

# Ethanol Fermentation of Starch from Field Peas

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## ABSTRACT

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Field peas (*Pisum sativum*) were evaluated as a potential feedstock for ethanol production. Ground peas were dry-milled and separated into starch, protein, and fibrous fractions by air classification. Starch-enriched fractions prepared from whole peas and dehulled peas contained 73.7% wt and 77.8% wt starch, respectively, a nearly two-fold enrichment compared with whole peas. The fractions were liquefied and saccharified

using industrial  $\alpha$ -amylase and glucoamylase at recommended enzyme loadings. A final ethanol concentration of 11.0% (w/v) was obtained in 48–52 hr, with yields of 0.43–0.48 g of ethanol/g of glucose. Starch present in whole ground peas was also saccharified and fermented, with 97% of the starch fermented when an autoclaving step was included in the liquefaction stage.

Field peas (*Pisum sativum*, dry peas) are consumed as a source of protein for human diets around the world and are used as feed for animals including swine and ruminants (Hickling 2003). Field peas are legumes containing  $\approx$ 46% starch, 23% crude protein, and 1.4% oil. The crop is grown in Europe, Asia, and increasingly in North America (Hickling 2003). In the United States and Canada, 502,000 (Larry White, North Dakota Dry Pea and Lentil Office, *personal communication*) and 3.3 million (Statistics Canada 2004) metric tons, respectively, of field peas were harvested in 2004.

Although field peas are mostly fed whole, it is possible to separate the protein fraction, which is most valuable from a feed perspective, from the starch (Vose et al 1976; Tyler et al 1981; Wu and Nichols 2005). Much of the research aimed at utilization of field peas in food and feed applications has targeted the protein and fibrous fractions (Satin 1980; Klein and Raidl 1986; Madsen and Buechbjerg 1987; Viacroze 1987; Richardson and Nickel 1988; Case 2003). However, economics suggest that the starch should also be used. Coproducts that utilize the starch are needed, and some research toward use of field pea starch in industrial and food applications has been conducted (Johnson 1979; Vasanthan et al 1998; Ratnayake et al 2001; Ratnayake et al 2002; Hoover and Zhou 2003).

In the United States, production of ethanol for use as a renewable fuel generates a commodity-scale market for starch. Currently, most ethanol in the United States is produced from corn starch by yeast fermentation. However, production of ethanol is expected to increase over the next decade (MacDonald et al 2003) and alternative feedstocks may be useful or necessary (Wisner and Baumel 2004). Field peas are a potential new source of starch for ethanol production. Here, we determined the feasibility of fermenting the starch from field peas to ethanol.

## MATERIALS AND METHODS

### Reagents

Field peas (*P. sativum*, cv. Eclipse) were grown in 2003 in Ogle County in northern Illinois. Enzymes were supplied by Genencor International (Beloit, WI) and included  $\alpha$ -amylase (Spezyme Ethyl), glucoamylase (Optidex L-400), glucoamylase plus pullulanase

mixture (Optimax 4060 VHP), protease (GC 106), and cellulase/xylanase (GC220). Enzyme units are as reported by the supplier.

### Separation of Field Pea Fractions

Field peas were ground in a pin mill (Alpine model 160Z, Augsburg, Germany) at 14,000,  $3 \times 14,000$ , or  $9 \times 14,000$  rpm and fractionated in a laboratory model air classifier (Pillsbury, Minneapolis, MN) according to particle size. The classifier was first set at a 15- $\mu$ m cutpoint to obtain a coarse and a fine fraction. The coarse fraction was then classified successively with 18-, 24-, and 30- $\mu$ m cutpoints to obtain four fine fractions (Fractions 1–4) and a coarse residue. Cutpoints were chosen to yield the best enrichment of protein and starch. Fraction 4 has the highest starch content with particle size of 24–30  $\mu$ m. A complete description of pin-milling and air-classification of field peas was presented earlier (Wu and Nichols 2005).

### Simultaneous Saccharification and Fermentation

Simultaneous saccharification and fermentation (SSF) of pea starch from whole or dehulled field peas was done in 250-mL Erlenmeyer flasks containing 100 mL of distilled water and 25 g (or in one experiment, up to 40 g) of a starch-enriched field pea fraction (Table I). The sample was adjusted to pH 6.0–6.5 with  $\text{Ca}(\text{OH})_2$ , and  $\alpha$ -amylase (60 U/g of starch) was added. The flasks were covered with foil, heated to 90°C in a water bath, and maintained at that temperature for 60 min with occasional mixing. The mash was allowed to cool slightly before adjusting to pH 4.0–4.5 with phosphoric acid. Glucoamylase (0.5 U/g of starch) was added along with 0.05% (w/v)  $(\text{NH}_4)_2\text{SO}_4$ , 0.04% Antifoam 289 (Sigma, St. Louis, MO) and corn steep liquor (1% solids final concentration, Grain Processing Corp., Muscatine, IA). In one experiment, cellulase (9 U of cellulase/g of starch plus unspecified xylanase activity) was added in addition to glucoamylase, or a glucoamylase plus pullulanase mixture (0.6 U of glucoamylase and 1.0 U of pullulanase/g of starch) was added instead of glucoamylase alone. Yeast inoculum (5%, v/v) was added from a preculture of *Saccharomyces cerevisiae* Y-2034 (ARS Culture Collection, Peoria, IL) grown overnight in a liquid medium containing 5 g/L of yeast extract, 10 g/L of peptone (both from Becton, Dickinson and Co., Sparks, MD), and 50 g/L of glucose. The flasks containing mash, enzymes, and yeast were capped with butyl rubber stoppers, vented with a 22-gauge needle, and incubated at 32°C with gentle shaking. Fermentations were monitored by measuring weight loss reflective of  $\text{CO}_2$  production, and ethanol concentrations were determined by HPLC analysis of culture supernatants at the end of the fermentations (usually 72 hr). In one time-course experiment, ethanol production was calculated from weight loss and then corrected based on final HPLC-determined ethanol values; correction was necessary because calculation based on weight loss tends to overestimate ethanol yield somewhat due to loss of other volatiles. All the experiments were conducted in duplicate.

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Fermentation residuals from each flask were dried at 60°C and ground for compositional analysis.

### Fermentation of Whole Ground Peas

Field peas were ground by processing through a plate mill (model 4E, Straub Co., Croydon, PA) and the whole flour was collected with larger hull pieces included. SSF was conducted as described above for starch-enriched fractions using 500-mL Pyrex bottles instead of flasks. The mixture (25 g of flour in 100 mL of water) was adjusted to pH 6.0–6.5 with Ca(OH)<sub>2</sub>, heated to 90°C, and mixed with 200 U of α-amylase (17 U/g of starch). The bottles were capped and either maintained at 90°C or autoclaved (121°C and 18 psi) for 15 min, followed in both cases by an additional 400 U of α-amylase (34 U/g of starch) and 60 min of incubation at 90°C. Next, the mash was adjusted to pH 4.0–4.5 with phosphoric acid and 0.05% (w/v) (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and 0.04% Antifoam 289 were added. Glucoamylase (0.4 U/g of flour or 0.87 U/g of starch) and 5% yeast inoculum were added to initiate ethanol fermentation. In some cases, a glucoamylase/pullulanase mixture was added instead of glucoamylase, along with cellulase (6.2 U/g of flour or 13.5 U/g of starch) or acid-stable protease (1.0 U/g of flour or 2.2 U/g of starch). The threaded caps were replaced with rubber stoppers vented with a 22-gauge needle, and the fermentations were monitored during 72 hr of incubation at 32°C as described above. Residual material was dried at 60°C and ground for compositional analysis.

### Analytical Procedures

Moisture was measured by drying samples at 105°C until samples reached a stable weight. Glucose and ethanol were measured by high-pressure liquid chromatography using an Aminex HPC-87H column (Bio-Rad, Richmond, CA) and a refractive index detector. Samples were run at 65°C and eluted at 0.6 mL/min with 5 mM sulfuric acid. Starch content in whole and fractionated field peas was measured enzymatically (Trinder 1969) and free sugars were determined by Official Method 2000.17 (AOAC 2000). Starch in fermentation solids was calculated from glucose liberated by trifluoroacetic acid treatment (Dien et al 1997). Nitrogen, oil, phosphorous, amino acid, and free sugar content were determined in a commercial laboratory. Protein was calculated from N × 6.25 using AOAC Official Method 976.06 for nitrogen determination.

Methods 920.39 and 968.08 were used to determine oil and phosphorous content, respectively (AOAC 2000). Amino acid composition was determined by the method of Gerhke et al (1987). All samples were analyzed in duplicate.

## RESULTS

### Milling and Air Classification of Field Peas

Table I presents compositional data for whole peas and starch-enriched (recovered as Fraction 4) samples. A substantial increase in starch content was observed for Fraction 4 compared with whole peas. As intensity of grinding increased, Fraction 4 had higher starch, lower protein, lower oil, and lower phosphorous. Fraction 4 from dehulled peas had higher starch, lower protein, and lower oil than the same fraction from whole peas.

### Fermentation of Starch-Enriched Fractions

Air-classified Fraction 4, which had the highest concentration of starch, was used in simultaneous saccharification and fermentations (SSF) to test the fermentability of starch obtained from field peas. Initial experiments (not shown) showed that neither pullulanase nor a cellulase/xylanase preparation was necessary for complete fermentation. Subsequently, the loading of α-amylase and glucoamylase was decreased to one-half or one-tenth of the original values, with no significant change in ethanol yield. The yields obtained from fermentation of starch-enriched Fraction 4 at different enzyme loadings are presented in Table II.

Next, an experiment was performed to determine whether the final ethanol concentration could be increased by adding more starch. Increasing quantities (25–40 g) of dehulled Fraction 4, corresponding to 0.20–0.29 g of starch/g of fermentation weight, were subjected to SSF. The amounts of α-amylase and glucoamylase added were kept constant on a starch basis. As shown in Table III, increased starch loading resulted in higher ethanol concentrations, with the metabolic yield (ethanol produced/g of glucose fermented) steady at starch loadings of 20–29% (w/w). The highest ethanol concentration obtained in this experiment was 10.6% (w/v). Fermentation at the highest starch loading was repeated, and ethanol production was monitored throughout the fermentation (Fig. 1); the final ethanol concentration was 11.0% (w/v) in that experiment.

**TABLE I**  
Composition of Whole Field Peas and Representative Starch-Enriched Fractions (% , w/w, db)<sup>a</sup>

Fraction	Crude Protein	Starch	Oil	Phosphorous	Soluble Sugars <sup>b</sup>
Whole Peas	22.2 ± 0.6	46.2 ± 0.6	1.20 ± 0.00	0.58 ± 0.00	3.7 ± 0.1
Fraction 4					
1× 14,000 rpm	12.9 ± 0.1	68.1 ± 0.4	0.70 ± 0.04	0.33 ± 0.01	nd
3× 14,000 rpm	10.3 ± 0.1	72.0 ± 1.0	0.59 ± 0.01	0.26 ± 0.01	nd
9× 14,000 rpm	7.4 ± 0.0	73.7 ± 1.7	0.34 ± 0.03	nd	nd
Dehulled, 9× 14,000 rpm	6.3 ± 0.1	77.8 ± 0.6	0.24 ± 0.03	nd	nd

<sup>a</sup> Values are the average of two determinations; nd, not determined.

<sup>b</sup> Soluble sugars included 0.40% glucose, 0.47% fructose, 2.4% sucrose, and 0.44% maltose.

**TABLE II**  
Varied Loading of α-Amylase and Glucoamylase in Fermentation of Field Pea Starch Fraction

α-Amylase <sup>a</sup>	Glucoamylase <sup>b</sup>	Ethanol Conc. (% , w/v)	Unfermented Starch <sup>c</sup> (%)	Ethanol Yield <sup>d</sup> (g/g)
1×	1×	7.51 ± 0.17	1.23 ± 0.04	0.47
1×	0.5×	7.52 ± 0.06	1.17 ± 0.04	0.47
1×	0.1×	7.24 ± 0.18	1.49 ± 0.20	0.45
0.5×	1×	7.55 ± 0.00	1.20 ± 0.01	0.47
0.1×	1×	7.44 ± 0.03	1.54 ± 0.12	0.47
0.5×	0.5×	7.68 ± 0.04	1.25 ± 0.01	0.48

<sup>a</sup> 1× α-amylase = 60 U/g of starch.

<sup>b</sup> 1× glucoamylase = 0.5 U/g of starch.

<sup>c</sup> Starch (%) present at the start of the fermentation that was unfermented after 72 hr (initial starch in Fraction 4 from whole ground field peas was 0.737 g/g).

<sup>d</sup> Ethanol (g) produced/glucoamylase (g) present (as starch) at the start of each fermentation.

### Fermentation of Whole Field Peas

Fermentations were conducted to determine the feasibility of directly fermenting whole ground peas (Table IV). Initial experiments indicated that the starch in whole pea flour was not completely fermented to ethanol. Approximately 22% of the starch was unfermented after 72 hr, and the final ethanol concentration was  $4.2 \pm 0.3\%$  (w/v). Addition of protease, pectinase, or cellulase enzymes to the SSF did not significantly improve the fermentation (data not shown). Subsequently, the SSF protocol was modified to include an autoclave step during liquefaction with  $\alpha$ -amylase. With the higher temperature heating step ( $121^\circ\text{C}$ ), 96% of the starch was fermented. Because whole peas had lower starch content than the starch-enriched fraction, only  $5.7 \pm 0.4\%$  (w/v) ethanol was obtained from fermentation of whole pea flour.

### Fermentation Residuals

Solids remaining after 72 hr of fermentation were dried and ground for compositional analysis (Table V). As expected, the residual material contained very little starch and oil, and was enriched in protein relative to the starting material (Table I). Amino acid contents of the fermentation residuals were determined for both starch-enriched and whole peas fermentations (Table VI).

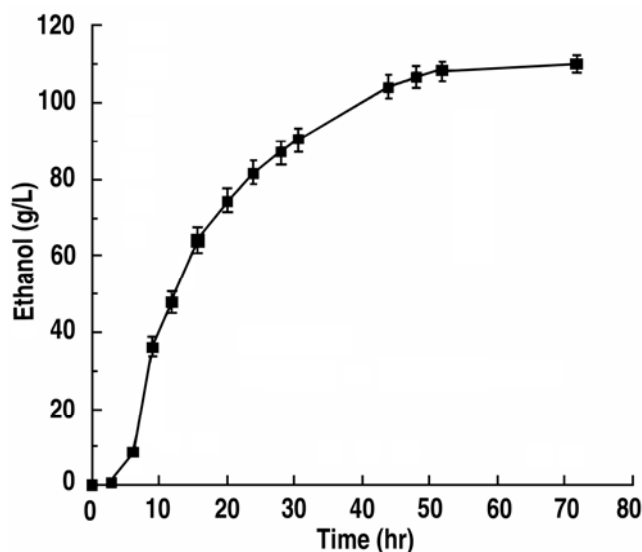


Fig. 1. Time-course of fermentation of field pea starch enriched Fraction 4. Final ethanol concentration determined by HPLC analysis of culture supernatants from four fermentation flasks was  $11.0 \pm 0.2\%$  (w/v).

The profiles for residual solids resulting from fermentation of whole peas and from the high starch fraction are similar, with glutamic acid, lysine, and arginine content somewhat higher in whole pea fermentation solids compared with the solids resulting from fermentation of the starch fraction.

## DISCUSSION

Field peas are growing in popularity as an alternative crop in the northern United States and central Canada (Miller et al 2003). The crop is currently marketed primarily as animal feed and much of the crop is exported but there is opportunity for developing alternate domestic uses. Because of the relatively high starch content of field peas, use in fermentative production of fuel alcohol is a potential additional or alternative use for field peas. In some cases, the crop is grown in the same locality as ethanol production facilities, meaning that field peas could be fermented in conjunction with corn in areas where both crops are grown. Although peas only have approximately two-thirds the starch content of corn, they are rich in protein, which would either enhance the quality of the animal feed coproduct (distiller's dry grains with solubles [DDGS]) or be a valuable product in its own right.

Two alternate schemes can be imagined for processing field peas to ethanol. In the simpler process, peas might be milled and directly mixed with ground corn before liquefaction and the two seeds could be fermented together. Alternatively, the legumes could be dry-milled, and the starch and protein fractions could be separated by air classification. The enriched starch stream could then be mixed with ground corn before liquefaction. The second approach, while requiring more capital, would offer the advantages of isolating the protein as a valuable coproduct and of concentrating the starch before fermentation, which would increase the final ethanol concentration. Both possibilities, fermentation of whole peas and fermentation of the pea starch fraction, were investigated in this study.

Whole ground peas should be readily amenable to cofermentation with ground corn, provided that the peas do not contain any inhibitors of amylase or yeast and the peas can be saccharified by the current process. To test both criteria, whole ground peas were directly fermented using a laboratory-scale dry-grind protocol that mirrors the corn fermentation process. Liquefying field peas at  $90^\circ\text{C}$  followed by SSF was inefficient; 22.6% of the starch was not saccharified and fermented (Table IV), presumably because the starch was not released from the plant matrix. However, the low yield was overcome by including an extra heating step ( $121^\circ\text{C}$  for 15 min in an autoclave) during liquefaction. This process is similar

TABLE III  
Effect of Starch Loading on Ethanol Yield

Starch <sup>a</sup> (% w/w)	Final Ethanol Conc. (% w/v)	Unfermented Starch <sup>b</sup>	Ethanol Yield (g/g) <sup>c</sup>
20	$7.25 \pm 0.19$	$1.50 \pm 0.02$	0.45
23	$8.34 \pm 0.15$	$1.91 \pm 0.00$	0.43
26	$9.71 \pm 0.24$	$2.31 \pm 0.00$	0.44
29	$10.61 \pm 0.24$	$2.70 \pm 0.09$	0.43

<sup>a</sup> Dehulled starch Fraction 4 used in this experiment contained 77.8% (w/w) starch.

<sup>b</sup> Starch (%) present at the start of the fermentation that was unfermented after 72 hr.

<sup>c</sup> Ethanol (g) produced/glucose (g) present (as starch) at the start of each fermentation.

TABLE IV  
Fermentation of Whole Ground Field Peas<sup>a</sup>

	Ethanol Conc. (% w/v)	Unfermented Starch <sup>b</sup> (%)	Ethanol Yield (g/g) <sup>c</sup>
Not autoclaved	$4.2 \pm 0.3$	$22.6 \pm 3.3$	$0.40 \pm 0.02$
Autoclaved	$5.7 \pm 0.4$	$3.5 \pm 0.3$	$0.53 \pm 0.02$

<sup>a</sup> Average of two experiments, each performed in duplicate.

<sup>b</sup> Starch (%) present at the start of the fermentation that was unfermented after 72 hr (initial starch =  $0.462 \text{ g/g}$ , db, of whole field pea flour).

<sup>c</sup> Ethanol (g) produced/glucose (g) present (as starch) at the start of each fermentation.

in effect to jet cooking, which is the current commercial technology used for liquefying corn starch. The result of the extra heating was that only 3.5% of the supplied starch went unutilized, a result similar to that obtained in dry-grind plants processing corn (Weigel et al 1997).

Ethanol yields for fermentation of whole ground peas (Table IV) were somewhat higher than those predicted from starch content alone. The higher yields can be accounted for by the presence of free sugars in field peas (Table I) (Cerning-Beroard and Filatre 1976), which would be converted to ethanol along with the glucose liberated from starch. The SSF yield was  $5.7 \pm 0.4\%$  (w/v), and the fermentation was completed within 72 hr. Although additional enzymes (cellulase, pullulanase, and protease) are beneficial for high-yield fermentation of some grain crops (Jones and Ingledew 1994; Thomas and Ingledew 1995; Ingledew et al 1999), the enzymes were not necessary for fermentation of field peas. Therefore, ground whole field peas are compatible with corn dry-grind processes and yeast fermentations. The ethanol and dried residual feed product can be converted to a per-ton basis from these laboratory results, assuming a constant yield with scale-up. The ethanol yield was 0.25 g/g of pea (9% moisture) and the residuals yield was 0.51 g/g of pea, corresponding to 314 L of ethanol and 510 kg of dried fermentation residuals (41% protein) (Table V) per metric ton of peas.

For the other fermentation scheme, an air-fractionation process was used to separate starch and protein-enriched fractions (Wu and Nichols 2005). In brief, the starch content was increased from 46.2% wt, db, in whole peas to 73.7% wt, db, in the pin-milled and air-classified starch fraction (Table I). The increased starch content is similar to that of dent corn ( $\approx 72\%$  wt). A protein-rich fraction was also generated (Wu and Nichols 2005). The enriched

starch fraction was readily fermented to ethanol using enzyme loadings (per g of starch) recommended for the ethanol industry (Bruce Strohm, Genencor International, *personal communication*). The ethanol yield was high (0.48 g ethanol/g of glucose; theoretical yield is 0.51 g/g), and only 1.3% of the starch was left unfermented (Table II). The isolated pea starch was fermented more easily than starch in ground whole peas, as evidenced by the complete fermentation of the starch fraction without an elevated heating step (121°C for 15 min) during liquefaction. Furthermore, even when the amount of either  $\alpha$ -amylase or glucoamylase was reduced tenfold, and when both enzymes were reduced by half, the ethanol yield remained high, showing the robustness of the process (Table II). Previously, an air-classified pea starch fraction saccharified less efficiently than corn and wheat starches and washed pea starch (Biliaderis and Grant 1979).

The ethanol concentration from initial fermentations of pea starch fractions was only 7.5% (w/v), while corn ethanol facilities achieve over 10% (w/v) ethanol. The lower product concentration was a consequence of the lower starch loading used in initial experiments. To determine whether the final ethanol concentration could be increased to  $>10\%$  wt, the starch loading was increased to  $\leq 29\%$  wt. Although unfermented starch increased from 1.5 to 2.7% wt, the average final ethanol concentration increased to 10.6% wt, in fermentations conducted over 72 hr (Table III). Typical industrial fermentations typically are complete in 48 hr. Therefore, the highest starch loading was repeated and ethanol production was monitored at 4-hr intervals. The fermentation was essentially complete in 48 hr (Fig. 1). In this experiment, the final mean ethanol concentration was  $11.0 \pm 0.20\%$  wt and the conversion efficiency was  $89.2 \pm 0.02\%$  of the maximum possible yield. Therefore, fermentation of enriched pea starch is feasible,

**TABLE V**  
Composition of Residual Solids from Fermentation of Field Peas and Pea Starch Fractions (% w/w, db)

Starting Material	Crude Protein	Starch	Oil	Calcium	Phosphorous	Magnesium
Whole peas	41.4 ± 1.38	0.79 ± 0.09	0.40 ± 0.10	0.15 ± 0.01	1.79 ± 0.04	0.23 ± 0.01
Fraction 4	42.8 ± 2.31	0.72 ± 0.25	0.29 ± 0.21	0.03 ± 0.01	2.12 ± 0.06	0.08 ± 0.02
Dehulled Fraction 4	36.7 ± 1.24	1.47 ± 0.19	0.33 ± 0.24	0.05 ± 0.01	2.13 ± 0.15	0.18 ± 0.02

**TABLE VI**  
Amino Acid Content (% w/w, db) of Field Pea, Field Pea Protein Fraction, and Fermentation Residuals

	Whole Peas	Pea Protein Fraction <sup>a</sup>	Dried Residuals from Fermentation	
			Whole Peas	High Starch Fraction
Taurine	0.15	0.04	0.00	0.00
Hydroxyproline	0.00	0.04	0.11	0.10
Aspartic acid	2.45	5.79	4.40	4.17
Threonine	0.79	2.03	1.61	1.58
Serine	0.93	2.51	1.79	1.67
Glutamic acid	3.51	8.52	5.61	4.56
Proline	0.83	2.22	1.76	1.67
Lanthionine	0.02	0.03	0.12	0.20
Glycine	0.97	2.29	1.84	1.82
Alanine	0.92	2.30	1.90	1.88
Cysteine	0.33	0.69	0.50	0.55
Valine	1.04	2.57	2.01	1.98
Methionine	0.23	0.50	0.41	0.41
Isoleucine	0.90	2.29	1.87	1.77
Leucine	1.55	4.03	3.07	2.86
Tyrosine	0.57	1.85	1.31	1.24
Phenylalanine	0.98	2.69	2.05	1.85
Hydroxylysine	0.00	0.00	0.00	0.00
Histidine	0.54	1.40	1.07	1.01
Ornithine	0.01	0.04	0.03	0.03
Lysine	1.62	3.97	2.83	2.41
Arginine	1.68	4.47	2.98	2.64
Tryptophan	0.22	0.50	0.38	0.39
Total	20.2	50.8	37.7	34.8

<sup>a</sup> Wu and Nichols (2005).

with ethanol yields and productivities comparable to those routinely obtained in fermentations of yellow dent corn.

Production of ethanol is only half of the story; dry-grind corn ethanol facilities depend on marketing the coproduct DDGS as animal feed to remain profitable (Jacques 2003). Consequently, mixing ground whole peas with corn must not have a detrimental effect on DDGS composition. Likewise, the fermentation residues of enriched pea starch should be comparable to that of DDGS. As DDGS is sold partially based on protein content, it is especially important that the relative protein content and amino acid profile remain similar to, or ideally better than, that of DDGS, which is typically 27–35% protein (Belyea et al 1989, 2004). In the work described here, fermentation of field peas yielded a dried residual material containing 36.7–42.8% protein (Table V), which means that mixing peas with corn should raise the protein content (and value) of the DDGS. The lysine present in field peas makes them a more attractive source of protein for swine because corn is somewhat deficient in lysine. Compared with soybeans, field peas contain higher levels of leucine and lysine, and less methionine and tryptophan (Reichert and MacKenzie 1982). The protein and amino acid content increased in the protein fraction compared with whole pea (Wu and Nichols 2005) and, in general, the protein value was retained in the fermentation solids (Table VI).

## CONCLUSIONS

Production of fuel ethanol has increased significantly in the United States over the last decade, with 3.35 billion gallons of ethanol produced in 2004 (RFA 2004). Currently, most ethanol is produced from corn starch, and further increases in fuel ethanol production may result in higher corn prices and tight supplies in the future (Wisner and Baumel 2004). Under this scenario, alternative crops could supplement corn as a feedstock for fermentation to ethanol. The production area for field peas, a cool-season legume crop, overlaps substantially with the expanding area of ethanol production in North America. Thus, field peas may be a locally available source of starch for some ethanol production facilities. Our studies demonstrate the feasibility of fermenting starch from field peas to ethanol, and suggest that whole or fractionated field peas are a suitable feedstock for ethanol fermentation.

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