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Nutrient Characteristics and Glycoalkaloid Content of Potato Distiller Byproducts

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Nine potato distiller byproducts were analyzed for nutrient composition. Estimates of feeding value to livestock were determined. Proximate analyses of the byproducts showed all the products to have a fair amount of crude protein, but amino acid determination revealed a large portion of the crude protein to consist of nonprotein nitrogen. The products were good sources of lysine and methionine. The products were high in ash content, which would limit their potential feeding value. The carbohydrate portion of the byproducts was highly available as determined by proximate analyses and digestibility studies. Estimates of net energy for lactation were found to be comparable to other distiller byproducts, but the determination of true feeding value must await feeding trials to determine palatability and productivity. The glycoalkaloid content of the byproducts raises concern of the products palatability to livestock.

INTRODUCTION

The quantity of potato waste products from potato processing plants is tremendous. These waste products are currently being used as fertilizer or are being dried and used as cattle feed. An additional potential use of these waste products is as a source of fermentable carbohydrates in the production of gasohol (gasoline and alcohol mixture as a fuel source).

The purpose of this study was to determine the nutrient composition and estimate the potential feeding value of the byproducts that result from the production of ethanol from the fermentation of potato waste products. Several combinations of potato waste products and oat grain were tested for ethanol yield, and the feeding value of the subsequent distiller byproducts was estimated from nutrient composition and digestibility data. Because glycoalkaloids are naturally occurring toxicants present in all potatoes and potato products (Hansen, 1925; Renwick, 1972; Mun et al., 1975; Keeler et al., 1976; Renwick et al., 1984), the potato distiller byproducts were analyzed for their glycoalkaloid content.

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MATERIALS AND METHODS

Materials. Nine samples of potato distiller byproducts were obtained from pilot distillation projects performed by Biochem. Technology (Malvern, PA 19355) for Johnson Products, Inc. (Boston, MA 02210). The constitution of the nine potato waste fermentation mash samples is depicted in Table I. The components of the fermentation mash are primarily byproducts of the french fry potato industry. Cull potatoes are potatoes of insufficient quality to be processed as french fries. Peel waste is material from the steam peelers; filter cake waste is the solid residue from the filtered processing water. Screen waste is composed of potato slices that are too small to be fried; whereas, french fried waste is composed of fried potatoes of insufficient quality to meet quality control standards. Drum waste is waste material from the drying of potato flour.

Samples of the byproduct residue resulting after the distillation of ethanol were received in the air-dried state. Protein (Kjeldahl N), fat (ether extract), ash, moisture, crude fiber, and available carbohydrate analyses were performed according to the AOAC methods (1984).

Amino Acid Analyses. Amino acid analyses were performed by the University of Maryland. The method of hydrolysis was an adaptation of the procedure of Moore and Stein (1963). Fat-free dried samples (20–200 mg) were hydrolyzed with 6 N HCl under nitrogen for 24 h and for 72 h. Kontes hydrolysis tubes were used, and no sample transfers were made. Norleucine was added as an internal

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Table I. Constitution (%) of Potato Waste Fermentation Mash Samples

sample	cull potatoes	screen waste	drum waste	peel waste	filter cake waste	french fried waste	oats	water
1	100.0							
2	50.0	17.0	4.0	16.0	8.5	4.5		
3		40.5	10.2	38.1		11.2		
4		47.3	13.2		25.3	14.2		
5	25.0	25.5	6.0	24.0	12.8	6.7		
6	35.0	12.0	3.0	11.0	6.0	3.0	20.0	10.0
7	26.0	9.0	2.5	8.0	4.0	2.5	23.0	25.0
8		34.0	8.0	32.0	17.0	9.0		
9				100.0				

standard to correct for recovery. Following hydrolysis, the samples were distilled under N_2 until completely dry, after which they were reconstituted with sodium dilution buffer, pH 2.2, and shaken vigorously. The supernatant was decanted and centrifuged for 5 min. Amino acid values were determined on the supernatant using the D-500 Dionex (1228 Titan Way, Sunnyvale, CA) amino acid analyzer. Standards and buffers were obtained from Pierce Chemical Co. (Rockford, IL 61105).

Cystine was analyzed by first oxidizing to cysteic acid with performic acid. Feed samples were placed in vacuum hydrolysis tubes, and 2 mL of freshly prepared performic acid was added and the resultant mixture allowed to stand under refrigeration for 24 h. HBr (0.3 mL, 48%) was added to the tubes; they were sealed immediately, and distilled to dryness. Upon dryness the samples were subjected to regular 24-h acid hydrolysis as outlined above.

Vitamin and Mineral Analyses. Fluorometric, spectrophotometric, and fluorometric methods were used to analyze riboflavin, niacin, and thiamin, respectively (AOAC, 1984).

Samples (0.5 g dry wt) for mineral analysis were digested in 5:2 nitric–perchloric acid (v/v) and then diluted to 40 mL with deionized water. All minerals were analyzed by inductively coupled plasma (ICP) spectroscopy using a Jarrell Ash Plasma 975, except sodium, which was analyzed by atomic absorption spectroscopy (Akpapunam and Markakis, 1981; Bushway et al., 1981). Procedures used were those prescribed by Jarrell-Ash (1973). Appropriate mineral standards were used.

Glycoalkaloid Analyses. Potato glycoalkaloids were determined by previously described methods (Bushway, 1982; Bushway et al., 1985).

Available Protein and Dry Matter Digestibilities. Acid detergent insoluble nitrogen (ADIN) was determined by the method of Goering and Van Soest (1975). ADIN determination evaluates the amount of protein (N × 6.25) that is bound to the fiber portion of feeds and is nutritionally unavailable to the animal. ADIN is suggested to be a sensitive assay for the nonenzymatic browning due to the overheating of the feedstuff during processing, i.e., heat-damaged protein. Available protein was calculated as the amount of crude protein minus the amount of bound protein as determined by ADIN.

Dry matter digestibility was estimated from its disappearance from dacron bags incubated in the rumen of a fistulated cow according to the modified method of Crawford et al. (1978). Approximately 10 g of test material was placed in two dried 20 cm × 10 cm dacron bags with a pore size of 37 μm. The bags were closed with nylon string and attached to a 60-cm section of nylon string containing a weight at each end. The bags were wetted with water and placed deeply in the rumen of a fistulated cow. The plug was replaced with one end of the string hanging on the exterior. After 24 h, the bags were removed and thoroughly rinsed with warm running tap water until the effluent was colorless when the bags were squeezed.

Table II. Proximate Analysis (%) of Potato Distiller Byproducts

sample[a]	crude protein	moisture	fat	ash	crude fiber
1	25.25	8.89	0.43	19.38	4.63
2	23.22	12.60	3.02	19.68	5.86
3	20.25	11.02	5.62	15.25	5.95
4	17.75	8.41	11.45	24.29	5.99
5	22.31	10.24	6.38	18.89	5.40
6	18.47	9.46	2.43	10.63	10.72
7	17.63	11.51	2.33	15.45	10.13
8	21.75	9.07	4.68	33.95	5.57
9	24.31	8.83	0.88	32.44	5.17

[a] Table I.

The bags were untied, dried at 100 °C to constant weight, cooled in a desiccator, and weighed. Twenty-four-hour dry matter digestibility was calculated as the difference in the dry matter content of the bags before and after incubation in the rumen for 24 h.

Feeding Value Determinations. Estimates of total digestible nutrients (TDN) for cattle were calculated from the proximate analysis data (dry matter basis) and the 24-h dry matter digestibilities using the formula

$$\text{TDN (\%)} = [\%\ \text{avail protein} \times 0.8] + [\%\ \text{crude fiber} \times 0.7\ (0.5)] + [\%\ \text{ether extr} \times 0.92 \times 2.25] + [\%\ \text{N-free extr} \times 0.95\ (0.5)]$$

Digestion coefficients (DC) for each proximate analysis fraction were estimated from the dry matter digestibilities. Lower digestion coefficients for the nitrogen-free extract and crude fiber fractions were used for distiller byproducts that contained oats because previous investigations have shown significant amounts of lignin in these fractions that are not digested by the rumen microbes (Van Soest, 1982). These are shown in parentheses. The 24-h dry matter digestibility data support this assertion.

Estimates of the net energy for lactation for the distiller byproducts were calculated from the formula suggested by the National Research Council (1978):

$$NE_l\ (\text{Mcal/kg}) = -0.12 + 0.0245\ (\%\ \text{TDN})$$

RESULTS AND DISCUSSION

The average crude protein (N × 6.25) value for all potato distiller byproducts was 21.21% with a range of 17.63–25.25% (Table II). True protein values, as determined from amino acid recovery (Table III), were considerably less than crude protein values and indicate the presence of an appreciable amount of nonprotein nitrogen (NPN). The percentage of crude protein in the nonprotein form ranged from 9.64% for sample 7 to 43.36% for sample 9 with an average of 23.67%. The high proportion of NPN in some of these samples would greatly reduce their feeding value to monogastric animals. However, both true protein and NPN are sources of nitrogen for rumen microbes. Nonetheless, true, good-quality protein is considered more valuable than NPN because a portion of the true protein

Table III. Amino Acid Content (g/100 g of Protein) of Potato Distiller Byproducts[a]

amino acid	sample[b] 1	2	3	4	5	6	7	8	9
aspartic acid	12.14	15.83	14.62	15.54	13.57	10.04	9.86	11.08	18.44
threonine	4.98	4.93	4.87	5.03	4.87	4.15	4.20	5.25	4.50
serine	4.62	4.64	4.49	4.58	4.48	4.93	4.83	4.82	4.07
glutamic acid	15.78	14.03	13.86	14.01	12.47	18.39	17.58	13.31	11.84
proline	4.57	4.58	4.56	4.52	4.54	5.89	5.40	4.82	4.65
glycine	4.67	4.52	4.49	4.58	4.54	5.17	5.15	4.96	4.14
alanine	5.60	5.80	5.95	5.67	6.30	5.29	5.27	6.33	5.23
half cystine	1.76	1.39	1.46	1.53	1.49	2.16	2.26	1.44	1.23
valine	5.66	5.45	5.82	5.86	6.10	5.53	5.59	5.90	5.45
methionine	1.87	2.09	2.02	2.10	2.08	1.80	1.82	1.94	1.89
isoleucine	4.46	4.23	4.18	4.46	4.48	3.97	3.95	4.53	3.92
leucine	7.73	7.65	7.66	7.83	7.99	8.11	7.97	8.27	7.33
tyrosine	3.22	3.25	3.42	3.57	3.57	2.94	2.95	3.52	3.41
phenylalanine	4.72	4.52	4.68	4.90	5.06	5.17	5.02	4.96	4.50
histidine	2.23	1.97	1.96	1.97	2.01	2.04	2.07	2.37	1.74
lysine	6.69	5.74	5.76	6.05	6.23	4.15	4.90	7.05	5.66
arginine	4.51	4.06	4.11	4.20	4.35	5.53	5.78	4.60	3.85
ammonia	4.77	5.33	6.08	3.57	5.84	4.75	5.40	4.82	8.13
tryptophan	not determined								
true protein, %	19.24	17.25	15.80	15.70	15.40	16.64	15.93	13.90	13.77
crude protein,[c] %	25.25	23.22	20.25	17.75	22.31	18.47	17.63	21.75	24.31

[a] Average of two determinations and corrected for 100% recovery protein basis. [b] Table I. [c] From proximate analysis, Table II.

Table IV. Mineral Concentration (μg/g) of Potato Distiller Byproducts

sample[a]	Ca	Mg	P	Al	Cu	Fe	Mn	Zn	Na	K
1	1515	3620	31050	1890	33.6	2600	68.2	1445	301	52000
2	4140	3340	24200	2610	54.3	3865	81.5	1160	933	41600
3	1840	2570	23900	441	25.2	1790	45.6	1105	18500	35400
4	3780	3190	32200	2990	28.3	4390	85.9	1323	28500	28200
5	7320	2970	21700	2325	45.5	3525	69.9	958	1340	34600
6	1001	1345	22500	645	17.5	487	43.7	405	286	14200
7	1320	1855	37600	1430	18.2	820	59.1	493	915	21500
8	2395	2135	61700	1085	26.7	455	59.3	964	2095	35100
9	1013	833	62600	649	22.5	749	28.0	632	1115	36300

[a] Table I.

can be digested in the lower gastrointestinal tract of the animal even if it escapes microbial fermentation in the rumen. Only 60–70% of the nitrogen in rumen bacteria is in the form of true protein. The remainder is composed of nucleic acids and indigestible cell wall peptidoglycans (Van Soest, 1982).

ADIN represents that portion of the protein that passes undigested through the rumen and is unavailable for peptic digestion by the animal and is excreted in the feces. ADIN values ranged from 0.208% to 0.272%. Goering (1976) suggested that only those materials containing above 0.3% of feed nitrogen in acid detergent fiber possess a detrimental level of heat damage. Using this criterion, none of the byproducts underwent excessive heat damage during processing.

The amino acid profiles of the byproducts are shown in Table III. All of the byproducts are excellent sources of lysine, an amino acid that is typically in short supply in traditional corn–soybean meal-based diets. Lysine content of the potato distiller byproducts was in the range 4.15–7.05 g/100 g of protein compared to 2.50–3.74 g/100 g of protein for distiller's spent grains (Ranhotra et al., 1982). Methionine content of the potato distiller's byproducts was in the range of 1.80–2.10 g/100 g of protein, compared to distiller's spent grains whose values were 2.87–4.58 g/100 g of protein. Soybean meal, which is typically considered low in methionine, averages about 1.48 g/100 g of protein whereas corn, a fair source of methionine, averages 2.27 g/100 g of protein (National Research Council, 1984). Methionine is of particular importance because it is, along with lysine, in limited supply in corn–soybean meal based rations and is frequently supplemented in the synthetic form.

Table V. Vitamin Concentration of Potato Distiller Byproducts

sample[a]	niacin, mg/100 g	riboflavin, mg/100 g	thiamin, μg/100 g
1	15.44	0.98	71.9
2	11.57	0.55	163.3
3	6.17	0.56	67.1
4	7.40	0.43	141.9
5	8.72	0.55	73.5
6	4.28	0.43	220.5
7	5.89	0.42	319.6
8	8.92	0.57	136.4
9	7.89	0.55	62.5

[a] Table I.

Crude fiber (CF) content of the byproducts was low for all byproducts except 6 and 7 (Table II) and reflect the nature of the products composing the fermentation mash (Table I). Samples 6 and 7 had a higher percentage of crude fiber because of the addition of oat grain to the mash. Crude fiber represents that portion of the carbohydrate that is unavailable to monogastric animals, whereas the nitrogen-free extract fraction estimates available carbohydrates. Ruminant animals, however, can digest portions of the crude fiber. Previous studies have shown that a portion of the nitrogen-free extract of oat grain is lignified and, therefore, represents unavailable carbohydrates for both monogastric and ruminant animals (Van Soest, 1982). Thus, the nitrogen-free extract fraction of the proximate analyses of samples 6 and 7 is probably an overestimate of the available carbohydrate fraction of the byproduct.

Table VI. Glycoalkaloid Content (mg/100 g) of Distiller Byproducts

sample[a,b]	γ-chaconine	β_1-chaconine	β_2-chaconine	α-chaconine	α-solanine	total glycoalkaloids
1	–	–	18.63	7.00	32.88	58.51
2	–	–	17.15	16.50	29.88	63.53
3	–	–	11.90	72.38	50.13	134.41
4	–	–	5.45	7.88	11.63	24.96
5	–	–	16.38	31.63	33.25	81.26
6	0.25	–	1.63	0.88	2.56	5.32
7	0.25	–	3.44	2.56	6.00	12.25
8	1.67	1.25	14.17	18.50	26.00	61.59
9	1.19	3.50	20.88	94.50	59.88	179.95

[a] Table I. [b] Average of two determinations. – = none detected at a detection limit of 0.15 mg/100 g.

The percentage of fat (ether extract) is quite variable among the products, suggesting that the composition of the raw products was not highly controlled. For example, the stillage of 100% waste without peels (sample 4) contained 11.45% fat, while the stillage of 100% waste (sample 8) and 100% peel waste contained only 4.68% and 0.88% fat, respectively. The potato waste product obviously varied considerably in fat content. Because the fat content of feedstuffs is an important aspect of their feeding value, its contents in the raw materials must be highly controlled.

A disturbing characteristic of the potato distiller byproducts is their high ash content (Table II). The high ash content of the byproducts would have detrimental effects on the feeding value of the byproducts by reducing digestibility of the other nutrient components. The nature of the ash material is shown in Table IV. The high content of all the minerals, but particularly that of phosphorus, would limit their use as protein feedstuffs for both monogastric and ruminant animals. The high mineral content of the byproducts is inconsistent with the mineral content of the products composing the fermentation mash samples and probably represents additives to the fermentation mash to enhance ethanol production or as drying aides in byproduct production.

The content of niacin, riboflavin, and thiamin is shown in Table V. The data suggest that the byproducts are good sources of these B-complex vitamins, particularly niacin and riboflavin. Yeast added to the fermentation mash no doubt contributes substantially to the vitamin content of the byproducts. There were no detectable amounts of vitamin A or vitamin C in any of the byproducts, which is not unexpected considering the constitution of the fermentation mash and the instability of the latter.

Because glycoalkaloids are naturally occurring toxicants present in all potatoes and potato products (Hansen, 1925; Renwick, 1972; Mun et al., 1975; Keeler et al., 1976), these potato distiller byproducts were analyzed for their individual and total glycoalkaloid content. The concentration of total glycoalkaloids found in each is shown in Table VI. Levels range from 5.32 to 179.95 mg of glycoalkaloids/100 g of product. The two fermentation products with greatest potential for animal feeds, 25% culls and 75% waste (sample 5), and 100% waste with no filter cake (sample 3), contained 81.26 and 134.41 mg of glycoalkaloids/100 g of product, respectively.

As can be seen, all waste products contain metabolites of α-chaconine, with β_2-chaconine (Table VI) being the primary one. The origin of these metabolites has not been ascertained, but most likely they came from the yeast fermentation and/or the natural glycosidases in potato peels. The most important factor, however, is that with these metabolites present the products may be less palatable. Previous investigations have shown that although glycoalkaloids may affect palatability of the feedstuff, it is not transferred into the milk of cows fed potato waste byproducts (Bushway et al. 1984), indicating no major health concern for humans.

Table VII. Estimates of Feeding Value to Ruminants of Potato Distiller Byproducts

sample[c]	dry matter digestibility, %	TDN,[a] %	NE,[b] Mcal/kg
1	95	69	1.57
2	92	70	1.60
3	92	80	1.84
4	90	78	1.79
5	90	76	1.74
6	70	53	1.19
7	77	51	1.13
8	91	57	1.28
9	91	55	1.23

[a] Total digestible nutrients for cattle as estimated from proximate analyses and dry matter digestibility. [b] Net energy for lactation as estimated from TDN (NRC, 1978). [c] Table I.

Estimates of the feeding value of the potato distiller byproducts to ruminants are depicted in Table VII. All of the byproducts except 6 and 7 had high 24-h dry matter digestibility as indicated by their disappearance from dacron bags placed in a rumen fistulated cow. Estimates of TDN ranged from 51% to 80%. Samples 6 and 7 exhibited the lowest TDN values because of their high crude fiber content and lower digestibility. The lower digestibility of these oat-containing samples is consistent with previous information indicating the presence of substantial amounts of lignin in oat products (Van Soest, 1982). The lower TDN values for samples 8 and 9 were primarily due to the diluent effect of their high ash content. Samples 1 and 2 were intermediate in TDN value. Although they exhibited high digestibility, their lower fat content and correspondingly higher ash content contributed to their lower TDN values. The high ash content of the samples, especially those of samples 4, 8, and 9, may have adverse effects on the true TDN values by increasing gastrointestinal motility and, thus, reducing digestibility in a real feeding situation.

The net energy for lactation values corresponds proportionally to the TDN values (Table VII). The energy values of the potato distiller byproducts are comparable to that of brewer's dried grains (IFN 5-02-141) with 1.55 Mcal NE_l/kg. However, they rank below that of corn distiller's dried grains with solubles (IFN 5-02-843), which has 2.32 Mcal NE_l/kg.

Of all the products, the stillage from 25% culls and 75% waste (sample 5) and the stillage from 100% waste without filter cake (sample 3) appear to have the greatest potential for use in animal feeds. The other products are limited by their low energy concentration and/or their low protein content. All of the products are limited by their high ash content. Decreasing the ash value would greatly improve their potential use in livestock rations. None of the products have much potential use in broiler diets but may

have limited value in replacement pullet diets. The final feeding value of the products must be determined by feeding trials to determine the effects of the feedstuffs on palatability and productivity of the resulting diet.

Registry No. Ca, 7440-70-2; Mg, 7439-95-4; P, 7723-14-0; Al, 7429-90-5; Cu, 7440-50-8; Fe, 7439-89-6; Mn, 7439-96-5; Zn, 7440-66-6; Na, 7440-23-5; K, 7440-09-7; γ-chaconine, 511-36-4; β-chaconine, 472-51-5; β_2-chaconine, 469-14-7; α-chaconine, 20562-03-2; α-solanine, 20562-02-1; vitamin B, 12001-76-2; niacin, 59-67-6; riboflavin, 83-88-5; thiamin, 59-43-8.

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Influence of Commercial Dietary Fatty Acids on Polyunsaturated Fatty Acids of Cultured Freshwater Fish and Comparison with Those of Wild Fish of the Same Species

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Polyunsaturated fatty acids (PUFA) of the dorsal muscle lipids of cultured and wild freshwater fishes, and of the artificial diet lipids used in culture, were analyzed. The muscle lipids of cultured carp and rainbow trout contained higher percentages of linoleic acid (18:2ω6) than those of the wild fish and eels. The amount of 18:2ω6 in the fishes depended upon the diet lipids. High percentages of arachidonic and eicosapentaenoic acids (20:4ω6 and 20:5ω3) in wild carp, of linolenic acid (18:3ω3) in wild rainbow trout, and of docosahexaenoic acid (22:6ω3) in cultured rainbow trout were observed. The ratio of ω3 to ω6 PUFA for dorsal muscle lipids was in the following order: wild rainbow trout > cultured eel and rainbow trout > wild eel > wild carp > cultured carp.

INTRODUCTION

The lipids of marine fishes have beneficial effects on the cardiovascular disease. It is believed that the effects are caused by ω3 PUFA (especially, 20:5ω3) present in the fish lipids (Dyerberg et al., 1978; Dyerberg and Bang, 1979). The mortality rate of the cardiovascular disease in Japan is lower than that in the United States and Europe. The significance of freshwater fish lipids to the disease in Japan cannot be disregarded because of a comparatively high consumption of these fishes. Both cultured and wild freshwater fishes are available in the food market. Comparative studies of the fatty acid composition between lipids of cultured and wild ayu (Ohshima et al., 1982; Hirano and Suyama, 1983) and of eels (Otwell and Rickards, 1981/1982) have been carried out. However, there is not enough basic data necessary to estimate the contribution of freshwater fishes in the prevention of cardiovascular disease.

We have examined the difference between lipids of cultured and wild freshwater fishes in terms of the fatty acid composition of the dorsal muscle lipids. Carp and rainbow trout fatty acids were modified more by diet than were those of eel.

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MATERIALS AND METHODS

Samples. Cultured carp (*Cyprinus carpio*, 2 years old), rainbow trout (*Salmo gairdneri*, 3 years old), and eels (*Anguilla japonica*, 1–2 years old) were supplied by the

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