Prececal digestibility of various sources of starch in minipigs with or without experimentally induced exocrine pancreatic insufficiency

A. Mößeler,*1 N. Kramer,* C. Becker,* P. C. Gregory,† and J. Kamphues*

*Institute for Animal Nutrition, University of Veterinary Medicine, Hannover, Foundation, Germany; and †Abbott Pharmaceuticals Research Laboratories, Hannover, Germany

ABSTRACT: Low prececal digestibility of starch leads to a higher starch flux into the hindgut, causing a forced microbial fermentation, energy losses, and meteorism. For exocrine pancreatic insufficiency (EPI), lack of pancreatic amylase can be compensated mostly by hindgut fermentation of starch. Even in pigs with complete loss of pancreatic secretion, starch digestibility over the entire tract is reaching levels of controls. To optimize diets for human patients with EPI, the proportion of starch that is digested by the ileum is important. Minipigs were fitted with an ileocecal reentrant fistula (n = 8) to determine prececal digestibility of starch. In 5 minipigs the pancreatic duct was ligated (PL) to induce EPI; 3 minipigs served as controls (Con). Various starch sources were tested in a 1-d screening test; therefore, disappearance rate (DR) instead of digestibility was used. Test meals consisted of 169 g DM of a basal diet plus 67.5 g DM of the starch (without thermal treatment; purified; starch content of 89 to 94.5%) and Cr₂O₃. The test meal contained (% of DM) starch, 67; crude fat, 1.69; CP, 15; crude fiber, 2.0; and Cr₂O₃, 0.25. In PL, prececal DR of starch was lower than in Con (P < 0.05) for all starch sources. In Con, prececal DR of starch was almost complete (>90%) but was lower (P < 0.05) for potato (Solanum tuberosum) starch (75.4%). In PL, prececal DR of starch was higher (P < 0.05) for wheat (Triticum aestivum) starch (61.2%) than corn (Zea mays) starch (43.0%) and rice (Oryza sativa) starch (29.2%) and intermediate for potato and field pea (Pisum sativum) starch. For patients with EPI, wheat starch seems favorable due to the higher prececal digestibility whereas raw corn and rice starch should be avoided.

Key words: exocrine pancreatic insufficiency, pig, prececal digestion, starch

INTRODUCTION

The adult pancreatic duct ligated (PL) minipig is an established model to study exocrine pancreatic insufficiency (EPI) in humans, to study effects of EPI on digestive processes, and to optimize enzyme substitution therapy (e.g., Tabeling et al., 1999; Kammlott et al., 2003). With EPI, enzymatic digestion of fat and protein is more impaired than of starch due to compensatory bacterial fermentation (Mößeler et al., 2007). Fermentation of starch produces VFA that contribute to energy supply of EPI patients but also increases intestinal gas production that impairs well-being of EPI patients due to intestinal pressure, abdominal pain, and flatulence (Keller et al., 2009). In EPI patients, high prececal digestion of starch will secure energy supply and reduce postileal fermentation; however, bacterial overgrowth may occur in the small intestine (Mößeler et al., 2006). Thus, ileal bacterial fermentation of starch may contribute to prececal starch digestion in EPI patients. The aim of the present study was to compare various sources of raw starch for prececal digestion in healthy control pigs and PL minipigs.

MATERIAL AND METHODS

The project was approved by the Ethics Committee on Animal Welfare of the Hannover District Government in accordance with German legislation on animal welfare. Eight female minipigs were fitted with an ileocecal reentrant fistula. In PL pigs (n = 5), a ligation of the ductus pancreaticus accessorius was also performed to induce EPI. Minipigs with a chymotrypsin activity <0.80 units/g feces were defined as PL pigs. The other minipigs (n = 3) with an intact pancreas served as
controls (Con). The BW of the minipigs used in the present study was 35.5 ± 4.68 kg for Con and 30.9 ± 0.55 kg for PL.

Starch sources were tested in a screening test (Becker, 2005); therefore, the term disappearance rate (DR) replaced digestibility. The test diet (including raw starch of various origin and Cr$_2$O$_3$) was fed once without adaptation. Chyme was collected for 8 h after first occurrence of green color in chyme indicated arrival of undigested parts of test diet at the fistula. The PL pigs did not receive pancreatic enzyme replacement therapy during the trial and pancrelipase substitution (Creon) was stopped at least 3 d before the study. The test meal consisted of 159 g DM of a complete basal diet (based on wheat semolina, polished rice, potato starch, corn starch, poultry meal, fish meal, casein, and cellulose) plus 67.5 g (DM) of test starch (purified; without thermal treatment; starch content ranging from 89 to 94.5%) and Cr$_2$O$_3$. The test meal contained (% of DM) starch, 67; crude fat, 1.69; CP, 15; crude fiber, 2.0; and Cr$_2$O$_3$, 0.25. At the evening before the test, 400 mL of a liquid diet (ProvideXtra drink Apfel Karotte flüssig; Fresenius Kabi Deutschland GmbH, Bad Homburg, Germany) was fed instead of a normal diet to ensure a complete gastric emptying and to avoid carryover of nutrients from the last meal before the test. Two screening tests were at least 48 h apart to ensure a complete gastric emptying and to avoid carryover of nutrients from the last meal before the test. Various starch sources were tested randomly (each pig received all diets). Samples of chyme were frozen immediately after collection, freeze-dried, and analyzed polarimetrically, and Cr$_2$O$_3$ (Petry and Rapp, 1970). The DR was calculated according to the collection technique with 1 modification: The Cr$_2$O$_3$ recovery rate during the 8-h collection was used to calculate the portion of test diet that reached the ileum and was used for calculation instead of DMI (Becker, 2005).

Data were analyzed by ANOVA using General Linear Models of SAS (SAS Institute, Cary, NC). Means between Con and PL and among starch sources were compared using a paired t-test; P < 0.05 was significant.

### RESULTS

In Con, prececal starch DR was high (>90%) for diets with all starch sources but was lower (P < 0.05) for raw potato starch (Table 1). In contrast, prececal DR of starch was consistently lower (P < 0.05) for PL than Con pigs. In PL pigs, starch DR was higher (P < 0.05) for diet with added wheat starch than with added corn and rice starch and with intermediate DR for added potato and field pea starch.

### DISCUSSION

Adult healthy minipigs were able to digest starch of various origins quite efficient prececellly, although starch was not heat treated, except for raw potato starch. These findings are similar to Rerat (1981) and are presumably caused by the high content of resistant starch in potatoes (Morales et al., 1997). Therefore, raw potato starch should be avoided if a high prececal starch digestibility is intended (e.g., for weaned piglets) but might be favored in situations to act as prebiotic substrate in the hindgut, for example, to reduce Salmonella prevalence (Kamphues et al., 2007). However in EPI patients, raw starch sources with a low DR, for example, rice or corn starch, should be avoided to minimize bacterial fermentation in the hindgut. Although consumed starch often will be cooked or thermally processed in human nutrition, food such as muesli exists that is not processed; therefore, present results are of interest for EPI patients. The screening test model is suited for testing pancreatic enzyme preparations in vivo (Ishihara et al., 2012) and for screening different feedstuffs and might be used to study effects of heat processing on starch DR. This study underlines that botanical characterization of starch is required in nutrition and dietetics.

The results of the present study are of special interest for dietary treatment of human patients with EPI but also for swine nutrition. For patients with EPI wheat starch seems to be favorable due to the high prececal digestibility whereas raw corn and rice starch are unfavorable regarding the aspect of obtaining a high prececal digestibility and minimizing postileal fermentation in the hindgut. Although consumed starch often will be cooked or thermally processed in human nutrition, food such as muesli exists that is not processed; therefore, present results are of interest for EPI patients. The screening test model is suited for testing pancreatic enzyme preparations in vivo (Ishihara et al., 2012) and for screening different feedstuffs and might be used to study effects of heat processing on starch DR. This study underlines that botanical characterization of starch is required in nutrition and dietetics.

The results of the present study are of special interest for dietary treatment of human patients with EPI but also for swine nutrition. For patients with EPI wheat starch seems to be favorable due to the high prececal digestibility whereas raw corn and rice starch are unfavorable regarding the aspect of obtaining a high prececal digestibility and minimizing postileal fermentation in the hindgut. Although consumed starch often will be cooked or thermally processed in human nutrition, food such as muesli exists that is not processed; therefore, present results are of interest for EPI patients. The screening test model is suited for testing pancreatic enzyme preparations in vivo (Ishihara et al., 2012) and for screening different feedstuffs and might be used to study effects of heat processing on starch DR. This study underlines that botanical characterization of starch is required in nutrition and dietetics.

The results of the present study are of special interest for dietary treatment of human patients with EPI but also for swine nutrition. For patients with EPI wheat starch seems to be favorable due to the high prececal digestibility whereas raw corn and rice starch are unfavorable regarding the aspect of obtaining a high prececal digestibility and minimizing postileal fermentation in the hindgut. Although consumed starch often will be cooked or thermally processed in human nutrition, food such as muesli exists that is not processed; therefore, present results are of interest for EPI patients. The screening test model is suited for testing pancreatic enzyme preparations in vivo (Ishihara et al., 2012) and for screening different feedstuffs and might be used to study effects of heat processing on starch DR. This study underlines that botanical characterization of starch is required in nutrition and dietetics.

### Table 1. Prececal disappearance rate (%) of starch (mean ± SD) in minipigs with or without experimentally induced exocrine pancreatic insufficiency with various raw starches added to a basal diet

<table>
<thead>
<tr>
<th>Item</th>
<th>Potato</th>
<th>Corn</th>
<th>Field pea</th>
<th>Wheat</th>
<th>Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Con</td>
<td>75.4 ± 4.61a</td>
<td>91.1 ± 4.12a</td>
<td>92.2 ± 1.38a</td>
<td>92.1 ± 1.46a</td>
<td>93.9 ± 2.26a</td>
</tr>
<tr>
<td>n = 3</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>PL</td>
<td>46.2 ± 9.63b</td>
<td>43.0 ± 7.16b</td>
<td>48.1 ± 19.6b</td>
<td>61.2 ± 11.0b</td>
<td>29.2 ± 10.6b</td>
</tr>
<tr>
<td>n = 5</td>
<td>AB</td>
<td>A</td>
<td>AB</td>
<td>B</td>
<td>A</td>
</tr>
</tbody>
</table>

*a,bWithin a column, means without a common superscript differ (P < 0.05).
*a,bWithin a column, means without a common superscript differ (P < 0.05).
abTest meal consisted of 169 g DM of basal diet and 67.5 g DM of starch source.
Con = controls; PL = pancreatic duct ligated.
fermentation processes.

**LITERATURE CITED**


