Utilization and application of wet potato processing coproducts for finishing cattle

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ABSTRACT: Wet coproducts fed to beef cattle include processing coproducts of the fruit, vegetable, juice, and brewing industries. Considerations for their utilization in beef cattle diets include quantity available, feeding value, quality of animal products produced, economics (e.g., transportation of water), storage and preservation, consumer perception, nuisance concerns, contaminants, and interactions with other diet ingredients. Potato (Solanum tuberosum) coproducts from processing for frozen food products may be quantitatively most important because the 11.3 million t of potatoes (fresh weight) processed in the United States and Canada in 2008 resulted in an estimated 4.3 million t (as-is basis) of coproduct. Chemical composition and feeding value of potato coproducts depends on the coproduct type. The names of coproducts vary among potato processors and some processors combine the different coproducts into one product commonly called slurry. The 4 main potato coproducts are 1) potato peels; 2) screen solids (small potatoes and pieces); 3) fried product (fries, hash browns, batter, crumbles); and 4) material from the water recovery systems (oxidation ditch, belt solids, filter cake). The coproducts, except the fried products, ensile rapidly, reaching pH 5 in 7 d or less. Dry matter content varies from 10 to 30% and on a DM basis varies in CP (5 to 27%), starch (3 to 56%), NDF (4 to 41%), and ether extract (3 to 37%) content among potato coproducts. Type of coproduct and frying greatly affect the energy value (0.6 to 1.6 Mcal of NE₄/kg of DM). Composition, quality, and shelf life of beef was not affected by potato coproduct feeding in contrast to perceptions of some purveyors and chefs. Potato coproducts are quantitatively important energy sources in beef cattle diets, which, in turn, solve a potentially massive disposal problem for the food processing industry.

Key words: beef cattle, potato coproduct


INTRODUCTION

Wet coproducts fed to beef cattle include processing coproducts of the fruit, vegetable, juice, and beer industries. Considerations for their utilization in beef cattle diets include quantity available, feeding value, quality of animal products produced, economics (e.g., cost of transportation of water), storage and preservation, consumer perception, nuisance concerns, contaminants, and interactions with other diet ingredients. Potato (Solanum tuberosum) coproducts from processing for frozen food products may be quantitatively most important because in the United States and Canada an estimated 4.3 million t (as-is basis) of coproduct was generated in 2008.

Practical guides discussing the feeding of potato coproducts include Weston (1922), Brugman and Dickey (1955, 1961), Heinemann and Dyer (1972), Dickey et al. (1974), Hogan and Highlands (1975), Nicholson (1974), Hinman and Sauter (1978), NRC (1983), and Bradshaw et al. (2002). However, potato peeling method, water recovery systems, types of cooking oils or grease, pasteurization, and ensiling have changed so that the coproduct composition and feeding value information and recommendations need to be updated. Further, none of the studies cited by those authors included meat quality evaluation, nor were antiquality components emphasized.

POTATO PRODUCTION AND PROCESSING

Of the 21.8 million t (fresh weight) of potatoes (Solanum tuberosum) produced in the United States and
Canada in 2008, less than 1% were fed, 7% were used for seed, 7% were shrinkage and loss, 28% were used as table stocks, and 57% (11.3 million t) were processed (Agriculture and Agri-Food Canada, 2008; USDA National Agriculture Statistics Service, 2008). The Pacific Northwest states (PNW) of Washington, Idaho, and Oregon produce more than 52% and process more than 42% of the US potato crop (National Potato Council, 2000). Even when the government diversion program buys potatoes to be fed to livestock (0.3 million t in 2000), the amount available in the United States is rather small. The reader is directed to Whitemore (1977) for feeding value data on the tuber itself. Of the 12.4 million t of potatoes processed, less than 1% was used in the production of starch and flour, 2% was used for canning, 16% was used for dehydration, 22% was used for chips, and 60% was used for frozen products, such as French fries, hash browns, and so on. Therefore, processing potatoes for chips and frozen products are quantitatively most important in coproduct generation.

Estimates of the amounts of coproduct generated by potato processing include 33 to 35% (Jones, 1973; Stanhope et al., 1980) of the potato fresh weight that was processed, 0.9 million t (Onwubueme, 1985) to 2 million t (Araji et al., 1999) of coproduct produced annually in the United States to 2.6 million t/yr using the estimate of Stanhope et al. (1980) in just the PNW of the United States (Bradshaw et al., 2002). Even though potato processing plants have improved efficiency in the past 20 yr, an estimate of 0.01 million t of coproduct generated each year from a typical potato processing plant or 1.4 to 2.3 million t/yr of potato coproducts in just the PNW (D. Hancock, Washington State University, Pullman, personal communication). Therefore, up to 4.3 million t (fresh weight) of potato coproducts are available in North America from potato processing plants. These coproducts need to be disposed of by the processing plants because the coproducts would limit production of human food in processing plants without suitable means for coproduct disposal.

**POTATO COPRODUCT DISPOSAL**

Disposal routes of potato coproducts include landfills, application to cropland, and composting (Smith, 1986; Dixon et al., 1987; Pailthorp et al., 1987; Woods End Research Laboratory, 1990). Clearly the volumes of potato coproducts are too large to be disposed reasonably and economically through these methods. Additionally, potential difficulties with disposal include drainage from coproducts contaminating surface water; sprouting and regrowth of potatoes; insects, nematodes, and pathogen exposure to surrounding crops; and nuisances from smell, insects, and animals. Feeding potato coproducts to ruminants can be the best disposal route if these high moisture coproducts are transported only short distances and are handled and fed properly. However, potato coproduct identification, nutrient composition, antiquality components and hygiene, storage and preservation, feeding value, and effects on meat quality must be considered for proper utilization in ruminant diets.

**POTATO PROCESSING COPRODUCTS**

There are 4 main types of potato processing coproducts available. The names vary among potato processors, and some processors combine the types into one product (commonly called slurry). The 4 types of potato coproducts are 1) potato peels; 2) screen solids, bits and pieces, white waste or hopper box (small potatoes and pieces); 3) cooked product (fries, hash browns, crowns, batter, crumbles), and 4) material from water recovery systems (oxidation ditch, belt solids, filter cake) that varies from mostly microbial cells and solubles (oxidation ditch) to fine potato particles from clarifiers after drum or belt-type vacuum filtration (filter cake). Chemical composition of potato coproducts varies depending on the combinations of coproducts (Table 1). Dry matter contents typically vary from 10 to 30% depending on the coproduct. Potato peels or pieces have a chemical analysis similar to that for barley except for greater ash content in the peels. Potato peels from the United Kingdom, however, had less ash content (Rooke et al., 1996). Note that potato slurry varied in CP and had increased ash content when processors used NaOH to peel the potatoes before about 1985. All potato coproducts have less ether extract (EE) except for cooked coproducts. The analysis of Rooke et al. (1996) is typical for cooked coproduct. For example, the composition of coproducts (n = 4) from production of 6 fried products across 3 yr (1993 to 1995) from 1 potato processing plant were analyzed and found EE to vary from 19 to 27%, and type of cooking oil varied from tallow to canola and soybean oil (Table 2). Therefore, not only EE, but also fatty acid composition varied dramatically. Currently, most processors use partially hydrogenated oils, so degree of fatty acid saturation does not vary as much.

Recent compositional data for ensiled steam peels, filter cake, and screen solids are shown in Table 3. All of the coproducts, except cooked coproducts, ensile rapidly, reaching pH 4 or less in 7 d or less. Therefore, most research studies have reported compositional data on ensiled coproducts. Ensiled filter cake and steam peels had less DM and greater CP than screen solids. Steam peels contained very little starch but did contain substantial fiber. Filter cake had greater EE due to cooking oil recovery, and steam peels contain less starch and ash than in older publications due to method of peeling and improved recovery during peeling.

Other potato coproducts include potato-corn primary waste/processing waste, which may contain peels, culls, pieces, filter cake, chips, screened solids, or scorched corn (Brown et al., 1983; Crickenberger,
POTATO STARCH

Potato starch has been described as “thin walled storage parenchyma filled with starch granules embedded in amyloplaster” (McDougall et al., 1996) and contains 75% amylopectin and 25% amylose (French, 1973). Most potato coproduct starch is reversibly swelled due to the imbibition of more than 50% water by weight. However, drying is probably not an economically feasible alternative due to the increased water-binding capacity of potato starch and the amount of energy needed for drying. Serena and Bach Knudsen (2007) estimated potato pulp water-binding capacity at 18 kg/kg of DM, which is why dewatering systems in potato processing plants do not remove a lot of water. Higgins (2001) estimated 2,420 to 4,440 BTU/kg of evaporated water from potato coproducts. In contrast, temperature-induced gelatinization is irreversible, wherein starch crystals lose crystallinity and form a colloidal solution (French, 1973). Retrogradation of gelatinized starch probably does not occur in any significant amount in any of the potato processing coproducts.

Commercial potato starch granules are described as slowly degrading. Monteils et al. (2002) reported in sacco potato peel starch disappearance rate was 5%/h compared with 34%/h for wheat starch. In contrast, Szasz et al. (2005) reported that ensiled potato slurry starch was 27 to 38% soluble, and the insoluble fraction disappeared in vitro at 14%/h regardless of pasteurization at 54°C. This slurry probably was mostly peels and cooked coproduct based on chemical composition, in which most of the starch would have been gelatinized. Duncan et al. (1991) reported the in vitro rate of disap-

### Table 1. Composition of potato coproducts

<table>
<thead>
<tr>
<th>Item, % of DM</th>
<th>Peels&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Steam peels&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Steam peels&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Potato slurry&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Potato slurry&lt;sup&gt;5&lt;/sup&gt;</th>
<th>Potato slurry&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Screen solids&lt;sup&gt;6&lt;/sup&gt;</th>
<th>Fries&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP</td>
<td>10.0</td>
<td>9.8</td>
<td>17.2</td>
<td>4.7</td>
<td>12.2</td>
<td>3.8</td>
<td>11.6</td>
<td>5.6</td>
</tr>
<tr>
<td>Starch</td>
<td>NR&lt;sup&gt;2&lt;/sup&gt;</td>
<td>56.3</td>
<td>34.8</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>55.9</td>
<td>NR</td>
</tr>
<tr>
<td>NFE&lt;sup&gt;2&lt;/sup&gt;</td>
<td>58.2</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>86.2</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>NDF</td>
<td>NR</td>
<td>12.8</td>
<td>28.8</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>21.0</td>
<td>4.4</td>
</tr>
<tr>
<td>ADF</td>
<td>8.2</td>
<td>9.2</td>
<td>1.2</td>
<td>NR</td>
<td>NR</td>
<td>4.4</td>
<td>17.4</td>
<td>NR</td>
</tr>
<tr>
<td>Ash</td>
<td>21.0</td>
<td>7.6</td>
<td>1.1</td>
<td>15.5</td>
<td>13.0</td>
<td>4.5</td>
<td>4.7</td>
<td>1.9</td>
</tr>
<tr>
<td>EE&lt;sup&gt;8&lt;/sup&gt;</td>
<td>0.8</td>
<td>NR</td>
<td>6.3</td>
<td>0.2</td>
<td>6.7</td>
<td>NR</td>
<td>22.0</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Data are from Sauter et al. (1985).
<sup>2</sup>Data are from Duncan et al. (1991).
<sup>3</sup>Data are from Rooke et al. (1996); 3:5:1 unsaturated:saturated fatty acid in fries.
<sup>4</sup>Data are from Heinemann and Dyer (1972). Crude fiber was 5.4%.
<sup>5</sup>Data are from Heinemann et al. (1978). Crude fiber was 3.5%.
<sup>6</sup>Data are from Nelson et al. (2000). Total fatty acid was 1.7%.
<sup>7</sup>NR = not reported.
<sup>8</sup>NFE = nitrogen-free extract.
<sup>9</sup>EE = ether extract.

### Table 2. Composition of fried potato coproducts<sup>1</sup>

<table>
<thead>
<tr>
<th>Item, % of DM</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>37.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>34.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>43.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>42.9&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>36.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.23</td>
</tr>
<tr>
<td>CP</td>
<td>6.0</td>
<td>7.5</td>
<td>6.8</td>
<td>9.3</td>
<td>7.3</td>
<td>6.8</td>
<td>0.91</td>
</tr>
<tr>
<td>NDF</td>
<td>49.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>63.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>67.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>49.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>32.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>51.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.08</td>
</tr>
<tr>
<td>ADF</td>
<td>7.6</td>
<td>9.5</td>
<td>9.3</td>
<td>8.8</td>
<td>6.3</td>
<td>10.8</td>
<td>2.47</td>
</tr>
<tr>
<td>EE&lt;sup&gt;3&lt;/sup&gt;</td>
<td>27.2</td>
<td>19.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>22.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>16.8</td>
<td>2.02</td>
</tr>
<tr>
<td>Ash</td>
<td>1.2</td>
<td>2.3</td>
<td>2.0</td>
<td>1.4</td>
<td>2.6</td>
<td>2.6</td>
<td>0.44</td>
</tr>
<tr>
<td>Ca</td>
<td>0.06</td>
<td>0.09</td>
<td>0.07</td>
<td>0.10</td>
<td>0.08</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>P</td>
<td>0.20</td>
<td>0.31</td>
<td>0.32</td>
<td>0.22</td>
<td>0.23</td>
<td>0.38</td>
<td>0.04</td>
</tr>
<tr>
<td>Mg</td>
<td>0.05</td>
<td>0.06</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>K</td>
<td>0.24</td>
<td>0.57</td>
<td>0.41</td>
<td>0.25</td>
<td>0.25</td>
<td>0.48</td>
<td>0.31</td>
</tr>
</tbody>
</table>

<sup>a</sup>Within a row, means without a common superscript differ (P < 0.05).
<sup>1</sup>Data are from M. L. Nelson (unpublished results).
<sup>2</sup>A = hash browns cooked in soy oil, B = natural twist French fries cooked in tallow, C = natural cut French fries cooked in tallow, D = red twist French fries cooked in soy oil, E = white French fries cooked in soy oil, and F = crinkle cut French fries cooked in soy oil.
<sup>3</sup>EE = ether extract.
pearance of ensiled potato peels to be 5.8%/h in barley mixtures and 13.2%/h in corn mixtures.

STORAGE AND PRESERVATION—ENSILING

Potato coproducts have been ensiled for numerous reasons. Sauter et al. (1979) reported feedlot operators ensiled caustic-peeled potato coproducts for 1 to 4 mo to reduce the pH from 12 to about pH 7 and to ensure a continuous supply of coproducts. After processing plants converted to steam peeling in the mid 1980s, authors and consultants recommended short or no storage (Drake et al., 1994; Bradshaw et al., 2002) before feeding mainly due to ensiling and effluent losses. However, the incidence of cysticercosis also increased based on USDA Food Safety and Inspection Service (FSIS, 2006) carcass inspection data.

Potato coproducts readily ensile even at their increased moisture contents. For example, in laboratory silos, cooked potatoes decreased in pH from 5.7 to 4.2 by d 4 (Lindahl et al., 1946), filter cake decreased in pH from 6.0 to 3.5 by d 2 (Sauter et al., 1979), and cull potatoes decreased to pH 4.5 by d 7 (Hough et al., 1994). Various potato coproducts ensiled in my laboratory silos or in bunker or pit silos between 15 and 35°C consistently had pH declines from about 6.0 to less than 4.5 in 5 to 7 d (M. L. Nelson, unpublished data). Lindahl et al. (1946) reported cooked potatoes at 2°C had no fermentation for 1 yr but net loss was 39%; at 17°C fermentation progressed for 6 mo with a net loss of 23%, but at 29°C fermentation was essentially complete in 14 d with a loss of only 14% of DM in laboratory silos. Himman and Sauter (1978) reported starch disappearances from potato slurry of 9, 19, and 41% for ensiling times of 4, 7, and 14 d in laboratory silos, respectively. Sauter et al. (1979) reported starch disappearances from potato slurry of 63 to 68% in 35 d of ensiling, but only about 10% of GE was lost in laboratory silos. Similarly, 21% of DM from cooked potatoes disappeared in 42 d from a trench silo (Lindahl et al., 1946). If effluent was lost from potato coproducts in bunker or trench silos, according to Allender (1946), large losses in feeding value occur. Hough et al. (1994) reported 451 mL of effluent/kg of silage lost in 52 d from 19% DM potatoes. This was 54% of the total moisture but only 8% of the OM. Mixtures of potato coproducts and straw substantially reduce effluent losses and ensile well based on fermentation end products (Sauter et al., 1985).

Sauter et al. (1976) isolated and identified 23 genera of bacteria and 13 genera of fungi from potato waste. Filter cake (Sauter et al., 1979) contained $10^{10}$ to $10^{9}$ aerobic, $10^{7}$ to $10^{8}$ lactic acid producing anaerobes, and $10^{6}$ to $10^{8}$ molds/g. Mayer and Hillebrandt (1997) reported $10^{5}$ to $10^{6}$ cells/g ($Pseudomonas, Acinetobacter$) wet pulp in upper layers, $10^{2}$ to $10^{4}$ cells $Clostridium$ spp., and $10^{1}$ to $10^{8}$ Lactobacillus spp. per gram wet pulp in lower layers. Endophytes are not a limitation for ensiling.

Nelson et al. (2004a) ensiled filter cake, steam peels, and screen solids for 56 d in 1.6 × 2.8 × 1.6 m wooden boxes, and sampled them at 28-d intervals to 140 d of ensiling. Peak temperatures during this period varied from 16 to 38°C. These coproducts continued to ferment because total VFA content increased linearly ($P < 0.05$) from 911 to 1,397 ± 125 μmol/g from d 56 to 140 mainly due to linearly increased ($P < 0.01$) acetic acid (41 to 82 ± 2.8 mol/100 mol). Average composition (Table 4) shows reduced lactic acid contents and, in general, 2 patterns of fermentation based on the end products. Filter cake, composed of microbial cells and small potato particles, had more extensive starch and protein fermentation than the low starch containing steam peels or potato pieces with their crystalline starch structure as indicated the amounts and molar proportions of VFA.

ANTIOQUALITY COMPONENTS

Potential antiquality components in potato coproducts include acrylamide (a carcinogen), flocculating agents, pesticides, and glycoalkaloids (GA). Acrylamide forms during cooking at high temperature [see review by Friedman and Levin (2008) for more detail]. The heat-induced reaction is between an asparagine amino-group and a carbonyl group of reducing sugars. The potato processing industry is reducing acrylamide in potato products by decreasing the precursors (asparagine and glucose), using asparaginase, and altering processing conditions (FDA, 2004; Friedman and Levin, 2008). The amount reported in French fries (FDA, 2006) is much less than the allowable 0.05% in animal feeds as a thickener and less than 0.2% in wash water for fruits and vegetables (FDA, 2009).

Flocculating agents (Heitner, 2004) have been used, especially with caustic peeling, in the water treatment

<table>
<thead>
<tr>
<th>Item, % of DM</th>
<th>Filter cake$^2$</th>
<th>Steam peels$^3$</th>
<th>Screen solids$^4$</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>13.3b</td>
<td>9.3a</td>
<td>19.4c</td>
<td>0.45</td>
</tr>
<tr>
<td>CP</td>
<td>20.6</td>
<td>27.1b</td>
<td>8.6a</td>
<td>0.05</td>
</tr>
<tr>
<td>Starch</td>
<td>25.1b</td>
<td>3.0a</td>
<td>55.9c</td>
<td>1.91</td>
</tr>
<tr>
<td>NDF</td>
<td>20.4</td>
<td>40.7b</td>
<td>20.0b</td>
<td>1.95</td>
</tr>
<tr>
<td>ADF</td>
<td>12.0</td>
<td>30.7b</td>
<td>6.2a</td>
<td>1.97</td>
</tr>
<tr>
<td>EE$^5$</td>
<td>6.9b</td>
<td>2.9a</td>
<td>3.7a</td>
<td>0.69</td>
</tr>
<tr>
<td>Ash</td>
<td>10.2</td>
<td>12.8c</td>
<td>3.1a</td>
<td>0.25</td>
</tr>
<tr>
<td>Organic acid</td>
<td>14.0</td>
<td>10.0b</td>
<td>3.3a</td>
<td>0.65</td>
</tr>
</tbody>
</table>

$^*$Within a row, means without a common superscript differ ($P < 0.05$).
1Data are from Nelson et al. (2004a).
2Small potato particles and microbial cells from a water recovery system.
3Potato peels removed with steam.
4Potato pieces and small whole potatoes.
5EE = ether extract.
he system to form flocs from the colloid formed when gelatinized starch on the surface of the potato was washed off (Grames and Kueneman, 1969). Various compounds used include clays, inorganic salts, and polymers like polyacrylamide. Single cell protein from a water recovery system containing polyacrylamide and FeCl₃ flocculating agents, when fed at 6 to 8% of the diet DM, resulted in refusal of the diet by finishing cattle for 7 to 10 d (Hsu et al., 1984). Similarly, Nelson et al. (2004a) noted a similar response by dairy cattle fed 5% filter cake, possibly due to the flocculating agent. However, most filter cake does not currently contain flocculating agents and is mixed with other potato coproducts as slurry.

If pesticides are used properly on the potato crop, there should be minimal risk to cattle or humans. Indeed, Schnell et al. (1997) concluded tissue samples from beef cattle that consumed potato slurry had no residues of oncogenic pesticides of the 10 they analyzed.

The major potato GA are α-solanine and α-chaconine, which have been incriminated as causing green potato death in ruminants (Bolin, 1962; Nicholson, 1974; Gelder, 1991; Bradshaw et al., 2002). Symptoms in ruminants included trembling, staggering, convulsions, weakness, diarrhea, and sudden death. Factors affecting GA content include part of the potato plant, variety, maturity, greening, and wounding. The greatest concentration of GA occurs in the sprouts and green potato skins (Kline et al., 1961). Peeling removes 60 to 96% of GA from the tuber (Maga, 1994) because they are concentrated just under the skin of the potato (Mondy and Gosselin, 1988; Smith et al., 1996). Indeed, Concon (1988) reported up to 1 g of GA/kg in the peel. There are large differences among cultivars in greening, which increases its GA content (Dale et al., 1993). Additionally, wounding stimulates GA synthesis (Olsson, 1986; Percival and Dixon, 1996). The potato industry screens new varieties for potato GA content, which must be less than 200 mg/kg (Cheeke, 1998).

Potato GA are cholinesterase inhibitors (Hopkins, 1995), which may explain neurological symptoms. In humans, gastrointestinal disturbances occur (Friedman and McDonald, 1997) before neurological symptoms. However, GA are rather rapidly fermented in vitro by ruminal microorganisms to the alkaloid, solanidine, and its dihydro analog (King and McQueen, 1981).

Glycoalkaloids are not destroyed during steam peeling or pasteurization because they are quite stable to decomposition with cooking temperatures below 170°C (Bushway and Ponnampalam, 1981; Takagi et al., 1990). Therefore, the potato coproduct with greatest risk for increased GA content is the potato peel due to greening, sun burning, or injury or wounding. See reviews by Lachman et al. (2001) and Nema et al. (2008) for more detail on potato GA.

### FEEDING VALUE

Heinemann and Dyer (1972) fed graded levels of potato slurry (0 to 52% of DM) to finishing steers and concluded that feed intake, BW gain, feed efficiency, and dressing percent were not affected until 52% potato slurry was fed (Table 5). Carcasses from the 2 middle levels of potato slurry averaged Choice−, and those from the other 3 treatments averaged Choice+. Additionally, Heinemann and Dyer (1972) measured DE and calculated ME content of the potato slurry at 19.2% (3.5 and 3.3 Mcal/kg, respectively) and 37.5% of DM (3.1 and 2.9 Mcal/kg, respectively). A contemporary study (Dickey et al., 1971) reported potato slurry to contain 2.0 Mcal of ME/kg with sheep. In comparison, barley, Pacific Coast, had a tabled value of 2.8 Mcal of ME/kg (NAS, 1971).

Heinemann et al. (1978) replaced a barley-beet pulp mixture with potato slurry (26.6% of diet DM). They concluded that potato slurry-fed steers ate more (9.2 vs. 8.4 kg/d), gained BW faster (1.2 vs. 1.0 kg/d), gained BW more efficiently (0.125 vs. 0.118 kg of BW gain/kg of feed DM), and marbled greater (Modest− vs. Small+) than steers not fed potato slurry. These responses most likely resulted from positive associative effects on rate of ruminal fermentation. These early studies indicated
that the energy value of the potato slurry was at least similar to barley but could also be greater than that of barley. However, these studies undoubtedly used Steptoe, a reduced energy barley (Ovenell-Roy et al., 1998a,b,c).

Large frame steers (371 kg) were fed for 152 d barley-based diets with ensiled steam-peeled potato peels at 0, 10 or 20% with 0, 7.5, or 15% forage (i.e., alfalfa hay, corn silage) on a DM basis (M. L. Nelson, unpublished data). Dry matter intake linearly decreased (P < 0.05) from 12.4 to 11.4 kg/d suggesting palatability problems or energy density changes. Average daily gain was quadratically affected (P < 0.05) where BW gain was maximized at 10% potato peels (1.5 vs. 1.4 kg/d). Therefore, BW gain efficiency was quadratically affected (P < 0.05) where BW gain was maximized at 10% potato peels. There were no effects of potato peel dietary level on ADG, dressing percent, or carcass characteristics, which averaged 72% Choice and Small30 marbling. These data show 42 and 21% more energy in potato peels than in the barley it replaced at 10 and 20% of the diet, respectively. Duncan et al. (1991) concluded that potato peels altered the in vitro rate of disappearance of insoluble DM, which contributed to altered energy content of potato peels.

Nelson et al. (2000) fed 10 or 20% ensiled screen solids (hopper box) coproduct DM to finishing steers and concluded that NE_{m} and NE_{r} content was the same as barley (2.2 and 1.5 Mcal/kg, respectively) at 10% of diet DM but was 5% less than barley at 20% of diet DM. Further, no biologically important impacts on quality or palatability of the beef were detected (Busboom et al., 2000; Nelson et al., 2000). Rooke et al. (1996) measured ME content of potato peels and French fries fed to sheep to be 2.8 and 3.09 Mcal of ME/kg, respectively. Using the Garrett (1980) equation, peels and French fries contained 1.2 and 1.8 Mcal of NE_{g}/kg, respectively, which are less than animal performance indicated. Due to lack of data, the energy content of the fried coproduct can be estimated as the weighted average of yellow grease in barley- or corn-based finishing diets (Nelson et al., 2004b, 2008, respectively) and hopper box coproduct (Nelson et al., 2000). These data show the impact of type of potato coproduct and cooking on energy value relative to modern, greater energy (ME, NE) containing barley varieties (Ovenell-Roy et al., 1998a,b,c).

### Table 5. Effect of level of potato slurry on finishing steer performance

<table>
<thead>
<tr>
<th>Item</th>
<th>0</th>
<th>15.4</th>
<th>27.8</th>
<th>42.5</th>
<th>51.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, kg/d</td>
<td>9.0</td>
<td>9.3</td>
<td>8.8</td>
<td>9.1</td>
<td>8.5</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>1.2</td>
</tr>
<tr>
<td>G:F</td>
<td>0.149</td>
<td>0.139</td>
<td>0.152</td>
<td>0.145</td>
<td>0.141</td>
</tr>
<tr>
<td>Dressing percent&lt;sup&gt;a&lt;/sup&gt;</td>
<td>62.8</td>
<td>65.5</td>
<td>62.9</td>
<td>61.8</td>
<td>60.0</td>
</tr>
</tbody>
</table>

<sup>a</sup>Less (P < 0.05) for 51.9% potato slurry.

<sup>1</sup>Data are from Heinemann and Dyer (1972).

### MEAT QUALITY

Some meat retailers, purveyors, and chefs in North America and Japan believed that barley/potato-fed beef was softer, more watery, inferior in color, tougher, and less flavorful than corn-fed beef, which limited marketing options for barley/potato-fed beef. Nelson et al. (2000) clearly showed that grain (barley or corn) and level of ensiled potato coproduct (0, 10, or 20% screen solids DM) had minimal effects on beef appearance and carcass characteristics, meat composition, and water retention properties. Further, no important effects of diet on drip loss, cooking loss, Warner-Bratzler shear force, or beef palatability evaluated by a highly trained flavor-texture profile panel, a trained sensory panel, or 2 large consumer panels were noted. Similarly, Radunz et al. (2003) fed 0, 10, 20, 30, or 40% potato coproduct slurry DM in corn-based feedlot diets. Decreased feedlot performance was reported, but little impact on carcass characteristics or beef palatability was noted with increased dietary level of potato coproducts (Radunz et al., 2003). Therefore, perceptions that barley- or corn-based feedlot diets containing potato coproduct resulted in beef with inferior water retention properties, tenderness, and palatability were unfounded.

The only report of a problem with meat quality, known to the author, was that of Daise et al. (1986) who reported postharvest contamination of beef with pseudomonas, resulting in a potato-like odor. In contrast, Zunong et al. (2009) suggested that potato pulp silage stimulated B. fibrisolvens to produce trans vaccenic acid (TVA), which increased milk content of TVA and CLA. Potato hopper box silage did not increase TVA or CLA in beef (Nelson et al., 2000); however, yellow grease did increase TVA in beef from corn-based diets (Nelson et al., 2008), but not barley-based diets (Nelson et al., 2004b). Therefore, meat composition and palatability were not affected by substitution of potato coproduct starch for cereal grain starch.

### CYSTICERCOSIS

At least since 1989 (Hancock et al., 1989), feeding potato coproducts has been suspected to be involved in the cysticercosis problem. Cysticercosis is caused by encysted eggs of the human tapeworm *Taenia saginata*. 
Rate of cysticercosis is persistently increased in feedlot cattle in the PNW (Hancock et al., 1989; Yoder et al., 1994) compared with other regions of the United States. For example, the USDA FSIS reported cysticercosis prevalence of 0.067% in the PNW and 0.004% in the United States (FSIS, 2008). At slaughter, if a carcass has cysticercosis (most cysts are degenerated and calcified), it may be frozen at −10°C for 10 d or condemned, resulting in severe financial discounts on infected carcasses. Whereas there are many possible routes for contamination with T. saginata, some potato processors and feedlots are pasteurizing potato coproducts to ensure hygiene.

Bradshaw et al. (2002) cited A. Turgeon (personal communication) that pasteurization of potato coproducts at 76°C for 30 s and then at 54°C for 2 h was used. One feedlot pasteurized a second time at 60°C after the potato processor did, and undoubtedly gelatinized the potato starch because the incidence of acidosis increased when only 5% potato coproduct DM was in the diet. Shiotsubo (1984) reported no potato starch gelatinization at 54.8°C for 10 min, but 100% gelatinization at 66.5°C for 10 min. Further, Tulyathan et al. (2006) determined, by 2 methods, that the onset temperature of potato starch gelatinization was 59°C. Treatment of potato coproducts that ensures hygiene, without starch gelatinization, is needed.

Limited data exist on time-temperature relationships to reduce infectivity of T. saginata. However, Bruce et al. (1990) using sewage sludge concluded that less than 10 min at 60°C was required for 90% destruction of T. saginata eggs. Additionally, ensiling at 35°C or lagooning at 7°C for 30 d appeared similarly effective to pasteurization. This might be why the prevalence of cysticercosis appears greater during winter months and why no carcasses were affected in any research studies at Washington State University because the potato coproducts were ensiled at least 28 d. Currently, processors heat the coproduct at 65 to 71°C for 1 min, then load it directly into a trailer for transport, relying on heat retention of the product to retain heat long enough to kill the T. saginata eggs. Buttar et al. (2009) used a surrogate species, Taenia hydatigena, for T. saginata. These species are phylogenetically very similar, but T. hydatigena has an intermediate host of sheep and a definitive host of the dog. Heat treatment of eggs to 60°C for 5 min resulted in no activation or motility in vitro and no cysts in finishing lambs 8 wk after dosing with 2,000 eggs. Egg activity at 22°C or after being heated to 40, 45, 50, 55, or 60°C for 5 min in vitro was measured, and their activity was fit to a sigmoidal 4-parameter model (r² = 0.89). Finishing lambs were dosed with 2,000 eggs at 22°C or 2,000 eggs heated to 50 and 60°C for 5 min and data fit the regression model percent encysted = 17.8 – 0.3 (°C); r² = 0.89. Both approaches predicted temperatures of less than 60°C for 5 min to attain 0% activity in vitro or no cysts in vivo, which is less that the onset temperature for potato starch gelatinization. Additionally, we also ensiled eggs in macerated potatoes for 0, 7, 14, 21, or 28 d and dosed finishing lambs (B. Buttar, M. L. Nelson, J. R. Busboom, D. Jasmer, and D. Hancock, Washington State University, Pullman, unpublished data). Using a linear plateau regression model [percent eggs encysted = 18.063 – 0.9(days of ensiling)], it was predicted that 20.89 d was the minimum duration of ensiling at which no eggs would encyst. Most PNW processors have instituted a hazard analysis critical control point (HACCP) approach to potato coproduct hygiene, and some will continue to pasteurize potato coproducts except those already heat treated (i.e., blanch water, potato peels, fried products) to be proactive in controlling cysticercosis outbreaks. Clearly, a HACCP approach is needed in the whole system to ensure hygiene with less comingling of dissimilar coproducts nutritionally, hygienically, or both.

KNOWLEDGE GAPS

Fried or Cooked Product

Data needed include determining the energy value, interactions with other dietary ingredients, and effects of their PUFA and MUFA content on ruminal fermentation and meat composition. These data are needed to properly utilize these potato coproducts.

Suitable Model for Pricing

Grames and Kueneman (1969) reported an Idaho potato processor selling potato slurry for $3.3/t at 14% DM. Turek (1984) calculated maximum price at the processor relative to grain but did include transportation cost. If forage price was constant, he concluded that potato waste was worth 84% of corn price and 113% of barley price on a DM basis. Drake et al. (1993) valued potato-corn processing waste at about 40% of corn price due to using data of Hsu et al. (1984), who reported very low energy values. Essentially, Drake et al. (1993) concluded the value was their assumed transportation cost of $11.1/t at 29% DM. Neither of these models determined value of currently produced potato coproducts nor did they consider other costs, including shrinkage during transportation, bunker- or pit-type storage facilities, pumps, agitators, holding facilities, losses due to fermentation, spoilage and effluent, pasteurization, starch gelatinization limiting diet inclusion rate, increased wear on equipment, bunk management challenges due to DM fluctuations, and cysticercosis.

SUMMARY AND CONCLUSIONS

The 4 main types of potato coproduct have good energy value and feeding value for finishing cattle. Limitation to potato coproduct use will mostly be economic, not due to antiquality components. Meat quality and palatability are excellent from cattle fed potato coproduct, and concerns about cysticercosis should be elimi-
nated by pasteurization or ensiling of the coproducts that are not already heated or cooked.

**LITERATURE CITED**


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