	0.002	0.003
ME	3,258^{a}	3,141^{b}	3,250^{a}	3,225^{ab}	3,269^{a}	3,234^{a}	24.79	0.004	0.010
NE	2,608^{a}	2,166^{b}	2,704^{a}	2,633^{a}	2,622^{a}	2,676^{a}	80.93	0.001	0.001

[1] Each least squares mean represent 6 observations, except for diets containing peas ground to 678 and 265 µm samples (*n* = 5).

[2] DM = dry matter; DE = digestible energy; ME = metabolizable energy; NE = net energy.

[a-b] Within a row, means without a common superscript letter are different ($P < 0.05$).

Table 5.8. Effect of origin and particle size of field peas on appartent total tract digestibility (ATTD) of energy, crude protein, and fiber and on energy measurements in growing pigs, Exp. 2[1]

Item Origin of peas:	U.S.			Canada 1	Canada 2	SEM	*P*-value	U.S. Contrast *P*-Value
Particle size (μm):	678	457	265	411	415			Linear
ATTD, %								
Gross energy	82.04^{b}	86.23^{ab}	86.23^{ab}	88.29^{a}	87.35^{a}	1.12	0.011	0.017
Crude protein	70.91^{a}	73.58^{a}	74.94^{a}	80.08^{a}	79.97^{a}	2.33	0.041	0.230
Total dietary fiber	74.61^{b}	78.90^{ab}	86.48^{a}	81.37^{ab}	82.08^{ab}	2.49	0.034	0.002
Energy utilization, %								
ME/DE	97.66	98.82	96.83	97.83	96.83	0.59	0.068	0.297
NE/ME	72.83	80.83	80.83	77.67	80.83	3.56	0.376	0.103
Energy values, kcal/kg DM								
DE	3,586^{b}	3,814^{a}	3,805^{a}	3,853^{a}	3,821^{a}	48.85	0.009	0.006
ME	3,440^{b}	3,751^{a}	3,690^{a}	3,769^{a}	3,695^{a}	48.61	0.001	0.001
NE	2,412^{b}	3,031^{a}	2,971^{a}	2,920^{a}	2,982^{a}	91.10	0.003	0.002
Energy values, kcal/kg as-is								

Table 5.8. (Cont)

DE	$3,211^{b}$	$3,403^{a}$	$3,399^{a}$	$3,460^{a}$	$3,428^{a}$	43.77	0.008	0.007
ME	$3,080^{b}$	$3,346^{a}$	$3,296^{a}$	$3,384^{a}$	$3,315^{a}$	43.53	0.001	0.002
NE	$2,160^{b}$	$2,704^{a}$	$2,654^{a}$	$2,622^{a}$	$2,676^{a}$	81.53	0.003	0.002

[1] Each least squares mean represent 6 observations.

[2] DM = dry matter; DE = digestible energy; ME = metabolizable energy; NE = net energy.

[a-b] Within a row, means without a common superscript letter are different ($P < 0.05$).

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CHAPTER 6: Conclusions

Results of Exp. 1 demonstrate that the reduction of particle size from 400 to 200 µm may not affect or improve the standardized ileal digestibility (**SID**) of most aminoacids (**AA**) and crude protein (**CP**), but the concentration of protein and AA in field peas, as well as the SID of CP and AA, may be influenced by environmental conditions, genetic factors, or location of growing since the SID of CP and some dispensable AA was greater in field peas from Canada than in U.S. field peas. However, the apparent ileal digestibility (**AID**) of starch increased when the particle size of field peas was reduced from 400 to 200 µm in the U.S. source, but the reduction of particle size did not affect the AID of starch in the Canadian peas. It is possible that the AID of starch in the Canadian field peas was not affected by the reduction of particle size because the content of inaccessible resistant starch may be greater in the U.S. source. However, further research should be conducted to evaluate how the origin of the peas may affect the carbohydrate composition of Canadian and U.S. field peas.

Results from Exp. 2 and 3, indicate that the standardized total tract digestibility (**STTD**) of P of field peas grown in Canada is not different from the STTD of P of peas grown in the U.S. and it appears that STTD of P is not affected by environmental conditions, variety, or particle size. When microbial phytase was added to diets, the STTD of P of field peas increased likely as the level of phytase inclusion increased. Therefore, the inclusion of inorganic P in swine diets can be reduced if microbial is included in diets containing field peas.

In Exp. 4 and 5, it was observed that the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of amino acids, as well as the apparent total tract digestibility (**ATTD**) of gross energy (**GE**), and nutrients did not change in corn-soybean meal diets containing field peas ground to approximately 400µm. It was also observed that inclusion of field peas in corn-soybean meal diets did not change the net energy (NE) in the diet. However, the ATTD of GE and nutrients and the NE may increase if the particle size of field peas is reduced.

Swine producers and nutritionists may use data generated from this research to formulate diets with field peas from Canada and the U.S. based on digestibility values: AID of starch, SID of AA, STTD of P. Likewise formulation of corn-soybean meal diets with the inclusion of 50% of field peas can be made based on the results obtained in this research: ATTD of GE and nutrients, and NE.