STEAM-HEATED CULLED BEANS: NUTRITIONAL VALUE AND DIGESTIBILITY FOR SWINE

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White culled beans were steamed at 80 or 100°C at various time intervals to determine the conditions necessary to inactivate the trypsin inhibitors and hemagglutinins. Steaming at 100°C for 30 or 45 min in a covered mixer completely destroyed the hemagglutinating activity and greatly reduced the trypsin inhibitor activity of the beans. The nutritional value of the processed beans was evaluated in two digestion experiments. The inclusion of 34.5% beans steamed at 100°C for 30 or 45 min in the diet depressed feed intake and induced scours in the pig. On the other hand, beans steamed for 75 min were readily consumed by the animals and did not induce scours. Beans steamed at 100°C for 75 min supplied 12.9 MJ of digestible energy, 12.6 MJ of metabolizable energy, 103 g digestible protein, 1 g of absorbable calcium and 2.9 g of absorbable phosphorus per kilogram. The processed beans should thus be considered as an energy source for swine.

Key words: Beans, digestibility, nutritional value, swine, steam processing

[Haricots de rebut chauffés à la vapeur: valeur nutritive et digestibilité pour le porc.]
Titre abrégé: Haricots culled chauffés à la vapeur pour le porc.
Nous avons traité à la vapeur des haricots blancs de rebut à 80 ou à 100°C et pendant divers intervalles de temps pour déterminer les conditions nécessaires à l’inactivation des inhibiteurs de trypside et d’hémagglutinine. Le traitement à la vapeur à 100°C pendant 30 ou 45 minutes dans un mélangeur couvert a complètement détruit l’activité d’hémagglutination et grandement réduit l’activité des inhibiteurs de trypsine chez les haricots. La valeur nutritive des haricots ainsi transformés a été évaluée lors de deux essais de digestion. L’ajout, dans une proportion de 34,5%, de haricots traités à la vapeur à 100°C pendant 30 ou 45 minutes a provoqué un baissé de la consommation d’aliments ainsi qu’une diarrhée chez les porcs. Par contre, les haricots traités à la vapeur pendant 75 minutes étaient consommés normalement par les animaux et ne provoquaient pas de diarrhée. Les haricots traités à la vapeur à 100°C pendant 75 minutes procureraient 12,9 MJ d’énergie digestible, 12,6 MJ d’énergie assimilable, 103 g de protéines digestibles, 1 g de calcium assimilable et 2,9 g de phosphore assimilable par kilogramme. Les haricots transformés peuvent donc constituer une source d’énergie intéressante pour les porcs.

Mots clés: Haricots, digestibilité, valeur nutritive, porc, traitement à la vapeur

About 65 000 metric tons of dry white beans (Phaseolus vulgaris) are produced each year in Ontario (Ontario Ministry of Agriculture and Food 1982) and approximately 5% of these beans are considered unfit for human consumption due to damage from weather, abrasion, mold or insects. Food-grade dry beans are a good source of protein and contain about 60% carbohydrates, mainly starch (Reddy et al. 1984). If culled beans had a similar composition, they could be a good feed for livestock. The raw beans, however, contain a number of antinutritional factors (Liener 1976), and have to be cooked or

otherwise heat processed prior to feeding.

A large amount of research has been conducted to define the cooking or processing parameters for beans for human consumption (Kon 1981; Walker and Kocchar 1982), but much less has been done on the processing of beans for livestock consumption. Roasted culled beans were not well utilized by finishing pigs, even when included at only 10% of the diet (Miller 1972). However, beans that were autoclaved (121°C for 15 min) or extruded (150°C for 16 s) had no adverse effects on animal performance when included as 15% of a diet for growing pigs, but caused a depression in the rate of gain when included at 40% of the diet (Myer and Froseth 1983). Autoclaving is not a practical method of heat processing, and roasting or extruding requires special equipment. Steam heating, on the other hand, could be a simpler means of heat processing culled beans.

The objectives of the experiments described here were threefold: (1) To determine the steam heating conditions under which the anti-nutritional factors in the culled beans would be destroyed; (2) To determine the ability of the pig to digest the nutrients in the culled beans processed under such conditions; and (3) To determine the effect of the level of inclusion of well-processed culled beans on the ability of the pig to digest the nutrients in a mixed diet.

MATERIALS AND METHODS

Description of the Culled Beans

Cull-grade white beans were purchased from Cooks (Hensall, Ontario), and were characterized for physical properties (foreign matter, bulk density, water absorption capacity) and chemical components (moisture, gross energy, crude protein, calcium and phosphorus) following standard procedures (American Association of Cereal Chemists 1976; Association of Official Analytical Chemists 1980). The beans were also analyzed for trypsin inhibitor activity (Smith et al. 1980), and for hemagglutinins (Liener 1955). Cow's rather than rabbit's blood was used in measuring hemagglutinating activity because Jaffe (1980) had found that values obtained with cow's blood were better indicators of actual toxicity than those obtained using rabbit's blood.

Experiment 1. Determination of Steaming Conditions

The objective of this experiment was to determine the optimal processing conditions (steam temperature and time of steaming) required to destroy or minimize the levels of the trypsin inhibitors and hemagglutinins in the beans. Three series of processing conditions were tested: (1) Steaming in an open mixer at a steam temperature of 80°C (a line pressure of 69 kPa) for 10, 20, 30, 40 and 50 min; (2) Steaming in an open mixer at a steam temperature of 100°C (a line pressure of 103.5 kPa) for 12, 19, 26, 40, 54, 61 and 70 min; and (3) Steaming in a covered mixer at a steam temperature of 100°C for 15, 30, 45, 60 and 75 min. A cover was placed on the mixer for the last test because of inadequate steaming of the upper layer of beans in the first two tests. The cover did not increase the pressure in the mixer.

The beans were coarsely ground (90% stayed on a 1-mm screen) in a plate mill (Model N-61, W.W. Grinder Corporation, Wichita, Kansas) and then loaded, in batches of 25 kg, into a 0.1 m³ steel concrete mixer equipped with a lance through which steam was introduced to the bottom of the mixer. The mixer rotated at 18 rpm during the steaming process. At the end of each steaming test, the beans were dried to a moisture of approximately 12% in a current of hot (75°C) air. Drying times varied with the steaming conditions. Once dried, the beans were finely ground in a plate mill (100% of the particles passed through a 1-mm screen).

Samples of the beans were taken at the beginning and end of each steaming period, stored frozen at -20°C and freeze-dried prior to analysis. Bean temperatures were also measured at the beginning and end of each steaming period using a digital thermometer equipped with a remote probe (Model 8502-25, Cole Parmer Instrument Company, Chicago, Ill.).

Experiment 2. Effect of Steaming Time on Nutrient Utilization

The objective of this experiment was to measure the digestibility of the nutrients in beans steamed for various times when they were included in the diet to supply half of the dietary protein. Eighteen Yorkshire barrows, with an average weight of 36.3 kg, were used to measure the digestibilities of a control diet and of diets containing 345 g kg⁻¹ beans which had been steamed at 100°C (without cover) for 30 or 45 min. The composition and nutrient content of the diets are shown in Table 1.
All pigs were initially offered 2 kg of feed per day but this amount was not consumed by the animals assigned to the bean diets and was later reduced to 1.65 kg d⁻¹. The feed was provided in two daily meals (0900 and 2100 h) each of which was mixed with 1.5 L of water. No additional water was supplied. Feces and urine were collected daily for 5 d following a 9-d adjustment period. The feces were quantitatively collected and stored frozen until analyzed. The daily production of urine was filtered through glass wool, and a 20% aliquot was stored frozen at −20°C.

Criteria of response in this experiment were: feed intake, scour incidence (measured in animal-days), the apparent digestibility of dry matter, energy and protein, energy metabolizability and nitrogen retention. The experimental design was a completely randomized one with diets as the single criterion of classification. The degrees of freedom for the diets were partitioned into single degree of freedom contrasts comparing both bean-containing diets with the control. The procedures used for the statistical analysis were those described by Snedecor and Cochran (1967).

### RESULTS

#### Culled Beans

The composition of the culled beans (Table 3) was similar to that reported in the literature for food grade beans (Tobin and Carpenter 1978; Sgarbieri et al. 1979). Except for any adverse effect of the presence of mold toxins, or of weather damage on nutrient availability, the culled beans should have a nutritive value comparable to that of the food grade beans.

#### Experiment 1. Determination of Processing Conditions

Steaming at 80°C, even for 50 min, inactivated only 50% of the trypsin inhibitor in the beans and the residual activity (7.2 units g⁻¹)
Table 2. Formulation and nutrient content of the diets used in exp. 3

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Dietary level of beans† (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Ground corn</td>
<td>425</td>
</tr>
<tr>
<td>Soybean meal (490 g CP kg⁻¹)</td>
<td>244</td>
</tr>
<tr>
<td>Ground steamed beans</td>
<td>0</td>
</tr>
<tr>
<td>Corn starch</td>
<td>30</td>
</tr>
<tr>
<td>Salt</td>
<td>5</td>
</tr>
<tr>
<td>Limestone (380 g kg⁻¹)</td>
<td>7.5</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>12.5</td>
</tr>
<tr>
<td>(210 g Ca, 180 g P kg⁻¹)</td>
<td>2.5</td>
</tr>
<tr>
<td>Vitamin supplement‡</td>
<td>1.0</td>
</tr>
<tr>
<td>Trace mineral supplement§</td>
<td>2.5</td>
</tr>
<tr>
<td>Chromic oxide</td>
<td></td>
</tr>
</tbody>
</table>

Determined:

- Gross energy (MJ kg⁻¹)
- Crude protein (g kg⁻¹)
- Calcium (g kg⁻¹)
- Phosphorus (g kg⁻¹)

In test 3 (steaming at 100°C in a covered mixer), the bean hemagglutinins were completely inactivated after 15 min (Fig. 2) but the trypsin inhibitory activity, although greatly diminished, was not completely destroyed.

Experiment 2. Effect of Steaming Time on Nutrient Utilization

Pigs fed the 45 min steamed beans diet and those fed the control diet had similar feed intakes during the collection period. Pigs fed the 30 min steamed beans diet, however, had lower feed intakes (Table 4). Both groups of bean-fed pigs showed a greater incidence of scours than the control pigs during both the adjustment and the collection periods (Table 4). Due to this high incidence of scours, feces suitable for analyses could be collected from only three pigs in each of the bean-fed groups. To preserve homogeneity in the statistical analysis, feces from only three (randomly selected) control pigs were used as controls for the analysis of digestibilities. Both crude protein digestibility and nitrogen retention were lower (P < 0.05) for the bean-containing diets, but there were no statistically significant differences in the other parameters studied.
Fig. 1. Effects of processing time on the levels of trypsin inhibitor (units per gram) and hemagglutinins (units per gram) in beans steamed at 100°C in an uncovered mixer.

Fig. 2. Effects of steaming time on the levels of trypsin inhibitor (units per gram) and hemagglutinins (units per gram) in beans steamed at 100°C in a covered mixer.

Experiment 3. Dietary Level of Bean and Nutrient Utilization
The animals readily consumed the diets with up to 34.5% beans but, although there were no effects on feed intake or scouring incidence, there was a tendency for the feces of
the animals fed the higher levels of beans to be bulkier and to have higher moisture contents (Table 5). Nutrient digestibility decreased linearly ($P<0.05$) as the level of dietary inclusion of beans steamed at 100°C for 75 min was increased (Table 5). Regression analyses of nutrient digestibility on dietary bean level indicated digestibility coefficients of 0.76 and 0.43 for the energy and crude protein in the beans, net absorbabilities of 0.65 and 0.53 for calcium and phosphorus, and an energy metabolizability coefficient of 0.74. Integrating these values with those for the chemical composition of the culled beans, the processed culled beans contained 12.9 MJ of digestible energy, 12.6 MJ of metabolizable energy, 103 g digestible protein, 1 g of absorbable calcium and 2.9 g of absorbable phosphorus per kilogram.

**DISCUSSION**

The data obtained in exp. 1 indicate that the activities of both the trypsin inhibitors and the hemagglutinins in the beans were destroyed or minimized after 30 min of processing. The decreased feed intake and the high incidence of scours observed in exp. 2, therefore, were unexpected and suggested that some other noxious bean components still remained active in the beans processed under these conditions.

Beans, like other pulses, contain some oligosaccharides (raffinose, stachyose, verbascose) for which no digestive enzymes exist in the small intestine of mammals but which, when metabolized by the intestinal microflora, result in the formation of flatulence and the production of intestinal discomfort and diarrhea. The oligosaccharides are watersoluble and are normally removed with the cooking water in beans prepared for human consumption (Reddy et al. 1984). Because no soaking or water removal (other than drying) was used in the present studies, these compounds may have remained active in the beans in exp. 2 and could be responsible for their noxious effects on the pigs. The absence of these noxious effects in exp. 3, on the other hand, would be understandable if it is assumed that the oligosaccharides became complexed with other bean components during the 75-min heating process rather than the 30 or 45 min used in exp. 2.

Nutrient utilization in the animals fed the control diets was remarkably similar in exps. 2 and 3 with the exception of nitrogen retention, which was lower ($P<0.05$) in exp. 3. No significant differences were

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Beans steamed 30 min</th>
<th>Beans steamed 45 min</th>
<th>SD†</th>
<th>$P&gt;F$‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed intake (kg d⁻¹)§</td>
<td>2.0</td>
<td>1.5</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maximum (precollection)</td>
<td>1.64</td>
<td>1.32</td>
<td>1.51</td>
<td>-</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Average (collection)</td>
<td>2</td>
<td>17</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scour incidence§</td>
<td>0.76</td>
<td>0.83</td>
<td>0.85</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>Digestibility</td>
<td>0.92</td>
<td>0.82</td>
<td>0.83</td>
<td>0.07</td>
<td>0.12</td>
</tr>
<tr>
<td>Dry matter</td>
<td>0.89</td>
<td>0.66</td>
<td>0.68</td>
<td>0.07</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Energy</td>
<td>0.90</td>
<td>0.80</td>
<td>0.81</td>
<td>0.06</td>
<td>0.13</td>
</tr>
<tr>
<td>Crude protein</td>
<td>0.66</td>
<td>0.53</td>
<td>0.53</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Energy metabolizability</td>
<td>0.66</td>
<td>0.53</td>
<td>0.53</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Nitrogen retention</td>
<td>0.90</td>
<td>0.80</td>
<td>0.81</td>
<td>0.06</td>
<td>0.13</td>
</tr>
</tbody>
</table>

†SD, standard deviation.
‡$P>F$, probability of a larger $F$ value in the following contrasts: C1, contrast comparing control vs. 30 min; C2, contrast comparing control to 45 min.
§Data for feed intake and scour incidence are averages of six pigs per treatment; all other data are averages of three pigs per treatment.
observed in the nutrient digestibilities or energy metabolizability of beans steamed for 30 or 45 min (exp. 2) and those steamed for 75 min (exp. 3). Nitrogen retention, however, was lower ($P < 0.05$) for the bean-fed animals in exp. 3.

No information appears to be available on the digestibility by pigs of the energy, calcium or phosphorus in the culled beans. The coefficient observed for protein digestibility (0.43), however, is lower than those reported for autoclaved (0.68) or extruded (0.79) red beans (Myer and Froseth 1983), and suggests that the processing conditions used in the present experiment may have overcooked the beans.

The results of the studies indicate (a) that the activities of the main toxic factors (trypsin inhibitor and hemagglutinins) are not, on their own, a reliable indicator of adequacy of processing; and (b) that steam heating for 75 min (but not for 45 min) inactivates other toxins in culled beans so that they are a good source of energy but not of protein. The latter effect may be due to overprocessing.

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